Development of an electronic educational material for the analysing of the structures and the bio-chemical processes of living organisms by imaging technology:

Chapter for Medical Imaging Diagnostics Gradual Education

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INTRODUCTION

Nowadays the imaging diagnostic is one of the most dynamically developing interdisciplinary scientific fields being an integral part of entire spectrum in everyday medical service as well as several fields of education and training for physicists/engineers. Furthermore, it is necessary to update continuously the acquired knowledge’s on these specialities. An online electronic educational material and method has been developed which is continuously updateable and possible to adjust to the nowadays requirements. In addition, hereby the tele-education is also supported on a high level.

The established educational material consists of three main parts:

I. Mathematical, physical, technological and informatics aspects of imaging
II. Medical diagnostic imaging – morphologic, functional, interventional –
III. Online available practical images

The online electronic educational material has been developed by the Semmelweis University (SU), Faculty of Medicine (FoM) Department of Diagnostic Radiology and Oncotherapy / Department of Nuclear Medicine and Budapest University of Technology and Economics (BME) Faculty of Natural Sciences, Institute of Nuclear Techniques. The medical and technical parts of the educational material is discussed separately, furthermore, both topics build upon one another’s knowledge’s. The image-based practical material is online available and evaluable independently of geographical position and a common platform with same image database is provided for both technical and medical users (by tele-radiology technology). Introductions of each field and chapter serve brief instructions and information about the structure as well as give some practical advices for efficient use.

The created electronic educational material has complex approach and modular structure, being competence based, interdisciplinary and inspires the life-long education as well as consists of the latest innovation of the related fields. The developed methods and the built-in technology is novel itself, and suitable for integration into the superstructure of the university education.

Nowadays not only in Hungary but also all over Europe a serious deficit exists in medical specialists supply on almost all fields and levels. One of the most affected fields is the diagnostic imaging, which has a very tight cross-sectional service of radiologist and nuclear medicine specialists. The domestic situation is more aggravated, because the radiology is the most preferred „emigration profession”. A similar situation can also be observed in the technical professional supply of diagnostic imaging and therapeutic activities. Behind the curtains, according to the latest surveys and prognosis on the engineering and natural science faculties the medical and biological frontiers of knowledge (like bio-medical engineering, medical physics and development of medical instruments, equipments and tools) are even more and more popular and attract increasing number of enquirers. The lack of professionals in the fields of research/development, everyday clinical services and the essential high-level technical services are very limited comparing to the increasing demands. Considering all these facts, one may conclude that health service including the connecting industry is a notable national economic interest in most of the countries from both social politic and economic aspects.

The online electronic educational material is recommended for the following target audience and curriculum:

- Gradual radiology education of Semmelweis University in Hungarian, English and German language,
- Postgraduate radiology professionals at Semmelweis University,
- Postgraduate nuclear medicine professionals at Semmelweis University,
- PhD training of Semmelweis University (if imaging fields are included),
- Continuous medical education for specialist doctors at Semmelweis University,
- Postgraduate clinical radiation physicists professionals at Semmelweis University,
- Medical informatics faculty of Semmelweis University, medical diagnostic imaging training (BSc level),
- Medical diagnostic imaging faculty of Semmelweis University (MSc level) (proposed),
- Physicist faculty at Budapest University of Technology and Economics, Faculty of Natural Sciences, BSc level,
- Physicist faculty at Budapest University of Technology and Economics, Faculty of Natural Sciences, MSc level, specialisation of Medical Physicis,
- Medical Engineering faculty at Budapest University of Technology and Economics Faculty of Electric Engineering, MSc level
Furthermore, there are very important target groups such as the industrial research, development and production of medical imaging devices professionals, as well as already the actively working medical physicists, technological and informatics professionals in the fields of radiation therapy and nuclear medicine. The established educational material and the new educational system constitute close connection with the information technology. Practically, a completely electronically controlled and available educational material has been developed with the telecommunication technology based practical training possibility. All of these supports help to adapt to the new era’s challenges as well as to educate and train new professionals, who may satisfy the present and future requirements. In addition, these professionals can integrate the higher level technical and technological knowledge on the healthcare field. The electronic educational material and the related methodology correspond with the renewal of universities and other higher grades of education according to the Bologna Process. The educational material promotes the improvement of education quality and its adjustment to international trends (e.g., establishing dual curriculum faculties /medical physicist, biomedical engineering,...etc.), where the acquired interdisciplinary knowledge base may support the fundament of the long-term maintainable progress of the domestic world standard medical instrument innovation and production technology.

Further consequence of our electronic educational material is to provide support and improvement of the equal opportunity in the covered professional fields, since the fundament of our method is the tele-education. Never the less, a valid option exists for those specialists who have to absent themselves from workplace (maternity benefit, temporary moving disability, etc.) in order to update their knowledge continuously and to maintain their daily routine practical capabilities independently of the geographical position. Tele-education considerable enhances the possibility of self-education supporting the superior qualification and a subsequent professional exam. The disable persons may have almost equivalent chances in the covered fields by the established electronic educational material. The material and method will be compulsorily maintained in the next five years and updated at least once a year.

Budapest, 20 November, 2011

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1. Introduction – Medical part

The medical e-learning material consists of four major parts:

- Gradual part in Hungarian, English and German
- Postgradual part in Hungarian
- CME – case reports and example cases for continuous medical education
- Practical part – to learn about postprocessing possibilities in a practical way; „must-see images” for gradual teaching in Hungarian and English.

1. The gradual chapters were written by the senior colleagues of our Clinic and University. The length and the content of the material contains the knowledge from radiology and related clinical issues that is important for a 4th year medical student. If a student learns all text and images from these gradual chapters, she or he will most likely get one of the best marks at the exam. When writing these chapters, the main focus was on what should a referring physician (e.g. internist, surgeon, neurologist, rheumatologist, etc.) know about the physical basis of the different imaging modalities (e.g. X-ray, ultrasound, CT, MR), and which modality should be selected as a first investigation. The referring physicians should be able to understand and interpret the report of the radiologist, and should know how to proceed in the patient care. It is emphasized that radiology is a speciality of consultation, in case of any doubt, the referring physician should ask, consult the radiologist about the specific clinical question in order to decide the best option as a first and possible additional investigation. The development in radiological protocols are rapid, major changes may occur in a few years time.

The referring physicians should also be aware of the presence and basic knowledge of all image guided therapeutic procedures (interventional radiological procedures). These procedures very often replace a major surgery with general anaesthesia, large wound, opened chest or abdominal cavity; all of these have a significant risk of minor or major (including fatal) complications. Image-guided therapy, however, needs only local anaesthesia, there is no wound (only a 1-2 mm whole for a needle or catheter), in-hospital and back-to-work time is remarkable shorter, therefore it is a considerably lower overall burden and less risk for complications for the patient with similar clinical benefit.

Any medical student who is interested in radiology in depth have the possibility to further improve their knowledge from the postgradual chapters.

The gradual teaching material was created in Hungarian, English and German, since medical courses are carried out on these three languages at our University.

The electronic teaching material can be systematically used both for the students in their preparation throughout the year and also for the lecturers to prepare questions for the midterm test and the final exam.

2. The postgradual chapters were written for the residents in Hungarian. This material by itself is undoubtedly not enough for the resident final exam, however, it gives a comprehensive overview of every major topics within radiology.

The residents should be aware of all diagnostic and interventional radiology procedures, including those that they will not practice following their final exam.
1. Introduction – Medical part

3. The case reports and example cases for continuous medical education (CME) consists of a mixture of simple and compound cases in Hungarian. The aim of these case reports are to give an opportunity for the radiologists to refresh their knowledge, whether it is an older colleague who has been working for decades in a chest X-ray unit, or a young colleague who is overspecialized working on a small selection of cases in large numbers, or an average radiologist who see a wide selection of diseases in a primary hospital.

Most cases - if available - contain medical history, relevant laboratory data, description of any surgical treatment, pathological findings and the therapy used.

4. In the practical part, postprocessing techniques (e.g. reconstructions, size, distance, angle measurements) can be overviewed and exercised on anonymized images. This file also contains a series of „must-see“ images for the gradual students in Hungarian and English.

Most of the images used throughout this electronic material are from our Clinic. Some authors work at our University, but do their radiological practice on different other clinics. This fact is mentioned in the list of authors. We also used images from the Asklepios Medical School, since we are in close cooperation with them as they are the Hamburg campus of Semmelweis University.

The whole electronic material has to be maintained and supported for five years. This will serve as a great benefit of the project since all new images from our clinical pratice can be inserted and all major new developments in radiology and interventional radiology will be upgraded approximately once a year.

We do hope that the electronic learning material will further improve our gradual teaching in Hungarian, English and German, will help the postgraduate students to get ready for the final exam; certified radiologists will hopefully also benefit from the CME chapters.

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2. The clinical significance of diagnostic modalities: X-rays

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2.1. Introduction

Wilhelm Konrad Röntgen, physicist and engineer, discovered X-ray radiation in 1895 by chance during his experiments with cathode ray tube. For his invention, in 1901, he was awarded with the first ever Nobel-price for Physics. He called the radiation X radiation.

X-ray diagnostics, according to the mode of detection, can be:

- analogue
  - imaging technique (X-ray film and amplifying foil combination)
  - fluoroscopy
- digital
  - indirect digital
  - direct digital

Museum in the Library of the Department of Diagnostic Radiology and Oncotherapy...:
2. The clinical significance of diagnostic modalities: X-rays

2.2. Physical basics of image production

The physical basics are valid for all the analogue, indirect digital and direct digital imaging techniques. The only difference is between the theoretical principles of X-ray detection.

Concept of X-ray radiation

X-ray radiation is a type of electromagnetic radiation, a form of energy spread. Its physical property:

\[ C = \mu \times \lambda \]

\( \mu \) = frequency
\( \lambda \) = wavelength
\( C \) = speed of travel, that has a constant value

Wavelength and frequency are inversely proportional to each other.
X-ray is characterized by the wavelength.
The shorter the wavelength, the harder the radiation beam, and the more penetrative power it has.

According to the principle of quantum theory, all electromagnetic resonance (X-ray included) is made up of energy packets, called photons. These all show wave-like characteristics, and according to the laws of classical mechanics, X-ray also shows collision phenomenon.
X-ray radiation is characterized by its intensity. Intensity shows the energy delivered by the radiation; it is the energy density perpendicularly passing through a unit of surface.

X-ray radiation is generated by the X-ray tube.
Electrons from a high voltage, direct current cathode tube travel in an electric space, and then a vacuum-tube accelerates them until they collide with a heavy metal object (anode). The heavily accelerated electrons impact on the anode and in various steps they emit energy.

X-ray tube structure:

Cathode Wolfram
Anode Wolfram, Molibdén - Rénium
Power voltage 10-20 kilovolt
Acceleration voltage 6-600 kilovolt

The production of X-ray radiation

There are two types of X-ray radiations differentiated by the way of their production
-characteristic X-ray radiation
-deceleration X-ray radiation
- **Characteristic radiation:**

The beamed electron collides and pushes out an electron from an inner electron-shell. In turn it is replaced by an outer orbital electron. The different electrons on different electron-shells, have different energy levels, and therefore, the replacing energy is always a distinct value. The produced quantum is always of a definite wavelength.

- **Deceleration radiation:**

The emitted electron pushes through all the electron shells, and in the vicinity of the atomic core it decelerates. The energy released at deceleration will produce a photon of equal energy to the deceleration. The point where the electron completely loses its momentum is called wavelength limit.

**The spectrum of X-ray radiation**

A continuous curve can describe the spectrum of wavelengths with superimposed characteristic peaks, that are specific to the material used as the anode. Molybdenum (used in mammography) has a characteristic peak at 35kV acceleration voltage. Wolfram has its peak at 60-70kV. These metals are effective anodes, because their peaks occur at diagnostically applicable values. (Medical X-ray diagnostics)

The energy loss is extreme, 99% of the kinetic energy is emitted as heat and visible light. The excitation mostly occurs on the outer electron orbit, as only one electron is pushed out. The beam energy depends on the tube current used. The spectral composition can be altered with increasing the voltage and also by filtering the beam.

**Filtering**

The produced X-ray beam is made up of photons of various wavelengths. The photons unnecessary for image production or the ones that distort image quality need to be filtered. This is done by using aluminum and copper plates. Filtering also decreases the radiation burden.

**Squared beam absorption law**

X-ray beam intensity decreases with the distance squared from the source of radiation. The dose registered at a 1 x 1 m² surface from a 1 meter distance of the source is distributed on a 4 x 4 m² square.

**Absorption**

X-ray radiation traveling in space will lose its intensity, as it interacts with matter within that space. The radiation also changes the state (biologic, chemical and physical) of the material.

The radiation absorption ability of a given material depends on its thickness, density and atomic number. The atomic number influences this ability by the power of 4.
As X-ray beam passes through matter five different phenomena occur. This process is called absorption.

- It passes through without energy loss
- Rayleigh scatter
- Compton scatter
- Photo effect
- Pair formation

Compton scatter is the most important factor in image quality distortion.

**Central projection**

Distorts the image and enlarges it.

### 2.3. The production of X-ray image

When a homogenous radiation beam travels through a body, it is scattered into the background and in some amount it penetrates through it. As the beam is absorbed the distribution of the X-ray quants will change, it will decrease unevenly in the plane of travel, thus causing a variable blackening effect on the film or on the detector (digital). This is how the so called beam image is produced. It is an inhomogeneous relief of the beam and it greatly depends on the quality of the matter. This beam relief has to be detected by some kind of an image transforming system. On analogue technique this happens through a large-format film-foil combination. This is the simplest detector system.

The detector is the plain film and contains silver halogenids. The amplifier screen and the foil are made up of calcium tungstate and zinc-sulfide (blue foil). The rare earth metal foils are made up of titanium or gadolinium (green foil). The latter achieves better quantum utilization, and less X-ray photon is needed for image production. It is an important radiation safety (efficacy, hygiene) issue as well. Faster exposition time in turn decreases motion/blurring effects. The particles in the foil, when hit by the X-ray, fluoresce and emit light photons. Blue foils will emit 2-3 photons per one X-ray photon, while green foils will emit 8-10 light photons. Image quality will be determined by the granularity of the foil. The grainier the foil, the worse the image resolution is going to be. The quality/resolution of an image transformation system is measured in line pair /mm units. If image formation would occur directly on plain film the resolution could reach 50 line pairs/mm, although then the delivered dose would be huge. This resolution ability with the use of foils decreases to 5-10 line pair / mm, at significantly lowers doses.

### 2.4. Factors influencing image quality

Scattered radiation decreases picture quality. It decreases image sharpness, it makes the image hazy and decreases the contrast.

(Filtering, tube, grids, Bucky, Potter-Akerlund)
Image quality is increased by:

- smaller distance between the object and the imaging plane
- greater the distance between the focus and object
- smaller focal point
- Tele-imaging can achieve the best image quality, but this is hindered by the generator’s capacity (see square law)

The quality of X-ray image increases as it carries more information; this is most influenced by the detector system. It also depends on the body size of the examined patient, for example with overweight patients more scattered radiation is produced.

**X-ray fluoroscopy**

During fluoroscopy examination a constant beam of X-ray is produced. This is achieved by the use of more recent rotating anode tubes. The image first appears on a primary zinc-cadmium sulfide or cesium iodine containing screen. An electron-optic chain in turn amplifies this image into a several thousand times stronger one, which will appear on the secondary screen. Finally, a camera delivers the resulting image on the monitor screen.

**Indirect digital technique**

This technique registers the image on a digital plate (such as phosphorous plate). The phosphorous plate at the end of the exposition will be scanned and the produced image delivered onto a monitor. This image is postprocessable and can be delivered to another medical workstation.

The phosphor storage disks are made up of barium-fluoro-bromine molecules immersed in phosphorous-crystals whose electrons are pushed to higher energy levels proportional to the energy of the impacting x-ray photons. Scanning the phosphorous plate with a laser light the barium-fluoro-bromine electrons show a luminescent phenomenon and by emitting light, they return to their original energy level. These light photons are detected. When the cassette is lit by normal light it loses its excited state and turns reusable again. Read-out should be performed within 15 minutes after exposure, because in 2-3 hours of time the data stored in the crystals vanishes.

**Direct Digital technique**

The exposition happens as the x-ray beam hits the detector plate. The detector is a thin transistor panel sensitive to electric signals, covered by an amorphous selenium layer. X-ray interaction with the selenium layer induces an electric charge difference and electric holes appear proportional to the x-ray intensity that hits the layer. This electric signal is detected by the thin transistor panel, which in turn is read out as lines and columns. The registered data can be acquired as images, they are sent to the clinical informational system and workstations through the Hospital Information System (HIS) or the Radiological Information System (RIS). Patient data and the digital image can be combined and fused on the same image.
2. The clinical significance of diagnostic modalities: X-rays

2.5. The clinical uses of X-ray examinations

X-ray examinations have several clinical advantages until today. In a lot of ways it has preserved its priority over other diagnostic methods. In most cases, X-ray is the first choice of examination of the diagnostic algorithm. In fact X-ray examination is still the most frequently used modality. In case of chest X-ray screening exam, if the result is negative it is considered sufficient. As a common rule, all X-ray exams need to be documented with an image and a complementary report.

Advantages of X-ray exams:

- cheap
- widely available
- can be specific for some diseases
- can set up a preliminary differential diagnostics and help in choosing diagnostic methods in order to acquire a final diagnosis the fastest and cheapest way. This is especially valuable in emergency cases such as the differentials of acute abdominal pain, traumatology and the diagnostics of postoperative complications.

Disadvantages of X-ray examinations:

- non-specific in many cases
- certain diseases do not have radiological X-ray sings
- certain lesions are invisible on X-ray (non X-ray absorbing bile stone or renal stone)

X-ray diagnostic methods

- chest X-ray
- plain abdominal X-ray
- contrast X-ray examinations
- bone X-rays
- interventional radiologic examinations
- special ENT X-rays

2.6. Methods of chest X-ray imaging

- The so called Zeiss and Odelka examination stations use a roll film technique. Images are made from a 2 meter distance; they are seemingly small, only 10 x 10 cm or 6 x 6 cm, but have a very high resolution.
  This technique was used for national chest screening exams, but it is not accepted nowadays.
- The 1:1 ration posterior-anterior (PA) chest X-ray image
- Lateral chest X-ray
- Chest fluoroscopy is always a complementary examination, when the chest radiograph
identifies a suspicious lesion. Chest fluoroscopy is not used alone, because its radiation dose is higher, and its resolution is lower than that of normal radiographs. Also it is too dependent on the examiner and is not properly documentable.

-Recumbent lateral (Friemann-Dahl) examination

Contrast material examinations

- gastro-intestinal exams
- biliary examinations
- fistula imaging with contrast materials, fistulography
- feeding tube filling exams
- cannula positioning
- radiologic interventions
- control examinations after surgical interventions

2.7. The message of this chapter

Knowledge of the physical properties of X-ray radiation is fundamental to the correct evaluation of X-ray images.

Translated by Balázs Futácsi
3. The clinical importance of diagnostic modalities: Ultrasound

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3.1. Introduction

Medical Imaging techniques:

- X-ray
- Ultrasound
- CT
- MRI
- Angiography, DSA
- Nuclear Medicine (scintigraphy, SPECT, PET)
- Fusion Imaging (PET-CT)

In the field of medical imaging methods, which are non-invasive and uses non-ionizing radiation, the Ultrasound has a privileged position. The clinical application has began to spread rapidly in the 70s, a few years later the order of application, the indication of radiological studies has been substantially "re-written". Nowadays this is the first method of choice in imaging procedures for many organ systems (such as liver - bile ducts - gallbladder - pancreas, kidney - urinary tract, superficial soft tissue), and the further needed imaging procedures can be built on information obtained by Ultrasound examination.

3.2. Physical and technical bases

3.2.1. The physical characteristics of Ultrasound:

The mechanical waves above 20 kHz are called Ultrasound, what the human ear can not hear normally. Ultrasound will be produced by lead-zirconate-titanate based small piezo-crystals. These are tiny ceramic plates, thick vibrators, they perform damped mechanical vibration driven by the AC power packs, so Ultrasound is generated (Fig. 1). The frequency of the transducer is determined by the thickness of the piezoelectric ceramic plates. In the fraction of a second several times the ceramic plate is working as transmitters and as receivers. In receiver function the reflected ultrasound, from the investigated area to the piezoelectric crystal, causes vibration in the sliver, from which electrical impulses can be collected. The Ultrasound images are high-performance PC-assembled echo-images (they can be displayed almost real time - 14 to 25 frames per sec, with minimal delay), visualizing the sound reflections from inside the body.
3.2.2. The propagation of Ultrasound

3.2.2.1. The velocity of the Ultrasound

The propagation of Ultrasound, of course, need some kind of medium. As the velocity of this mechanical vibration in the medium is constant, with biological tissue structures this is around the value of 1540 m/sec. This rate varies significantly in different fluids or tissue structures, eg.:
- Water (20 C degree) - 1480 cm/s
- Water (36 C degree) - 1530 cm/s
- Brain - 1540 cm/s
- Fat - 1450 cm/s
- Bone - 2500-4700 cm/s

3.2.2.2. The frequency and wavelength of the Ultrasound

The wavelength (λ) can be calculated from the frequency and velocity of the Ultrasound: 
\[ \lambda = \frac{c}{f}, \]
for example by 5 MHz frequency the wavelength is: \( \lambda = 0.3 \) mm.
In the medium along the longitudinal propagation of the Ultrasound there will be thickening and thinning, which obviously depends of the density of the medium.

3.2.2.3. The propagation of Ultrasound through Surface

In image the Objects are not "exactly there", where displayed by the Ultrasound, because of the propagation through Surfaces. With this should be reckoned specially by US-glided Intervention.

3.2.3. The energy content of the Ultrasound, safety concerns

One more important physical parameter is energy per unit of area, what we provide in the form W / cm². The intensity is typically below 100 mW / cm² by medical diagnostic applications.
According to our today knowledge, the amount of energy in an average, 10-12 minute Examination is not harmful for the human body. However in the affected area already a few
degrees of increase can be discovered in temperature, in the case of longer duration, Doppler tests. This explains that - especially in the first Trimester - Doppler test during pregnancy Examinations can only be done in limited time interval.

3.2.4 Ultrasound Imaging

A-mode (Amplitude mode)
In this method, the image displays on the horizontal axis the depth of the area under consideration and the vertical axis represents the Amplitude of the echoes. By the biometric Use in ophthalmology it is primarily used for distance-measurement (Fig. 2).

![Figure 2. A-mode US in ophthalmology (with B-image correction)](image)

M-mode (Motion mode)
It can display in which way the position of echoes along a single US beam are changing in time (Fig. 3). It has greatest importance in echocardiography.

![Figure 3. Heart-US, M-Mode](image)

B-mode (Brightness modulation)
The US-beams from the piezoelectric crystals in a transducer (e.g. 256 pieces) are on the tissue surfaces reflected in various ways. Due to rapid data collection and processing by a computer this device is capable of demonstrating these reflections as tiny "bright" or "less bright" dots on the Monitor, they are the Pixels of a picture (Fig. 4). The resulting images are changing each other on the Monitor very fast (25-40 Frames/sec), so it will result a real-time examination.
3.2.5. The types of echo structures

US passing through interfaces:
For US the interfaces with air, and chalky, bone structures results in a significant reflection, that the underlying areas are practically not visible.
The following echo structures are distinguished based on the US beam propagation and reflection through tissues:
Cystic: 1. echo free
Solid: 2. echo-poor
3. echo-rich
4. echo dens

Nowadays US diagnostic is based on the real time B-mode US imaging. In the structures, examined with US, the above mentioned four different types of echo intensity are - many different ways - mixed.

3.2.6. The Ultrasound images Resolution

Depth (axial) and sideway (lateral) Resolution
The better the resolution in the appropriate directions are, the better picture, that is rich in details, will be the result of the Examination with the same device. The axial resolution will be better by the transducer with higher frequency. Improving the lateral resolution by adequate depth zone(s) is in need for focused US beam. The usage of the dynamically focused beam allows almost identical lateral resolution along almost the entire depth of Examination.

3.2.7. Doppler Method by US (spectral Doppler)

The Doppler technique is based on the reflection of the sound from the streaming (approaching, receding) particles with different velocity.
In the simplest cw (it works with continuous wave) Doppler instrument there is one sender and one receiver. By this technique the velocity measurement has no known limits.
By the pulse Doppler we are signing the place along the US-beam with a variable-width sampling Gate, from where we want to get velocity information (arteries - fig. 5, venous - fig. 6). Based on the measured curve with the velocity from the chosen vessel section we can quantitatively characterize the flow in time relation.
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3.2.8. Color Doppler US

In the sampling area (color box) the flow will be encoded by your computer basically to the transducer in red, and from the transducer in blue. Other tint will be assigned to variable velocity of the flow. Therefore you will get variable shapes of colors (Fig. 7) at the field of strictures and by major curves. Besides the color Doppler, for quantitative measurement of territorial flow serves the Doppler spectra. (The smaller the sampling gate you chose the less "noisy" Doppler curve can be gained)

3.2.9. Power Doppler US

By this Doppler technique the fact of the flow is amplified in the applied sampling box region, it is 7-8 times sensitiver as compared to the Color Doppler, but it can not appoint the direction of the flow. This method (Fig. 8) is very suitable to detect the small flow in variable velocity region.
3.2.10. Three-dimensional (3D) and four-dimensional (4D) US

Recently by conventional 2D US examination imaging is done on one selected plane. However, by 3D US investigation the visualization of the sampled three-dimensional volume will prepared with processing the received large amount of echoes (Fig. 9). The heavy development of 3D US technique in the last 8-10 years made it possible, that 3D US images created by special transducers can be plot as moving structure almost in the same time as acquisition. So we got to display of the reconstructed 3D image in motion, namely 4D US examination.

3.3. Contrast enhanced US procedures

The gas bubbles as Ultrasound contrast agents have been used in1968, but radiology only uses it more widely since the mid 90's. Initially the cardiac Doppler examinations used the contrast agents to increase sensitivity of ultrasound. Doppler studies can still detect flow in vessels with few mm of diameter, but with intravenous administration of 2-3 ml of ultrasound contrast agents capillary-level flow detection is possible. At low mechanical index, the contrast material gives a strong, well-separable sign.
In Hungary there is only one approved and clinically used contrast agent, the Sonvue (lifetime of about 5min after iv. administration, and consists of Sulfur hexafluoride gas bubbles and phospholipid).

The use of contrast material by US-methods is becoming increasingly in various Organs imaging (Fig. 10, 11).
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Figure 10. FNH CEUS, star shaped, very early arterial (25s), centrifugal fill

Figure 11. HCC, CEUS, small late (35s) arterial filling

3.4. Tissue Harmonic Imaging - THI

In the imaging method by the performed 2D US examination at a specific frequency (e.g. 3.5 MHz) in the tissue nascent harmonics can also be used, they are integer multiple of the emission (fundamental) Ultrasound-frequency. Accordingly, we distinguish the tissue (THI) and contrast-enhanced harmonic imaging methods used harmonic imaging (Contrast Harmonic Imaging - CHI).

The harmonic waves are integer multiples of a fundamental US frequency. (e.g. 5 MHz - 10 MHz). The harmonics are formed in the tissues as a result of fundamental US, because the propagation velocity of the US is slightly higher during the higher pressure half-period (thickening), while it is lower at rarefaction. As a result in the original sinus vibration will be a distortion, i.e., harmonics generated. By the reception of the ultrasound using only the harmonic frequencies, and deleting the basic frequency vibrations, we can get more valuable, much less noisy two-dimensional images. This method primarily can be used to produce more detailed assessment of the structure of parenchymal organs, and to visualize localized lesions with sharper contours (Fig. 12). In relation to the basic frequency procedure gain setting adjustment is required. THI and CHI techniques assume the use of broadband transducers.

Figure 12. Gallbladder increment THI
3.5. Endocavit, endoscopic Ultrasound methods

Besides over skin surface applied Ultrasound techniques - phased array, with divers convex (3.5-6 MHz) and linear (5-10 MHz) (Fig. 13) Ultrasound transducers - due to ongoing technical development the different endocavital and laparoscopic Ultrasound methods are becoming more important. By these transducers the Ultrasound image resolution is dramatically improved by applying very high, 10-14 MHz frequency:

Endoscopic US - oesophagus, stomach, duodenum, endobronchial, endonasal
Intraductalis US - bileducts, Wirsung-duct
Transrectal US - rectum, prostata, perirectal space (Fig. 14)
Transvaginal US - vagina, uterus, ovariums
Laparoscopic US - abdominal, pelvic, mediastinal region

The non-palpable differences (er. smaller metastases in the liver parenchyma) can be imagined with special intraoperative transducers used on the surface of the parenchymal organs.

For example on the usage of the endoscopic Ultrasound we can mention, that in gastric cancer it is an important imaging method in the accurate evaluation of the propagation in the wall, as well as in detection of the pathological lymph nodes around the stomach, and its sensitivity and specificity can be considered identical with MDCT. In the assessment of distant metastases, of course MDCT, MRI and PET-CT imaging techniques are the adequate methods.

In the case of the tumors located in the pancreatic head, with the help of endoscopic Ultrasound in the height of the duodenum, the propagation of the lesion, the inner structure and vascularisation can be very well classified. Furthermore with special needle we can do Ultrasound guided biopsy.
3. The clinical importance of diagnostic modalities: Ultrasound

3.6. The role of Ultrasound imaging in oncology

It is very important and non-invasive examination method in all cases of tumor types; they can be examined and visualized. The method compared with CT and MRI is significantly examiner dependent procedure, therefore, for example in oncologic imaging - where the reproducibility, comparability and regular monitoring is very important - it can not comply with the same degree despite the considerable technical development.

All parenchymal organs and superficial soft tissue can be examined well with help of the conventional 2D imaging techniques, but the air, the bones and chalky structures are impenetrable obstacle for the US, as they fully reflect it. In the assessment of the intra-abdominal organs the image quality of Ultrasound can be disturbed and worsened by significant obesity and postoperative status (bandages, drainage).

In visualizing and morphological assessment with US a gel pad might help by the very superficially located tumor suspicious lesions in the subcutaneous layer, and lymph nodes located in the superficial regions.

With the use of Color-Doppler and Power-Doppler procedures we can obtain valuable information regarding the vascularisation of the tumors (Fig. 15). In some tumors (such as hepatocellular carcinoma, FNH, adenoma) with vascularisation analysis using Doppler spectra important information can be obtained, that can help in the differential diagnostic assessment.

![Figure 15. Tumor of the tongue root, color Doppler, increased vascularisation](image)

3.7. Sonoelastography

In the sonoelastographic examination they gently compress the selected region with the transducer, so the soft tissues in this region will be compressed more, the harder lightly. Afterwards these results are color coded in the B-picture, due to be easily distinguished.

The tissue structures in the body are becoming harder and more inflexible through different inflammatory or neoplastic processes. The rate of this change can be measured in the modulus of elasticity. The tissues sizes are lengthened, through the compression with the transducer due to the elasticity, both in axial and in lateral dimension.

With proper use of autocorrelation software these alterations in scale can be quantitative assessed. The hard structures will be displayed in B-picture with blue, and the soft tissues with red color. Since the hardness values are also transitions, so there will be shading in the color coding (Fig. 16). The first releases of the breast, thyroid and pancreatic cancer studies had already appeared in the literature, regarding to the sonoelastographic examinations.
Figure 16: Lymph nodes on the neck with US, Sonoelastography

Translated by Csaba Korom
4. The clinical importance of diagnostic modalities: The Computer Tomography

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4.1. Introduction

The computer tomography (CT, computerized tomography) was created from the concurrent application and combination of the X-ray analysis technique and the computer technology. Godfrey Hounsfield and Allan Mc. Cormack received the Nobel Prize for medicine in 1979 for developing the CT. The CT scan is basically a new, spatial approach taken in the radiology.

4.2. The CT Imaging

X-rays suffer attenuation when passing through the human body, with the help of computer application the mathematical methods can convert these losses into visible images. The process consists of two parts. The first part is the measurement and data collection phase, and the second is the image reconstruction phase, which ends with image capture.

4.2.1. The basics of CT imaging

In 1917 Radon formulated one of the underlying principles in CT imaging: "A three-dimensional body composed by an infinite number of points can be mathematically reconstructed, and produced at any time."

A narrow X-ray beam scans across the transverse section of the body part which will be examined.

The difference in the amount of radiation entering and leaving the body is known as absorption profile. The quintessence of tomographic imaging is that we can determine the value of radiation absorption for each of the different space elements in a slice with a sufficiently large number of absorption profiles taken from different directions.

We detect the weakened radiation leaving the body with detector-rows. The detectors convert the radiation to electronic signals, which is analyzable with digital data processing systems, and can be changed into numerical data.

The CT-image is a sectional image calculated from multi-directionally measured radiation attenuation values.

4.2.2. Digital picture (Raster image)

One voxel is a volume element of the same size in an irradiated slice of the body. It is a prismatic formation, which base is a pixel (the spatial resolution of the CT is 300 micrometer on the average). The height of the prism is basically determined by the chosen slice thickness.
4.2.3. Basic concepts of CT

Gantry - ring shaped gear, which encompasses the X-ray tube and the detectors
Table motion - periodic or continuous
Matrix (raster) - 512x512, 1024x1024

Density - tissue "solidity"

- -1000 HU vacuum
- -100 HU fat
- 0 HU water
- 0-15 HU clear watery fluid
- 15-20 HU denser fluid
- 20-70 HU soft tissue
- 70-100 HU fresh bleeding in soft tissues
- 100-1000 HU contrast agent, calcification
- 3000 HU total radiation absorption

A CT scan can theoretically produce 4000 shades. The extent of the attenuation is expressed as so called Hounsfield units (HU), which is characteristic to the through radiated material density. This scale has a negative endpoint (-1000 HU) accordingly to the attenuation of the vacuum, the positive endpoint (3000 HU) fit the total attenuation. The null-point (0 HU) is the density of the water.

4.2.4. Windowing

The human eye can recognize only 40-60 shades of gray. The CT can measure up to 3000 different density. To avoid that it will be all uniformly gray, we will narrow the visible gray scale to the target density, underneath all density will be set to black, and above all to white. We look at the resulting images with different windows, depending on the tissue structure that is considered a goal.

4.3. CT devices

One-slice (slicing-stepping) CT- the movement of the patient table is periodic, with one measurement there will be mapping of one transverse slice of the body.
Spiral (helical) CT- they appeared from 1990.

The movement of the patient table is continuous, so it is possible to measure whole body volume.
Multislice - multidetector CT- they are since 1992 widespread.
Dual energy, dual-source (with two X-ray tubes) CT- has been used from 2005.
PET-CT is a combined diagnostic method.
4. The clinical importance of diagnostic modalities: The Computer Tomography

4.3.1. The benefits of multislice CT

The continuous table movement allows for continuous measurement, so there is no information loss. A single breath hold is enough for the whole body "scan". There are less motion artifacts (examination of patient with severe medical conditions). The thin-slice imaging is more accurate for analysis of density. Based on the fast, high-volume collection of data is possible to reconstruct in any plane. The measurement of volume allows spatial visualization. Favorable radiation The amount of contrast agent can be reduced.

4.3.2. Dual-Source imaging

Concomitant use of two X-ray sources and two detectors
The two tubes are located perpendicular to each other, and the information is collected by the detectors in sync with each other. There are two different operating modes.
In dual source mode both X-ray tubes works with the same kV value. The collection for axial slices requires only 90° rotation.
In dual energy mode the tube voltages are 80 and 140kV, and for one transverse slice the two tubes rotate 180°.
The absorption of X-rays with different energy will be different. Two sets of data are created, containing different information.

The benefits of dual-source imaging

Tissue differentiation in new ways
Blood vessels or bones can be directly subtracted.
Oncological classification of tumors
Vascular plaque characterization, more detailed image quality
Body fluid differentiation in the emergency diagnostics
Collagen visualization (direct imaging of tendons)
Stone analysis
Imaging of heavy elements
Perfusion imaging based on iodine quantification

4.3.3. PET-CT

It is a combined diagnostic method, an alloy of the computer tomography (CT) and the positron emission tomography (PET).
The tracer material is radioactive isotope (18F)-labeled glucose molecule (FDG), which has a very short half-life, and only a small amount is injected.
PET measures the metabolic processes occurring in cells and the CT shows the anatomical structure.
It is used in the first place for early detection of malignant tumors, for determining the stage of them and for following the effectiveness of the treatment.
4.4. The CT examination

4.4.1. Patient preparation for CT examination

Patient preparation for elective CT examination is the referring physician’s responsibility. Before and after the examination, the patient must be hydrated (with drinking plenty of fluids or with infusion) to avoid the influence of the injected nephrotoxic intravenous contrast agent. Intravenous contrast material will be administered only by the knowledge of renal function (serum creatinine, GFR), which will be verified in all cases by the radiologist too. Particular attention should be paid to high-risk patients or patients with chronic kidney disease.

Patients with impaired renal function get special (Iomeron, Visipaque) contrast material, for patients with very low GFR we give intravenous contrast material only in case of vital indication.

A contrast-enhanced CT examination takes place after four hours of starvation to avoid the contrast agent side effects (nausea, vomiting and aspiration).

If the patient anti diabetic medication contains metformin, it should be skipped before and after the test 48 hours to avoid the lactic acidosis, which may occur mainly in patients with impaired renal function.

The intravenous injected iodinated contrast material changes the serum levels of iodine by the iodine-containing drug-treated patients, so it can fake the control examination results.

Before the examination, we will tell the patient about the risks of the test, that will he acknowledge and justify by signing the consent form.

4.4.2. Examination technique

Each test includes two basic types of recording: the topogram (scout) and the tomogram (slice, layer).

All CT studies begins with a drift slicing picture, this is the topogram. The study region is included in this picture. In fact, this is a digital X-ray image, which can be taken from postero-anterior or from lateral side, depending on the part of the body which will be examined. We select the beginning and the end of the examination area. After that the tomograms - the transverse slices - will be prepared, of that part of the body.

The measurement parameters can be chosen from the opportunities offered by the computer, according to the clinical question and the examined region, but it is possible to prepare own protocols.

The tomography usually carried out in two series, first natively and after administration of contrast material.

4.4.3. By CT examinations applied contrast materials

A CT scan can be done natively, without introduction of any external material. However in most cases different contrast agents are used. We can get the contrast media routinely to the examination area one of two ways. For signaling the alimentary tract oral contrast material and for the better general tissue resolution achievement intravenous iodinated contrast media can be used, most commonly in a cubital vein. In most cases, we use injector for the intravenous application of contrast agent. The injector delivers the contrast material into the vascular system smooth, with constant, administered flow. In special cases we can use contrast media in other ways, such as through the rectum, or a tube into special anatomical region, or through an opening of a fistula.
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4.5. The clinical use of CT

Most common, routine CT examinations:

- Head CT (and / or CTA) scan (brain, bones, blood vessels)
- Neck CT (and / or CTA) scan (cervical soft tissue, lymph nodes, blood vessels)
- Facial CT scan (sinuses)
- Chest-CT (and / or CTA) scan (lung, mediastinum, great vessels, heart)
- Abdominal-pelvic CT (and / or CTA) scan (abdominal parenchymal organs, digestive tract, urography, abdominal blood vessels)
- Lower limb CT angiography
- CT-scan of bone (e.g. spine)

CT scan of the patient takes place commonly in the examination algorithms after some other imaging methods (X-rays, ultrasound) but in some cases it can be the first modality of choice (stroke, polytrauma, pulmonary embolism, suspected aneurysm rupture).

In all cases, the rules applicable to the study are that both written and pictorial documentation has to be prepared. The study design is based on the clinical question.

It is the radiologist competence to determine that, how "routine" is a study and how to implement the examination on the basis of the clinical question(s).

The task of the clinical doctors is to completely inform about the relevant clinical datas. For the radiologist doctor the examination-request paper and the review of the available clinical data are always essential. We can model our examination based on these facts so, that we can obtain the maximum amount of information with minimum charge for the patient in examinations supporting the clinical diagnosis.

For routine scans we usually use pre-written protocols, which will be tailored and optimized by the patient's individual endowments.

In some cases it may be sufficient to prepare only native series (e.g. consideration of fresh bleeding or urinary tract stones), sometimes we has to do an examination with more than one phase or other special way.

Arterial, parenchymal, venous and late phase images can be produced after administration of intravenous contrast material.

The high-volume, quick data collection allows mapping with various technical parameters even in body regions or even in the whole body, and even several different times after the intravenous administration of contrast material. So this quick data procedure creates the possibility of doing different types of examinations shortly after each other.

**Dynamic CT**: after the intravenous injection of the contrast material the same body region will be several times scanned, that means we detect the time course of the contrast enhancement (e.g. by the focal liver lesions).

**HRCT (high resolution CT)**: it visualizes thin layers with high resolution. The measurement time is longer and the radiation exposure is higher (e.g. examination of the lung parenchyma or focused investigation of the inner ear).

Three-dimensional (3D) images can be produced from the large amount of data.

Arterial CT angiography: the measurement is done by bolus detection at injection of the intravenous contrast material. The flow is high 4-5 ml/sec. In the selected altitude (location) the bolus detection may be done under the control of eye or it is possible to set up automatic bolus detection. The images of transverse slices are made by a software solution in 3D.
Venous CT angiography: with comparison of the arterial angiography more contrast material should be injected with slow flow (1.8-2 ml/sec). Due to the prolonged contrast enhancement automatic 3D representation is not possible; the different planar reconstructions are preferred. Virtual colonoscopy: instead of colonoscopy it is a CT-scan (with screening purposes, or if the endoscopic examination can not be performed); with this method we can diagnose cancers and pre-cancer conditions (polyps). Virtual bronchoscopy: a non-invasive assessment of bronchial structures (foreign body, tumor).

CT perfusion: with the help of time-density curves (perfusion maps) it is possible to determine by the acute ischemic stroke the Penumbra, the extent of brain tissue that can be saved. With the newest machines it is possible to do perfusion examinations in liver, kidneys and lung. These studies have advanced technical and personnel conditions, the assessment of them is more time-consuming than the average examinations.

The CT can guide invasive diagnostic procedures (FNAB, biopsy) and therapeutic interventions (drainage, RFA) also when it is not possible with ultrasound. In many cases the CT-guided biopsy can be carried out more accurately and safely, than the US-guided procedure.

4.6. Advantages and disadvantages of CT examination

The benefits of CT examination

The CT-scan - against the summation effect of X-ray procedures - has an excellent spatial resolution (better than MRI) and gives a good anatomical orientation. Contrast to the ultrasound the set of the sections is standard, it has a good reproducibility and it has the ability for cross-sectional imaging of the total body.

The contrast resolution, especially with proper contrast-enhancement techniques - except the magnetic resonance imaging - is over other imaging procedures. Based on the density measurements (Hounsfield-value) the individual lesions can also be ordered into different tissues.

Short examination time
The CTA takes out the diagnostic angiography.
Based on 3D images it is possible to design reconstructive surgery.

The disadvantage of CT examination

The greatest and almost only disadvantage of the CT is, that it uses ionizing radiation that is even multiple fold bigger than by conventional X-Ray examination (in some cases it can be 5-20 fold bigger). Compounded by direct and scattered (1-2 scale smaller) radiation exposure. In many cases the radiation doses suffered by the patient aren’t in the centre of attention in clinical doctors.
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4.7. Summary

The CT is one of the most effective methods in the diagnostic algorithms based on the great diagnostic accuracy, despite the considerable radiation exposure. The resolution can be further enhanced by application of contrast material. The examination time is short; it is possible to scan even the whole body in seconds that is a unique diagnostic ability.

Translated by Csaba Korom
5. Magnetic Resonance Imaging
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5.1. The educational goal of the chapter

The goal of this chapter is to provide familiarity in the field of magnetic resonance imaging (MRI) to the 4th year medical students at the University of General Medicine. With this knowledge they are expected, upon finishing as general practitioners, to properly understand the physical properties of MR imaging, in order to correctly refer patients for examination, to avoid dangers of contraindications and to understand the fundamental characteristics of images. Thus, when receiving a definitive diagnosis / patient report, they are ready to guide their patients' examinations and route.

5.2. Shortly about the phenomenon

Magnetic resonance imaging (MRI) is based on the detection of various magnetic properties of the protons of hydrogen atoms in the human body, when placed within magnetic field. Hydrogen is vastly abundant in our body (water, proteins and fat all contain hydrogen, and water makes up more than 70% of our body.) When paced in a strong external magnetic field, the unpaired nucleons (=1 proton) of these precessing hydrogen atoms arrange themselves parallel to the external magnetic field force. They behave like little dipole magnets, but each of them differ in their phase. When triggered by a specific radio frequency wave they resonate with them (excitation) and upon finishing these RF pulses they radiate (emit) energy (relaxation).

During relaxation the hydrogen protons, on one hand, tend to align in a specific direction, determined by the magnetic field (spin-magnet = longitudinal = T1 relaxation). On the other hand, their RF impulse generated uniform phase deteriorates (spin-spin = transversal=T2 relaxation, or also called phase decay).

The two processes occur independently from one another and they can be detected separately. The radio waves emitted by hydrogen protons are registered by a radio receiver, and a sophisticated computer records and analyses the signals coming from each point of the examined field. This set of data is then turned into an image by complicated mathematical algorithms (Fourier transformation.)

The external magnetic field varies in between 0.3-3 Tesla field strengths. The radio frequency pulses used for excitation can either be 8 – 64 – 128 MHz. Therefore, the image acquired, is basically a hydrogen- or “proton map” (= areas where there is only a little amount / no hydrogen is present, little / no signal is registered: e.g.: air / cortical of the bone.)

Until today, we consider the energy and the magnetic environment harmless or without any bio-negative effect on the human body: it is repeatable and has no proven direct effect on the fetus either. (The magnetic filed strength is measured in units of Tesla (T), and its diagnostically accepted limit is up to 3T.)
5. Magnetic Resonance Imaging

5.3. Basic concepts in MRI

5.3.1. Magnets used for MRI examination

To achieve the phenomenon of nuclear magnetic resonance and to carry out the examination the magnet is required to have a sufficiently strong magnetic field, and has to have an opening big enough to house the inserted body part.

Types of magnets

- Permanent or stable magnet (like a huge horseshoe magnet)
- Electromagnet (two types):
  - Resistive magnet (huge energy consumption, used infrequently)
  - Superconductive magnet (its internal metallic spiral is an excellent conductor, but its external cooling system (liquid helium) also provides (additional) superconductivity as well)

5.3.2. Coils or radiofrequency antennas

They radiate the radiofrequency pulses for excitation and they also receive the signals emitted by the examined material (patient).

These two functions can also occur separately, for instance, a body coil works as the transmitter, and a superficial antenna as the receiver. The latter is used in imaging smaller anatomic regions in greater resolution.

5.3.3. Signal localization, the production of the MR image

The external magnetic field has to be slightly adjusted by additional magnets. These magnets need to tune the magnetic field gradually, so that protons in adjacent slices become distinguishable from one another, based on their resonance sequence differences. If we perform this “fine tuning” in all the three planes of space (x, y and z plane) then we are able to localize the position of certain protons.

The signal intensity measured in one voxel is determined by various factors, such as the amount of protons in the volume, the type of chemical bonds they have and their environmental relationship with other molecules. These effects sum up in the net signal intensity and are projected to a pixel (image element defined by line/ column coordinates), which in turn represents the signal information of the whole depth of the voxel (slice thickness.)

More image elements + thinner slice thickness = better spatial resolution, but also decreases the signal/noise (S/N) ratio. More acquisition can enhance S/N ratio, but on the other hand, it increases examination time.
5.4. Concepts used in MRI

**T1 relaxation**: is the rebuild of the original longitudinal magnetization, after the radiofrequency pulse is turned off, as the direct effect of the external magnetic field. This occurs along an exponentially growing (build-up) curve.

**T2 relaxation**: is the disintegration of the phase synchronizing effect of the radiofrequency pulse (phase decay). It is described by an exponentially decreasing curve. (It happens faster by one order of magnitude than the T1 relaxation time.)

**The technical concepts of MR measurement**

TR or repetition time: is the time interval between radiofrequency pulse repetitions.
TE or echo time: is the point in time at which the signal is registered during T2 relaxation. In a spin echo sequence it is the interval between two echos.

**Base sequences:**

Spin echo sequences:

T1 weighted (T1W) image: TR and TE are short. (TR = 700 ms, TE = 20 ms). Characteristic signal intensities: water is mild, fat is very intense, muscle is medium intense, flowing blood has no signal (black).

T2 weighted (T2W) image: TR and TE are long. (TR = 2000 ms, TE = 80 ms). Characteristic signal intensities: fat is weak, water is very intense, the signal intensity of other tissues is determined by their water content, flowing blood is still signal free.

Proton density (PD): TR is long, TE is short. (TR = 2000 ms, TE = 30 ms). The signal intensity is determined by the number (density) of the protons in each tissue. There is a rather small difference between the intensities of the various tissues, all appear in shades of grey. Bound water has a stronger signal than free water. Flowing blood is still signal free.

Certain tissues with strong, sometimes disturbing signal intensity can be suppressed specifically:

Fat suppression is achievable with STIR (Shot T1 Inversion Recovery) DIXON, FatSat and fat suppression gradient echo sequences.

Specific suppression of free water is also possible (e.g.: cerebrospinal fluid) with FLAIR (Fluid Attenuation Inversion Recovery) sequence.

The so called **fast sequences** are used to decrease acquisition time (= imaging time for a certain sequence).

The knowledge of certain tissue signal intensity characteristics is essential in MR image “interpretation” and differential diagnostics.

**Hyperintense tissues on T1 weighted imaging are**: fat, high protein content (cysts), certain hemorrhages (subacute or chronic (intra- or extracellular methemoglobin), melanin (in tumor tissues); slow, turbulent and peripheral blood flow phenomenon, paramagnetic metallic deposits (iron, copper, manganese – Wilson’s disease), certain cases of dystrophic calcifications, paramagnetic contrast material (Gadolinium).

The different stages of hemoglobin decomposition have such characteristic intensities on T1 and T2 weighted images, that the age of a hemorrhage or re-bleeding can be indentified.
5. Magnetic Resonance Imaging

5.5 Some MRI examinations:

**MR angiography (MRA)**
Flow void phenomenon: flowing blood, within the crossected vessels in the examination slice, will be signal free. This happens because blood that gets excited by the RF pulses will move out of the imaging slice at signal registration, and it will be replaced by non-excited blood. Therefore, blood vessels in Spin Echo sequences will be highly distinguishable due to this signal void.

**Angiographic techniques:**
- **Time of Flight (TOF)** is the time it takes for flowing blood to pass through a slice. With the use of very short repetition time, blood vessels will show very high signal intensity. (Fast acquisition is provided by a GRE sequence).

- **Phase contrast technique (PC)** relies on the fact that the flowing spins lose their phase (desynchronize) faster than stationary tissues. Its advantage is that it can measure flow velocity as well.

**Magnetic resonance cholangiopancreatography (MRCP)**
With the use of fast sequences (strongly T2 weighted images), all intra- and extrahepatic biliary tracts and pancreatic ducts can be depicted within one breath hold of time, due to their relative stationary fluid content. It is extremely useful to visualize stenotic lesions, caused by tumors, in a non-invasive fashion, together with their environmental state (hepatic infiltration, lymph node metastases).

**MR Lymphography**
With the help of an iron-oxide containing nanoparticle sized contrast material, USPIO (<50nm), it is (would be) possible to distinguish metastatic lesions in lymph nodes. On T2* weighted images, normal lymph nodes have no signal intensity (because macrophages in normal conditions phagocyte iron deposits.) Whereas metastatic lymph nodes on T2* weighted images appear hyperintense, due to their high water content (necrosis) and because they do not enhance this contrast material. (Unfortunately this contrast material is extremely expensive at the moment.)

**Special MR sequences:**
Ultrafast acquisition techniques optimize the tissue specificity and sensitivity of MRI without decreasing spatial resolution.
It is now possible to assess functional, diffusion and hemodynamic parameters. Special MR sequences are able to calculate hemodynamic and metabolic changes in both normal and pathologic organ functions.

**Functional MRI:**
It is able to measure and characterize tissue hemodynamics as well as water mobility/diffusion (it is sensitive method and an early detector of cytotoxic edema.) It can distinguish signal intensity from oxygenated and deoxygenated blood (functional exams). It can assess normal and pathologic tissue status, therefore characterizing metabolic abnormalities, already pushing the boundaries of molecular imaging.
**Magnetic Resonance Spectroscopy (MRS)**
It is able to identify certain metabolites in tissues, in the living (in-vivo.) MRS is very valuable in the differential diagnostics of tumor and inflamed tissues (brain: N-acetyl aspartate, cholin, lipid – glioma vs. abscess) and also for tumor residue / recurrence vs. scar tissue differentiation (prostate tumor – citrate/ cholin).

### 5.6. Artefacts

Their occurrence should be considered when indicating MRI examinations, informing our patients and when producing or evaluating MRI exams.

Metallic artefacts: various clothing, implanted metals, metallic clips used at laparoscopic cholecystectomy, adrenal surgery (proximity of the inferior cave vein!), even cutaneous ferromagnetic materials (tattoos) can distort the magnetic field and decrease or even damage image quality to a state that they are impossible to interpret. The loose magnetic metallic objects (clips) can move/fly from their places endangering the patient.

Motion artefacts: Voluntary or involuntary motion also cause artifact. Certain image distortions, by periodic or rhythmic movements can be expected to occur, and if considered upon the examination, some can be avoided or reduced.

There are several other types of artefacts such as susceptibility, flow, chemical shift and aliasing artefacts. Truncation artefact, burn out artefact and artefacts caused by static electricity and even crossed excitation can occur and distort image quality.

### 5.7. Cardiac motion artefacts are avoided by ECG gating.

#### 5.7.1. ECG-gating

The ECG electrodes have to be made of special metallic alloys and the wires need to be placed in a fashion that induction loops are not produced. At regular cardiac rhythm, the radiofrequency pulses can be synchronized with the ECG “R” waves.

#### 5.7.2. Breath gating

To avoid breathing related motion artefacts, breathing gated synchronization is possible. Measurements, taken at the same breathing phase (end expiratory), assure the reproducibility of and exclude most of the breathing related artifacts. It is a reliable technique, although this method considerably extends acquisition time.

### 5.8. The biological effects of MRI examination:

3 types of radiation affect a person during an MRI examination:

- static magnetic field (external magnet)
- non-static (changing) magnetic field (gradient coils induce electricity in the body)
- radiofrequency radiation (“microwave” effect, the body heats up during the examination) Radiofrequency energy doses are automatically measured by the machine and any errors are noted.
5. Magnetic Resonance Imaging

It should be considered that the lens of the eye and the testicles are less resistant to heat effects. It is also known that in sedated states warming up is greater (especially in children), therefore more attention should be paid to the energy absorbed. It has to be assured that certain organ temperatures remain under:

- Head 38 0C
- Trunk 39 0C
- Extremities 40 0C

5.9. Contraindications

The knowledge of absolute and relative contraindications is essential for the ordering physician; the neglect of these can have more severe consequences than in other examinations.

It is FORBIDDEN to even get to the proximity of an MRI machine for persons with pacemaker. The examination can severely affect the integrity and the functionality of any electronic, metallic or mechanically operated machines built in the body. (These include implanted pacemakers, heart defibrillators, hearing devices, implanted bone growth inducing machines, implanted drug releasing devices, neuro-stimulators and similar products.)

The dangers for pacemaker: movement, turning on or off, reprogramming, desynchronization, electromagnetic interference, induction of (Eddy) current in the electrodes can all occur due to the effect of the magnetic field. It is important to know that even a left-over electrode from a pacemaker is capable to cause fibrillation or burning effects.

Implants: if they are made of ferromagnetic materials they can heat up, electricity can be induced within them or in their surroundings. They can leave their place, electric arches can occur between them producing metallic artefacts. Aneurysm-, vessel clips, orthopedic or traumatology metallic objects, filters in veins, intrauterine devices, and certain artificial heart valves can be regarded as such implants. The above mentioned dangers are also influenced by the strength of the magnetic field and the gradients used in the MRI machine and by certain characteristics of the implants (composition, ferromagnetic properties, shape, place, orientation, and time passed since the implantation.)

Metallic foreign bodies: patients often do not even know or remember to mention that they have ferromagnetic material in them (blast injuries in molding or metallic polishing workers). These are usually dangerous if localized intraorbitally, intraocularly or when placed close to the spine. A fast orientation with CT examination is usually the way to go, before MRI. (We do have to remember however, that x-ray is not sensitive enough in cases of small metallic bodies or ones close to bony structures.)

MRI examination during pregnancy

During early fetal life, physical effects are more likely to affect cell division negatively, therefore in early stages of pregnancy (1st trimester) MRI is not advisory, unless unavoidable (although, direct fetal damaging effect, has not yet been proven.) At later stages (2nd and 3rd trimester), it is suspected that noise from the MRI machine can cause auditory damage and the conductive cooling of the amniotic fluid is not a match against the heating effects of MRI.
5.10. MRI contrast materials:

They help the differentiation of normal and pathologic tissues. Differences between tissue signals can be pronounced in a way, that signal intensity change of an enhancing tissue results in the increase of tissue contrast. It is either done by increasing tissue signal intensity or by suppressing the detectable signal of another tissue.

Specificity levels are different for contrast materials. We differentiate organ-, tissue-, cell- or receptor specific contrast agents.

Contrast materials used in MRI are fundamentally different in physical nature than contrast agents used in other imaging modalities.

The MRI contrast agent selectively alters the inner magnetic properties of the protons of the enhancing tissue compared to its surroundings. Its tissue-specific distribution in healthy and damaged tissues creates a concentration gradient that further increases these contrast differences.

Contrast materials do not have hydrogen atomic nucleus, they affect the nuclei of hydrogen atoms found in their surroundings. They can either have paramagnetic (T1 shortening) or superparamagnetic as well as ferromagnetic (T2 shortening) properties.

5.10.1. Paramagnetic contrast agents:

We generally use Gadolinium Gd3+ (and Manganese, Mn2+) based contrast material, where the metallic ion is bound to a chelate frame. They induce small local magnetic field changes in tissues and therefore decrease their relaxation times (T1 and T2). In practice, we utilize the T1 relaxation shortening effect for contrast creation.

Gadolinium is a rare earth metal. After intravenous administration it distributes in the blood evenly and stays in the extracellular space in the organs for a certain time, after which it is excreted through the kidneys. In pathologic tissues, (inflammation, tumor) its concentration increases, causing a hyperintense T1 signal. It is unable to cross the intact blood-brain barrier.

5.10.2. Superparamagnetic and ferromagnetic contrast materials:

Iron (SPIO = Superparamagnetic Iron Oxide and USPIO = Ultrasound Superparamagnetic Iron Oxide) and also the isotope of O17, strongly decrease T2 relaxation times by creating a local magnetic field inhomogeneity at the tissue (while minimally affecting T1 relaxation.) Therefore, they produce strong SI (signal intensity) decrease on T2 weighted images. In the intact tissue they accumulate intracellularly (RES – reticuloenothelial system cells). Focal spleen lesions, diffuse spleen lymphoma, hepatic tumors and hepatic metastases can be visualized by these contrast agents. The viscosity and osmolality of contrast agents are adjusted to tolerable levels, upon preparation. Bio-distribution of the contrast material is influenced by the kinetics of distribution, clearance and excretion.

5.10.3. Organ specific contrast agents:

Organ specificity is a natural requirement. Intensive research is ongoing to produce even more organ specific contrast materials. Organ- and tissue specificity of paramagnetic contrast materials depend on their carrier agent.
5. Magnetic Resonance Imaging

5.11. Summary:

MRI is able to distinguish normal and pathologic tissues from one another with its remarkable tissue characterization properties, which can be further enhanced by the use of contrast materials. Further, highly sophisticated examinations (MRS, fMRI) are also part of the MRI realm. In order to correctly indicate MR examination, the clinical practitioner has to be fully aware of its advantages as well as the limits and the contraindications of MRI.

Figure 1.: T1W image: (brain, sagitta slice, arachnid cyst)

Figure 2.: T1W image + iv. contrast material (enhancement is seen in the right ponto-cerebellar angle: Schwannoma.)

Figure 3.: Metal artefact

Figure 4.: Proton density, SM
Figure 5.: T2 subacute infarction

Translated by Balázs Futácsi
6. Digital Imaging

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6.1. Introduction

In radiological imaging, spatial distribution of physical quantum converted to visible image. This quantum can be the absorption of X-ray in different tissues, reflection of the ultrasound waves from the tissue borders, or the distribution of radioisotopes in the body. This quantum and their distribution have to be converted into visible images with different transformations to be used in diagnostic radiology.

6.2. Image recording

In diagnostic radiology, the generated information can be recorded in two ways, the analogue and the digital mode. In analogue technique, the physical sign, containing the information (the X-ray absorption, ultrasound wave reflection, radioactive isotope distribution), is observable transformed to visible light, or viewed after fixed in chemical way.

Analogue images in nowadays are only used in radiography. They could be snapshots, made on film, or dynamic examinations, when – in fluoroscopy – the x-rays are amplified with an image intensifier, and they are visualized on a display. With this technique, we can examine the processes in real time (for example we can image the progress of the contrast material through the esophagus during swallow fluoroscopy).

In digital imaging, the physical signals transformed into electric impulses, and after it, these signals are recorded in the computer’s memory as digital codes.

6.3. The digital image

The basic element of the image is the pixel. The pixels can be imagined as little squares arranged in a grid, and they seem to points, because of their size.
Every pixel is a sample of an original image. The more samples are taken, the more, and lesser size pixels can obtained, and the higher resolution and accuracy reached.

The pixel is defined with three data. Two are the coordinates; they locate the pixel in the grid. The third data is the real information, in color images, it represents the color, or on grayscale ones, it represents the intensity. One pixel can only represent one color at once. The bitrate or color depth shows the maximum number of the different colors, the pixel can display. The higher bitrate allow more colors, and more accurate images, but the image files are also will be greater size. The color depth is measured in bits. The bit is the basic unit of information, and it represents a positional notation in binary numeral system. Its value can be 0 or 1 (two bits’ combinations are: 00, 01, 10, 11, i.e. 22 or 4 combination is possible.) The 1-bit color depth means two colors, black and white. The 8-bit color depth can express 256 (28), the 16-bit color depth can express 65536 (216) different colors.

In radiology grayscale images are used usually. The color depth of these pictures represents the intensity that how many gray tones are taken by a pixel.
6. Digital Imaging

Figure 2: The same picture with different color depths. a: 4 color – 2 bit, b: 256 color – 8 bit, c: 65536 color – 16 bit

The numeric data of coordinates and color are exactly defining the image. The images can be visualized on the computer’s display, and with the proper software, the findings can be described, and image manipulating can be applied subsequently.

In nowadays’ radiology, digital images are used in every modality practically. The CT and MR are unimaginable without digital technique, because in these modalities the images are generated with a vast number of mathematical calculations, which are cannot be processed without a computer.

Two different methods are known in digital imaging, the direct and the indirect recording. In direct method, the pictures are created directly. In the indirect method, the pictures created in analogue mode first, and after it, the analogue medium is digitalized subsequently, for example the photostimulable phosphor plate (PSP plate) technique, or the subsequent scanning of films.

6.4. Post processing

After a digital image created, it is possible to change the images’ parameters. The most important and basic is the possibility of altering the brightness and the contrast. The contrast in radiography is the difference between two adjacent pixels’ intensity. The more difference between these intensities, the more the structures can be separated sharply.

The brightness of the picture is also can be changed subsequently, so the too dark or too light parts of the picture can be made visible and examinable. The windowing allows changing the brightness and the contrast at the same time. If we change them appropriately, in the picture, the tissues with different absorption can be highlighted. For example, low brightness and low contrast allows visualizing the bone structures well, and the other tissues are moderately pale. High brightness and contrast are result the lung tissue to be visualized well and the other tissues are bright and pale.
Digital images can be rotated and zoomed easy on the display. We can measure distance or specify relative density, which allows assigning the type of the tissue with ease. Reconstructions in arbitrary planes (MPR - Multi Plane Reconstruction) or 3D reconstruction can also be made from the axial CT and MR images. These reconstructions allow judging the lesions more accurate. For example, the 3D reconstructions of the digestive system, the cavity of the bowels can be visualized from the inside, like an endoscopic examination, but without the invasiveness of endoscopy.

6.5. Advantages of digital imaging

Digital images can be viewed instantly, no need of any photographic processing. The sensors have a wider dynamic range than the analogue film, and this enables the correction of the exposure. The under- or over-exposed images shouldn’t have to be repeated, so the patient’s radiation is reduced.
6. Digital Imaging

Post processing, like the magnifying, measuring, windowing, or the 3D reconstruction is easily applied on the images viewed with special software on the computer. The images can be stored digitally, and can be viewed from more computers in the same time, they can be sent over the internet or the hospital network to other departments, so the consultation becomes easier.

Infinite copies can be made without the loss of quality.

The produce and store of the images are significantly cheaper, and the retrieval of archived pictures is easier, they became available instantly.

The processing chemicals and the films are very polluting. They can be ignored in digital radiology departments.

6.6. Disadvantages of digital imaging

Installing the imaging equipment, workstations, radiological displays, servers, networks is very expensive, so establish a new labor is a large investment, and it will profitable in a long-term period.

We have to count with different errors from analogue technique. Such errors came from the information technology, for example: virus protection, power failure, network overload.

The image processing requires a great experience, because the not properly manipulated images can imitate pathological processes.

6.7. Digital image transmission, hospital networks

The intention of digital transmission and storage is to access the images on any graphical workstations on the network and the pictures and the information of every digital modality can be retrieved any time from the archives. A unified format is required to the transmission and the storage in order that the images made with different machines are displayed the same on every computer, and be comparable. Therefore the radiology associations and the medical companies developed the DICOM (Digital Image Communication in Medicine) standard. This standard is handling the images from all modalities unified. In nowadays, this standard is used in every radiology departments in the world. The technical conditions required handling and storing the digital images, are provided by the PACS (Picture Archives and Communication System).

The RIS (Radiological Information System) is planning, organizing and controlling the radiological services. The RIS assigns the radiological patient data (findings, examining parameters, and contrast material) with the images stored on the PACS, so all radiological data stored on the RIS.

The HIS (Hospital Information System) integrates the patient data and the administrative, the economic, and the financial aspects of the clinical activity, so it provides all informatics task. With HIS, we can assign the data on the RIS with the patient’s other data (medical chart, specialist examination, laboratory findings).

These information systems (PACS-RIS-HIS) requires a sufficient network and the unified communication between the different databases.
6.8. Summary

In modern radiology, the digital imaging is displacing the analogue techniques. The easy handling, the better image quality, and the wide variety of post processing methods help the radiologist in everyday work. The opportunity of reaching the radiological images beside the clinical data on the HIS is also very helpful to the clinical doctors as well, ultimately the more effective medical work.

Translated by János Norbert Gyebnár
In this chapter the main characteristics of the radiographic contrast media (or contrast agents) are introduced to the medical students. It is important for a future doctor to be familiar with the types, classifications, indications, contraindications and side effects of radiographic contrast media.

I. What is a contrast medium?

Contrast medium is a substance in medical imaging that modifies the detected signal by enhancing the contrast of structures within the body. Legally contrast medium is a pharmaceutical drug.

II. Why is a contrast agent required?

Radiocontrast - used to improve the visibility of internal bodily structures in an X-ray based imaging techniques – can increase or decrease the density of the given structure. Ultrasound contrast agents enhance the reflection of ultrasound waves by increasing the number of acoustic interfaces. MR contrast agents alter the relaxation times of tissues in which they are present. Using contrast agents the contrast of the medical image is increased which enhances the visibility and improves detection. Both static and dynamic images can be made during contrast examination. Static image (i.e. radiographic film) provides morphological information, while continuous monitoring during contrast administration provides additional functional information beside morphology (i.e. barium swallowing). In tomographic imaging (CT, MR) images are made at different phases after contrast administration, which provide information about contrast enhancement of a given organ or mass in function of time helping differential diagnosis.

7.2. Classification of contrast media

1. Radiocontrast

a.) Positive contrast media

A positive contrast agent means that it absorbs more x-ray than the surrounding tissue. Today’s contrast agents are mostly positive, and their further classification is based on their physical characteristics.

- Iodine-based, water soluble contrast media
Medical Imaging Diagnostic Gradual English

- Nephrotrop, ionic contrast media

Ionic contrast media have higher osmolarity (above 1000 mOsm/kg), they are excreted by the kidney, and cause more side effects, therefore it is not in use intravenously anymore, however, it is used for enterography routinely. Due to its hyperosmolarity ionic contrast media exert laxative effect. (In adhesional ileus they also might have therapeutic effect.) Fractionated iodine-based, ionic contrast medium is given orally in certain abdominal CT studies to differentiate bowels from other structures, for example abscesses.

- Nephrotrop, nonionic contrast media

Ionic contrast media are hypo- (290-800 mOsm/kg) or iso-osmolar (290 mOsm/kg) compared to blood. These types of contrast media are also excreted by the kidney. They are generally used for intravenous and intra-arterial administration because they are safer. They causing fewer side effects, their nephrotoxicity are less common, which are not related to their osmolarity, but the single molecules’ nephrotoxicity.

- Hepatotrop contrast media

Intravenously administered contrast agents, which are excreted by the liver, therefore they are able enhance the biliary system. In Hungary they are not registered as a clinically used contrast agent.

- Iodinated, oily contrast media

Recently these oils are used for chemoembolization of certain tumors.

- Non-iodinated contrast media

Most frequently used non-iodinated contrast agent is barium sulphate. It is can be used orally or rectally, as a suspension of fine particles in aqueous solution. Barium-sulphate is insoluble in water, and if it gets into the peritoneal or mediastinal cavity it can lead to barium peritonitis and mediastinitis respectively. In case of aspiration it can cause pneumonitis. For these reasons, using barium is contraindicated in suspected bowel perforation and in patients at risk for aspiration.

b) Negative contrast media

Negative contrast agent means that it absorbs less x-ray than the surrounding tissue: air and carbon-dioxide are most frequently used. Air as a contrast agent is used mostly in double-contrast barium enema, in which procedure barium is administered rectally, followed by air injection.
2. MRI contrast agents

MRI contrast agents cause changes in local magnetic fields by inducing proton relaxation time shortening. According to their physical characteristics intravenous MRI contrast agents can be classified into the following two major groups.

a) Paramagnetic contrast agents

Paramagnetic contrast agents shorten T1 relaxation time of the protons. Gadolinium, a rare-earth metal, is the most commonly used paramagnetic contrast agent. Gadolinium as a free ion is highly toxic, therefore stable chelated gadolinium compounds, which is generally regarded as safe, are used in medical imaging. Apart from the gadolinium-containing contrast agents there are other, so-called organ- or tissue-specific contrast agents containing other metallic elements.

b) Superparamagnetic contrast agents

Superparamagnetic contrast agents reduce the T2 relaxation time of the protons in absorbing tissues.

Similarly to abdominal CT, the enhancement of the gastrointestinal tract with oral contrast medium might be necessary during MR examination. A wide variety of oral contrast agents can be used for enhancement of the gastrointestinal tract, which includes manganese chelates, iron salts and natural products with high manganese concentration such as blueberry juice and green tea.

3. Ultrasonic contrast agents

A contrast agent can be applied also during ultrasound examinations, although their usage has not been worldwide spread. Commercially available contrast media are gas-filled microbubbles that are administered intravenously to the systemic circulation. Microbubbles with their high degree of echogenicity increase the number of acoustic interfaces in the examined region leading to ultrasound wave reflection. Thus, tissues with high contrast accumulation become whiter, so-called hyper echoic on B-mode images.

7.3. Side effects of contrast agents and treatment of adverse reactions

Legally contrast media are registered as pharmaceutical drugs, so thus they might cause side effects and adverse reactions. Their clinical use is regulated strictly. Not only radiologists, but also the referring physicians must be familiar with contraindications of the contrast agents.

1. Oral contrast media

Oral contrast media are classified by their water solubility:
- Insoluble: barium sulphate

Barium contrast administration is contraindicated in suspected bowel perforation and in patients at risk for aspiration.

- Soluble: iodinated contrast media

Due to their hyperosmolarity they exert laxative effect, and have to be used with caution in dehydration and in patients with electrolyte imbalance.

2. Intravenous contrast agents

- Radiocontrast

One of the adverse effects is extravasation at the intravenous injection site. Small amount of extravasation causes mild local pain, however, larger amount might lead to necrosis or compartment syndrome, both of which urges surgery. Extravasation is avoidable by careful manual injection; however, modern injectors are stopped automatically by sudden pressure elevation.

After injection early and delayed adverse effects might develop. Their severity range is from a mild inconvenience, such as itching to life-threatening emergency, such as laryngeal edema and hypovolemic shock. Delayed adverse reactions include contrast-induced renal impairment and thyreotoxic crisis.

All contrast materials might cause allergic reactions (e.g. itching, urticaria, diarrhea, flush, skin redness, nausea, vomiting and anaphylaxis). It is important to report which contrast material evoked the adverse effect. If a patient is proved to be sensitive to a given contrast agent, other type of contrast agent can be administered with precaution.

Modern contrast agents are excreted by the kidney, which put extra load on the kidneys. Thus, in non-urgent cases renal function has to be checked prior to intravenous contrast administration (serum creatinine, GFR). In impaired renal function (30<GFR<60) the use of iso- or hypoosmolar contrast is mandatory. In patients with GFR under 30 it is recommended to avoid intravenous iodinated contrast administration, or to refer the patient to other medical imaging modality.

Before intravenous contrast administration metformin and certain antibiotics which are excreted by the kidney should be stopped temporarily. In patients with normal renal function metformin should be stopped the day of the procedure, and you should not restart the medication until at least two days after the procedure. In patients with impaired renal function withholding administration of metformin for two days before and after administration of an intravenous contrast agent is generally recommended. Patients should be kept well hydrated before receiving the intravenous contrast agent.
In untreated hyperthyreosis, the administration of iodinated contrast material is contraindicated, since it might lead to thyreotoxicosis 3-5 days after the study. Treated hyperthyreosis does not contraindicate these studies.

In pregnancy contrast administration is generally not recommended. However, in emergency situations contrast administration might become truly necessary. In these cases, all neonates exposed to iodinated contrast in utero should have their thyroid function tested in the first week of life due to the theoretical risk of contrast-induced hypothyroidism.

- MR contrast agents

Gadolinium MRI contrast agents have proved safer than the iodinated contrast agents. Anaphylactic reactions are rare, but might occur similarly to X-ray radiography and computed tomography. There is a risk of a rare but serious illness called nephrogenic systemic fibrosis that has been linked to the use of gadolinium-containing MRI contrast agents. Although its pathophysiological background is unknown, renal impairment carries a risk of its development. For this reason contrast MR is contraindicated in patients with GFR under 30 and in children under the age of one year.

**Take-home points**

- Legally contrast medium is a pharmaceutical drug; therefore it has contraindications and might have side effects.
- Barium sulphate, an insoluble oral radiocontrast, is contraindicated in suspected bowel perforation and in patients at risk for aspiration.
- Kidney function has to be checked prior to intravenous contrast administration. In hyperthyroidism the thyroid function has to be checked before a iodinated contrast study.
- It has been recommended that all drugs which are excreted by the kidney be stopped temporarily before intravascular administration of contrast media.

Translated by Zsuzsanna Lénárd
8. Cardiovascular imaging

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8.1. The heart

8.1.1. Developmental abnormalities

Echocardiography plays a decisive role in the imaging of the vast and widely complex field of congenital heart diseases. Its value is further increased by the fact that this harmless examination is safe to perform in the primarily involved age group, newborns and infants. Many of the congenital heart anomalies lead to left-to-right shunts in the form of atrial and ventricular septum defects, or patent ductus arteriosus and pulmonary vein transposition. The shunt leads to a state where the right side of heart and the pulmonary circulation suffers a volume and pressure increase and their signs can be detected on chest radiographs.

One of the fundamental questions of the primary diagnostics and the postoperative control examinations is to assess cardiac chamber and valvular morphology. Their other main concern is to determine the cardiac functional status. It is essential to demonstrate precisely, for the success of reconstructive surgical procedures, which are at many times multi-step interventions, how the ventricular myocardial volume and functionality are, including the individual (split) functional parameters of the left and right ventricle. These sophisticated requirements can be best investigated with MRI. MRI is also able to quantify the blood volume flow in the great vessels, the shunt volumes between the circularity sides and the function of the cardiac valves. With complementary MRA examination, the accompanying abnormalities of thoracic vessels can also be revealed.

8.1.2. Primary cardiomyopathies

Hypertrophic cardiomyopathy most often involves the inter-ventricular septum of the heart. The involvement can be asymmetrical, more pronounced on the left side and patients demonstrate an obstruction to the outflow of blood from the left ventricle. With US examination it is relatively easy to detect the uneven thickening of the subaortic septum and the consequent obstruction. MRI examination, besides the detection of the left ventricular morphological and functional disorders, is able to depict the degenerative processes occurring in the myocardium.
Fig.1., 2.: Hypertrophic obstructive cardiomyopathy: Longitudinal and short axis slices of delayed enhancement of contrast material in the heart: pathologic enhancement is visible in the myocardium in the asymmetrically thickened left ventricular wall, referring to a degenerative-fibrotic process.

In case of dilated cardiomyopathy the enlargement is visible in the ventricles. The wall becomes thinner and the pump function becomes impaired, leading to the decrease of the ejection fraction. Most commonly it is caused by coronary diseases, but metabolic diseases, inflammatory processes and toxic damage can also be a cause. The cardiac morphology and function is well assessable with echocardiography, while MRI can play a role in the differential diagnostics. Arrhythmogenic right ventricular cardiomyopathy and non-compact cardiomyopathy can only be diagnosed with MRI examination. It is usually necessary to perform when patient presents with recurring, equivocal arrhythmias. In cases of Tako-Tsubo cardiomyopathy the base of the left ventricle shows a circular hypertrophy, while the apex appears normal. In rare instances the disease can present in a reversed distribution. Echocardiography is considered the primary examination, while MRI is only complementary.

8.1.3. Myocarditis

MRI examination is able to detect the direct signs of edematous-infiltrative changes in the myocardium. Moreover, after contrast administration with a delayed image acquisition, it is able to depict irregular and increased contrast enhancement and differentiate it from ischemic damage, which shows a subendocardial distribution.

8.1.4. Ischemic heart disease

The role of diagnostic imaging of ischemic heart disease is to demonstrate the obstructive and congenital anatomic abnormalities of the coronary system. Moreover, it has to assess myocardial damage and its consequent functional impairment. Furthermore, it has to inform about the complications of myocardial infarction and assist in the planning of surgical or interventional therapeutic procedures and finally it needs to be able to evaluate the efficacy of these treatments.

The traditional imaging modality of the coronary vessels is cardiac catheterization (coronarography) and it still has an absolute indication in acute coronary syndrome. During the examination not only the identification of the symptom causing stenosis or occlusion (culprit lesion) can be done, but it is also possible to perform dilatation with a balloon catheter or to restore flow with stent implantation.
If either of these procedures is carried out within 6 hours of symptom onset, myocardial dearth can be avoided, or it is possible to achieve a radical reduction of its size. Coronarography of patients with stable angina is only recommended if a high risk of coronary disease persists clinically. CT coronarography can replace cardiac catheterization in low and medium risk patient groups who present with angina-like chest pain. The examination has a very high sensitivity and negative predictive value for coronary disease; therefore it is a sensitive screening tool for patients who present chest pain as a symptom of coronary stenosis. Moreover, it can provide alternative diagnoses for chest pain syndromes. CT examination is not only good in representing the vascular lumen, but it is also capable of sensitively detecting possibly vulnerable plaques showing a special morphologic appearance; a lipid rich composition. These lesions might remain hidden for coronarography, producing false negative results with regard to an existing significant atherosclerotic involvement.

Myocardial ischemia causes ventricular wall motion abnormalities, which in latent ischemia only appear with provocation. Ischemia induced cardiac hypokinesia and akinesia can be sensitively detected with stress echocardiography or with MRI. Coronary stenosis related angina is caused by the decrease in myocardial perfusion. This can occur in resting states, but can be reliably demonstrated with stress tests. Traditionally, perfusion evaluation is carried out with radionuclide examinations: either 99mTc-sestamibi SPECT scan or even PET examination is able to detect perfusion anomalies. MRI examination, carried out with complementary pharmacological stress examination, can also prove to be sensitive with this regard.

If the diagnosis of coronary disease has already been established, then imaging is used to examine the viability of the myocardium. This is an important influencing factor, because either of the revascularization techniques is only expected to create a significant improvement in the ventricular function if the recanalized myocardial territory shows viability in at least 50% of its wall thickness. Viability can be assessed with isotope examination, CT or MRI. With MRI, on the delayed contrast enhanced images (5-10 minutes after iv. injection) the non-viable territories or scar tissue show characteristically increased enhancement; and they are easily distinguishable form viable myocardium. The wide-spread use of MRI in cardiac viability assessment is further justified by the fact that it does not necessitate the use of ionizing radiation. Moreover, with only one diagnostic session it still provides the best anatomic and functional analysis, demonstrates the functionality and the state of the myocardium and myocardial viability.
8. Cardiovascular imaging

Fig.: 6., 7., 8.: MRI: Extended myocardial infarct of the inferior ventricular wall Late phase contrast enhancement in the thin inferior wall of the ventricle in cross sectional and longitudinal images, MRI

Echocardiography can be used for the detection and the follow-up of complications of acute myocardial infarcts. Its great advantage, compared to other modalities, is that it can be performed as a bedside examination, at any time and repeated as often as it is necessary. It can sensitively analyze the state, the function and the wall motion abnormalities of the left ventricle. The papillary muscles and any septum rupture are also detectable with it. Moreover, echocardiography is sensitive for the detection of aneurysms, intramural thrombus or for the appearance of pericardial fluid collections. Chronic and stable patients can normally be controlled with MRI, which in turn provides detailed information.

8.1.5. Valvular diseases

Indirect signs that indicate valvular abnormalities can be identified by traditional chest radiography examinations. In aortic insufficiency a pronounced expansion of the left ventricle is seen, while the aortic arch appears widened and elongated. In mitral insufficiency both the left atrium and ventricle are enlarged and pulmonary edema is frequently present as a result of left-sided cardiac failure. In mitral stenosis the left ventricle appears smaller while the left atrium and the auricle are both expanded. There is also an elevated pulmonary pressure and congestion. Furthermore, in more advanced cases of mitral stenosis, an increased arterial pressure and the expansion of the right ventricle can be seen. In pulmonary stenosis and in pulmonary insufficiency both the right ventricle and the pulmonary trunk are enlarged.

Echocardiography provides real-time imaging of the valvular structure and its function. It is able to visualize anatomic distortions of the membranous valve structure and related valvular vegetations and it can equally well identify stenotic lesions or septal closure abnormalities. Doppler examination can precisely measure the acceleration in the blood flow, which in turn can be used to estimate the pressure gradient of the stenosis, or in case of insufficiency, the grade of regurgitation. Echocardiography can be used to reliably measure and to follow-up the dilation of any cardiac chamber. Compared to the radiographic evaluation of left ventricle hypertrophy in aortic stenosis, ultrasonography examination is also superior, since left ventricle enlargement on radiographs can remain unnoticed up until the heart failure is so advanced that the ventricle is already irreversibly damaged.

MRI or CT examinations are not routinely used for the assessment of the valves. However, for other reasons (primarily in congenital heart diseases) these techniques can also be informative about the valvular morphology and function. MRI has the advantage that it is able to measure flow rate, while CT is more sensitive in the identification of valvular calcifications.
8.1.6. Radiologic aspects of arrhythmias

Cardiomyopathies predispose for arrhythmias, amongst which the most typical is arrhythmogenic right ventricular cardiomyopathy. MRI has the greatest diagnostic role in this aspect, since it is able to judge the morphologic deviation of the right ventricle and the structural changes of the myocardium with a remarkable accuracy.

In atrial fibrillation due to the altered hemodynamic states, thrombus formation in the atrium is a frequent complication; it is most prevalent in the left auricle and it threatens with the risk of systemic embolisation. Echocardiography is routinely applied in patients with atrial fibrillation to rule out the cardiac origin of the embolisation. Intra-auricular thrombosis, the most frequent source of cardiac embolisation, is evaluated best with transesophageal echocardiography technique.

Catheter thermoablation is an available procedure to prevent atrial fibrillation. For the planning and the implementation of this intervention it is necessary to know the precise anatomic arrangement of the left ventricle and the pulmonary vein ostia. Both, MRA and CTA examinations can provide the necessary 3D information for these procedures.

8.1.7. Diseases of the Pericardium

Pericardial effusion appears as an opacified, dense mantle about the heart on the chest X-ray image. However, echocardiography is the technique to detect pericardial effusion with in the easiest and most reliable manner. It can already be helpful in the optimal localization of a possible puncture site. If ultrasonography cannot provide unequivocal acquisition in complex inflammatory states or cancerous conditions, then CT or MRI examinations are required. The complications of pericarditis can be subsequent thickening of the pericardium and sclerotic callus formations that all lead up to the development of constrictive functional disorders, which might require surgical interventions. Although echocardiography can depict sclerotic lesions, it is unable to visualize the pericardial surfaces in their full extent. CT scanning is sensitive in the imaging of sclerosis and when it is performed with ECG gated guidance it is even capable of functional analysis. Even with regard to pericardial diseases the most complex characterization is still possible with MRI, although it has a reduced sensitivity for the determination of sclerotic lesions.

8.1.8. Cardiac tumors

The most common primary cardiac tumors are myxomas originating from the endocardium and the valves. They are typically depicted as mobile, intra-cavitai masses; their imaging is possible with echocardiography, CT or MRI. The most common tumor originating form the myocardium is – the often multifocal – rhabdomyoma. Secondary tumors of the heart can be metastases from real hematogenous spread; the primary tumors are most often breast-, lung carcinomas or melanoma. Secondary tumors can also result from direct propagation of thoracic, most commonly, primary pulmonary tumors that reach the heart. Echocardiography can raise the suspicion that a tumor is infiltrating the cardiac wall and chamber, however it is not able to completely demonstrate the possible extra-cardiac tumor component and it is not as effective in differentiating the lesion from the normal myocardium.
Another fundamental question is to determine how much of the actual intra-cavital pathologic lesion is made up of viable tumor tissue and how much of it is a thrombogenous growth on its surface. This is best assessable with MRI examination. Tumors with extra-cardiac, mediastinal or pulmonary infiltration might require the use of CT examination in order to determine the full extent of the tumor components.

8.1.9. Injuries

Injuries penetrating the cardiac chamber cause pericardial hematoma – if they do not cause pericardial tamponade – then echocardiography can be used for identification and follow-up. Blunt force trauma causes myocardial contusion that can appear as a myocardial infarct both clinically and in the lab results. Edema and necrosis involving the myocardium can be demonstrated with MRI.

8.2. Vascular system

8.2.1. Diseases of the pulmonary circulation

8.2.1.1. Developmental disorders

The majority of the developmental anomalies of the pulmonary arteries and veins are usually associated with congenital cardiac disorders. Such a case is – the many times multiplex and bilateral – peripheral stenosis of the pulmonary arteries. Another is the aneurysmatic dilatation of the pulmonary artery. Unilateral hypoplasia or the complete agenesis of the pulmonary artery lead to the hypoplasia of the ipsilateral lung as well as consequent thoracic asymmetry. Chest radiography demonstrates a scarce peripheral vascularization so that the normal arterial pattern is barely identifiable. CTA or MRA examinations are both capable to depict the thin trunk of the pulmonary artery or in some cases its complete absence.

The most common anomaly of the pulmonary veins is transposition. In these cases partial or complete venous transposition can occur resulting in their connection to the right side of the heart instead of the left atrium. At other times they can connect to the main systemic venous branches creating a functional left-to-right shunt. Both CTA and MRA are able to visualize the aberrantly running veins. A very typical picture can also be seen on chest radiographs in cases of isolated anomalous drainage of a lower pulmonary vein. This variant is called “scimitar” syndrome; as the vein’s shape resembles a scimitar running to the inferior vena cava-right atrial junction.

Pulmonary arteriovenous malformations (AVM) usually involve the peripheral pulmonary arteries and they most typically appear in Osler’s disease. Radiologic imaging findings show the dilation of the afferent arterial and draining venous branches due to the increased blood flow, while at the nidus of the lesion various sizes of aneurysmatic dilatations can be seen.
Since the surrounding normal pulmonary tissue demarcates the malformation quite well, a non contrast enhanced CT examination might be enough for a diagnosis. The most precise characterization of the lesion is provided with CTA that is able to depict even the smallest lesions. MRA examination may not be used for the complete coverage of the whole thoracic space. This is certainly disadvantageous if surgical or radiologic interventional procedures (catheter embolisation) are considered, because the therapeutic planning requires the full coverage of the lungs in order to identify AVM multiplicity.

8.2.1.2. Pulmonary embolism (PE)

Traditional chest radiography might not be indicative in pulmonary embolism or it might just show slight alterations. This is due to the fact that infarction pneumonia only occurs in the minority of the cases. In case of the occlusion of a larger vessel a hypovascularized area might appear. Peripheral infiltration, small amounts of pleural effusion or the elevation of the diaphragm can also be seen on X-ray images. Sonographic Duplex examination is primarily used to locate the embolic source by identifying deep vein thrombosis.

Earlier, pulmonary angiography was carried out by the catheterization of the right atrium of the heart with the subsequent injection of dye into it. This, besides its invasiveness has had limited differential diagnostic value; therefore it is not yet considered the appropriate method. The main limitation of the technique is that the embolism has to be identified by an indirect sign, as a filling defect: partially occluded arterial branches appear with decreased opification, while occluded vessels are seen as amputated branches with a decreased number, or without any distal arterial arborisation.

Perfusion lung scintigraphy can be used to depict pulmonary areas which were cut-off from the blood circulation. Ventilation is typically preserved in pulmonary embolisation, therefore a combined perfusion-ventilation scintigraphy, because of its relative specificity, used to be the most important imaging modality for a long time in cases of suspicion of acute PE. The main limitations of scintigraphy are indirect visualization and restricted sensitivity.

Contrast enhanced CT examination is capable of representing both the pulmonary vessels and the lung parenchyma in highly detailed images. The partially or completely occluding thromboembolic mass can be directly detected and it can be easily distinguished from the contrast filled lumen. CT angiography technique (with a CT scanner of a necessarily large number of slices) can confidently identify the involvement of distal, subsegmental, 2-3 mm wide vessels. A main advantage of CT scan is that even if no PE is present, it is still able to identify other pathological processes in relation to the thoracic symptoms (e.g.: pneumothorax, pneumonia …etc.) Therefore, in suspected cases of pulmonary embolisation CT angiography is the imaging method of choice.
8. Cardiovascular imaging

CT angiography examination of acute pulmonary embolisation

Fig. 9. Saddle embolus is blocking both branches of the pulmonary trunk

Fig. 10. Bilateral, multiplex emboli in the hilar branches

In the diagnostics of acute chest pain, a 64-slice CT machine is already capable to be used for the so called “triple-rule-out” evaluation. By means of these advanced scanners, pulmonary embolism, acute aortic syndrome and acute coronary syndrome can all be identified, or ruled out in one examination. Dual source CT examinations, based on the most advanced technological applications, are even capable to perform perfusion analysis.

MRI examination is usually considered as an alternative for CT examination in patients with iodine radiocontrast sensitivity. Contrast enhanced MR angiography provides a less precise visualization compared to CTA, but it is capable to prove the embolisation of the larger pulmonary arteries. The so called “steady state” sequences, which play an outstanding role in non-contrast enhanced cardiac MRI examinations it is also possible to visualize the lumen of the central branches of the pulmonary artery. This technique might prove to be exceptionally useful in cases of suspected pulmonary embolism in pregnant women.

8.2.1.3. Pulmonary arterial hypertension

Chest radiographs reveal a characteristic enlargement of the central arteries while an abrupt caliber decrease is visible in the peripheral ones. This is normally regarded as centroperipheral discrepancy. Radiography can also reveal certain advanced chronic lung conditions that may explain the development of chronic pulmonary heart disease (chronic cor pulmonale).

Echocardiography can identify the signs of right heart-side strain, but it cannot differentiate between primary or secondary conditions.

CT examination is primarily required to rule out chronic pulmonary embolisation, and in progressive cases, it is used as an assessment tool for lung transplantation.

8.2.1.4. Pulmonary venous hypertension

In cases of left ventricular insufficiency, radiographs present an apicobasal caliber discrepancy of the vessels. The apical veins of the lung are more expanded than the basal veins. Parallel with this, interstitial edema develops – initially at the base – and leads to the thickening of the basal interlobular septa, called Kerley B lines.
Today this phenomenon only proves to be secondary, since echocardiography is able to monitor sensitively both the functional state of the left ventricle as well as the status of the patient. Idiopathic or iatrogenic pulmonary stenosis can also be a reason for pulmonary venous hypertension which can be detected either with CTA or MRA.

8.2.2. Diseases of the systemic circulation

8.2.2.1. Congenital anomalies of the large vessels

8.2.2.1.1. Aortic coarctation

Two main types:

1. preductal – the narrowing (hypoplasia) of a longer segment of the aortic arch;
2. postductal – classically located at the level of the isthmus, as a smaller segmental narrowing, originating distal to the left subclavian artery

It is usually diagnosed in infancy due to its prevalent symptoms. Its classical diagnostic method is catheter angiography. The injected dye can reveal the degree and the length of the stenotic lesion as well as the associated collateral vascular system and other accompanying abnormalities. Its main advantage is that it allows a direct measurement of the arterial pressure and the pressure gradient in turn can be informative in choosing a therapeutic protocol. Furthermore, catheter angiography also makes subsequent angioplasty (dilatation) or stent implantation possible. After the primary surgical correction, follow-up examinations are necessary in order to assess any residual stenosis. On the other hand follow-up is needed because there is an elevated risk for the development of pseudoaneurysms at the postoperative areas. (This is usually a segmental dilation of the artery at the surgical territory, that has none or just partial components of the normal blood vessel wall.) The repeated control examinations should be carried out in a non-invasive manner and with techniques that do not utilize ionizing radiation.

Echocardiography in the neonates can still help with the diagnostics, since it can directly represent the aortic arch. Later, it is significant in the determination of left ventricular strain signs and it is needed for the detection of frequently associated developmental disorders of the heart. The most commonly associated anomaly is the bicuspid aortic valve.

CTA provides a high detail image about the stenosis and postoperative complications. Moreover, it is more easily performed in infants, but because of its relative high dose of radiation, MRI is the preferred method. MRI is ideal in the age group of children who can already cooperate.

It can be used to assess aortic morphology and associated cardiac anomalies. It is also capable for the quantitative evaluation of the collateral flow (flowmetry measurements).
8. Cardiovascular imaging

Coarctatio aortae

Fig. 11. Contrast enhanced MR angiography

Fig. 12. CT angiography – volume rendering

8.2.2.1.2. Aortic arch anomalies

The supraaortic arteries show a great deal of variability in origination and in branching pattern. These presentations of the arteries are not pathologic, but their knowledge is essential, because they can be hard to localize in catheter interventions.

The involution of the appropriate segments of the fourth aortic arch pair leads to the regular anatomy of the aortic arch. If this process takes place atypically it leads to the formation of anomalously running vessels, often referred to as “vascular ring”. Their clinical significance lies within their possible compression of the airways and the esophagus, which are revealed normally by stridor, and dysphagia. One of the simplest of these anomalies, that normally only becomes apparent as an incidental finding in adulthood, is the aberrant subclavian artery (a retro-esophageally running right subclavian artery). The classical example of the complete vascular ring is the double aortic arch, which usually requires an early reconstructive surgery. Radiography plays an important role in the identification of the ring-spectra, possibly with techniques capable to assess the tracheal shadow. A contrast swallowing examination is able to visualize the typically laterally and dorsally localized impressions on the esophagus.

CTA and MRA can clarify the precise anatomic arrangement; they can identify which aortic segments are unobstructed, which ones are hypoplastic and which ones are missing completely. They can also be used to locate the origin of the various supraaortic arteries. These findings are all necessary for the precise planning of any surgical procedure. CT is more advantageous, especially if the lung and the airways are also needed to be analyzed.

8.2.2.1.3. Anomalies of the large veins

The anomalies of the superior and inferior vena cava are in most cases encountered accidentally on imaging examinations and they do not predispose for any complications alone. The venous aberrations are only partially assessable with ultrasound examination; intrathoracic segments, parts at the level of the diaphragm, and retroperitoneal segments can only be partially visualized.

One of the main concerns if any atypically running vein is found is whether this is an innate or an acquired condition. In order to clarify this, the traditionally used contrast injection techniques (phlebography) only provide partial information. The most precise diagnostic results are to be expected from a venous phase contrast enhanced CT examination.
8.2.2.2. *Peripheral vascular malformations*

This disease group has still been erroneously referred to as hemangiomas. It can be divided in two types: high flow anomalies and low flow malformations.

High flow arteriovenous malformations are typically represented with shunt circulation, the speed of flow increases, afferent arteries and efferent veins expand due to the increased volume of blood flow. With Duplex US examination, as a direct sign of shunt circulation, a very high flow velocity with a low resistance index can be registered or pulsatile flow in the veins can be noted at the nidus. The traditional diagnostic tool is catheter angiography, which still provides the most detailed picture about the feeding arterial branches of the shunt, and about its draining veins. Moreover, it informs about the extent of the nidus and about the velocity of the flow. A major advantage of the catheter method is the possibility for intervention. The feeding arteries can be selectively or super-selectively localized and occluded through embolo-therapeutic procedures. The contrast enhanced MRA produces images similar to DSA revealing the architecture of the abnormal vessels.

Low flow malformations can be made up of veins, capillaries and lymphatic vessels in a variable, mixed form resembling tumor-like structures. They can also be made up as a network of vessels traveling in different directions, with various calibers. Ultrasonography examination can identify the expanded venous plexus, while a lymphatic vessel malformation system is often seen containing cystic components. Radiography is usually used to assess the accompanying bone structure alterations and deformities. Traditional angiography can be completely negative or it may only indicate filling defects (opification decrease) in the venous stage. The most precise localization can be made with MRI: on T2 weighted images the slow flowing malformations typically appear as high signal intensity abnormalities, and they differentiate clearly from the nearby healthy tissues.

8.2.2.3. *Atherosclerosis*

Imaging methods have two purposes a) to prove the atherosclerotic process and to identify the plaques of the region in question and b) to quantify the degree of the consequent stenosis and to assess its hemodynamic significance. The diagnostic strategy has to be indicated in a way that the chosen procedure is able to provide information for therapeutic decision making for the given vascular territory, it has to be the least invasive for the patient and it should be as cost effective as possible. (One cannot forget the fact that atherosclerosis is an endemic disease and therefore the diagnostic protocol can put from a few thousand, up to ten thousand examinations worth of excess on the burden of the healthcare system.)

8.2.2.3.1. *Stroke – cerebrovascular diseases*

In the majority of the cases, the cause of stroke is related to the atherosclerotic lesion of the supplying arterial system of the brain. Ultrasound examination can reliably depict a long segment of the four main extracranial large vessels supplying the brain. It is diagnostically advantageous that the majority of atherosclerotic lesions that cause cerebrovascular symptoms are to be found in the carotid bifurcation and therefore they can be well represented on carotid US examinations.
US can depict plaques and it can measure their size and characterize their composition. Lipid-rich plaques that are covered with a thin, easily rupturing fibrotic cap, that are mostly soft in composition are considered unstable. Also, inhomogeneous structure and irregular surface are both likely to indicate a poor prognostic factor. Exulceration, a consequently appearing excavation on the surface of the plaque carries the highest risk for embolisation. Color Doppler examination can help to precisely define the contours of the plaque. It can clearly depict the residual lumen of the narrowed arterial segment and it is able to confidently differentiate cases of complete obstruction from lesions causing a high grade stenosis. Contrast enhanced ultrasound examination is able to show angiogenesis at the basal part of the plaque and it is as sensitive as MRI examination. One of the main diagnostic goals of cerebrovascular imaging is to determine the grade of stenosis of the internal carotid artery, since the risk of stroke grows parallel with the grade of the stenosis. Possible cerebrovascular events can be avoided with reconstructive surgery or with stent implantation. A 50% diameter reduction is usually considered the limit at which a stenosis is thought to be hemodynamically significant. Under this level the grade of stenosis can be well estimated with 2D planimetric measurements. In order to quantify stenotic lesions that reduce the diameter by more than 50% it is better to consider the hemodynamic effect caused by the narrowed lumen, based on the measurements of flow velocity increase. If a significant stenosis is found, the patient has to be closely followed. A stenosis of about 70% is suggestive for surgical or interventional procedure. In these cases and in equivocal cases it is important that the duplex sonography is followed by an imaging method that can visualize the cerebrovascular system completely.

Arteria carotis interna stenosis

The traditional catheter angiography is still considered the gold standard imaging method due to its high detail anatomic imaging and due to its ability to determine the hemodynamics of the circulation. The complete assessment of the arterial cerebrovascular system can be achieved with CTA and MRA techniques that give a map-like visualization of the cerebrovascular arterial tree.

The aim in both methods is to depict the arterial system from the aortic arch to the Circle of Willis with a good image quality. The main advantage of MRI is that it combines intracranial assessment with angiography, therefore certain therapy modifying lesions (e.g.: acute ischemic lesion) can be diagnosed in the most precise manner.
Reversed blood flow in the vertebral artery is indicative of a steal syndrome. It indicates a high grade stenosis or an occlusion at the proximal segment (before the origin of the vertebral artery) of the ipsilateral subcalvian artery.

8.2.2.3.2. Renovascular hypertension

The stenosis of the renal artery causes therapy resistant hypertension. If clinical suspicion is raised a radiological examination or scintigraphy is indicative for the diagnosis. If the stenosis is detected on time, then surgical reconstruction or catheter dilatation of the vessel can be used to cease hypertension and avoid a possible renal failure that the stenosis related hypoperfusion could have eventually caused.

With Doppler examination, if the renal arteries can be directly visualized, a high velocity flow and a post-stenotic turbulence is notable. From a dorso-lateral angle the flow of intrarenal segmental arteries can be analyzed: if proximal arterial segments have any stenosis, then the registered Doppler curves show a post-stenotic appearance. However, this technique requires a great deal of experience and is very operator-dependant, thus it is not performed on a regular basis.

Perfusion scintigraphy is able to identify significant arterial stenosis by comparing the different perfusion rates between the two kidneys. The method can be made more sensitive by giving the patient an ACE inhibitor, which in turn, further decreases the activity of the involved kidney. Upon ending ACE inhibition, on the repeated renal scan an improving perfusion is indicative of arterial stenosis. The identification of bilateral lesions with this method is rather difficult, since the use of ACE inhibitors is contraindicated.

CTA and MRA are both capable of diagnosing renal artery stenosis. Both methods are able to identify anatomic variations, atherosclerotic lesions at the origin of the vessels or at distal segments on the artery. These techniques, not only identify the contour irregularities and the narrowed lumen, but they are also able to reveal the secondary parenchymal lesion of the kidney. However, in patients with decreased renal function, both types of contrast materials should be avoided or only applied with care.

Renal artery stenosis

Fig. 15. Contrast enhanced MR angiography

Fig. 16. Control CT angiography after stent implantation to correct a bilateral arterial stenosis
8. Cardiovascular imaging

8.2.2.3.3. Mesenteric ischemia

Stenotic lesions or occlusion of the unpaired splanchnic branches of the aorta cause chronic mesenteric ischemia, which in turn presents as abdominal angina. Acute occlusion is usually caused by mesenteric embolism, and it presents as acute abdominal catastrophe; as a grave condition with high lethality. In all circumstances CTA provides the best diagnostics and it is also able to demonstrate actual state of the abdominal organs.

8.2.2.3.4. Peripheral arterial disease (PAD)

Obliterative diseases of the lower extremity arteries can occur from the subrenal aorta to the distal, end-arteries of the limbs. It can affect any segment, in any combination; depending on its severity and the dynamics of its development it causes variable arterial pressure changes and consequent complaints. The gradually developing atherosclerotic stenosis/occlusions appear as intermittent claudication. The acutely presenting critical limb ischemia is usually related to arterial embolism and requires urgent surgery. Imaging examination is not even necessary if the actual clinical state does not suggest a revascularization.

According to the traditional approach the adequate method for imaging is catheter angiography, possibly DSA technique. It requires the repeated injections of smaller volumes of dye, and with a few steps it is able to demonstrate the whole arterial system in a way, that on the appropriately adjusted late phase images, the depiction of arterial outflow is possible even at the slower flowing territories.

The advantage of DSA is that smaller branches and collaterals can also be visualized; it provides hemodynamic information and even makes an ad hoc balloon catheter dilatation or stent implantation possible. In case there is no femoral artery appropriate for catheterization, an alternative approach from the brachial artery can also be used. Stenotic lesions can be semi-quantitatively categorized: below 50% is considered mild, between 50-75% moderate and above 75% pronounced stenosis is differentiated.

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DSA examination in lower extremity obliterative arterial disease

![Fig. 17. Proximal aortic occlusion – Leriche’s syndrome](image1)

![Fig. 18. Bilateral multiplex femoral artery stenosis](image2)
Left sided segmental occlusion at the iliofemoral segment

Fig. 19. Contrast enhanced MR angiography Fig. 20. CT angiography

Multi-slice CT is able to perform CT angiography scans that can cover a field from the diaphragm to the ankles to depict the complete arterial tree with a good intensity and with appropriate spatial resolution. In most cases this provides an adequate diagnostic value and it is especially advantageous for the rapid assessment of patients in a debilitated state. Contrast enhanced MRA, with a large field of view, for the depiction of abdominal and peripheral arteries requires a special table toggling technique. This method applies the prolonged injection of intravenous bolus of contrast medium, and in three table-toggling steps it can visualize the arterial system of the abdominal aorta and the peripheral arteries up to the ankle with an acceptable spatial resolution.

Altogether both CTA and MRA examinations give the best diagnostic value for lesions presenting at the aortoiliac and femoropopliteal regions with a relatively limited extension and a reasonable severity.

8.2.2.4. Aneurysm disease

Aneurysms are certain dilatations of the vessels that are 50% wider than the normal arterial diameter. In an aneurysm, the dilated segment contains all the layers of the normal arterial wall. This is the differentiation criterion that is used to distinguish them from pseudoaneurysms. Pseudoaneurysms are also segmental dilatations of the arterial lumen, that due to some local effect (e.g.: trauma, iatrogenic injury, etc.), are only partially covered by the normal layers of the arterial wall, in particular cases their wall does not show any of the regular arterial layers.

A large vessel dilatation can cause compression signs, depending on its localization. The circulation slows down within the expanded vessel and a consequent a thrombogenic process occurs along the luminal wall, at many times it can reach such a grade that the permeable lumen barely shows any dilatation. The thrombus can serve as the source of distal embolisation and cause acute ischemic signs when it reaches certain arterial territories. Finally, the most important complication of the continuously expanding aneurysm is rupture. Aneurysm rupture without intervention causes circulatory collapse and presents as a high mortality condition, leading to patient death within a few hours. The risk for rupture increases exponentially with the size of the diameter.
The role of imaging an aneurysm on one hand is to provide precise measurements of its size, especially about its greatest diameter, and on the other hand it is used for the follow-up of the patients. Aortic aneurysms from about 6 cm diameter present a higher risk for rupture and require intervention. Dilatations over 5 cm all require a close control for timely diagnosis. Aneurysms of a size smaller than 5 cm require imaging control at every 6 months or if they are stable in size, control should be performed once a year. Besides the precise measurements, the role of imaging is to characterize the appearance of the lesion in order to select the ones that require surgical reconstruction and to differentiate the ones that are suitable for endovascular intervention. The anatomic characteristics that should be considered at each imaging examination are: the location of the proximal and distal neck of the aneurysm, the relation of the origin of the side branches, wall thickness and the thickness of the mural thrombus and finally to detect signs in the perivascular tissues that are suggestive of an impending rupture.

Ultrasound examination is a reliable screening tool and is also useful in patient follow-up. However, the reproducibility of the measurements of the diameter of an irregularly shaped vessel needs to be considered limited. Contrast enhanced US can increase the diagnostic sensitivity for these hardly depictable deformations. CT and MRI are able to assess aneurysms independently from their location and size. They provide the highest visibility in primary diagnostics as well as when surgical interventions are planned. Intrathoracic and intracranial aneurysms can only be followed up with these techniques since US examination has limited visualization ability in these regions. In case of planned examinations if MRI is available it is the preferred method, since it does not represent any harmful radiation for the constantly controlled patient. In cases when rupture is suspected CT is the method of choice due to its higher availability and its better time-resolution.

Abdominal aorta aneurysm, CT angiography

Fig. 21. A non-ruptured (stable) aneurysm with an extended mural thrombus

Fig. 22. Ruptured aneurysm with retroperitoneal hematoma

8.2.2.5. Aorta dissection

There are two main types of aorta dissection differentiated according to the Stanford classification: Type “A” dissection involves the ascending aorta, while type “B” dissection occurs distal to the origin of the left subclavian artery and it does not propagate to the level of ascending aorta and the aortic arch. The two types are primarily distinguished because of their acute complications. Type “A” dissection can cause the obstruction of the coronary ostia and, in case of a pericardial rupture, it can cause consequent pericardial tamponade and sudden death. Hence these cases require immediate surgical intervention with a cardiac surgical background.
As opposed to this, type “B” dissection can cause the acute obstruction of the abdominal aortic branches and can lead to life-threatening conditions in a subacute manner (intestinal ischemia, renal insufficiency). These conditions require surgical intervention (vascular surgery) but they normally never have an immediate indication. Both dissection types can threaten with a common, late phase complication that occurs due to the weakened and constantly expanding vessel wall. These dissection aneurysms increase the risk for aortic rupture.

Primary diagnostic imaging is usually performed as an emergency examination, at many times the patients are unstable, gravely ill and in poor condition. Therefore, CTA is a more advantageous method; it can still examine a non-cooperative patient with a diagnostically valuable imaging quality. The most important is always to categorize the type of dissection. CTA needs be able to determine the involvement of the supraaortic and abdominal branches, to localize the origin of the side branches. It must also assess what is the anatomy of the false and the real lumen and what is their permeability. A highly pulsating aortic root can cause diagnostic problems because of the vessel movement. The moving arterial wall can cause artefacts that might suggest the impression of an intimal-flap. However, this can be avoided with the modern technical applications such as ECG gated examination.

Type B aortic dissection CT angiography

![Fig. 23.](image1)
![Fig. 24.](image2)
![Fig. 25.](image3)

The lumen is divided by the detached intimal layer that can be followed from the origin of the left subclavian artery to the descending aorta. The real lumen shows a fast filling and a more intense contrast enhancement, while the false lumen shows a less intense contrast enhancement due to its decreased flow.

For a programmed control examination MRI is the preferred modality, because contrast enhanced dynamic MRA with the ECG gated technique can very well visualize the motion of the intimal flap.

8.2.2.6. Inflammatory diseases of the blood vessels

Takayasu’s arteritis involves the large arteries, and the similar, but less common temporal arteritis involves the more peripheral arteries, both cause abnormalities of the vessel wall that can be clearly identified with US, CT or MRI examinations. In the active phase of the inflammation cuff-like thickening of the media-adventitia layers of the arterial wall can be seen. In the parenchymal phase an increased contrast enhancement and the inhomogeneity of the perivascular tissues can be noted. On MRI images the involved vascular segment is edematous and shows restricted diffusion.
Typically the process progresses with stenosis of the arteries which eventually leads up to occlusion. In Takayasu’s disease the vasculitis appears at the proximal segments of the branches of the aortic arch, but it can appear at the abdominal arteries and in rare cases the pulmonary circulation can also be involved. Sometimes the vasculitis can cause the development of aneurysms. Surgical correction however needs to be considered seriously, because if the anastomoses of the bypass graft meet with the inflamed segments then the chance for restenosis or inflammation is increased. Patients are often of a younger age, therefore the use of US and MRI examination should be favored. In any case if disease progression is suspected MRI is necessary, or if unavailable, CTA needs to be performed. Kawasaki’s disease is a form of vasculitis that affects children the most and it can cause the development of aneurysms. The most common site is at the coronary arteries but less frequently peripheral arteries can be involved. The process should possibly be diagnosed and control follow-up examinations should be performed with US examination.

8.2.2.7. Venous thromboembolism

Deep vein thrombosis of the limb can cause chronic venous insufficiency as a local complication. Its systemic complication is consequent pulmonary embolism. Without adequate therapy the thrombosis can spread along the venous wall, in both an ascending and a descending direction. It can lead to increased segmental involvement that can further increase clinical symptoms. This is the reason why if there is suspicion of a deep vein thrombosis, an imaging examination should be carried out, in order to prove the existence of thrombosis and to describe its extension. Thromboses affecting the limb and the pelvis, as well as the ones found on the upper extremities or on the neck, can all be effectively examined with US examination: the involved vascular branch will show an increased diameter, the lumen is filled with a hypoechoic mass that cannot be compressed with the transducer. The thrombotised segment does not show a Color Doppler or a Doppler pulse curve. In all cases, comparison with the healthy, contralateral side helps with the evaluation, as long as there has not been any previous thrombosis there.

Lower extremety cdeep vein thrombosis – color Doppler examination

Fig. 26. The complete occlusion of the superficial femoral vein...

Fig. 27. …the partial occlusion of the popliteal vein

The precise imaging of the main, thoracic and abdominal venous branches, require CT or MRI examination. The occlusions of the porto-splenic veins compose a special diagnostic category that can appear as a complication of several disorders, such as cirrhosis, other cases of portal hypertension, hypercoaguability, cancer and septic states.
The clarification of the exact state is necessary whether to plant a palliative TIPS (transjugular intrahepatic porto-systemic shunt) or to plan a surgical procedure. Moreover, the examination needs to consider an evaluation for the possibility of a liver transplant.

8.2.2.8. Vascular injuries

Penetrating injuries mostly require immediate surgical intervention and imaging methods are barely necessary. On the other hand blunt force trauma can cause hemorrhage into the luminal organs, or interstitial bleeding where the source is not always known, thus the adequate therapy planning requires diagnostic imaging. The most useful is CTA examination for any traumatic assessment, since the exam provides an overall, rapid visualization of the vascular branches, parenchymal organs and the skeletal system. In case the damaged vessel does not suffer a complete rupture, a partial fissure can be the cause of a traumatic dissection or pseudoaneurysm. Blunt force trauma of the neck can lead to the dissection of the carotid artery or result in the thrombosis of the jugular veins, therefore in these cases a routine US is the indicated examination.

8.2.2.9. Tumors

Real tumors that originate from the blood vessels are rare. Rather erroneously, the tumor-like vascular malformations are called “angiomas”. The hypervascularized abnormalities can be identified with Doppler ultrasound examination. MRI with complementary MR angiography is able to provide a full scale assessment. In adulthood primary vascular tumors are less common lesions. Imaging is primarily used in the treatment of the tumors of large arteries (e.g.: glomus tumor of the carotid bifurcation), it is also necessary to employ in cases that require a precise vascular depiction in the planning of complex oncologic surgeries (penetrating renal tumor to vena cava). All these are best represented with CTA examination.

Translated by Balázs Futácsi
9. Chest Radiology

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9.1. The Lung

9.1.1. Imaging modalities

Chest radiograph (P-A, A-P, supine, Friehmann-Dahl view)
Pulmonary abnormalities appear as consolidations on the transparent lung areas, because of their different radiation transparencies.

Fluoroscopy shows the respiratory movement of the diaphragm and the mediastinal pendulum movement during inspiration and expiration. The pulsation of the hilus and the exact localization of the lesion on the projected chest or any visible pathologic pulmonary changes can be noted. For example, the Holczknecht-Jacobson sign indicates one of the main bronchus is obstructed, most frequently due to aspiration of a foreign body without consolidation on the radiograph. The hilus moves towards the obstructed lung during inspiration, while during expiration it moves in the other direction towards the entire lung, which crushes its air out. This can be precisely followed on the radiograph screen.

Computed tomography (CT) - spiral CT, MSCT, HRCT – First, data are acquired by transverse slices, next, volumetric data collection is processed, and then, noncontrast and contrast-enhanced slices can be obtained. Post-processing methods include: windowing, density measurement, magnification, size determination, etc. In addition, secondary reconstructions (MPR: sagittal, frontal, 3D) and programs (volumetric, angiographic evaluation opportunities) can contribute to the diagnosis. The most refined lung structure imaging can be achieved by HRCT using very thin slices, which is principally important in the diagnosis of interstitial lung diseases.

MRI is helpful in the examination of chest, mediastinum, heart, and vascular abnormalities.

Ultrasound can confirm the pleural effusion in the sinus.

9.1.2. Anatomy

The lung is surrounded by the skeletal chest wall (sternum, ribs, and vertebral column), which is lined by the parietal pleura. Each lung is composed of two to three lobes: the upper, middle, and lower lobes. The visceral pleura invests the surface of the lung, while the interlobar pleura lines the fissures between the lobes. The horizontal fissure lines the border of the upper and middle lobes, whereas the oblique fissure is located between the lower and upper-middle lobes. The lobes of the lung can be further divided to smaller parts, the segments. The trachea divides into two main bronchi, which subdivide dichotomously into lobar and segmental bronchi at the level of the hilum. The pulmonary trunk (main pulmonary artery) originates at the right ventricle and branches into right and left pulmonary arteries; from this point on the branch system of the pulmonary artery follows alongside the bronchial branches.
The secondary pulmonary lobule, which measures 1.5-2 cm, is the anatomical and functional unit of the lung. The interstitium provides the lung frame, which follows the bronchovascular bundle starting from the lung hilum. In the secondary pulmonary lobule, the space between the acini and alveoli is filled by a network of connective tissue with spider web-like fragility (intralobular interstitium).

9.1.3. The normal chest radiograph

Negative chest radiograph

Unless a multitudinous screening examination is required, a bidirectional, posteroanterior (PA), latero-lateral radiograph is employed. Hard beam technique (120-130 kV, 5 mAs) indicates a 2 m focus-film distance with radiograph taken at full inspiration.

The PA beam direction tempers the covering effect of the heart, which lies close to the film/detector. The heart should be “smaller”, similarly to its normal size, and its contours must be sharp (central projection). Exposition, inspiration, and rotation characteristics of a technically acceptable PA chest radiograph include:

- Exposition: the thoracic vertebral bodies should be just visible wanly in the upper part of the mediastinal consolidation
- Inspiration: if the posterior arch of the 9th and 10th ribs at the level of the diaphragm is visible, then the patient has taken an adequate inspiration effort
- Rotation: optimal when the sternoclavicular joints are equidistant from the midline

![1a: Normal chest X-ray 1b: Chest HRCT examination](image)

9.1.4. Basic radiograph abnormalities

9.1.4.1. Hyperlucencies (increased transparency)

Bilateral: emphysema (see chronic obstructive lung diseases)
Well-defined: bullous emphysema, lung cysts

Partial or total Hyperlucency occurs if the air content of the lung partially or totally increases (diffuse or bullous emphysema), if there is accumulation of air within the pleural cavity (pneumothorax), or if air-containing cavities in the lung parenchyma also “light up” from the lung view.
9. Chest Radiology

9.1.4.2. Hypolucencies (decreased transparency)

Unilateral: Volume expansion (fluid), Volume reduction (atelectasis), or No volume effect (pneumonia)

Hypolucencies (consolidations) may indicate fluid, atelectasis, pneumonia, alveolar diseases, or interstitial diseases. Hyperlucency occurs if there is less lung air content; if a transparent item occupies the space of the air-containing lung; or if the permeability of the pleura lines decreases. Accordingly, the hypolucency causing abnormalities appear as consolidations. Consolidation characteristics include:

- Intensity: metal, calcific or soft tissue intensity, pale or veiled
- Extension: variable. Smaller, well-defined consolidation is called solitary pulmonary nodule
- Number: variable
- Location: Apical, central (hilar) or peripheral. Can be characteristic for certain diseases. Location of nodules is marked with lobar and segmental accuracy
- Contour: sharp or blurry
- Homogeneity: homogeneous or inhomogeneous

The shape of smaller consolidations can be bundle-shaped, streaking, rounded, or patchy (if the small nodules are located in a dense, end-to-end superprojection and cannot be distinguished sharply). In some diseases, certain consolidation assortments can be identical or similar.

Homogeneous consolidations
Homogenous consolidation covering the hemithorax can be caused by: wide exudative pleuritis (mediastinal shift, the mediastinum is pressed to the opposite side); large pleural fibrosis (draws the mediastinum to its own side); or atelectasis due to the obstruction of the main bronchi (the mediastinal pendulum movement during inspiration and expiration).

Atelectasis
Atelectasis is the decline or complete lack of air content within alveoli due to a lack of connection with the external airspace, the air dissolves from the alveoli and the otherwise normal lung collapses because of its elasticity.

Types and causes of Atelectasis:
resorptive (obstructive) – bronchial obstruction
passive (compressive) – pneumothorax, hydrothorax
adhesive (subsegmental) – postoperative, viral pneumonia, radiation pneumonitis
fibrotic – diffuse interstitial fibrosis

Radiograph findings indicating Atelectasis:
Homogeneous blurry consolidation in the air-containing lung due to the lack of gas exchange. The anatomic borders are respected, the affected part of the lung lessens, the normal pattern of the fissures and the adjacent intact lung zones are dislocated, Holczknecht-sign is positive. Same-side hemidiaphragm elevation might occur.
Differential diagnosis: pneumonia
Infiltrative shadows
In the case of any inflammatory lung disease, an “infiltratory” blurry consolidation can be seen with indistinct and not sharply determinate margins, which are more dense in the middle and more lucent towards its margins. Causes of infiltrative shadows include: bronchopneumonia, abscess, mycosis, tuberculotic infiltrations, severe congestion, and central lung cancer.

Bundle-shaped, striped shadows
Bundle-shaped, striped shadows are observed when the connective tissue accumulates and thickens around the lymphatic vessels along the bronchi. These shadows are seen most frequently in tuberculotic diseases, early and resolving phases of pneumonia, bundle-formed perivascular infiltration from coniosis, lymphangitis carcinomatosa (bundle-formed, but a more reticular pattern), chronic bronchitis (less expressive and located mainly in the lower lobes), pulmonary congestion (strengthened lung pattern, reticular, but more dense and regular), interlobal pleural fibrosis (line-shaped, thin, sharp consolidation), and Fleischner-type atelectasis (a slightly wider strip or zone).

Round, homogeneous shadows
Round, homogeneous consolidations are caused by encased, pleural effusion or fibrosis. When the direction of the beam is changed, the shadow loses its shape; when the beam direction is horizontal it narrows becoming stripe-like. Ball-like objects are indicated by round consolidation, which are listed here in the order of their frequency: tuberculoma; benign tumors; cysts (congenital or Echinococcus); neoplasms (carcinoma, sarcoma, etc.); lung metastases; early phase tuberculotic infiltration; full caverna; mycotic nodules; peripheral lung cancer; adenoma; and a-v shunts.

Patchy, miliary shadows
Pinhead- or millet-sized, densely scattered nodules occurring most frequently in cases of: tuberculosis, coniosis, sarcoidosis, miliar carcinomatosis, etc.

Ringed shadows
Most frequently indicate tuberculotic caverna, and less frequently indicate abscess or fused tumor cavity, particularly if the cavity’s fluid content depletes and is replaced by air. Ringed shadows may also indicate sac-like cavities of bronchiectases, air-containing lung cysts, or emphysematous bullae.
2a: Atelectasis, PA chest radiograph. Hx of esophagus exstirpation surgery. Parahilar right side hypolucency. (small amount of pleural effusion in the right lateral sinus)

2b. Atelectasis, left upper lobe. CECT, coronal reconstr. (by the contribution of Zsuzsanna Monostori, MD, PhD)

3a: Round shadow: multiple lung metastasis. Chest radiograph (PA)

3b: Multiple lung metastasis, CT lung window (axial, coronal reformat)

3c, coronal reformat

70 year old man, colon tumor. Radiograph: Bilateral extensive, confluencing patchy-nodular shadowing with diffuse reticular pattern. The diaphragm contour is partially blurry bilaterally: lymphangitis carcinomatosa. CT: Numerous 1-6 cm round and irregular, lobulated-spiculated contrast enhancing lesions in both lungs, everywhere sporadically.

4: Miliary pattern: sarcoidosis, CT, lung window. Axial image and sagittal reformat.
A 67 year old female suffering from COPD. Bilateral rough branching interstitial widening and patchy, miliary nodules with perihilar dominance along the bronchovascular fibres and the fissures.

5a,b: Lung abscess. Chest radiograph, bidirectional (PA+lateral - right side near the film).

61 year old woman. Laparoscopic esophagus diverticulum resection 2 months ago. 7 cm air-fluid level with air space above: „basket sign” above the right diaphragm laterally measuring 2.5 cm in lateral diameter and 7 cm mediadorsally.

6. c 6. d

64 year old man. Infiltration and abscess development in the right lower lobe. c.) CT lung window, coronal reformat, d.) axial, mediastinal window. Extensive area in the right 8-9th segments without air, including many associated lesions of fluid density, with tiny air bubbles, larger air spaces and air-fluid level. The lesion has almost a triangular shape, its dorsal and ventral contours are arched, its peak points towards the lower pole of the hilum.

6. e 6. f
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e, f.) Chest (PA and right lateral) radiograph: 10 cm large shadow in the RLL, the wall of the „basket sign” measures 0.5 cm + an other one measuring 7 cm possibly with one-two smaller air-fluid levels + small pleural effusion.

6. g

US: The lung parenchyma has an inhomogenous pattern on the right side above the diaphragm measuring 10 cm in wideness, without air content. It includes hypoechoic areas of irregular contours measuring 18-39 mm in diameter including tiny „bright” gas bubbles.

9.1.5. Diseases of the Lung

9.1.5.1. Alveoloacinar diseases

In alveoloacinar diseases, the alveolar air is replaced by:
Fluid: heart failure, lung edema, ARDS
Blood: contusion, vasculitis
Pus: bacterial pneumonia, TB
Protein-rich fluid: alveolar proteinosis
Cells: BAC, lymphoma, eosinophilic cells

Radiological findings: amorphous, inhomogeneous shadows, without volume loss; air bronchogram has a diagnostic value.

Localised alveoloacinar diseases

- Pneumonia
- Atelectasis
- Infarction or bleeding (PE – pulmonary embolism, if peripheral)
- Lung contusion
- Collagen vascular diseases or vasculitis
- Drug or allergic reactions
- Tumor
- Roentgen radiation pneumonitis
- Eosinophilic pneumonia (usually multinodular)
- Amyloidosis
- BOOP
Alveolar system diseases according to course
Acute: edema, pneumonia, bleeding, aspiration, shock lung
Chronic: TB, sarcoidosis, BAC (bronchoalveolar carcinoma), haemosiderosis, lymphoma

9.1.5.2. Interstitial lung diseases

Inflammatory: Viral, Mycoplasma, Haemophilus influenzae, Aspergillus pneumonia
Non-inflammatory: Pneumonitis, Pneumoconioses, Fibrosis, Lymphangitis carcinomatosa

Radiological features: well-structured linear and nodular reticular pattern = miliar, reticular, nodular, reticulonodular.

According to distribution in the lung
Upper lung field dominance: P A G E S
pneumoconioses, allergic alveolitis or ankylosing spondylitis, granulomae, eosinophilic
granuloma, sarcoidosis
Lower lung field dominance: C I A
connective tissue diseases (scleroderma), idiopathic fibrosis (most frequent), asbestosis

Lung fibrosis
Inflammation of the lung interstitium by tumor, edema, or fibrosis, which manifests as an
irregular, rougher-finer, linear reticular pattern (piled-up fibroreticular pattern) that not only
covers the normal lung structure but also deforms it. In cases of a severe fibrosis, a
honeycomb pattern develops. Causes of diffuse pulmonary fibrosis include: TB, fibrotic
alveolitis, pneumoconioses, chronic lung diseases, asbestosis, silicosis, chronic
inflammations, and sarcoidosis.

9.1.5.3. The morphology of lung abnormalities

Nodular lung abnormalities
Solitary lung nodules may indicate:
Tuberculoma, bronchial carcinoma, metastasis, hamartoma, abscess, aspergilloma, adenoma,
round atelectasis, a-v shunt, bronchogenic cyst, sequestration, Echinococcus cyst, infarction

Multiple lung nodules, based on sized, may indicate:
Miliary: TB, sarcoidosis, histiocytosis, silicosis, metastases
Middle (submiliary): Bronchogenic TB, metastases, peripheral Kaposi sarcoma
Large round nodules: Metastases, Wegener’s disease, lymphoma

Annular (ring) shadows
Indicate that the lesion has a relatively sharp margin and a lucent center, with a well-defined
(sometimes thick) wall. Lesions include: caverna, bulla (emphysematous), bronchiectasis,
cyst, pneumatocele, abscess, aspergilloma, Echinococcus, or fusion (infarction pneumonia,
tumor).

Calcifications
Nodular: Tuberculoma, granuloma, hamartoma, carcinoid, metastasis
Diffuse: TB, histoplasmosis, varicella pneumonia, chronic pulmonary congestion,
broncholitis, silicosis, hypercalcaemia
9. Chest Radiology

7. Lung tumor. CT, coronal reformat.

73 year old woman, right sided spiculated round shadow (op: planocellular carcinoma)

8. Pulmonary fibrosis Chest radiograph, PA

86 year old man with DM without chest pain. Fibrosis + emphysema

9. Postirradiation fibrosis. CT

66 year old woman, right-sided breast cancer recidiva resection + multiple irradiation therapies.
Radiation-induced fibrous bands under the chest wall on the right side.
9.1.5.4. Lung parenchymal diseases

Chronic obstructive lung diseases
Symptoms include: recurrent cough, shortness of breath during physical activity, and recurrent bronchitis.

Chronic bronchitis
Bronchus walls thicken due to inflammation, bronchoalveolar spaces congest with mucus, and there is superinfection, alveolar wall damage, and development of emphysema.

Emphysema
Pathology: abnormal permanent airway enlargement of distal air spaces (from the terminal bronchioli towards the periphery), enlarged air content, and elongated, damaged walls resulting in capillary and precapillary destruction and increased lung volume.

Pathophysiology: air is trapped during expiration, causing the residual air to accumulate and the volume of the affected lung zones increase.

Forms of emphysema
Diffuse: chronic bronchitis without obstruction (essential)
chronic bronchitis with obstruction
Partial: Bullous emphysema (progressive lung dystrophy)
Ventillation emphysema

Radiograph signs of diffuse emphysema
Barrel chest
Diaphragmatic depression, flattened or concave domes of the diaphragm
Shallow respiration
Increased lung volume (hyperinflation)
Tapering of pulmonary vessels (air/blood quotient shifts + capillary destruction)
Increased lucency of the lung
Dilatation of the central hilar pulmonary arteries developing in cases with pulmonary hypertension centroperipheral discrepancy
Small, vertically-oriented cardiac consolidation (due to diaphragmatic depression)

Emphysema types according to the localisation (often referring to the origin)
Centrilobular
Panlobular
Paraseptal
Bullous

Bullous emphysema (progressive lung dystrophy) has defined emphysematous bullae and, usually, diffuse emphysematic changes. Bullae have subtle walls and unstructured air-containing abnormalities that can be observed nearby in particular areas, often on the margins or near the fissures.

62 year old women suffering from COPD.

11: Centrilobular emphysema, CT image.

76 year old man, previous therapy because of metastatic rectum carcinoma. Bilateral extensive emphysematous bulla development, fibrotic shadows.

12. Bullous emphysema. CT axial image and coronal reformat.

59 year old man. RUL: 2-5 cm large subpleural bullae.
90 year old woman, hx of breast cancer, secondary pulmonary disease, TB therapy.

**Bronchiectasis**
Causes: congenital (e.g. bronchus wall faintness)
secondary impairments (inflammations, bronchostenosis)

Bronchiectasis causes and maintains a perifocal recurring pneumonia and lung fibrosis.
Primary symptom: listen for defined crackles not ending for cough
Forms: cystic, cylindrical, and varicose
Localisation: often lower lobe dominance

Radiograph signs of bronchiecstasis: Summation pattern constisting of small, ring-shaped consolidations

HRCT indications: A signet-ring sign indicating a small caliber arterial branch next to a broad bronchus

70 year old man, RML long cylindrical bronchial dilatations.
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9.1.5.5. Inflammatory diseases: pneumonias (lobar, broncho-, interstitial pneumonia)

Localisation: lobe, segment

Pneumonia

Radiograph signs: Blurry consolidation (patchy opacities) in various forms and extensions. Note that the radiograph is “delayed”, meaning consolidation appearance and disappearance is later, as anticipated based on the clinical signs. In general, the radiograph is not specific to the causative organism, except in the case of Staphylococcus.
- Bronchopulmonar (spreading along the bronchioli): no air bronchogram
- Lobar (spreading from alveoli to alveoli): air bronchogram can be seen
- Atypical (interstitium): linear opacities

Differential diagnosis: Similar consolidation may originate from lung infarction, tumor, TB, or lung edema. Clinical features and dynamic observations help in the diagnosis.

Types of pneumonia:
Primary: develops in the basically healthy lung; causative organisms: bacteria, Mycoplasma, or virus

Secondary: develops in the previously diseased lung fibrosis, bronchiectasis, azygos lobe, lung sequestration, bronchial stenosis /occlusion (aspiration, foreign body, bronchial tumor), cardiovascular diseases (eg. pulmonary congestion)

Perifocal: develops around a lung infarction or tumor

Secondary pneumonias are characterized by long-lasting disease course, and a likelyhood of recurrence (“superior cause”). Aspiration pneumonia is patchy and multifocal, with right lower lobe dominance. In bronchial stenosis-associated forms, pneumonia may be complicated by atelectasis, as indicated by sharper margins with increasing extension during its course.

Staphylococcus pneumonia: has a pathognomonic appearance of multiple, round nodules that are liable to assimilate. Localisation can be anywhere, but is typically solitary, rarely multiple. Consolidation intensity depends only on the thickness in the beam direction. Consolidation structure is inhomogeneous-homogeneous-inhomogeneous, according to the phase of the disease course.

The edema fluid is closer to the lower border (gravitation); therefore the lobe border stands out (eg. the horizontal fissure in upper lobe pneumonia). The edema does not suddenly change its size nor does it change the volume of the concerned lobe. It does not result in hilar lymph node enlargement, but can be associated with slight pleural effusion.
15. Atypical interstitial lobar pneumonia a.) CT b.) radiograph

45 year old man. He had a chill, serious cough, yellow-green tracheal excretion. Left-sided lymphadenopathy next to the aortic arch on the left. Irregular infiltrations (opacities) in the lung parenchyma in subpleural and LUL dominance. (by the contribution of Zsuzsanna Monostori, MD, PhD)

16. Right lobar pneumonia. a.) PA b.) lateral radiograph.

Mycoses

Increasing incidence since the adaptation of antibiotics and steroids. Examples include actinomycosis, candidiasis, and aspergillosis. Radiograph sign: pneumonia-like, small, blurry, multifocal or extent, homogeneous consolidation.

TB (tuberculosis)
(Only the radiological signs of lung TB forms are discussed here, not the disease itself)

The primary TB complex usually develops unilaterally in the periphery of the middle lung zone. This primary nodule is a solitary, small blurry infiltration that is associated with a hilar lymphadenitis or lymph node enlargement demonstrated by the widening of the same side hilum. A peribronchial lymphangitis-associated reticular pattern can be observed inbetween the primary nodule and the lymphadenomegaly. The primary complex is susceptible to calcification. As a result, there may be extensive affection or enlargement of the hilar lymph node. Lobar or segmental bronchial stenosis may be caused by these lymphadenopathies, and associated with ventil atelectasis or emphysema.
Hematogenously spreading (lung) TB causes symmetrical, miliary dissemination indicated by small 1-2 mm nodules. These small nodules can only be distinguished by CT, because the summation effect superposes their consolidations on the radiograph. The pellets cumulate in the upper lobes may have a tendency to conflate, resulting in pleural effusion. Hilar lymphadenopathy is not characteristic here. Hematogenous dissemination can be confined to certain lobes and these can calcify having a traction effect with focal scarring (sintering) causing local emphysema. Certain nodules, particularly Simon nodules in the lung apex, can progress and remain active. The Assmann-type early infiltration is located infraclavicularly.

The rapid course form of TB is Landouzy sepsis (sepsis tuberculosa acutissima) and is observed as various sizes of more or less slurred patches instead of nodules.

Lung phthisis can appear in very polymorphic and varied in images. The patterns are very unsteady, such that the radiographic picture can change from day-to-day. Images can be:

- assymmetric with side-by-side localisation
- cavernous (ring-shaped) with wall thickness depending on disease stage. May include air-fluid level and draining bronchus with thickened wall
- cirrhotic/fibrotic parenchymal scarring, striated and blurry pattern, including traction emphysema, bronchiectasis, calcification
- exsudative (blurry, conflating, blurred margin) or productive (sharp margin, fine or rough, blurry) nodular pathologies

17a, b: Apical TB. HRCT, coronal reconstruction

Right apex, segment 1: reticular pattern and mosaic-like ground glass opacity (similarly mind changes in b. 6th segment, too). Extensive TB-specific lesions in apical dominance.
18. Tuberculosis a.) CT, b.) PA radiograph

45 year old man, pulmonary TB proven by microbiological culture.
LLL on CT: irregular, multicavitary nodular lesion: caverna.
(by the contribution of Zsuzsanna Monostori, MD, PhD)

19. Tuberculosis, bidirectional chest radiographs and HRCT. (coronal reconstruction)

75 year old man: hx of hypertension, smoking. Symptoms: dyspnea, productive cough. Moist
rales of auscultatory findings above the LLL, tension irritability in the level of lower dorsal
spine.
a.) Chest radiograph, bilateral: Mild increased vascular markings. Extensive patchy lobar
infiltration in the RUL Previous TB specific lesions in the left apex. The diaphragm contour is
blurry on the right side (appr. 4 finger-wide pleural effusion). Cardiomegaly. Medium large
dilated sclerotic aorta.
b.) HRCT: Reticular pattern of 10x10x5 cm area in the right apex (1st segment), (septal
thickenings), mosaic-like ground glass opacity in the righ apex. Subpleural total atelectasis
(mainly 1st segment): irregular mainly nodular soft tissue streak associated with the pleura
(max. appr. 1 cm thickness). Some tiny subpleural emphysematous bullae in the right apex.
9.1.6. Tumors

9.1.6.1. Primer tumors

Benign or semimalignant (adenoma, hamartoma, carcinoid)
Benign tumors (hamartoma, chondroma, lipoma) are rare. Bronchial adenoma is a semimalignant tumor that is benign histologically, but can metastasize.

Radiograph sign: round or lobulated nodule with well defined border may include calcification
Clinical importance means that it may mimic a malignant tumor

On CT scans, small hilar lymphadenopathy can indicate the possibility of metastasis.

Malignant bronchial carcinoma
Malignant lung cancers originate mainly from the bronchi. According to its position, central and peripheral bronchial carcinoma can be distinguished.

Central bronchial carcinoma originates from a bronchus at the level of the hilum, initially causing an undefined hilar widening. The carcinoma includes its surroundings and metastasizes to the adjacent lymph nodes. This type of tumor releases broom-like spurs into the lung parenchyma.

The tumor narrows and increasingly obstructs the lumen of the bronchus, indicating a consequent atelectasis. Superinfection develops in this lung area with characteristically bad ventilation, and recidivating pneumonias will occur. CT examination can certify the presence of a bronchial carcinoma.

Peripheral bronchial carcinoma is located in the lung parenchyma or along the chest wall. The radiograph sign characteristic of this carcinoma is a solid nodular consolidation with a plain, lobulated, or spurred border. A peripheral bronchial carcinoma with a particular location is the Pancoast tumor. This tumor appears in the lung apex (upper sulcus tumor) and spreads through the chest wall transpleurally, infiltrating the cervical sympathetic ganglia. This infiltration causes neurological symptoms including Horner’s syndrome or oculosympathic palsy with miosis, ptosis, and enophthalmos. MDCT or MRI examination can accurately verify the chest wall infiltration.

The appearance of BAC (bronchoalveolar carcinoma) is highly variable and bewildering. The BAC tumor spreads in the alveoli, indicated by a multinodular, infiltrative consolidation in the lung periphery, but it may appear as round consolidation as well.

9.1.6.2. Metastases (intrapulmonary, pleural, lymphangitis carcinomatosa)

Tumors that metastasize by hematogenous spread include: breast, prostate, kidney, thyroid, cervical, testicular, bone, melanoma, gastrointestinal, and pancreatic tumors.
Radiograph sign: multiple small nodules of various number and size

Tumors that metastasize by lymphatic spread include: breast cancer and bronchial carcinoma. These cancers often result in lymphangitis carcinomatosa.
Radiograph sign: radially expanded reticulolinear markings
20. Miliary lung metastases. HRCT, coronal reconstruction:

Jobb tüdő adenocarcinoma miatti lobectomia, (agyi metastasis). (dr. Monostori Zsuzsanna anyagából)
60 year old man, secondary pulmonary lesions due to kidney tumor, underwent target therapy. Lobulated nodule in the left lung, associated with the pleura dorsobasally.

Lobectomy because of right lung adenocarcinoma, (brain metastasis). (by the contribution of Zsuzsanna Monostori, MD, PhD)

21. Left sided peripheral lung tumor

22. Central lung tumor with mediastinal lymphadenopathy. CT coronal and sagittal reconstructions.
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70 year old man, COPD, hoarse. Right hilar mass, bronchoscopy was negative. The larynx is rotated to the right, no motion of the right side of the larynx can be observed, swollen left plica ventricularis area. CT: 13x11 mm large nodular mass in the left 10th segment. Bilateral hilar lymphadenomegaly with central hypodensity. A 34x21 mm large lymph node conglomerate can be observed in subcarinal location (peripheral contrast enhancement). Lymphadenopathy in the aortopulmonary window (15 mm large), and a 26 mm large lymph node can be observed in paraaortic location above the trachea bifurcation which has an esophagus-compressing effect. In the superior chest aperture there is a 38x28 large fused lymph node conglomerate which causes the left shift of the esophagus and trachea.

23. Pulmonary metastases, bidirectional (PA and right lateral) plain chest radiograph. 51 year old woman, endometrial carcinoma. Numerous ring shadows bilaterally in basal dominance (max. appr. 12 mm). Left pleural effusion of one finger wide.

9.1.7. Diseases of the pulmonary circulation

Pulmonary hypertension
Causes of pulmonary hypertension include: increased arterial side blood pressure (left-right shunt), an secondary lung diseases (emphysema, chronic bronchitis, chronic pulmonary embolisation, fibrosis).

Radiograph sign: centroperipheral caliber discrepancy, with central hilar artery dilatation followed by abruptly marked stenosis. The peripheral vessel structure is unremarkable.

Postcapillary Pulmonary Hypertension
Postcapillary pulmonary hypertension is caused by raised pulmonary venous hypertension.

Radiograph sign: apicobasal caliber discrepancy, with upper-zone redistribution of blood flow (“twiddled moustache sign”), followed by the development of parahilar airspace consolidation. Accumulated fluid in the lung parenchyma causes a patchy consolidation. If the congestion abruptly worsens, lung edema develops.
Pulmonary congestion/edema
Pulmonary congestion is a buildup of fluid transudation from the capillaries into the interstitium that cannot be transported by the lymphatic vessels. Causes of the extravascular fluid increase are: higher hydrostatic pressure, increased capillary permeability, overflow, pulmonary vein occlusion, pulmonary emboli, decreased osmotic pressure, transfusional reaction, decreased plasma protein level, and adult respiratory disease syndrome (ARDS).

Pulmonary congestion and edema develops in two stages.
Stage 1: Interstitial edema (fluid congestion in the interalveolar septa) and visible Kerley B lines (thin, horizontal, 3-6 mm long lines basal or along the lateral chest wall).
Stage 2: Combination of alveolar (overflow) and interstitial consolidations.

Radiograph signs: Kerley A and B lines (interlobular-interalveolar septa in both hila or basal along the lateral chest wall); apicobasal caliber discrepancy (upper-zone redistribution of blood flow); confluent symmetrical, bibasal airspace shadows without air-bronchogram; principally the hilar regions are concerned (perihilar bat’s wing pattern); usually cardiomegally occurs.

Pulmonary embolisation
A pulmonary artery thrombus originating from the peripheral veins results in pulmonary artery occlusion. The radiograph has a poor diagnostic value for pulmonary emolisation. Instead, the practical examination is CT pulmonary angiography, in which the thrombus appears as an intraluminal filling defect. This is an emergency situation and the CT must be performed on the critical patient immediately, even in the middle of the night! The source of the emboli must be sought (ultrasound), and lower extremity deep vein thrombosis must be excluded. A D-dimer assay is an important diagnostic parameter, because a negative test makes the presence of thrombosis unlikely.
25. Massive pulmonary embolism. CT angiography (axial image and coronal reconstruction) 84 year old woman: dyspnea, elevated D-dimer. Pulmonary embolism, riding embolus in the pulmonary trunk and in both pulmonary arteries + in smaller branches bilaterally as well. Contrast filling defects are seen according to the emboli.

ARDS (adult respiratory distress syndrome) interstitial infiltrations
Causes of ARDS: toxin (fume) inhalation or oxygen therapy, sepsis, aspiration, grave operation, acute pancreatitis, disseminated intravascular coagulation (DIC), trauma, transfusion, hemodynamic shock, and fat embolism.

Radiograph sign:

26. ARDS, CT, coronary reconstruction
52 year old woman, dyspnea, septic shock.
Bilateral opacity according to rough, diffuse interstitial edema, irregular atelectasis and bronchogram in the basal segments
27. Cardiomegaly, bidirectional chest radiograph (PA, left lateral). 70 year old woman, hx of hypertension. Enlarged heart shadow, elongated aorta, moderate congestion pattern (skoliosis).

Imaging modalities: chest radiograph, CT.

9.2. The Hilum of lung

Imaging modalities
Chest radiograph posteroanterior and lateral views
CT axial series and reconstruction algorithms

Anatomy
The hilum of lung consists of the primary branches of the main bronchi and the pulmonary artery. Tracheobronchial lymph nodes are situated along the bronchovascular bundle. In a healthy case, the pulmonary vessels create the hilar shadow mainly on the chest radiograph.

Pathological hilar shadows
Hilar shadow widening can be caused by dilated vessels, lymphadenopathy, or tumor. Bilateral, ill-defined tubular shadows indicate dilated pulmonary vessels (pulmonary hypertension, chronic embolisation). Lobulated shadows suggest lymphadenopathy (structures without branching). Bilateral lymphadenopathy can be caused by sarcoidosis and lymphoma. Causes of unilateral lymphadenopathy include: lung tumor metastasis, malignant lymphoma, and infections (TB, histoplasmosis).

9.3. The Pleura

9.3.1. Imaging modalities

In a healthy case, normal pleura thickness does not appear on the radiograph. The pleura consists of two right layers, the horizontal and oblique fissures, and one layer on the left side, because there is no middle lobe. The layers appear only in tangent to the X-ray beam (orthoroentgenograd direction), and only through the horizontal fissure on the posteroanterior radiograph.
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CT shows the “fissure-making” visceral pleura layers in transverse plain, which can be recognised even in a healthy subject. The sagittal and coronal reconstruction algorithms provide further enhancements.

In certain cases, ultrasound can be very helpful in imaging the fluid in the costopulmonary sinus and its ultrasound guided puncture. However, as it is known, ultrasound is not employed for the evaluation of the lung, since it is not able to “see deeper”.

MRI can be an appropriate imaging method for the pleural pathologies, because of its multiplanar algorithm, eg. frontal (coronal) or sagittal planes.

9.3.2. Diseases of the pleura

9.3.2.1. Pleural effusion

Causes of transudates include: heart failure, chronic renal failure, hypoproteinaemia, and overfill. Causes of exudates include: TB and other infections, subphrenic abscess, lung cancer, systemic lupus erythematosus (SLE), and rheumatoid arthritis (RA). Hemothorax can be seen after chest trauma, or in haematological patients. Bloody pleural effusion is an indication of pulmonary embolisation, or lung cancer. Chylothorax is often caused by thoracic duct injury. Causes of empyema are: pneumonia, trauma, or breakthrough of a liver abscess.

Pleural effusion cannot be differentiated radiologically except in special cases, nor can be differentiated by CT or MRI, for example the transudate vs. exudate. (punction)

The quantity of effusions varies, ranging from sinus shadowing to consolidation of the minor-major part of the lung. A large quantity of fluid can cause mediastinal shift away from the effusion. In addition, subpulmonic localisation might occur. (Importance of Frimann–Dahl type radiograph)

In cases of pleural fibrosis, encased effusions can develop. Moreover, encased effusion in the horizontal fissure can mimic pneumonia on the chest radiograph.

Pleural thickenings (fibrosis) can occur due to various reasons: pleuritis, as a consequence of an infection, encased effusion, complication of haemorrhage, and in association with pulmonary fibrosis in the apices (TB). Extensive fibrosis can result shallow respiration and chest deformity. Calcification of fibrosis occurs in certain cases (TB, asbestosis). Beyond the radiograph and fluoroscopy, CT can be conclusive for fibrosis.

9.3.2.2. Pneumothorax (ptx)

When ptx is suspected, an expiratory radiograph must be performed! In the varying extents of lung collapse, pulmonary vascular markings are absent lateral to the hairline pleural shadow between the chest wall (parietal pleura) and visceral pleura. It is important to remember that, for a slim patient, a skin fold can mimic ptx on the supine radiograph. In cases of tension ptx, an associated mediastinal shift to the opposite side is seen and requires immediate therapy! In cases of hydro-ptx, the air-fluid level is a pathognomic sign, which can be heard by listening for a splashing noise while shaking the patient.
9.3.2.3. Pleural tumors

Primary pleura neoplasms and metastases result in pleural effusion, therefore malignant disease must be assumed in cases of chest effusion of unknown origin. Variations caused by the pleura malignancy appear flat (along the chest wall or interlobar) or nodular.

Benign pleura tumors include fibromas and lipomas, as well as benign mesothelioma.

Asbestos inhalation-related mesothelioma, a primary pleural malignancy, is rare.

CT is the appropriate imaging method for pleural tumors, because the effusion and soft tissue can be differentiated.

Confirmation of the pleural metastases diagnosis is simple only in cases, for example, when rib destruction is caused. If the pleura metastasis is large enough, enhancement can be observed by CT. Often, only biopsy can confirm the diagnosis.

28. Pleural effusion (+ foreign body), AP chest radiograph, supine.
85 year old man. No differentiation of diaphragm is possible on both sides. Basal lung areas: hypolucency. Along the right lateral chest wall, mild hypolucent streak can be observed extending to the apex (fluid).
Remarkable left cardiomegaly, almost reaching the lateral chest wall.
Pacemaker + its electrodes on the right side. The end of the right internal jugular vein catheter ends at the projection of the superior vena cava. At the projection of the anterior arch of the left 3rd rib a 1.5 cm large arched shadow can be seen in metal intensity in the medioclavicular line (6-7 cm long, thin, linear metal foreign body)
9. Chest Radiology

29. Lung fibrosis and pleural fibrosis: Asbestosis, P-A chest radiograph
78 year old man. Fibrotic peribronchial fibres can be seen in bilateral lungs in basal
dominance from the hilum towards the pleura. Roughly calcified, concentric armor-like
pleural fibrosis (callus) is on the pleura extending from the apex to the diaphragm.

30. Hydro-pneumothonax, right side, cloak-form, adhesive, chest radiograph, P-A.
68 year old man. St.p. oesophago-gastrostomiam. Right sided pneumothorax measures 3.5 cm
in the apex, 1.7 cm in the basis and 1 cm along the lateral chest wall.

9.4. The Mediastinum

9.4.1. Anatomy

The mediastinum includes the middle part of the chest and lies between the two lungs. It is
bounded superiorly by the soft tissues of the thoracic inlet, inferiorly by the diaphragm,
anteriort by the sternum, and posteriorly by the vertebral column. Its three parts are:
1. Anterior mediastinum: thymus, large vessels
2. Middle mediastinum: heart, trachea, main bronchi, phrenic nerves, lymph nodes
3. Posterior mediastinum: esophagus, descending aorta, vagus nerve, sympatric chain,
thoracic duct, azygos vein, haemiazzygos vein.
Mediastinal lymph nodes are located in all the three regions. Lymph nodes can be classified
according to their position: paratracheal, tracheobronchial, carinal, and bronchopulmonary
(hilar).

9.4.2. Imaging modalities

When using radiography to image the mediastinum, the following criteria must be taken into
account: width, contours, location, and size and passage of the trachea. Focused trachea
examination on the radiograph (passage, width, contour distortion, wall contours) can be also
informative. Upper gastrointestinal contrast swallow during radiography provides information
on possible paraesophageal malignancies by the location, passage, and outside contour of the
esophagus. In addition, fluoroscopy using Müller and Valsalva maneuvers provides
information about substernal goiters.
CT, particularly contrast-enhanced MDCT, allows precise images beyond the large vessels of mediastinal tumors, lymph nodes, and calcifications. An advantage of MRI over CT is that there is no radiation exposure, which is especially important for children. In addition, the vessels can be easily differentiated from the soft tissues and tumors due to the absence of signal.

9.4.3. Mediastinal diseases

9.4.3.1. Pneumomediastinum

Pneumomediastinum can have traumatic causes, such as trachea rupture or perforation, or iatrogenic causes, such as esophageal suture failure, complications of pressurized mechanical ventilation, and esophageal rupture or perforation. Radiograph signs are gas bubbles and linear collections of air between the tissues that appear as a hairline shadow running parallel to mediastinal structures, tracing out the aorta and the mediastinal pleura.

9.4.3.2. Infection

Mediastinitis
Mediastinitis is a life threatening infection caused by esophageal perforation by a foreign body, or as an iatrogenic consequence of endoscopy or expansion. The most frequent cause of chronic mediastinitis is radiation, with prevailing fibrosis. Radiograph signs are mediastinal widening, which can be accompanied by pleural effusion. CT images show an immediate increase of fat tissue density due to inflammatory edema in acute mediastinitis. MRI indicates a signal increase on the T2 weighted images (the fat suppression images).

9.4.3.3. Tumors (benign, malignant)

Mediastinal tumors

Distribution according to the origin:
Most mediastinal tumors are of neurogenic (20%), thymoma (20%), lymphoma (13%), or germ cell origin (20%).

Tumors and cysts according to the localisation:
1. Anterior mediastinum (54%):
Thymoma, germ cell tumor, lymphoma, haemangioma, parathyroid adenoma, thymus cyst, lipoma, aberrant thyroid tissue, lymphangioma, lipomatosis.
2. Middle mediastinum (20%):
Enterogenic cyst, mesothelial cyst, lymphoma, thoracic duct cyst, granuloma, foreign body (aspiration, trauma, iatrogen).
3. Posterior mediastinum (26%):
Neurogenic tumors, neurenteric cyst, lymphoma, esophageal tumor.
Clinical features
Clinical features of mediastinal tumors are chest pain, cough, and dyspnoea. However, 2/3 of patients have no symptoms, which increases the chance of a benign lesion. 20-40% of mediastinal tumors are malignant. Characteristic symptoms include chest pain, cough, and fever. Mechanical compression or the infiltration of the mediastinal structures is indicative of malignancy.

Imaging diagnosis
Chest radiograph shows tumor localisation, with or without calcification. CT, particularly MDCT with or without contrast, shows chest wall infiltration, multifocal structures, and vertebral column infiltration. MRI is more sensitive for vascular infiltration and for intracardiac pathology (substernal goiter, thymoma).

Malignant lymphomas
Malignant lymphomas have symmetric mediastinal enlargement (hilar lymph node enlargement). In malignant lymphomas, wide range of lung manifestations occurs. In fact, 30-40% of Hodgkin’s lymphomas are associated with lung manifestation.

Leukemias
Leukemias show a similar appearance such that beyond the mediastinal lymphadenomegaly, interstitial and alveolar (reticular and nodular) shadows can be observed.

Report: enlarged lymph nodes can be observed in the level of the superior mediastinum forming a conglomerate.

31. Hodgkin disease, bidirectional chest radiograph (PA, lateral)
45 year old male, investigated for cervical lymph node enlargement, enlarged lymph nodes are at the right side of middle mediastinum, close to the hilum.
32. Mediastinal sarcoma. Chest radiograph and CE CT (cor. rec.)
54 year old woman. CT: round soft tissue mass in the 6th segment and the middle lobe in the left lung parenchyma. Large left pleural effusion causing the compression atelectasis of the lung parenchyma. Appr. 14x12 cm large inhomogeneous soft tissue mass in the LLL dislocates the diaphragm downwards. (by the contribution of Zsuzsanna Monostori, MD, PhD)

Sarcoidosis
Sarcoidosis is a diffuse, non-encasing granulomatosis of unknown origin. Radiograph signs are mediastinal and hilar lymph node enlargement with blurry parenchymal nodules, which are initially 1-3 mm and can later develop to be 1-3 cm.

43 year old man. Chronic alcoholism. Abdominal tightness and dyspnea. Right pleural effusion reaching the level of the hilum, including a wider and narrower air-fluid level (empyema). The right diaphragm can not be differenciated. Slight left shift of the heart.
9.5. The Diaphragm

9.5.1. Imaging modalities

Static and dynamic imaging methods are necessary/possible, including: radiography and fluoroscopy, MDCT volumetric data acquisition and MPR, MRI, and ultrasound.

34. Normal (a) and elevated (b) diaphragm. The reason of the diaphragm elevation was alcoholic liver fibrosis. Chest radiograph, P-A

9.5.2. Evaluation of diaphragm:

Reasons for diaphragm elevation:
Insufficient inspiration
Obesity
Pregnancy
Ascites
Meteorism
Large abdominal tumor
Hepatosplenomegaly
Subphrenic abscess
Volume loss of the basal lung zones

Reasons for unilateral diaphragm elevation:
Scoliosis associated thoracic deformity
Volume loss of the lung
Pulmonary embolisation or atelectasis
Phrenic nerve palsy
Subphrenic abscess
Subphrenic tumor
9.5.3. The most important diaphragm alterations:

Diaphragmatic hernias
Hiatus hernia: the partial prolapse of the stomach into the chest through the esophageal hiatus (fixed, paraesophageal, upside down)
Anterior hernia: Morgagni’s hernia
Posterior hernia: Bochdalek hernia

Translated by Dávid László Tárnoki
The purpose of the chapter
The goal of this chapter is to provide an introduction of the fundamentals of neuroradiology to the 4th year medical students of the University of General Medicine. Special emphasis is put on the imaging algorithms used in case of syndromes with sudden onset of neurological deficit (stroke), inflammatory diseases, demyelization disorders of the central nervous system (CNS) and the imaging of neoplasms.

10.1. The skull and the brain

10.1.1. Discussion

We discuss the diagnostic of the skull / cerebrum and the spine (relevant onto marrow) from practical reasons apart. For the spine bones see chapter 17. For trauma see the emergency chapter.

10.1.2. Diagnostic Imaging methods for the brain and the skull:

10.1.2.1. X-ray radiography

It is only limited to the “bony frame” of the central nervous system. Nowadays it is primarily preserved for imaging the abnormalities of the spine. Radiographs should be acquired at least from 2 imaging planes and in certain cases it is necessary to produce images from additional, special planes (i.e. neurovascular foramen).

10.1.2.2. Ultrasonography

is only used in certain (rather limited) cases, namely, if there is a presence of an acoustic window for proper imaging. The most common uses of US in neuroradiology are the cerebral imaging of infants through the fotanella or intraoperative US examinations. Trasncranial Doppler (TCD) is useful in imaging the cerebral blood flow and velocity, in these cases the temporal bone is used as an imaging window. (It can be used in the diagnosis of vascular stenosis, occlusion, in the examination of vasospasm of the cerebral vessels or in case of brain death.)

10.1.2.3. Computed Tomography (CT)

It is an excellent and a widely available method for imaging the central nervous system. It reliably depicts bony structures, calcifications and cerebrospinal fluid. It is also capable to distinguish white matter from grey matter, as well as the CSF (0 HU) based on their density differences. Fresh hemorrhage on CT appears hyperdense, therefore hemorrhagic stroke and subarachnoid bleeding can be promptly diagnosed with CT examinations.
CT angiography (CTA) produces high resolution images with the help of intravenous iodinated contrast material.
Dynamic contrast enhancement examinations are used to produce brain perfusion measurements.
Multiplanar and 3D reconstructions can be derived form the source images (the latter is used to visualize bony deformities of both the skull and the spine).

10.1.2.4. Magnetic Resonance Imaging (MRI)

It provides excellent tissue contrast, making MRI the distinguished imaging method of the central nervous system. However, availability is still limited (only a few number of 24 hour on-call centers) and patients often cannot schedule for a necessary MRI examination on time.
As opposed to the volumetric data acquisition of CT scanning, MRI has the advantage that its image production is not distracted by bony artefacts. In cases of spinal trauma, when spinal chord injury is suspected, the patient must be immediately scheduled for an MRI examination.
White matter lesions, old hemorrhages (hemosiderin) can only be depicted with MRI.
MR angiography (MRA) is an excellent method to visualize brain vessels (arteries, veins, sinuses).
Diffusion weighted MRI (DWI) is the most sensitive method in the detection of early stroke.
Diffusion weighted imaging is also able to take measurements of the movement of protons along the fiber tracts of the brain, thus enabling the visualization of cerebral white matter tracts.
MR spectroscopy (MRS) is used to investigate tissue components and therefore it is able to distinguish various pathologic tissues from one another (such as tumor and abscess).
Attention must be paid to the contraindications of MRI examinations when ordering emergency examinations!

10.1.2.5. Catheter digital subtraction angiography (DSA)

It is an invasive method, therefore it not performed for diagnostic purposes.
MRA and CTA have completely replaced diagnostic angiography. (Both the sensitivity and the specificity of MRA is greater than 90% in the diagnostics of lesions in the carotid bifurcation.)
DSA is reserved for interventional procedures (embolisation, balloon angioplasty and stent implantation) for both extra- and intracranial arteries.

Therapeutic (palliative) X-ray/CT guided interventions are primarily performed on the spine; these include: the insertion of pain relief canulus, periganglionic injections, intradiscal injections (chemodiscolysis). Moreover, fractured vertebral bodies can also be expanded with image guided interventions.

10.1.2.6. Nuclear medicine

It has two diagnostic methods SPECT and PET (both can be combined with CT to form hybrid diagnostic machines.) SPECT is usually used for the imaging of cerebral circulation, and it is performed at resting and (pharmacologically) stimulated states.
SPECT offers a way to investigate various neuropharmaceuticals. It is also possible to perform brain function analysis with neuroreceptor scintigraphy.
PET examinations are primarily used to detect tumors/metastases (FDG-PET fluoro-desoxy-glucose) and also in psychiatric investigations.
10. Neuroradiology

10.1.3. Pathological lesions of the central nervous system

10.1.3.1. Cerebrovascular diseases

10.1.3.1.1. Stroke

Acute neurologic deficit syndromes that result from brain parenchyma infarction have ischemic origin in 80% of the cases. These can occur as a result of embolisation or vessel occlusion. Hemorrhagic infarcts make up 15% of strokes. The underlying cause is usually hypertension, but vascular malformation, aneurysm rupture, cerebral amyloid angiopathy, tumor bleeding and the hemorrhagic transformation of ischemic infarcts can all lead to cerebral hemorrhage. Moreover - as a rather common cause - patients with coagulopathies (mostly the ones receiving antithrombotic therapy) can also suffer hemorrhagic stroke.

The remaining (5%) of the patients can suffer spontaneous subarachnoid hemorrhage that most often results from brain aneurysm (on the branches of Circle of Willis) or from vascular malformations.

Etiological differentiation of ischemic infarcts:

Infarcts of microangiopathic origin can be lacunar infarcts that develop due to the complete or the partial occlusion of the cerebral arterioles. They predominantly occur at the basal ganglia, thalamus, internal capsule and the pons. Binswanger’s disease (subcortical arteriosclerotic encephalopathy) is also results from microangiopathy. Infarcts due to hemodynamic changes can occur as a result of perfusion reduction at the end-arteries or at the border-zone (watershed) regions.

Thromboembolic infarcts show a territorial distribution restricted to the supplied areas of certain arteries.

1: Lacunar infarcts MRI, FLAIR.
2: Binswanger's disease, CT
3: Left posterior border-zone infarct, CT
Cerebral infarcts (ischemic)

CT: The primary goal of the diagnostics is to rule out hemorrhage, for which CT is very sensitive. It is essential to differentiate ischemic stroke from hemorrhagic stroke because their therapeutic approaches and consequences are fundamentally different. When bleeding is excluded, based on the neurologic assessment of the patient (deficit, age of stroke etc.) thrombolytic therapy can be initiated by the neurologist either as a generalized (intravenous) or a local procedure (selective thrombolysis – performed by a radiologist).

In hyperacute infarctus (12 órán belül). A CT kép normálisnak tűnhet ez esetek 50-60 %-ában. A hyperdens arteria jel (Gács jel), melyet az arteria lumenén belüli thrombus hyperdensitása okoz a folyó vérhez képest kb az esetek 25-50 %-ában látható az érben. Ez leggyakrabban az a. cerebri media főága, néha kisebb ágai is, de a. basilaris thrombosis esetén is látható lehet az érben a hyperdensitás. Igen korai jel lehet a nucleus lentiformis határainak elmosódása.

CT angiographiával jól ábrázolódnak az érelzáródás okozta telődési hiány MRI vizsgálattal a diffúzió súlyozás (DWI) igen korán mutatja az infarctus kiterjedését.

In acute phase (12-24 hours after the occlusion of the middle cerebral artery) on CT hypodense basal ganglia, the loss of cortical white-grey matter differentiation and sulcal effacement are the characteristic imaging findings. On MRI, diffusion restriction causes hyperintense signal on T2W images. The leptomeningeal border of the infract zone will show contrast enhancement.

After 1-3 days the “mass-effect” of the infarct increases. It is more apparent in case of large territorial infarcts, the sulcal effacement completes, the loss of cortical white matter and grey matter differentiation is more pronounced (especially in the white matter) due to the increased hypodensity. Hemorrhagic transformation in the grey matter (cortex, basal ganglia) can also occur at this stage. It is worth to note, that for hemorrhagic transformation one should not always blame thrombolytic therapy; it rather occurs spontaneously in a great majority of the cases.

After 4-7 days the edema and the “mass-effect” persist, there is a marked hypodensity and even contrast enhanced CT can detect enhancement at the leptomeningeal border of the infract zone.

Within 1-8 weeks contrast enhancement and mass-effect still persist. Later a slow regression in the mass-effect can be noted. In children (transient) calcification can also occur.

In the chronic phase of the infarct (months to years) the hypodensity of the lesion (CT) reaches the level of the cerebrospinal fluid. There is no more contrast enhancement, the lesion is well differentiated and it degenerates into a cyst secondary to encephalomalacia. The brain parenchyma experiences a volume decrease due to the degeneration (sometimes calcifications can occur at the marginal border of the infarct).

Diffuse arterial sclerosis and elevated hematocrit may increase the arterial density, both mimicking hyperdense media sing, and leading to differential diagnostic problems.

- For the record: acute and chronic stages of the ischemic infarct may differ in various educational centers.
4. a-c: CT: territorial infarction of the left MCA. Hypodensity progression from early acute to later subacute stages

5. Chronic right MCA infarction CT.
6. Right hyperdense MCA sing, CT.
7. Hyperacute infarction in the right basal ganglia, DWI.

10.3.1.2. Cerebral venous sinus thrombosis:

Usually, cerebral sinus thrombosis occurs secondary to the propagation of a local infection. Sinus thrombosis can be caused by mastoiditis or extradural cervical infections, but also it can occur as the complication of intradural infections (meningitis or abscess). Sometimes dehydration, coagulopathies and cerebrospinal trauma can be the cause of the thrombosis. In sinus thrombosis 2/3rds of the patients are female, in half of the recurring cases the use of oral contraceptives is reported and 1/3rd of the women have thrombophilia. The most common location for thrombosis is the superior sagittal sinus followed by the transversal sinus and the sigmoid sinus. The thrombosis of the carvernous sinus (usually infectious origin: thromboplebitic complication) is a very dangerous condition. Internal venous thrombosis usually results in the bilateral necrosis of the basal ganglia (+ thalamus, hypothalamus, or cerebellum can also be involved).

The CT appearance of a thrombotic vein/sinus, similarly to an occluded artery, is hyperdense. A very characteristic sign is the loss of enhancement in the thrombotic segment (“empty delta sign”), that can only be confirmed unequivocally if the slice is perpendicular to the sinus (MDCT reconstruction). The infarct edema shows a delayed appearance and it is a frequent complication of cerebral venous/sinus thrombosis. It shows a different localization/distribution than the ones seen in arterial territorial occlusion. Hemorrhages occurring adjacent to the sinus can also cause an obstruction in the blood flow of the sinus. Non contrast enhanced MRI shows loss of signal void, while a loss of contrast enhancement can be noted in contrast enhanced examinations.
8. Empty delta sign in the left sigmoid sinus, CTA

9. Left transverse and sigmoid sinus thrombosis MR (PC sequence)

10.1.3.1.3. Hemorrhages

**Parenchymal hemorrhage** most often occurs in patients with hypertension, after malignant hypertensive states. The initial localization for its occurrence is at the basal ganglia (putaminal-claustral hemorrhage) that can extend into the ventricles or to the subarachnoid space. The mean age of these patients is usually younger than that of the ones with ischemic infarcts.

Bleeding usually originates from saccular “berry” aneurysms (on the branches of the Circle of Willis). Aneurysm rupture besides subarachnoid hemorrhage can also cause intraparenchymal bleeding when it breaks into the parenchyma.

The so called lobar hemorrhage is usually caused by tumor bleeding, hemorrhagic vascular malformations, rebleeding of ischemic infarcts. Bleeding secondary to **cerebral amyloid angiopathy** frequently occurs in the elderly without prevalent hypertension. It often presents as a sequential hemorrhage, each bleeding following one another, resulting in various ages of hemorrhages.

On CT images acute bleeding always presents as hyperdensity. (One has to keep it mind that hyperdensity of the blood is affected by the hematocrit levels, hence making the diagnosis more difficult.) Intraparenchymal blood is dominated by a destructive appearance (mass-effect) and it is surrounded by hypodensity as a sign of perifocal edema. It often breaks into the ventricles. In patients lying in a supine position they collect (sediment) at the occipital horn of the lateral ventricles, creating a hyperdense liquid-to-liquid levels. Later on, the density of blood decreases and shows a peripheral ring or rim-like contrast enhancement without mass-effect.

Although, **subarachnoid hemorrhage (SAH)** is most often caused by the rupture of a berry aneurysm, arteriovenous malformation (AVM) and trauma can also lead to it. SAH is typically located at the basal subarachnoid spaces, which then propagates along the lateral fissures or it fills up the interhemispheric fissure till the convexities. The main collection of the blood is usually indicative of the source of origin. In cases of parenchymal spread the mechanism, whether it broke in, or it broke out from the parenchyma could represent a differential diagnostic challenge. When accompanied by brain edema, the consequent herniation can result in parenchymal infarcts as well.

CT angiography examination is usually advisory in order to confirm the site of the bleeding. It is also effective when a hemorrhagic tumor is in the differentials, although complete differentiation might only be achieved by follow-up examinations. CTA is also essential in the diagnostics of multiple aneurysms (which are prevalent in 20-30% of the cases based on autopsy reports.) In case of a subarachnoid hemorrhage the consequently developing...
hydrocephalus and its degree might only be detected on follow-up CT examinations. It is very important to note that an initial brain aneurysm rupture might be followed by a second one within the first 7 – 10 days and the resulting vasospasm carries a much higher risk of mortality than the one at the time of the first SAH. This is why the scrutinious review of the acute diagnostic imaging is essential and it plays a fundamental role in patient treatment. Open brain surgery of the aneurysm (clipping) has been replaced by catheter angiography (DSA) nowadays. The aneurysm is either filled up with thrombogenic coils through its neck or recently bypassing stents are inserted to exclude the aneurysm from the cerebral circulation.

10. Neuroradiology

10.1.3.2. Brain tumors

10.1.3.2.1 The classification aspects:

Central nervous system tumors can be of various origins: 
**Neuroepithelial cell tumors:** astrocyte, oligodendrocyte, ependyma, cells of the pineal gland, neurons and ill-differentiated, embryonic tissue cell tumors 
**Nerve sheath cell tumors:** neurilemmoma, neurofibroma, neurosarcoma 
**Mesenchymal cell tumors:** meningioma, meningiosarcoma, melanoma 
Other tumors and tumor-like masses: primary lymphomas, vascular tumors, other neuroepithelial tumors (craniopharyngioma, dermoid, epidermoid), vascular malformations, adenohypophyseal tumors, regional tumors with local infiltration (glomus tumor, paraganglioma, chordoma). 
**Metastases**
**Primary tumors of the central nervous system** make up 10% of all neoplasms of which one third will be glial, another third non-glial and the remaining third are metastatic in origin. (Brain is a common metastatic location for certain somatic malignancies).

CNS tumors just like any other types of tumors can be **benign** or **malignant**. However, the outcome of benign tumors and their classification is influenced by the fact that expansile lesions within an enclosed space (either intracranial or intra-spinal) can damage the surrounding parenchyma due to their mass effect even if they are not regarded as invasive, infiltrative or metastasizing.

Tumors originating from the building blocks of the nervous system (astrocytoma, oligodendroglioma) are **intra-axial**. Metastases of primary tumors (such as pulmonary-, breast cancer, melanoma, colon- or renal carcinoma) are usually also intra-axial. **Extra-axial** tumors are actually (strictly speaking) not brain tumors. They originate from outside the brain such as the meninges or other structures including pituitary-, parasellar tumors and craniopharyngiomas.

The primary goal of diagnostic imaging is to differentiate between the **intra- or extra-axial** origins, because this will determine treatment options as well as the outcome. This however is not always easy.

Other classification categories distinguish **supratentorial** or **infratentorial** localization, which can be very specific for certain tumor types.

Localization and the age of the patient can be indicative in narrowing down the differential diagnostics of a tumor. According to large statistical data, 80% of extra-axial tumors are meningeomas or schwannomas, while (in adults) intra-axial tumors will usually be metastases or astrocytomas (together accounting for 3/4ths of all cases).

**The most common localizations of various CNS neoplasms**

- **Hemisphere** (multilocular): astrocytoma, glioblastoma
- **Frontal-temporoparietal**: meningioma, oligodendroglioma
- **Cerebellum** spongi-, medulloblastoma
- **Sella** adenoma, craniopharyngioma
- **Cerebellopontine angle** neurinoma (schwannoma)
- Any localization (multiplicity) metastases

Tumors according to their localization and origin can be the following:

**Supratentorial:**
- **Intra-axial**: glial tumors such as astrocytoma, oligodendroglioma, glioblastomas, but also this is the most typical localization of metastases and CNS lymphomas.
- **Extra-axial**: meningioma

**Infratentorial:**
- **Intra-axial**: the most common cerebellar tumors are astrocytomas, but medulloblastoma, hemangiblastoma and metastases also frequently occur in the cerebellum. Brain stem tumors are usually glioblastoma, astrocytoma.
Extra-axial: most tumors are located in the cerebellopontine angle and they are regarded as one entity due to their resulting neurological symptoms. Acoustic neuroma is the most common form (vestibular Schwannoma if unilateral, or as part of neurofibromatosis if bilateral), meningioma and epidermoid are also frequent in this localization. Arachnoid cysts at this location can also produce similar symptoms. The jugular foramen is usually obstructed by glomus tumors, en plaque meningioma can descend to the foramen magnum and neurofibroma can also occur there. The typical tumors of the clivus are chordoma and chondroma (chordosarcoma).

Sellar (and parasellar) tumors: are naturally extra-axial. The most common type is pituitary adenoma that can be either active (hormone producing) or inactive (usually already extensive at the time of diagnosis). Craniopharyngiomas are also located here, they cause diabetes insidipus. Meningiomas and aneurysms of this region cause differential diagnostic difficulties. Rathke’s pouch cysts also behave like tumors due to their mass effect.

Pineal tumors are pinealoma, germinoma (usually bilocular) and glioma.

Tumors originating from the ventricles can be ependymoma, choroid plexus papilloma, epidermoid (and colloid) cysts. Their symptoms are always related to CSF obstruction. Typical findings in the ventricle are the choroid plexus papilloma and colloid cyst.

Skull base tumors:

Quite often it is needed to consider the possibility of a tumor spread (such as in cases of sinonasal tumors, or chondrosarcoma originating from an upper cervical vertebra).

Age distribution of tumors

Child and adolescent medulloblastoma, craniopharyngioma, ependymoma
Adulthood astrocytoma, oligodendroglioma, meningioma, pituitary adenoma, neurinoma
Elderly glioblastoma, metastases

10.1.3.2.2. CT and MRI characteristics of CNS tumors

CT can usually lead to definitive diagnosis regarding brain tumors. A non-territorial localization (as opposed to arterial occlusion) of a usually “glove” shaped perifocal hypodense zone is highly suspicious for a tumor. MRI provides even more definitive proof. On T1 weighed images they are usually hypointense, on T2 weighed images their signal is strong. Although these signs are very characteristic, normally they are still insufficient for exact differential diagnostic criteria.

Contrast enhancement of tumors, specific forms of enhancement:

Intravenous contrast agents (iodinated contrast media in CT, or chelated Gadolinium in MRI) normally do not pass over the blood-brain barrier. Contrast material cannot leave the blood vessels towards the parenchyma (secondary to its strong triple layer defense). Therefore, where contrast enhancement is seen, the blood-brain barrier is damaged. This is only possible in intra-axial brain tumors, inflammatory states, certain types of demyelinating diseases (multiplex sclerosis) and at certain states in ischemic infarcts. Low-grade
astrocytomas typically do not enhance. A more pronounced enhancement is seen in a gliomas and it reflects their malignancy. This also means that if a low grade glioma during a follow-up study suddenly changes its enhancement pattern, the increase is regarded as a sign of malignant transformation.

Contrast material has to be administered in required volumes and enough time has to be given for the interstitial appearance as well (late phase).

Extra-axial tumors do not have a blood-brain barrier protection, therefore meningioma, schwannoma, pituitary adenoma, pineal and choroid plexus tumor enhance differently. Cystic lesions naturally do not show any enhancement, these include dermoid, epidermoid and arachnoid cysts.

**Radiological characteristics of certain neoplasms**

MRI has the greatest sensitivity in the detection of neoplastic brain lesions. The relaxation time of tumor is usually longer than that of the surrounding normal tissues. Therefore on T1W images neoplasms have slightly weaker signal intensity, while on T2W images they are more hyperintense than normal parenchyma.

This signal pattern can be very characteristic and has great diagnostic value. However, secondary neoplastic signs, such as mass-effect of the tumor cannot be neglect either. A space occupying lesion can cause:

- the dislocation of the midline structures,
- the impression or dislocation of the ventricle,
- hydrocephalus as a sign of liquor obstruction

Besides the morphological signs, contrast enhancing properties are also characteristic. On the other hand, although MRI is very sensitive for brain tumors, its specificity cannot be overestimated, otherwise this will eventually lead to diagnostic errors.

In order to appropriately suggest a diagnosis, besides the consideration of the clinical picture, there are other factors that need to be though of:

- the localization of the tumor
- the characteristic age group
- signal intensities (measured relaxation times)
- contrast enhancement, distribution

Tumors frequently presenting with hemorrhage are: choriocarcinoma, melanoma, metastases of renal cell carcinoma and bronchial carcinoma, pituitary adenoma, glioblastoma multiforme and medulloblastoma.

Even with these considerations the diagnosis can only be a most likely estimation. Clinicians and radiologists alike should keep in mind that pathologic diagnosis is only provided by the histologic examination of the tumor!
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Astrocytoma:

It is essential to note that in cases of low grade astrocytomas the differentiating ability of MRI is considerably higher than that of CT examination!
Contrast enhancement in astrocytomas increases with the malignancy of the tumor.
In higher grade astrocytomas there is a very typical, extensive perifocal swelling (finger-in-glove white-matter edema).
Contrast enhancement is usually round or it resembles a garland shape.

Oligodendroglioma:

These neoplasms show an infiltrative growth and their contrast enhancement is poor.

Ependymoma:

It characteristically manifests in children and in adolescents.
There is no perifocal edema present. Due to its intra-ventricular growth this tumor can quickly lead to occlusive hydrocephalus because of the obstruction of CSF flow.

Medulloblastoma:

Clinical symptoms:
It is the most common pediatric CNS malignancy (between 5-15 years, it takes up 2-6% of all brain neoplasms).
On CT images it is mostly hyperdense.
On MRI (as opposed to CT images) the tumor can be depicted without any disturbances caused by the bony wall of the posterior fossa.

PNET:
Primitive Neuroectodermal tumor primary presents in children but it also appears in adulthood.
The tumor contains cystic and necrotic parts, at many times it is multi-centric and it shows an intense contrast enhancement.

Meningioma

Most often its symptoms present poorly and disease progression is long. It is the most common intracranial tumor, but it is typically benign. Its complications are determined by the localization and the size of the tumor.

Meningiomas are often (but not always) surrounded by sharp edged swelling and perifocal edema. They might appear isodense compared to brain parenchyma on CT. They often contain sclerotic parts and usually they show an increased enhancement of iodinated contrast media.
MRI: Meningiomas show a good Gadolinium enhancement with a characteristic “dural tail” sign (a thickening in the neighboring dura).

Tumors of the myelin sheath:
These tumors most commonly derive from the sheath of the vestibular part of the VIII cranial nerve (vestibulocochlear nerve).
MRI shows a substantial contrast enhancement. (MRI is preferred, since as opposed to CT – it is able to depict the internal auditory canal and its surroundings without any artefacts.)

**Hemangioblastoma:**

It is typically a cerebellar neoplasm.
Intravenous contrast material differentiates its markedly enhancing nidus, from the cysts that of course do not enhance at all.

**Arachnoid cysts**
They show liquor density on CT, they do not enhance contrast material.

**Lipomas:**
On CT they show a pronounced hypodensity (-100 HU) and therefore cannot be confused with anything.
On MRI they are also very characteristic, on T1W images they are markedly hyperintense.

**Metastases:**
The most common primary tumors that metastasize to the brain are: bronchus carcinoma, breast cancer and renal cancer. A so called early metastasis is especially typical for bronchus carcinoma, when the primary broncus carcinoma is still unknown.
Small metastases can produce very extensive edemas. Multiplicity is common. Due to the consequential blood-brain barrier disorders their contrast enhancement is very intense.

**Angiomas – vascular malformations**
At many times the collecting term, angioma is used for these lesions: capillary teleangieciasias, cavernosus angiomas, arteriovenosus malformations.
Vascular anomalies can be depicted reliably with MRI, even without the use of contrast medium.

**Pituitary gland**

**Method of choice:** MRI
The analysis of the sellar floor can be done with CT, if possible in the coronal plane.
==The appearance of the normal pituitary gland on MRI:==
On non contrast enhanced T1 weighted images the anterior lobe of the pituitary gland has average signal intensity, similar to brain parenchyma.
The dorsal/posterior lobe of the pituitary gland however, shows hyperintense signal.

In the anterior lobe of the gland adenomas derive from the glandular structure. They can be grouped according to their hormone producing status:
hormonally active
hormonally inactive

According to their size they can be:
microadenomas (< 1 cm)
macroadenomas (> 1 cm)
The indications for sellar examinations can be the following:

- Endocrine: due to the clinical picture or the biochemical (lab) reports.
- Ophthalmologic: large parasellar lesions can cause quadrant anopia secondary to the pressuring of the optic chiasm.
- Radiologic: a parasellar bone anomaly can be noted on radiographs

**The types of pituitary gland adenomas**

**Prolactin producing adenoma**

**GH (growth hormone) producing adenoma:** Acromegaly

**ACTH producing:** Cushing’s disease

**Hormonally inactive**, or tumors that only produce hormonal fragments do not cause clinical signs, therefore they are diagnosed due to their space occupying effect, and their symptoms are only detected in advanced states. Since patients only get to examination at this late stage the tumors can reach a large size. Expansive symptoms include bitemporal hemianopia, constantly increasing visual defects and headaches secondary to CSF obstruction.

**Signal change on MRI in pituitary adenomas:**

Microadenomas on T1WIs appear with much lower signal intensity compared to white matter, while compared to the grey matter they are only less intense.

On T2 weighted images they show great variability. They can be bright, isointense and hypointense as well.

Macroadenomas can show necrobiotic phenomena, thus due to hemorrhage and cystic degeneration their signal is inhomogeneous, especially on T2 weighted sequences. However homogenous macroadenomas can also be seen.

**The effect of contrast agent in pituitary adenomas**

The natural signal intensity difference on MRI, between the frontal and dorsal lobes of the pituitary gland ceases to exist when Gadolinium is administered (T1 weighted imaging) because of the enhancement in the frontal lobe.

Contrast enhancement is immediate in the frontal lobe because of the lack of the blood-brain barrier. In adenomas the contrast enhancement is slow.

**Other pituitary tumors and tumors in the neighboring tissues**

**Craniopharyngioma:**

Originates from the remains of the epithelial cells of Rathke’s pouch.

CT can reliably differentiate its three components (calcification can already appear on conventional X-ray images, but it is certainly detectable with CT). MRI can also differentiate its 2 or 3 components based on their characteristic signals.

**Metastatic tumors:**

The pituitary gland is a frequent location for metastatic lesions, especially the pituitary stalk.

Their primary cancer is breast carcinoma, lung cancer and also lymphoma.

The leading clinical symptom is diabetes insipidus and panhypopituitarism.

**CT & MRI:**

The contrast enhancement of metastases is greater than that of adenomas.
Empty sella

The sellar diaphragm at the insertion of the pituitary stalk can remodel the upper portion of the gland due to the pulsation of the surrounding CSF, until the pituitary gland is pushed and compressed to the bottom of the sella. The contents of the suprasellar cistern then protrude to the sella.

Empty sella can be symptom free, but typically observed in obese women, whom present with frequent headaches around menopause, sometimes they have hypertension and slight hyperprolactinemia.

"Balloon sella" is the extreme form of empty sella, which develops due to the prolonged, increased intracranial pressure (usually in cases of the obstruction of aquaeductus cerebri Sylvii).

Secondary empty sella usually is a result of a postoperative state. However, it can also be a possible effect of bromocriptine treatment of a (micro)adenoma or it can be the consequence of adenoma apoplexy.


15. Glioblastoma multiforme in the right frontal lobe, MRI (T1W+contrast).

16. Lymphoma in the left lateral ventricle MRI, FLAIR.

17. Solitary metastasis in the right frontal lobe, MRI (T1W+contrast).

18. Solitary cerebellar metastasis, MRI (T1W+contrast).

19. Pituitary gland adenoma, MRI T1W, postcontrast.

10.1.3.3. Inflammatory diseases of the central nervous system

Causes of inflammation:

Bacterial;
Viral;
Prion;
Parasitic;
Fungal;
Unknown etiology (autoimmune?)
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Bacterial: e.g.:

- Meningitis
- Parenchymal, circumscribed (abscess, disseminated septic)
- Tuberculosis

Viral: e.g.:

- Herpex simplex
- Enteroviruses
- Poliomyelitis
- Varicella- zoster
- Epstein-Barr virus
- HIV encephalitis

**Meningitis:**

Clinical symptoms: the bacterial infection can be due hematogenous dissemination, due to the continuous spread of an infection or secondary to trauma. An aseptic form is also differentiated (lymphocytic, viral). In tuberculosis meningitis can turn to a chronic infection (tuberculous basal meningitis)

Localization: can occur at the vicinity of an external infection, entry point, it can also spread in the basal cisterns, it can spread along the subarachnoid space and penetrate inside the sulci. Meningitis has to be based on the clinical data: liquor pressure, cytology, meningeal signs. Diagnostic imaging is mostly restricted to detect its complications.

Radiology: Negative scans are not uncommon, the ventricles can appear expanded at an early stage. Contrast agent enhancement can be noted in the meninges / along the dura mater not just at the dural base (TB) but also in the sulci (bacterial - frontoparietal) on both CT and MRI.

**Abscess:**

Clinical symptoms: It can be secondary to the invasion of an inflammatory disease (otitis, mastoiditis, sinusitis), thus abscess localization is determined by the site of the original infection. Traumatic origin is rare, postoperative complications are a lot more common. Abscesses that develop from a hematogenous dissemination (endocarditis, pneumonia) are usually multiplex.

In case of uncontrolled states multilocular states can develop and produce complications such as meningitis, ependymitis or in cases of ventricular breach, ventriculitis.

Localization: according to its infectious source (see above)

Radiology:

CT:
In the early stages (cerebritis) the imaging results can be normal, perifocal edema might be apparent or mass effect might be visible. In some cases, gas production can occur (its localization is influenced by the supine position of the patient).

In more advanced stages of abscess development (“mature” abscess, early capsule phase) the central hypodensity deepens further, the rim of enhancement becomes better defined and thin. The multilocular appearance is also possible. A slight vasogenic edema is seen outside the
enhancing rim of the abscess.
In the late capsule phase – during the healing process – the central necrotic lesion starts shrinking while the capsule (granulation tissue) begins to thicken. The mass effect and the edema begins to moderate.

**Tuberculosis:**

*Clinical signs:* it is usually a complication of the secondary stage of TB infection. There are three forms of TB differentiated in the CNS, each of them having a different predilection sites:

- Leptomeningeal TB (tuberculous basal meningitis) + extracerebral tuberculosis
- Pachymeningeal TB
- Intraparenchymal TB

*Radiologically* the density, or the signal intensity of meningeal TB is not different from any abscess. It also shows a pronounced contrast enhancement.

Tuberculoma (intraparenchymal form) needs to be differentiated from other space occupying lesions of the brain.

One of the goals of radiologic examination is to monitor their most common complication, hydrocephalus that is present in 3/4ths of the cases. Other tasks are to identify possible cerebral infarcts (in more than 1/3rds of the cases) as well as radiology needs to inform/follow up meningeal – ependymal sclerosis.

**Viral inflammations (encephalitis):**

- Herpex simplex
- Enterovirus
- Poliomyelitis
- Varicella- zoster
- Epstein-Barr
- HIV encephalitis

The cause of encephalitis is usually a viral infection of the central nervous system. The most common form is herpes encephalitis, that is neither epidemic nor sporadic and cannot be connected to any seasonal occurrence. Acute and chronic encephalitis are differentiated. MRI is the method of choice for examination.

**Demyelinating diseases:**

**The method of choice is MRI**

It is a very important field of MR diagnostics, since none of the other imaging methods can compete with the sensitivity of MRI in relation with demyelinating diseases. Today, the suspicion of multiple sclerosis is the primary indication for a cerebral MRI examination. In about 90% of the cases a certain diagnosis can be reached with its help. However, it is not just multiple sclerosis, but other demyelinating diseases (leukoencephalopathies, leukodystrophies) that can also be identified only with MRI.
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**Multiple Sclerosis:**

Multiple sclerosis typically appears with lesions presenting in the hemispheric white matter with a periventricular predilection. Other less usual locations for MS lesions include the cerebellum and the pons. In the later stages the periventricular lesions can become confluent.

The method of choice for the imaging of multiple sclerosis is MRI. MS lesions secondary to their increased water content appear as increased signal intensity lesions on (T2 weighted), PD images and on FLAIR sequence.

![Figure 20.](image)

**Figure 20.:** Left fronto-parietal abscess, ring-like enhancing wall. a) Contrast enhanced CT és b) MRI T1W (air bubble)

![Figure 21.](image)

**Figure 21.:** MS (Multiple Sclerosis), MRI sagittal T2W hyperintensive nodules

**10.1.3.4. Developmental disorders of the central nervous system:**

Developmental disorders are characterized by the complete lack or the partial development of the normal anatomic structures. MDCT with coronal and sagittal reconstructions is able to provide a detailed anatomic image that is capable to show developmental anomalies (except for migration disorders). MRI examination with its multiplanar imaging ability is capable to produce an excellent anatomic image with T1 weighed sequences.

**Arnold – Chiari malformation**

Type I. the cerebellar tonsil appears pointy and extends below the level of the foramen magnum, but it does not exceed 5 mm. In Type II. the caudal part of the cerebellum also extends below the foramen magnum while the medulla oblongata and IV. ventricle sink to the widened segment of the spinal canal. It is accompanied by neural tube closing disorders. Type III is the combination of type II. with occipital cephalocele.

Radiologically they are the best depicted in sagittal (+ coronal) imaging planes.
Corpus callosum

Developmental disorders: Grades of developmental anomalies can be found from partial development (dorso-rostal appearance according to its developmental process) to the complete agenesis of corpus callosum.

Radiology: due to its lack, the sulci can extend down to the level of the 3rd ventricle. 
CT: coronal plane (tall 3rd ventricle) and sagittal reconstructions are needed.
MRI: In adults the lack of the hyperintense white matter components of the corpus callosum is easily distinguishable from grey matter on T1 weighed images. No cingulate gyrus is apparent either.

Dandy-Walker spectra

The imaging spectra can constitute of cases of simple hypoplasia of the cerebellar vermis; at other times, the 4th ventricle can show various grades of expansion together with the elevation of the tentorium (the confluence of sinuses is elevated). The gravest form of these states is the consequential development of hydrocephalus. 
The common characteristics of Dandy-Walker syndrome include expanded posterior fossa with a large liquor cyst, the lack of the 4th ventricle, elevated tentorium, bulked occipital bone with thin internal lamina (scalloping). 
Its mildest form is mega cisterna magna that does not cause any compression nor does it create any hypoplasia of the vermis and even the 4th ventricle is preserved.

Developmental abnormalities of the cortex, migration disorders

Microlissencephaly: is represented by a small skull and decreased gyrification. 
Hemimegalencephaly: is the enlargement of a cerebral hemisphere or the enlargement of one isolated part of the brain.
Disorders of the neuronal migration: the neurons in their migration – in a nodular or fusiform manner – are hindered or they lose their track. Heterotopy, lissencephaly (agyria, pachygyria)

Cortical organization disorders include polymicrogyria and schizencephaly (opened – communicates with the CSF, closed – does not communicate with CSF)

MRI is the imaging method of the cortical migration and organization disorders (strong T1 weighted imaging).

22. Arnold Chiari

23. Dandy Walker
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10.2. Spine

10.2.1. Imaging methods

10.2.1.1. X-ray

Radiographs are especially useful to detect degenerative bone diseases (spondylo/phytes); structural abnormalities of the bones (e.g.: primary – hemangioma, secondary – metastatic bone destruction or osteoplastic lesions); developmental disorders and instability (dynamic /functional), and is also capable to depict traumatic bone lesions (fractures).

Myelography:
Conventional myelography due to its invasive nature is not used for diagnostic purposes any more. MRI myelography provides an equal diagnostic gain and can readily replace its conventional predecessor. CT myelography is still applied in exceptional cases during which intrathecal contrast material is necessary to be injected. It is still recommended if the communication of the cerebrovascular fluid spaces (e.g.: CSF leakage) is needed to be determined, for which MRI is not completely informative.

10.2.1.2. CT

It can depict bone abnormalities. Reconstructions in the transversal plane are able to represent complex fractures or depict the spinal architecture. 3D HRCT reconstructions provide detailed spatial representations. In cases when MRI examination is contraindicated CT is able to provide some information on herniated intervertebral discs. However, CT is not able to depict the intraspinal status. The use of X-ray exposition on young and fertile female patients for lumbar spine imaging has to be avoided; the method of choice is MRI.

10.2.1.3. MRI

As opposed to CT examination MRI, thanks to its superior soft-tissue contrast, is excellent for the representation of intraspinal structures. Depending on the magnetic field strength / resolution ability it is a unique imaging method of the spinal chord.

10.2.2. Developmental abnormalities

Spinal chord and meninges

Arnold-Chiari malformation:
This malformation is characterized by the abnormality of the posterior fossa (cerebellum), medulla oblongata and the cervical spinal chord. The craniocervical spinal chord shows a cone-like expansion, the cerebellar tonsils extend behind the medulla oblongata and according to the degree of the structural changes CSF obstruction or consequential hydrocephalus can be seen. Its imaging method is MRI which can clearly demarcate the lesion based on the signal intensity differences between the neural structures and the spinal chord.
The various degrees of the spine clefts:
Meningocele, meningomyelocele, myelocele.
Imaging methods: US, MRI

Tethered cord:
The term stands for the phenomenon that the spinal chord is “anchored”. MRI examination can reveal the deep, fixated position of the medullary cone, which can even show a deformed shape.

Syringomyelia:
According to its development it can be primary (innate) and secondary (due to traumatic injuries, inflammations and tumors). Syrinx describes the condition when cerebrospinal fluid enters the interior of the spinal cord and forms a cavity in its center in a tube or a flute-like manner. It can even be a few segments long. MRI: only MRI can provide a definitive diagnosis by depicting the expanded region within the axis of the spinal chord as an expansile lesion showing liquor intensity on all sequences (weak T1 signal and strong on T2 weighted imaging).

10.2.3. Myelopathies

A defined myelopathy can result of trauma, inflammation, ischemia, irradiation and compression (venous congestion).
MRI: segmental high T2 signal intensity lesion, which later turns into a well defined atrophy.

Central pontine myelinolysis:
It is a demyelinating disease that has various names.

Its cause:
iatrogenic in most cases. The sudden correction of Sodium /Potassium imbalance (hyponatremia) or other osmotic stress can all case it (such as azotemia, hyperglycemia, vomiting or starvation).
MRI is the method of choice. Most commonly the signal alteration occurs in the centum of the pons, almost symmetrically, while the periphery is circularly preserved. In acute cases on T1 weighed sequences it cannot be differentiated, or it is slightly hypointense, while on T2W images or with FLAIR it is hyperintense.

Arachnoiditis:
It can occur as a consequence of trauma or after surgical procedures. Sometimes it is the result of chemical irritation, such as a myelography, epidural injection or infection. As the result of the inflammation scar tissue and adhesions occur and the nerve roots attach: adhesive arachnoiditis.
MRI: thickened nerve roots, tangled arrangement, fixated cauda equina can be seen. Contrast media does not increase the diagnostic precision – lesions vary from strongly enhancing to barely enhancing ones.

Spinal arteriovenous malformations (AVM): a rare disease, usually manifesting in early childhood. They can be intradural, extradural and dural in localization – often combined with fistulas.
10. Neuroradiology

On MRI its characteristic loss of signal is accompanied by edema in the spinal chord (strong T2W signal).

**Spinal hemorrhages:**
Epidural, subdural, subarachnoid and intramedullar hematomas.
Fresh bleeding can be detected with CT but a more precise localization and diagnosis can be reached with MRI.

### 10.2.4. Intraspinal masses

Intraspinal masses can be abscess, tumors /metastases. If the narrowing of the spinal canal is caused – independently from their cause – the first step of their assessment is to describe its relation to the dura / spinal chord.

#### 10.2.4.1. Extradural (epidural)

**Neurofibroma, vertebral metastases, inflammations** (spondylitis, spondylodiscitis, psoas abscesses), vertebral collapses: (traumatic / osteoporotic bony propulsions), hematomas.
**MRI:** An epidural hemorrhage shows the signal intensity pattern characteristic of blood breakdown materials, abscess on MRI shows a peripheral contrast enhancement.

#### 10.2.4.2. Intradural- extramedullar

**Meningiomas**
**MRI:** T1 and T2 weighted images it shows a signal intensity similar to the spinal chord. Usually its contrast enhancement is intense.
**CT:** it better depicts sclerosis in the lesions.

**Neurinomas and neurofibromas.** They follow the path of the nerves (neuroforaminal expansion is even visible with X-ray = hourglass tumor). Multiple: Neurofibromatosis I (phacomatosis)
**MRI:** On T1 weighted images it is usually isointense with the spinal chord + enhancement, on T2W images it is hyperintense.
**Metastatic** tumors:
medulloblastoma, ependymoma, choroid plexus papilloma and PNET („drop” metastases), pinealoma.
**MRI** signal intensities are similar to the primary tumor and in most cases they show intense contrast enhancement

#### 10.2.4.3. Intramedullar

**Astrocytomas** appear both in childhood and adulthood (cervical segments of the spinal chord)
**MRI:** On T1W images they are isointense with the spinal chord. On T2 weighted images they have a high signal intensity and appear as a mass expanding the spinal chord.
Contrast enhancement is strong, it can be inhomogeneous.

**Ependymomas** rather occur in adulthood (they can also be the metastases of primary cerebral ependymomas) thoracic spinal chord, medullary cone, filum terminale.
MRI: On T1 weighted images it shows isointense with the spinal chord, while on T2W images it is hyperintense. Contrast enhancement is strong, it can be inhomogeneous.

The appearance of intramedullar metastases is rare.

24. Vertebral body metastasis MRI, T2W
25. Thoracic intramedullar metastases MRI, STIR
26. Sacral chordoma T1W+contrast, note the sacralisation of the 5th lumbar vertebra.

10.3. The message of the chapter:

It is essential to know the radio-morphologic appearance of cerebral ictal events and to be able to differentiate ischemic infarcts from hemorrhagic infarcts. The rapid differentiation between subdural and epidural bleedings is mandatory based on their radiological characteristics.

The use of ionizing radiation has to be avoided in young and fertile female (lumbar) spine examinations; the method of choice is MRI.

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11. Head and neck imaging

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11.1. Aim

In this chapter an overview of head and neck imaging is presented to the medical students. It is important for a future doctor to be familiar with the different imaging modalities, their strengths, weaknesses and contraindications to adequately choose imaging study in a clinical problem.

11.2. Radio-anatomy of the head and neck

The diversity of pathology of the head and neck region is due to its very complex anatomy. The head and neck region encompasses tremendous spectrum of tissues in a compact space. Understanding both this special anatomic region with its normal tissue content and the scope of pathologic entities are the basis of the accurate assessment of a lesion in head and neck.

Head and neck section can be divided into clinically important subregions: 1) skull base; 2) orbit; 3) temporal bone; 4) paranasal sinuses; 5) facial bones; 6) floor of the mouth; 7) neck (supra- and infrahyoid) and 8) thoracic aperture.

The level of the hyoid bone is an important border in the neck section, that separates the suprahyoid neck compartment from the infrahyoid neck compartment.

Significance of the neck compartments: Recognition of the compartment in which a lesion is located is the basis of the adequate radiological evaluation of a lesion. This table summarizes both the suprahyoid and infrahyoid neck compartments. Those spaces that cross the entire length of the neck are in Italic.

Suprahyoid neck compartments

- pharyngeal mucosal space (visceral space)
- parapharyngeal space (prestyloid compartment)
- parotid space
- masticator space
- sublingual space
- submandibular space
- buccal space
- retropharyngeal space
- Danger-space
- perivertebral space
- carotid space (poststyloid compartment)
Infrahyoid neck compartments

- anterior cervical space
- posterior cervical space
- visceral space
- retropharyngeal space
- Danger space
- perivertebral space
- carotid space (poststyloid compartment)

Orientation is further helped by the central localization of the parapharyngeal space, which is named as “compass of the suprathyroid neck compartment”. Danger space - found behind the retropharyngeal space - is bounded superiorly by the skull base, anteriorly by the alar fascia and posteriorly by the prevertebral fascia. It comes to an end at the level of the diaphragm. It gets its common name from the risk that an infection in this space can spread directly to the thorax.

Knowledge of the head and neck lymph node chains and the usual modes of spread of diseases is essential for accurate assessment of a head and neck malignancy or inflammatory process. Cervical lymph nodes are divided into six levels. Characteristics of the lymph nodes such as size (shorter diameter < 10 mm), shape (oval), and structure (cortical-hilar differentiation) have to be evaluated. In lymphadenitis (which is the most common cause of palpable neck mass in children), the lymph nodes become enlarged, but the echogenic fatty hilum and the thin hypoechoic cortex can be differentiated. However, in malinancy, the enlarged lymph nodes become hypoechoic, round, with loss of structure and cystic or necrotic degeneration in many cases.

11.3. Imaging modalities

11.3.1. Radiography (noncontrast and contrast)

Paranasal sinus radiography provides information about the air-content of the frontal and maxillary sinuses. Air-fluid level or decreased transparency in the paranasal sinuses suggests abnormality.

Facial bone radiography and orbit radiography can detect radiopaque foreign bodies and major fractures of the orbital walls; however, the part played by conventional radiography has decreased significantly with the widening availability of CT.

Conventional x-ray films (Stenvers and Schüller views) are capable of detecting ear disease with concomitant large bony destructions or deareation of the mastoid cells. However, for more subtle ear pathology CT or MRI is the modality of choice.

Lateral neck radiograph can evaluate thyroid enlargement by demonstrating tracheal narrowing or tracheal dislocation.

Dental panoramic radiograph of the teeth (Orthopantomogram) is used in everyday practice, and its most common indication is to determine the status of wisdom teeth and trauma to the jaws. Radiopaque sialolith can be also discovered by this modality.
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Swallow study is used to diagnose pathology in the pharynx and esophagus. It can be performed with barium in patients with dysphagia, pain on swallowing and mass lesions, or with iodine in perforation and in clinically suspected postoperative leakage. Sialography – a radiographic examination of the salivary glands and associated ducts following the injection of a radiographic contrast media - is helpful in suspected cases of ductal stricture, calculi or sialectasia.

11.3.2. Angiography

Digital subtraction angiography (DSA) is a type of fluoroscopy technique - using ionizing radiation - to clearly visualize blood vessels of the neck in a bony or dense soft tissue environment. Advantage of the DSA – beside its excellent diagnostic value - that it allows therapeutic interventions. Intravenous iodine administration is contraindicated in contrast allergy and renal impairment. In neck, it excels in the diagnosis and treatment of carotid artery stenosis. Chemotherapy and embolization of tumors can be applied as well.

11.3.3. Ultrasonography

Most of the soft tissues in head and neck can be easily evaluated by ultrasonography. These examinations are performed with high-resolution 7-13 MHz linear array transducer, which have 3-5 cm penetration. The advantages of US include good availability, multiplanar visualization, repeatable (no ionizing radiation), fast, and it provides real-time imaging. Postoperative sutures, tracheostoma and former irradiation of the neck make US examination more difficult. Superficial soft tissues such as floor of the mouth, salivary glands, surrounding structures of the cervical visceral region, buccal, occipital and supraclavicular regions can be evaluated by B-mode ultrasonography. In the neck, thyroid gland, carotid and jugular vessels and lymph nodes can be examined by US. US can determine whether a mass is cystic or solid, and therefore able to differentiate between cellulitis and abscess. Superficial bony destruction of the mandible and facial bones can be evaluated by US. With Doppler function, direction and velocity of flow in neck vessels can be determined. Doppler-US also can provide information about the vascularisation of a neck mass. Ultrasound-elastography is a newly developed imaging technique for the reconstruction of tissue stiffness by measuring the degree of tissue's deformation in response to the application of an external force. It provides information about solid and cystic masses, and can give help in biopsy planning by demonstrating the optimal site for puncture. Contrast-enhanced US is not part of the diagnostic modalities used routinely; however, it is capable of demonstrating vascularity, enhancement pattern and cystic or necrotic areas of a mass.

11.3.4. Computed Tomography

CT has several advantages over traditional 2D medical imaging: provides cross-sectional imaging; eliminates the superimposition of images of structures outside the area of interest; provides good soft tissue resolution when intravenous contrast is administered; visualizes bony detail in complex fractures and bone destruction. Multidetector-row CT (MDCT) - with its submillimeter spatial resolution - is also capable of creating multiplanar reformatted imaging. Disadvantages of CT include high radiation-dose (which is approx. hundred times higher than that of conventional radiographs), and artifacts related to dental fillings.
Paranasal CT — nowadays — is performed in supine position, which constructs primarily axial images. Coronal view — which has similar appearance to sinus radiography — can be later digitally reconstructed. Earlier, CT was performed in a position to primarily get the coronal view; however, the quality of this technique was not satisfactory due to artifacts caused by metal-containing dental fillings. Noncontrast paranasal CT plays important role to assess more complicated, recurrent disorders, e.g. chronic sinusitis. Contrast-enhanced paranasal CT is a helpful imaging tool in soft tissue evaluation, e.g. in inflammation and tumours. However, in these cases, MRI provides an even better soft tissue resolution.

HRCT excels in the evaluation of air spaces and fine bone structures - including hearing ossicles - of the temporal bone. HRCT is primarily performed at submillimeter intervals, which allows reconstructions in all three planes.

Noncontrast orbit CT has an important role in the assessment of orbital bony injuries and localization of foreign bodies. Contrast-enhanced orbit CT — if MRI is not available — can be indicated in inflammation and tumours.

Contrast-enhanced head and neck CT (from the skull base to the aortic arch) can evaluate acute inflammation and tumours. It can be used for tumour staging; however, for that MRI is the first-line modality by providing better soft tissue resolution. One of the disadvantages of head and neck CT — especially in children - is the relatively high radiation dose to which the eye lenses are sensitive.

CT angiography is performed to evaluate neck vessels. Carotid arteries can be examined from aortic arch to skull base by bolus technique in arterial phase.

It is important to mention an emerging new technique: the cone-beam CT (CBCT). A CBCT scanner utilizes a 2D flat panel detector, and it can acquire the image of the whole volume in a single rotation around the patient. The scanning software collects the data and reconstructs it by a mathematical algorithm, producing 3D images. This method uses ten times less ionizing radiation than conventional CT, while provides all the same information. Length that can be imaged by CBCT is approx. 5-16 cm; however, C-arm equipments used in interventional radiology are also based on the cone-beam principles. CBCT’s advantages are the lower cost and smaller size, which make this technique increasingly important. CBCT can be used to visualize anatomical detail of paranasal sinuses, in dental imaging and implantology.

11.3.5. Magnetic Resonance Imaging

MR provides outstanding sensitivity for the discrimination of soft tissues; therefore it excels in the evaluation of inflammatory and tumorous processes. MRI examinations take longer time than CT studies; however, it can provide direct multiplanar imaging. One of the advantages of MRI is the lack of ionizing radiation; therefore it is the modality of choice in pregnancy and paediatrics. In trauma emergency, metallic foreign bodies and life support appliances can be a problem. CT is superior to MRI in the assessment of air space anatomy and cortical bone structure in detail.

In orbit, facial and head and neck MRI, T1, T2, fat-saturated and contrast-enhanced T1 sequences are the most popular imaging sequences, which can be taken primarily in all three orientations (axial, sagittal, coronal), depending on the clinical problem.

Head and inner ear MRI is recommended to evaluate pontocerebellar soft tissue processes. MR angiography is a group of techniques - based on flow effects (phase-contrast MRI) or on contrast (gadolinium-enhanced MRI) - to image blood vessels.
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11.3.6. Nuclear Medicine

Thyroid scintigraphy – the most frequently used nuclear medicine technique in head and neck – is performed by utilizing radioactive iodine, and it is capable of assessing the physiologic function of the gland. The functional status of a thyroid nodule may be categorized as hyperfunctioning (hot nodule) and hypofunctioning (cold nodule). Hot nodules (which are typically adenomas) are more often benign than cold lesions. Malignancies usually appear as cold nodules, while cysts typically present as cold nodules.

Parathyroid scintigraphy is performed to localize parathyroid abnormalities (e.g. ectopic parathyroid adenoma) in patients with hyperparathyroidism.

Functional status of the salivary glands can be evaluated by salivary gland scintigraphy. PET is a functional imaging modality based upon the distribution of a glucose analogue radioisotope (18F-fluorodeoxyglucose, FDG). In combination with either CT or MR imaging - which modalities provide morphological information -, PET has greatly increased the sensitivity and specificity in the evaluation of primary as well as recurrent malignancies, in tumour staging, and plays an important role in inflammatory processes.

11.4. Radiology of the regions of head and neck

11.4.1. Skull Base

The skull base – which includes the sellar and parasellar region - can be subdivided into three regions: the anterior, middle, and posterior cranial fossae. For accurate radiologic assessment, the knowledge of skull base anatomy is crucial, since it contains many foramina through which both vessels and nerves pass.

Two-view skull x-ray films and projected petrous pyramid x-ray film can visualize major fractures, but they are not capable of detecting intracranial complications, therefore their significance in clinical practice diminished.

As a general rule, bone detail is best evaluated by CT, while MRI is the modality of choice for soft tissue visualization both in inflammation and malignancy. Noncontrast CT is the modality of choice in trauma to evaluate bone detail, and in malignancy to evaluate bony destruction. Skull base CT and MRI are always performed as part of either skull or head and neck examination. Contrast-enhanced MRI is required in inflammation and soft tissue propagation. For hypophysis examination, beside static CT and MRI - dynamic MRI can be performed, which allows excellent contrast between normal and abnormal intrasellar tissue, and also provides information about the hypophyseal perfusion in endocrinological disorders.

Scintigraphy and PET-CT are the modalities of choice in the detection of bone metastases.

11.4.2. Temporal bone

The temporal bone is the most complex bone in the human body. It consists of four parts: external ear, middle ear, inner ear and mastoid air cells. The temporal bone not only comprises the auditory and vestibular system, but also the place through which the internal carotid artery and the facial nerve pass. It is also tightly connected to the internal jugular vein, venous sinuses and nerve plexuses anatomically.
The middle ear is linked to the epipharynx by the Eustachian tube, which allows propagation of pathological processes. Ear disease can spread to the intracranial space also (to the middle and posterior fossae). Both air-containing (middle ear, mastoid air cells) and fluid-containing (labyrinth, cochlea) areas can be found in the temporal bone, which makes imaging protocols even more difficult.

Conventional x-ray films (Stenvers and Schüller views) are able to detect ear disease with concomitant large bony destructions or deareation of the mastoid cells. However, for more subtle ear pathology CT or MRI is the modality of choice.

High-resolution CT (HRCT) is primarily performed at submillimeter intervals, and excels in the evaluation of bone and air space anatomy, and in disorders of the temporal bone, hearing ossicles and air cells. However, its role is limited in soft tissue pathology, mucosal thickening and fluid accumulation. In abnormalities of the middle ear HRCT is superior to MRI in most cases (except in tumours). HRCT is the modality of choice in conductive hearing loss, otosclerosis, and malignant otitis externa in diabetic patients and in surgery planning. One of the disadvantages of HRCT – especially in children - is the relatively high radiation dose to which the eye lenses are sensitive. Differentiation between hypodens structures filling the ear and air cells also might be problematic. HRCT’s role is also limited in the early detection of intracranial complications. Intravenous contrast administration in HRCT is not possible due to technical difficulties.

To evaluate soft tissue pathology, mucosal thickening and fluid accumulation, MRI is recommended, especially in the middle and inner ear. MRI plays an important role in inflammatory and tumorous processes, and in their intracranial and extracranial complications. MRI is the modality of choice to assess extracranial and intracranial complications of inflammatory ear disease, including most commonly epidural and cerebral abscesses and sinus thrombosis secondary to chronic otitis media. Examination of the pontocerebellar angle in sensorineural hearing loss is performed by a special thin-slice T2W MRI sequence and postcontrast T1W MRI, since these sequences are capable to detect acoustic neurinoma, while HRCT cannot visualize this abnormality. In some complex diagnostic cases both CT and MRI are needed for accurate diagnosis.

1. image: Patient with sensorineural hearing loss and tinnitus. MR-study (T2, precontrast T1 and postcontrast T1) reveal a mass in the left pontocerebellar angle without significant contrast enhancement. HRCT proves that the mass arises from the petrous pyramid, suggesting cholesterol granuloma. (Asklepios Klinik Altona, Hamburg)
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11.4.3. Facial bones (orbit and paranasal sinuses)

11.4.3.1. Orbit

Orbit is a bony socket, which contains the globe, the muscle cone, and the extraconal and intraconal spaces. The orbit communicates with the intracranial space and the paranasal sinuses through fissures and foramens. The early diagnosis of any orbital pathological process is crucial to prevent intracranial involvement, visual loss or cavernous sinus thrombosis. Orbit radiography can detect radiopaque foreign bodies and major fractures of the orbital walls, however, the part played by conventional radiography has decreased significantly with the widening availability of CT. Eye and orbit ultrasonography is mainly used by ophthalmologists. It is a very useful modality to evaluate ocular disease, however it has a limited role in peribulbar and retrobulbar disorders. CT has an important role in the assessment of orbital bony injuries and localization of foreign bodies. In trauma the advantages of CT are its ability to visualize any region without summation, to provide tomographic image and to detect tiny bony fractures without dislocation. Radioopaque foreign bodies can be localized easily by CT; however, the localization of radiolucent foreign bodies can be assessed only by indirect signs, especially in perforating bulbar injury. Bony destructions can be assessed by CT in either primary or secondary orbital tumours.

2. image: Axial view of the orbits in noncontrast CT. Metallic foreign body (indication for CT) in the medial part of the right orbit.

MRI with its excellent soft tissue resolution - performed with special orbital coils -, plays an important role in soft tissue imaging, both in inflammation (e.g. retrobulbar optic neuritis) and in tumours (e.g. optic nerve glioma and meningioma). Ocular masses can be assessed with ultrasonography and – with the use of high-resolution coil - MRI. Once a mass lesion has been found in the orbit, its accurate anatomical localization – ocular vs. non-ocular, intraconal vs. extraconal - may aid the differential diagnosis. It is also important to diagnose possible cavernous sinus thrombosis, a potentially life-threatening condition. In most non-traumatic orbital imaging studies contrast administration is necessary, therefore contraindications has to be evaluated before the examination.

11.4.3.2. Paranasal sinuses

Paranasal sinuses - a group of four paired air-filled spaces, namely the maxillary sinuses, the ethmoid sinuses, the frontal sinuses and the sphenoid sinuses - form anatomical-functional unit. In everyday routine, air-content of the sinuses, factors that modify ventilation (septal deviation) and anatomical details have to be assessed by the radiologist. The ostiomeatal complex (OMC) is a collective term encompassing the ethmoidal infundibulum, the bulla ethmoidalis, the uncinate process and the middle nasal concha. OMC has many anatomic variations, which influence maxillary, ethmoid and frontal sinus ventilation.
Paranasal sinus radiography is a good first-line modality to evaluate the air-content of sinuses, especially in the case of the maxillary and frontal sinuses. In acute sinusitis it is rarely used: clinical information is sufficient to set the diagnosis in most cases. In recurrent sinusitis and nasal congestion paranasal sinus radiography is helpful to decide whether any further imaging study is needed. In trauma paranasal sinus radiography can detect only major fractures. Radiopaque foreign bodies, elongated styloid process and the upper cervical vertebras can be evaluated by it as well. For further evaluation, CT is the modality of choice. Paranasal sinus CT plays important role to assess more complicated, recurrent disorders. By noncontrast series, thin cortical bones, bony destruction and air-fluid levels, opacification of the sinuses can be determined. CT is of great value for determining anatomic landmarks and OMC variants. This information is of vital importance to the ENT-surgeon. Noncontrast CT allows rapid and detailed evaluation of facial bones including paranasal sinuses. Contrast administration is mandatory in soft tissue evaluation. Contrast MRI is superior to contrast CT in tumorous processes; and lack of ionizing radiation makes it an even more important technique. The lens of the eye is sensitive to radiation, and children undergoing CT scanning of the head are vulnerable to this complication. MRI is extremely helpful in complicated sinonasal disease, is also the study of choice for detecting intracranial extension of sinonasal disease.

3. image: Paranasal sinus examination, coronal reconstructions (right panel: cone-beam CT; left panel: MDCT). Concha bullosa (asterisk) with ethmoidal infundibulum narrowing (arrow). Cone-beam CT and MDCT information correlates almost 100%.

11.4.4. Neck

11.4.4.1. Suprahyoid (SH) neck compartments

The most complex region in the head and neck is the suprahyoid neck. Precise clinical questions and good cooperation between the referring doctor and the radiologist are required to plan adequate imaging study. Facial bone x-ray is rarely indicated in SH abnormality: only radiopaque foreign body, elongated styloid process and the upper cervical vertebras can be evaluated by this technique. For further evaluation, CT is the modality of choice. Superficial regions such as floor of mouth, submandibular, buccal, occipital and facial regions can be easily evaluated by ultrasonography. However, for deep structures such as parapharyngeal compartment, masticator space behind the ramus of the mandible, retropharyngeal space and deep portion of parotid space, cross-sectional imaging modalities (CT and MRI) are necessary. US – an ideal tool for the examination of neck lumps and masses – practically has no contraindications. It is usually the first-line modality for evaluation of lymph nodes, and to differentiate cystic from solid lesion. US with Doppler function is capable of depicting stenoses and thrombosis of vessels.
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Submandibular, sublingual salivary glands and superficial part of the parotid gland can be examined by US: size, structure, stones and duct dilatation all can be assessed. For the evaluation of the deep portion of the parotid gland, cross-sectional imaging modalities are necessary.

MRI can be considered as a first imaging choice to evaluate the suprahypoid neck; however, CT also can be performed. Both noncontrast and contrast series are needed. CT is indicated in infection and trauma. In tumours, CT has lower sensitivity in comparison to MRI. 90% of primary suprahypoid neck malignancies are squamous cell carcinomas. Other common tumours are adenocarcinomas of the salivary glands. Warthin tumour of the salivary glands and glomus tumour that arises from the carotid space can occur in suprahypoid neck also.

Salivary gland scintigraphy is used in Sjögren’s syndrome and parotitis.

11.4.4.2. Infrahyoid (IH) neck compartments

The infrahyoid neck is the region of the neck extending from the hyoid bone to the thoracic inlet.

Two-view cervical x-ray film can visualize bony alterations of the cervical spine. It is indicated in headache, vertigo and minor trauma. A special oblique view of the cervical spine can be important in patients with pain and/or altered sensation in their upper limbs, which can show the intervertebral foramina narrowed by degenerative bone disorders or cervical rib. Lateral neck x-ray, which is a useful tool to visualize dislocation or compression of the trachea, can be indicated in thyroid enlargement, stridor and upper airway compression. Erosion and irregularity of the mucosal lining and narrowing of the lumen can be signs of pharyngeal mass.

US – an ideal tool for the examination of neck soft tissue - can be first-line modality in case of palpable neck mass, thyroid enlargement, dysphagia and persistent hoarseness. US is widely available and capable of multiplanar, real-time visualization. US can determine whether a mass is cystic or solid and therefore able to differentiate between adenitis, cellulitis and abscess. One of the most frequent cystic neck mass is the branchial cleft cyst, which arises on the lateral part of the neck from a failure of obliteration of the second branchial cleft in embryonic development.

Most common palpable neck mass in adults is related to metastatic lymphadenopathy, which is the early sign of pharyngeal or laryngeal carcinoma in many cases. A round, enlarged (> 10 mm) lymph node with loss of internal structure suggests malignancy. Enlarged lymph nodes in children are caused by lymphadenits most frequently; however, in this case the central hilus remains echogenic and the internal structure is normal.
4. image: Young male patient with a left supraclavicular lump. Upper panel: complex cystic mass with separations; normal flow in the neighbouring vessels. Lower panel: T2W, postcontrast T1W, fat-saturation T1W MRI suggest cystic lymphangioma (Asklepios Klinik Altona, Hamburg)

In regard to the superficial position of the thyroid gland, ultrasonography is the first-line imaging modality after physical examination and blood test. Size of the thyroid lobes and isthmus, its homogeneity and possible masses all can be evaluated by ultrasound. Ultrasound-guided FNAB provides cytological information about the mass. Thyroid scintigraphy provides a visual display of functional thyroid tissue.

Hot nodule suggests benign adenoma, while in the case of a cold nodule, cyst or malignancy are the most common diagnoses. Goiter extending into the retrosternal space can be visualized by thyroid scintigraphy as well. Parathyroid scintigraphy is a helpful tool in the localization of parathyroid adenoma, especially if they are ectopic.

CT and MRI are fairly comparable techniques for soft tissue evaluation in the infrahyoid neck. Advantages of CT include the fast scanning and minimal motion artifacts of the larynx and pharynx. Disadvantages of CT are the use of ionizing radiation and the artifacts related to the high concentration of iodine-based contrast in the proximal neck vessels. For this reason, MRI is the modality of choice for soft tissue disorders at the level of thoracic inlet. MRI is distinguished in its superior capacity to resolve soft tissue details; however, muscle artifacts from swallowing can be a problem. MRI is a useful tool for TNM staging of laryngeal and pharyngeal tumors, especially to determine the extent of local invasion.
11.5. Summary

Accurate assessment of head and neck region can be accomplished by deep understanding of its compartmental anatomy and scope of pathologies entities that may occur. Knowledge of strengths, weaknesses and contraindications of the imaging modalities significantly helps the referring doctor to choose adequate modality to the patient.

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12. Diagnostic Breast Imaging  
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The purpose of this chapter:

The goal of this chapter is to provide an introduction to the 4th year medical students at the University of General Medicine on up-to-date breast imaging methods and their basic principles. It is also important to mention the role of breast screening examinations and to outline what diagnostic gain are to be expected from the different examination methods and what sequence of protocols are to be used. A fundamental knowledge is necessary for future doctors to be able to understand mammography reports and to have a familiarity with the codes and abbreviations they would encounter during their practice.

12.1. Introduction

Today, mammography is one of the fastest evolving areas of diagnostic radiology. Many new technical applications have evolved in the recent decades that have improved image production and processing, as well as diagnostic tissue sampling. These advancements have modified the diagnostic algorithms in breast imaging. The reasons for the recent advancement have been partially influenced by the technical developments of new methods, and also by the pressing need for better imaging. All of this is accordance with the fact that the number of breast cancer patients is on the rise worldwide, including Hungary.

The cause of breast cancer is still unknown; consequently its primary prevention has not yet been made possible. However, it is a proven fact that early detection and the start of adequate therapy can significantly decrease the rate of mortality due to breast cancer. Improved imaging has helped the detection of small, neoplastic lesions at their early, clinically non-symptomatic phase.

Today, in breast imaging we differentiate screening mammography from clinical mammography.

1./Screening mammography: Regularly repeated examination of asymptomatic and complaint free women within the prevalent age-group within determined and controlled circumstances. It does not provide a definitive diagnosis.

The purpose of screening is to significantly decrease the mortality of breast carcinoma related deaths with increasing the diagnosis of small (under 14 mm size), asymptomatic aggressive tumors. Since 2002 Hungary has established a nation-wide breast screening program. Women between the ages 40-65 are screened methodically, the service is free of charge and repeated biannually.

2./Clinical mammography: is the examination of women with complaints and clinical symptoms, independent from their age. The examination provides a definitive diagnosis.
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12.2. Breast Imaging Modalities

12.2.1. The general role of diagnostic imaging

- o screening
- o identification of pathologic lesions
- o determination of lesion dignity
- o biopsy guidance
- o staging
- o preoperative localization of non-palpable lesions
- o specimen mammography
- o therapeutic planning
- o remainder marking of a lesion
- o breast implant examination
- o control examination

12.2.2. Diagnostic Imaging Methods

- Mammography: traditional (analogue), digital technique, and tomosynthesis
- Breast Ultrasonography
- MRI examination (Breast MRI)
- CT examination: with the current technical circumstances its role in breast imaging is very limited.
- Nuclear medicine examinations: breast scintigraphy, sentinel lymph node tagging, SPECT, PET/CT examinations
- Interventions:
  - o Diagnostic: pneumocystography, ductography, biopsy, localizing methods
  - o Therapeutic: percutaneous tumor ablation, radiofrequency ablation (RFA)

12.2.2.1. Mammography

It is a fundamental diagnostic method in both diagnostic and clinical mammography, during which plain pictures are taken.

Advantages:

Disadvantages:

12.2.2.1.1. Types of Mammography:

1. Traditional (Analogue) mammography: image production, appearance and storage all occur at the same place, the X-ray film. Technical requirements are low voltage (25-32Kv, = soft beam technique, high beam intensity, mAsec), special anode, double focus X-ray tube.
2. Digital mammography: (pictures 1,2,3) phosphorous plate or direct digital methods. For breast imaging the latter is the method of choice. Phases of image production separate. The image is produced on the detectors, but appears on the high resolution monitor and can be stored as a digital data set at various storage mediums (e.g.: CD, hard disk drives).

Advantages:

- o significantly decreases radiation
- o higher contrast and sharpness
- o stable image quality
- o depicts microcalcifications better than the analogue techniques
- o no need for picture development, dark room
- o eco friendly
- o larger capacity
- o image postprocessing possibilities (magnification, image inversion, contrast effects)
- o teleradiology, telereporting
- o supervisory function
- o easier patient follow up, unnecessary exam or biopsy repetitions can be avoided
- o simplified archiving
- o CAD computer aided diagnostics

The spatial resolution of the digital technique is not higher than that of the analogue one!

3. Tomosynthesis: is a supplementary examination method. It is still not a part of the daily routine, but this technique is becoming more popular and widely available. With this method lesions can be highlighted from their surrounding environment.

Mammography exposition: all breast images have to be acquired at least in two directions!
Standard images: cranio-caudal (CC) and half-oblique medio-lateral (MLO)
Additional images: lateral (medio-lateral, latero-medial) magnified images etc.

I2.2.2.2. Breast Ultrasonography

The second most commonly used diagnostic method. For women above 35 years of age it is a complimentary examination, while for women under 35 years – except for cases of suspected
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malignancy – it is a stand alone or first choice examination. In breasts of greater volume, mammography is necessary as well.

US is used as primary examination during pregnancy and lactation, as well as in patients with acute phase inflammatory processes. Technical requirements: a high resolution linear head of 7.5 MHz, with a maximum length of 4-5 cm. A second supplementary head of 12-18 MHz is also recommended. The examination needs to be archived.

Diagnostic indications:

Therapeutic indications:

- cyst puncture
- abscess drainage

Doppler examinations: can only be used as auxiliary exams. It depicts higher vascularization in malignant tissues.

12.2.2.3. Magnetic Resonance Imaging of the Breast (Breast MRI)

Requirements: At least 1.5T MRI machine, breast coils, iv. contrast agent. (For interventional procedures MR compatible biopsy equipment, marking wires are required). Background: malignant neoplasms show increased blood supply due to neo-angiogenesis.

The most important indications of MRM:

Dynamic Breast MRI:
Benign and malignant lesions in most cases show different contrast enhancement dynamics and morphology. However, its differentiation ability of benign from malignant is limited.

Disadvantages of breast MRI:

12.2.2.4. Nuclear medicine examinations

1. Breast scintigraphy: has lost its significance in the recent years. Malignant tissues in the breast show enhanced Tc99 MIBI radiopharmacon uptake, due to increased cell activity, that can be registered by gamma cameras.

2. PET, SPECT, PET/CT:
The basics of breast PET/CT diagnostics are based on the change in the metabolic activity of tumor tissue, represented by increased glucose metabolism of malignant cells. FDG (18F-deoxi-glucose) is used as radiopharmacon.

Indications:
Limitations:

3. Marking of small, non-palpable lesions before surgery.
4. Marking of sentinel lymph nodes.

12.2.2.5. Interventions in breast imaging

- Pneumocystography: In certain cases (e.g.: dense cysts or cysts with septations) after cystic drainage the cystic cavity is inflated with air in order to rule out intracystic tumors.
- Galacto- or Ductography: (Picture 4,5) is an examination that requires contrast material. It is indicated in breast bleeding or discharge, performed after mammography, ultrasound examination and cytological aspiration have all been carried out. The ducts are injected with contrast material which then either can reveal intraductal lesions causing sharp, margined filling defects, distortions or complete obstructions in the duct.

![Picture 4](image1)
![Picture 5](image2)

- Targeted biopsies:

1. Cytologic aspirations: fine needle aspiration biopsy (FNAB)(Picture 6., 7., 8., 9.)
2. Histologic biopsy: core (tissue column) biopsy (CTB):
   a) Automatic gun biopsy sampling, guiding: US or X-ray
   b) Stereotaxic Vacuum Core biopsy: Mammotome (sVCB)

The majority of pathologic lesions are detectable with ultrasound, therefore US is a major guiding tool. In other cases (e.g.: in case of apparent microcalcifications only) X-ray guided stereotaxic (3D) or the so called compression hole plate (2D) guidance are available. In case of lesions only detectable with MRI of course MRI guided biopsy is the only method of choice.

![Image](image3)
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12.3. The anatomy of the breast
The breast is made up of glandular tissue, fat, connective tissue and blood vessels. The composition ratio of these elements change over the age. The glandular tissue is made up of 15-20 lobes, each of them opening with a proper duct at the nipple. The smallest unit is terminal ductal lobular unit (TDLU = extra- and intralobular ductal parts – acini) (Picture 12.)

Many types of normal breast variants exist on mammography. The 5 most common types have been described by Tabár by his classification system: I. Young, Fibro-glandular, II. Completely involuted, III. Transient type between I. and II., IV. Adenotic V. Fibrotic.

12.4. Radiologic appearance of pathologic lesions of the breast

Pathologic lesions in the breast appear as various shapes and densities of soft tissues or calcificications or as the combinations of these two on mammography (Picture 16.). At many times only a few scattered, ill-defined, pleomorphic microcalcifications indicate the presence of a pathologic lesion. The soft-tissue lesions can appear as well-defined, rounded or oval shaped (Pictures 13.,14.) or as ill-defined, star-shaped masses (Picture 15.). Rounded or oval lesions are in most cases benign and their malignant proliferation is rare, they do not require surgical removal. These lesions are usually cysts and fibroadenomas, at other times harmartomas, lipomas and at very few times malignant tumors.

Ultrasoundography can help in their differentiation; can depict anechoic cystic lesions (Picture17.) or solid masses (Picture 18.). These lesions usually each have a smooth, sharp edge and echo-enhancement can appear behind them. Rarely, cysts contain tumors. (Picture19.).

Ill-defined margins, with uneven contours and blurred edges are usually characteristic of malignant lesions. During ultrasound examination echo-attenuation occurs frequently behind these inhomogeneous hypo-echogenic masses (Picture 20).

Star-shaped lesions are very typical of malignant tumors.

- “White star”: describes the tumor body with dense spiculations of various lengths appearing around the core = carcinoma
- “Black star”: there is no tumor body, the central part is transparent. The spiculations are arched, long and thin. These usually do not indicate the entity of the lesion; they can either be benign or malignant. Examples are lobular carcinoma, post-radiation scar tissue, fatty necrosis or postoperative scar tissue (patient history is indicative!).
Calcifications appearing in the breast:
Calcifications usually occur in the secretions or in the necrotic parts of the lesions, but they can also be found within the arterial walls or old hematomas as well as scar tissues. (Picture 22.)
Calcifications are encountered in the breast quite often. Most of them accompany benign process (Picture 21.) and only a smaller percentage actually indicates malignancy. These malignant signs are basically always micro-calcifications. They are ill-shaped, with various pleomorphism (Pictures 23., 24.) and they are usually show a clustered arrangement. Their number is irrelevant to the grade of malignancy. Differential diagnosis is usually hard, if not impossible with mammography only, but targeted and magnified images can help in their analysis. The solution for differential diagnostics is biopsy.

12.5. The operated breast

Operated breast most commonly is a result of a therapeutic solution of a malignant lesion (e.g.: mastectomy, breast conserving operations, or after reconstructive surgery). At other times cosmetic reasons (plastic surgery) lead to the state of operated breast. Operated breasts are always to be examined, controlled by the radiologist and the imaging modality is always to be adjusted to the current situation with determined protocols.
12.6. Male breast examinations

Breast cancer ratio is relatively rare in males compared to females, about 1:100. The morphologic appearance is similar to that of the female breast and the imaging process is the same as well. Physical examination due to the smaller size of breast is usually more indicative in males.

A quite common breast alteration at childhood or adolescence is gynecomastia (Pictures 25., 26.), when the retro-mammillary region shows increase in the glandular tissue. Imaging methods: in adolescence breast ultrasound alone is enough to be performed. Mammography together with ultrasonography is performed above 30 years of age. In certain cases breast biopsy can be indicated. Surgery is only necessary in cases of malignancy and for cosmetic reasons.

12.7. Summary

The recent developments in breast imaging methods, the appearance of new technologies and the wide-spread availability of breast cancer screening have lead to the emergence of “increased invasive breast diagnostics”. Nowadays, it is essential to organize and centralize these different diagnostic methods. Breast imaging has become a team-work, which requires tight co-operation of all its participants (radiologists, cyto-histopathologists, surgeons, oncologists and radiotherapists.) All of these factors together provide the chance to significantly decrease the mortality of breast cancer. In order to provide a more organized workflow of the subspecialties and a more comparable reporting system, each method of the complex clinical breast imaging diagnostics currently use the same coding terminology, developed by the American College of Radiology (ACR). This is the so called BI-RADS code and is an organized and internationally recognized system that appears in all radiological reports and is in very close relation to the pathology reports.

BI-RADS coding *
0 Incomplete examination (additional imaging is needed)
1 Negative
2 Benign
   Probably benign: short term, (6 moths) follow up or biopsy is needed (chance for malignancy 2%)
3 Suspicious for malignancy: biopsy is necessary (chance for malignancy 2-94%)
4 Highly suggestive of malignancy (95%+): requires adequate therapy

"*" Breast Imaging-Reporting and Data System
12.8. References:

László Tabár: Teaching Course of Mammography
Diagnosis and in-depth differential diagnosis of breast diseases
Update 2010 Magyar Radiológia 2010;84(1): 8-21
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Translated by Balázs Futácsi
13. Imaging in Gastroenterology

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13.1. Introduction

Conventional gastrointestinal contrast studies are considered to be antiquated by many as newer imaging modalities provide more details on gastrointestinal morphology and achieve greater sensitivity and specificity. Imaging modalities in addition to conventional upper GI series include endoscopy examinations, CT and MRI enteroclysis as well as virtual colonoscopy studies which have been more recently added to the diagnostic tool set.

The different types of imaging modalities however, advance modalities have not replaced rather complement conventional studies.

In many cases upper GI series alone is adequate to establish diagnosis while, advanced modalities can be used to reveal additional details. For example, in a patient with difficulty of swallowing the upper GI series are most of the times diagnostic, or at least help to decide if additional examinations are necessary. When a tumor is detected, a subsequent endoscopy is performed and the lesion is biopsied. Meanwhile, a CT scan is also performed to determine the tumor size, invasion to the adjacent organs and to detect distant metastases. Thus, it is still debated whether in all cases endoscopy should be preferred over the GI series as the primary diagnostic modality. First and foremost, individual variations and position of the lesion must be considered. The availability of a given diagnostic modality, the patient’s general condition and his consent are equally critical factors in modality selection. Endoscopic examinations use various luminal instrumentations, which can also cause complications. Furthermore, in specific cases when the endoscope can not pass a significant stenosis the aboral segments could not be examined.

Upper GI series are simple, quick to perform and widely available. Often, even after an endoscopy diagnosis has been established complementary upper GI series still has to be performed. A good example is reflux esophagitis when endoscopy is sufficient to obtain a definite diagnosis. Still, for therapy selection extent of the reflux should be determined with a barium swallow examination. Another example where combination of both modalities is required is the work up of linitis plastica or scirrhus. Endoscopy can raise the suspicion of decreased gastric motility. While, on the upper GI series gastric wall rigidity, which is the earliest and most characteristic finding in this disease, can be clearly demonstrated. Biopsy has limited value in these cases as cancerous infiltration does not involve the mucosal lining.

Moreover, a significant advantage of the upper GI series is that functional disorders of the GI tract can also be examined. Meanwhile, endoscopy, CT and MRI can be primarily used to assess morphology.

Radionuclide studies may also have a role in the evaluation of certain upper GI tract diseases. With radioactive tracers foci of active inflammation in Chron’s disease can be specifically detected. Furthermore, the method can be used to determine activity of other abdominal inflammatory processes as well.
Overall to best decide, when and what type of imaging modality should be used for the examination of the esophagus, stomach and intestines, the planning must be based on the patient’s status as well as on the differential diagnosis indicated by the clinical presentation. Unfortunately, the decision is often restricted by the local availability of the different imaging modalities.

In general, for functional studies single contrast, while for morphological assessment a double contrast technique is recommended.

(Unfortunately, the contrast medium required for the modern double contrast examinations is not commercially available at this time.)

### 13.2. Examination of the esophagus, stomach and intestinal tract

#### Contrast media:

- **Absorbable (water soluble) iodine based contrast media**
- **Barium sulfate (water insoluble) based contrast media**

Absorbable/water soluble contrast media contain iodine. These are not absorbed from the intestinal lumen, but in case of a peritoneal or mediastinal perforation they are taken up by the lymphatics causing no complications. The iodine is in an organic bond with a benzene ring. Currently, Peritrast and Gastrografin are available. Gastrografin has a strong laxative effect.

Barium based contrast media contain barium sulfate salt, which upon its use is made into slurry. (The suspended barium ions are insoluble and toxic.) Thus, it is incorrect to state that the barium sulfate powder is dissolved. It is better to say that a barium sulfate suspension is prepared from the insoluble stable salt. When barium sulfate leaks into the peritoneal cavity it is absorbed into the peritoneum and intestinal serosa, where it can cause paralysis of the intestinal wall, a serious complication with high mortality rate.

#### Methods:

- single-contrast study
- double-contrast study

Single-contrast studies give good depiction of the luminal relief of hollow organs, while motility and function of hollow organs can also be examined to some extent. Smaller intraluminal lesions however, could not be visualized as they may be fully covered by the thick radiopaque contrast medium.

In double-contrast studies when barium and air are simultaneously administered to obtain positive and negative contrast of the luminal surface, even fine details of the mucosal relief could be depicted. Smaller irregularities of the wall contours however, may not be identified. The assessment of peristalsis and dynamic function is also limited, as the whole organ is distended during the examination. The use of barium based contrast agents is strictly contraindicated in a number of conditions listed below.
Use of barium is contraindicated:

- suspected leak or perforation
- postoperative states, presumptive suture dehiscence
- retained foreign body
- following instrumental procedures
- presumptive aspiration
- suspected broncho-esophageal fistula
- fistulography
- filling of bile ducts
- definite intestinal obstruction
- severe gastrointestinal bleeding

Types of GI contrast examinations:

- upper GI series/barium swallow (video assisted swallow examination)
- esophagram (single- and double-contrast)
- collapsed view (hypotonic) esophagram
- gastric fluoroscopy (single- and double-contrast)
- gastrointestinal follow-through
- collapsed view duodenography
- double-contrast or selective enteroclysis (since the introduction of CT and MRI scans it is considered obsolete)
- barium enema/colonography (when performed single-contrast it is called irrigosopy)

13.3. Examination of the oesophagus

13.3.1. Indications of upper GI swallow studies:

- difficulty with swallowing / dysphagia
- painful swallowing / odynophagia
- heartburn / pyrosis
- chest pain
- esophageal foreign body
- esophageal varices
- following endoscopy to exclude perforation

Preparation:

The patient needs to be with empty stomach.

13.3.2. Method

The selection whether to use water-soluble iodine based or barium based contrast media depends on the clinically indicated diagnosis.
The patient is asked to stand into the fluoroscopy equipment in an anterior oblique position; this is to make the esophagus project outside the spinal shadow. For a proper study the patient must be examined in both upright and recumbent positions, as sometimes perforations can only be detected from one direction. In order to identify potential alterations in the pharyngeal recesses the pharyngo-esophageal segment should also be examined in the frontal view.

![Fig.1.: Normal anatomy of the esophagus](image)

In the double-contrast esophagram the negative contrast is generated by indigestion of CO2 producing crystals. Orientation of the mucosal folds is longitudinal. The luminal diameter is 2-3 cm.

### 13.3.3. Diseases of the esophagus

#### Achalasia

Clinical presentation: difficulty with swallowing. In severe cases inability to swallow. Upon cold water indigestion the gastric cardia suddenly opens up. Based on this diagnostic test achalasia could be differentiated from esophageal neoplasms. The disease follows a protrated course, symptoms may persist for decades. Clinical symptoms are more reliable in the assessment of disease status. Weight gain signals improvement.

![Fig.2.: Achalasia](image)

Radiographic findings: marked dilatation of the esophageal lumen. Luminal diameter can be seriously widened. In advanced cases the tortuous gullet constitutes the mediastinal interface. The cardia shows conical narrowing. The esophageal lumen is filled with undigested food. Opening of the cardia is delayed, emptying is intermittent. The stomach is shrunken. The result is a so called microgaster as the esophagus takes over the stomach’s reservoir function.

Pseudo-diverticulosis, also Bársny-Tessendorf syndrome:

Clinical presentation: difficulty with swallowing, dysphagia. Swallowing may be painful. It presumably has a psychosomatic origin as symptoms worsen during periods of mental stress.
Radiographic findings: rosary-bead like outpouchings of the esophagus. Static peristaltic waves are seen. These are ineffective in passing forward the esophageal contents.

**Esophageal stenosis:**

Frequently, it is a complication of esophageal inflammation, which causes narrowing of the esophageal lumen. The degree of narrowing can be so severe that the lumen almost completely obliterated by scarring. It may also occur due to corrosive effect of acid or alkali indigestion as well as in reflux disease, or precipitated by long term duodenal tube placement. Irritation of the esophageal mucosa causes inflammation. Alkali indigestion usually results in more severe injury as it causes coagulative necrosis in the deep wall layers, while after acid indigestion the mucosal surface is covered with a fibrotic crust which prevents deeper penetration of the corrosive agent. In addition to the stricture inflammatory diseases are also complicated by esophageal shortening, thus part of the fornix is pulled up into the mediastinum. Frequently, in patients with reflux esophagitis the stricture only involves the cardia sparing the esophagus; still a shortened esophagus could be detected.

Radiographic findings: A long segment, sharp contoured esophageal stricture is detected. Due to stiffness of the fibrotic wall no peristaltic activity can be seen. Differentiation from tumors can be difficult, thus patient history is important. Tumors cause slowly progressing dysphagia, but generally involve shorter segments.

**Esophageal diverticula**

Esophageal diverticula are classified according to their pathogenesis and anatomic location.
Anatomic site:

- pharyngo-esophageal junction
- epibronchial
- epiphrenic
- epicardial

Based on pathomechanism:

- traction diverticula
- pulsion diverticula

Pulsion diverticula are caused by high esophageal pressure due to the increased tone of the lower esophageal sphincter.

Traction diverticula are the result of inflammatory processes adjacent to the esophagus. The inflammation leads to fibrosis and adhesions, and the contracting scar tissue exerts a pulling force on the esophageal wall. Generally, traction diverticula have a wide opening, and stay asymptomatic. Retained food particles can easily enter and exit the diverticulum. They are often discovered accidentally. As their size increases pulsion diverticula can lead to dysphagia.

Clinical presentation: Presentation depends on the anatomic location. Diverticula located at the pharyngo-esophageal junction, are also called Zenker’s diverticula. In addition to causing dysphagia they can block swallowing completely. The patients complain of food regurgitation when they lean forward. However, they deny feeling sick when they are asked directly. Regurgitation without nausea is a characteristic symptom of Zenker’s diverticulum. All patients have to be asked about this sign, as it could divert the usual gastric disease centered work up towards an upper GI series which can promptly localize the Zenker’s diverticulum.

Fig.5.: Epiphrenic diveticulum

Radiographic findings: Pulsion type epiphrenic diverticula manifest as rounded contrast retaining objects, with sharp contours. Pulsion diverticula characteristically have a narrow orifice.

Malignant processes in the esophagus are mostly esophageal carcinomas.

Clinical presentation: Carcinomas have a slow and insidious onset. Patients can stay symptom free for months, thus the lesion is rarely detected in an early phase. Most patients fail to contact their physician even after developing the first symptoms. The disease primarily affects alcoholic men who smoke and who are often in a deteriorated physical condition. The earliest
symptom is dysphagia, which gets worse by time. Frequently, the diagnosis is delayed till the patient can consume only liquids. By this time the disease is usually in an advanced stage and curative surgical resection is not possible.

Fig.6.: Esophageal tumor.

Radiographic findings: Relatively short segment esophageal stenosis with markedly irregular contours. The esophageal wall is stiffened at the tumor site.

Fig.7.: The CT scan shows prominent wall thickening in the narrowed esophageal segment.

13.4. X-ray examination of the stomach

13.4.1. Preparation

The patient has to take a fast. The examination is performed in the morning hours when the amount of the fasting gastric secretion is the smallest.

Materials and methods

- functional
- double-contrast

13.4.2. Functional studies

Functional studies examine peristaltic activity of the stomach. Physiologically, peristaltic contractions are travelling down in parallel on both the smaller and greater curvatures, with folding of the gastric wall and axial propagation of the peristaltic waves. The signs of abnormality are stationary waves, sluggish contractions, and parietal stiffness. Motility studies are often performed to detect disorders of gastric emptying. A single-contrast technique is used. Depending of the indication either water-soluble iodine based, or barium based contrast medium is selected.
In postoperative states when the danger of early complications is high, water-soluble contrast media must be used for the examination.

Disorders of gastric emptying:

- mechanical
- paralytic

Mechanical emptying disorders are caused by:

- tumors of the pancreatic head
- post-operative states, stenosis following pylorus preserving pancreato-duodenectomy (PPPD)
- incarcerated hiatus hernia

A middle aged female with an eight day history of abdominal pain was emergently admitted to the surgery department. The chest and abdominal radiographs showed no alteration, thus the patient was released home. Four days later she was readmitted to a different hospital where the upper GI series revealed an incarcerated hiatus hernia. Surgical exploration confirmed perforation of the ulcerated wall in the incarcerated gastric segment. Second review of the initial chest x-ray found a right lower mediastinal soft tissue mass that had already been present at the time.

Upper GI series must be always performed in these patients!

Paralytic gastric emptying disorders could be precipitated by multiple factors, and can advance into gastroparesis.

- peritonitis
- in the first 24-48 hours post operatively
- poisoning
- bulimia related over-distension
- severe diabetes
- side effect of medication
An 18 years old bulimic female patient was admitted after eating a pot of lentil stew. She was immediately transferred to the operating room, but she died during the surgery. On the plain film the overtly distended stomach almost completely fills the abdominal cavity.

Selection of contrast media for the gastric emptying studies should be based on the anamnestic data (ie. if a gastroscopy was performed) and on the clinical question. While with a double-contrast study the luminal relief is examined, with a single-contrast technique we can evaluate gastric wall motility and the coordination of peristaltic contractions. The opening of the pylorus and the speed of gastric emptying should also be checked. If sings of abnormal gastric emptying are detected, the patient has to be further examined. Control examinations may be necessary at one, two, and four if necessary even at 24 hours after the initial study. Radiographs in the series are labeled with “hpc”. (ie. 1 hpc, 2 hpc). “Hpc” is acronym of the latin expression “hora post coenam”, which stands for hours after contrast indigestion.

**13.4.3. Double-contrast examination of the stomach**

A double-contrast study is performed whenever morphology of the stomach has to be evaluated. We primarily look for fine lesions of the gastric mucosa. For example, presence of a gastric polyp signals a precancerous condition. Mucosal folds of the stomach (columnae rugarum), surface pattern of the mucosal glands (area gastrica) have to be visualized as well. Barium coating helps to better examine gastric wall contours and recognize excess collections. Luminal distribution of barium can be controlled by turning the patient to his side.

**13.4.4. Diseases of the stomach**

In general, diseases of the stomach, irrespective of the etiology, most frequently affect the gastric antrum, or they are originating from the antrum. As it is also often said in the stomach the antrum is the “locus minoris resistentiae”.


13. Imaging in Gastroenterology

Gastric ulcer

Clinical presentation: Epigastric pain that typically occurs after meals.

Characteristically, ulcers cause tissue defects in the stomach wall, therefore on radiography they present as excess contrast collections in profile views. When pictured “en face” an adhesive spot is seen, as the contrast media fills out the tissue defect. Ulcers can reach a large size when they are called giant ulcers. In postoperative states, in burns and in trauma patients the gastric mucosal defects evolve rapidly forming stress ulcers.

Typically, gastric ulcers follow a relapsing remitting disease pattern and could spontaneously heal by time. However, as soon as a recurrent inflammation is seen at the same site the diagnosis is changed for chronic ulceration. The clinical symptoms worsen as the recurring cycles of inflammation and fibrosis lead to scar tissue formation. Scarring can be constrictive. It is visible on the radiographs that due to the fibrosis the gastric folds are radially arranged around the ulcer rim leading to a characteristic stellate appearance.

Ulcers located on the greater curvature show greater tendency of malignant transformation; sometimes they begin with an ulcerated carcinoma. In contrast to benign lesions malignant ulcers typically do not form round contrast collections, and due to infiltration of the stomach wall no peristaltic activity can be detected around them, rather parietal rigidity is seen.

Benign gastric ulcers are seen as round collections on the GI series. At the neck of the ulcer a collar formed by the edematous mucosal ring is called the Hampton line, which appears as a thin, sharp translucent line on the radiograph. Opposite to the ulcer the gastric wall shows a permanent finger like invagination corresponding to a stationary peristaltic wave.

Fig.13.: Gastric ulcer

Fig.14.: Radiographic image: typical gastric ulcer

Fig.15.: Ulcerated carcinoma occurs typically on the greater curvature with irregular filling defect and infiltration of the surrounding wall
Medical Imaging Diagnostic Gradual English

**Gastric polyps**

Clinical presentation: asymptomatic, can be an accidental finding.

Identification of gastric polyps is a highly important role of the upper GI series. Polyps in the 5 mm range are already well detectable. It is considered a precancerous condition and generally presents as a round mass with a luminal protrusion. If pictured “en face” in the sagittal plane they can be seen as round, sharp contoured lesions.

![Image](image1.png)

Fig.16.: Radiographic image: in the gastric body multiple, 5 mm long and smaller ring-like lesion can be identified.

**Hiatus hernia**

Clinical presentation: axial hernia is typically associated with complaints of gastroesophageal reflux; patients can also experience tightness around the chest. Larger hernias can lead to a gastric emptying disorder.

Axial and paracardial hiatus hernias can be distinguished. The clinical signs are important to differentiate between the two entities as they may require a different therapeutic approach. In axial type hernias the gastric cardia and part of the stomach is displaced into the thoracic cavity. This condition is always accompanied by gastroesophageal reflux as the cardia loses its function and it does not prevent regurgitation. The patient complains of heartburn. In paracardial hiatus hernias the cardia is located below the diaphragm, while the herniated segment of the stomach may compress the cardia. The patients usually remain symptom free, thus paracardial hernias are often diagnosed accidentally.

In the everyday practice we also often see sliding hernias. In these, the hernia could only be detected in certain body positions or by applying provoking maneuvers. While in upright position the hernia reduced back into the abdominal cavity, and a normal anatomical configuration is seen. In extreme cases the whole stomach can be herniated into the mediastinum and rotates 180 degrees alongside the esophagus, which is also called the upside-down stomach sign.
Fig. 17: Radiographic image: Axial hiatus hernia. No gastric air bubble could be found in the regular subdiaphragmatic position. The gastric fundus and the cardia can be localized above the diaphragm. High grade reflux is detected in supine position.

**Gastric neoplasm**

Classification of gastric tumors:

- benign (polyp, adenoma, leiomyoma, fibroma, neurofibroma)
- semimalignant (villous polyps, papillary adenoma)
- malignant (gastric carcinoma)

Classification of malignant gastric tumors according to their gross appearance (Bormann classification):

- I. Polyp like: sharply demarcated polyp like carcinoma (cauliflower like filling defect)
- II. Superficial: sharply demarcated ulcerating carcinoma, polyp like, with intraluminal contrast collection due to necrosis (favorable prognosis, usually in the antrum, the center can be digested and disappear forming a bowl shaped lesion with a 5-8 mm wide collar)
- III. Excavated: poorly circumscribed ulcerating carcinoma (invasion front on the circumference, could not be sharply demarcated from its surroundings)
- IV. Infiltrating: diffusely infiltrating carcinoma (in an extensive disease it can completely infiltrate the gastric wall – linitis plastica (carcinomatous shrinking of the stomach) aka. scirrhus.

Clinical presentation: In an early stage symptoms are vague including abdominal discomfort and fullness. Loss of appetite, later disgust from meat is experienced. Weight loss, nausea, occasionally bloody emesis are also seen.

The radiographic picture is quite variable. Often a concomitant gastric wall deformity is detected. Frequently, the tumor arises in the antrum. Lesions protruding into the lumen appear as shadows of lost luminal filling. In advanced cases the whole stomach is deformed, with luminal narrowing. The gastric wall is stiffened progressing into a gastric emptying disorder by time.

A distinct form of gastric cancer is linitis plastica or scirrhus. The clinical symptoms are identical with those are seen in other types of gastric carcinomas. However, it is associated with characteristic radiographic and microscopic features.
Radiographic findings: Generally, the lesion starts in the antrum. In the beginning it does not produce any overt symptoms other than parietal stiffness, until the infiltrative tumor spread remains confined to the gastric wall and does not involve the mucosa. Endoscopy can suggest altered wall motility. This can be verified on the upper GI series. The affected wall segment does not show peristaltic activity. The relief of the lesser curvature has a serrated appearance, and wall stiffness could expand to the entire stomach. The stomach morphology transforms into a tube like configuration, while the gastric size is shrunken.

13.5. Examination and diseases of the duodenum

Materials and methods:

Upper GI series are performed. (In addition to the stomach the duodenum must always be examined as well.)

The most common alteration is duodenal ulcer.

Clinical presentation: Characteristically, it almost never shows malignant transformation, but recurs frequently. The patients complain of epigastric pain which is usually precipitated by fasting and the symptoms are relieved after meals. Duodenal ulcers can also bleed causing anemia. Ulcers can occur in the pylorus as well. Frequently, recurring ulcers heal with scarring and contraction of the bowel wall which leads to deformity and narrowing of the duodenal bulb. Pyloric ulcers may cause pyloric stenosis.

Radiographic findings: They form a prick like collection in the wall of the duodenal bulb. If the ulcer is small it could be only seen when external pressure is applied on the region. The instrument that is used for compressing the abdomen during the examination is called the distinctor.
Diverticula can also be located in the duodenal curve. It is more common however, that
diseases of the pancreatic head propagate to the duodenum. As the pancreatic lesion grows the
duodenal lumen can be mechanically obstructed thus blocking the gastric emptying. In
diseases of the pancreatic head the duodenal curve could be distended the common bile duct is
occluded eventually, leading to jaundice.

Clinical presentation: nausea, vomiting, abdominal pain, jaundice, feeling of gastric fullness.

Radiographic findings: In space occupying lesions of the pancreatic head the duodenal curve
is distended. Due to the compression, the Kerckring folds are blunted and show a semi-
opaque filling pattern. Initially the lumen is narrowed, later it can be completely obstructed.

13.6. Examination and diseases of the small bowel

Contrary to the upper GI tract and the colon the small bowel could not be visualized with
endoscopy. Thus its radiographic examination requires a different approach.

Material and methods:

Studies can be either morphological or functional. For assessment of the morphology selective
enterography is the most suitable method. Functional studies are called follow through or
passage examinations.

Examination technique:

Nowadays, selective enteroclysis is performed with CT or MRI scanning. With the more
detailed imaging technique not only the parietal morphology of the small intestine, but lesions
in the surrounding abdominal structures can be simultaneously detected.

Capsule endoscopy is a novel method, when the patient swallows a plastic capsule equipped
with a miniature camera, which takes serial pictures of the intestinal wall as it moves forward.
It exits the anus by the natural bowel movements, thus pictures taken by the capsule can be
analyzed.

Follow through studies are performed when there is clinical suspicion of a mechanical bowel
obstruction, also called as ileus. After an initial plain abdominal film has been taken the
patient consumes water soluble contrast which passes through the intestinal tract. Meanwhile,
additional abdominal radiographs are taken with one hour intervals. These are the so called
“hpc” radiographs. If a mechanical obstruction is suspected the examination is continued until
the contrast agent gets to the rectum. The follow through study can differentiate whether the
patient has ileus or partial block of the intestinal transit, also called subileus.

The original meaning of the term “ileus”: A word of Greek origin, it was initially used to
describe only intestinal twisting or volvulus. Nowadays, it is used in a more general sense to
all kinds of mechanical or functional blockage of the intestinal contents.
On the abdominal radiograph distension of the small bowel loops and air-fluid levels can be identified. It is important to describe forwarding of the contrast media by time or if mechanical obstruction is seen. Morphology of the intestinal loops could not be assessed with this method. This study is specifically conducted to examine the transit function only.

**Chron’s disease**

Clinical presentation: diarrhea, weight loss.

Radiographic findings: Most frequently luminal narrowing of the terminal ileum is detected. The wall is thickened, intramural and inter-intestinal fistulas may develop. The abdominal plain film is not suitable for identification of abdominal abscesses.

Diverticula can form in the small bowel, but with a very low frequency. In addition to regular diverticula rarely a Meckel diverticulum is seen.
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13.7. Examination and diseases of the colon

13.7.1. Radiographic examination of the colon, material and methods:

- single-contrast (irrigoscopy)
- double-contrast (colonography, barium enema)
- virtual colonoscopy

The barium sulfate suspension forms positive contrast while air is the negative contrast. Irrigoscopy is a method to examine the large bowel which requires a careful preparation. Only the fully cleansed colon can be imagined properly:

**Preparation:**
On the night before the examination the large bowel should be cleared. Nowadays, we try to avoid enema preparations. For endoscopy preparation a clear-liquid diet is recommended which is best achieved by consuming mixed electrolyte rich fluids. Some preparations are specifically formulated for this purpose such as the X-prep.

Single-contrast acute irrigoscopy examination with water-soluble contrast medium:

**Indication:**

- large bowel ileus
- suspected perforation
- suspected enteral fistula

13.7.2. Diseases of the colon

**Colon diverticulosis:**

One of the most common disorder of the large intestine, its frequency increases by age.

Clinical presentations: Patients can be symptom fee. If complicated with diverticulitis it can cause abdominal pain in the region corresponding to the affected bowel segment. Bleeding, perforation can occur.

Radiographic findings: multiplex round collections are seen on the sigmoid and descending colon. Double-contrast irrigoscopy.

Fig.23.: Radiographic image: multiple, round filling defects are seen on the sigma and on the descending colon.

Fig.24.: Double-contrast irrigoscopy
Colorectal polyp

Clinical presentation: Usually colon polyps are asymptomatic and constitute an accidental finding. They can bleed, thus a positive fecal blood test can draw attention to their existence. They are also considered precancerous lesions. Polyps larger than 2 cm are potentially malignant.

Fig. 25.: Radiographic findings: A round lesion with sharp edges protrudes into the intestinal lumen.

Morphologic types:

- sessile poly
- polyp like with stalk
- villous adenomas

Colorectal tumors

Most commonly they are detected on the sigmoid colon however; all segments of the colon can be affected with variable frequency. Tumors in the right half of the colon bleed more frequently while, tumors in the left half show greater tendency for stenosis.

Clinical presentation:
Abdominal fullness, constipation, and with time diarrhea is characteristic, with complete obstruction of the lumen no stool is passed and ultimately colonic ileus ensues.

Fig. 26.: Napkin ring sign (or apple core sign), is a typical presentation of colon tumors.

Fig. 27. Rectal cancer arising from a villous adenoma causes a rugged contour and an extensive filling defect.
13. Concluding message

The purpose of this chapter is to aid the preparation of medical students. The author’s primary intention was to specifically emphasize and to help the students to master the proper radiographic terminology. Thus, when reading a radiology report they can associate the findings with a radiographic image, and can understand the types of alterations described by the radiologist. The consultation between the clinician and the radiologist could only reach completeness, and can benefit the patient the most, if they are mutually familiar with the terminology of the each other’s fields of specialty.

Translated by Pál Kaposi Novák
14. Imaging of abdominal parenchymal organs
(liver, biliary ducts, gallbladder, pancreas, spleen)
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14.1. Liver

- Normal anatomy and variations
The liver is the biggest human abdominal parenchymal organ. It weighs between 1500 and 1600 grammes in case of an adult of average built.
The liver is located in the right hypochondrium, under the diaphragm. The lateral margin of the left lobe reaches the inception of the small gastric curvature in a normal case. However in case of a variation, the liver can also extend under the left diaphragm contour superior or anterior to the spleen. The caudal margin of the right lobe extends to the margin of the middle and lower thirds of the right kidney in case of a normal liver size. This margin can change if developmental abnormality or locational variation is present.
A frequent shape variation occurring usually in women is called Riedel lobe, in which the lateral pole of the right lobe flags caudally. The isolated hypertrophy or the lessening of the left lobe can rarely occur, without any particular pathological background. Multiple fissures can develop mainly on the right diaphragmatic surface corresponding to a shape variation.
Situs inversus is an extremely rare developmental variation, indicating a left-sided liver located under the diaphragmatic contour in the left hypochondrium.
Due to its special physiologic function and anatomical structure (dual blood supply: hepatic artery, portal vein) its complex imaging consists of various methods.
The knowledge of the liver segmental anatomy (segmental classification by Quinaud – figure 1) is necessary in the accurate marking and localisation of the intrahepatic lesions.
In addition, the accurate cognition of various arterial blood supply variations (hepatic artery system) is very important by the planning, performance and adaptation of both surgical and interventional oncological (TAE, TACE) treatments.

Figure 1.: Schematic segmental anatomy of the liver
14. Imaging of abdominal parenchymal organs

14.1. Imaging methods of the liver and the biliary ducts

14.1.1. Conventional radiograph

In a typical case, the liver shadow is located under the diaphragm on the right side on the conventional abdominal radiograph. (Figure 2).

![Figure 2: Hepatomegaly, native abdominal X-ray](image)

Since it is a parenchymal organ, a sort of circumscribed radiographic abnormality can be only seen on its projection, if the beam absorbance or the beam transmission of the abnormality is notably different. An Echinococcus cyst bearing with a calcified wall, a calcified gall stone, or possibly a porcelain gallbladder can appear as such a beam absorbing lesion. The beam transmitting gas bubbles can refer to gas inside the biliary ducts (normal postoperative situation or pathologic abnormality, eg. in case of gallstone ileus) and probably to gas bubbles inside a liver abscess due to their shapes, locations and amounts.

14.1.1.2. Ultrasound

Using an accurately set and good resolution ultrasound (US) device, it is considered as a very sensitive imaging method. However, it is a non-specific and – similarly to other US examinations – very operator depending method. The specificity of the contrast enhanced US examinations is relatively similar to that of CT and non hepatocyte-specific contrast enhanced MRI.

It is important to note that using a top category device, a better qualified radiologist, who has a better imaging experience, can gain significantly more additional information in case of a repeated US examination of a certain intrahepatic lesion (accordingly, CT is definitely not the next step…!). This special, unknown and unadopted way of the progressive patient care would be essential to consider.

The US examination is an indefinitely repeatable, easily accessible, relatively cheap method. The value of the standard examination (2D, real-time US) can be advanced notably by color duplex US. In case of nodal liver diseases and pathologic circulation circumstances, the specificity can be raised especially by contrast enhanced US examination. The flow direction (color) and intensity (doppler spectrum) can be determined accurately in certain diseases considering the intrahepatic arteries and veins.

In the report of a liver US, its size, shape, echo structure, shape variation, possible focal lesions and obviously, the adjacent lesions around the liver must be declared as well.
The echogenicity of the normal liver tissue is mildly hyperechoic (Figure 3) due to the intrahepatic connecting tissue structures, small veins, arteries and bile ducts (its echogenicity is principally comparable with the adjacent normal right kidney cortex, the liver has a bit hyperechoic structure than the right kidney, and its echogenecity is principally the same as the spleen's).

Figure 3: Normal liver, 2D US image

The portal vein and its branches have hyperechoic walls which can be easily differenciated in the liver structure. The walls of the hepatic vein branches have remarkable less echogenecity. The normal diameter intrahepatic bile ducts and the smaller liver arteries cannot be imaged and observed. The wall of the hepatic ducts and the main biliary duct (ductus choledochus) is also moderately hyperechoic. The hepatic hilum consists of the „double barrel” configuration (main biliary duct – portal vein, inbetween the cross-sectional view of the hepatic artery trunk) in the typical anatomical location, using an appropriate longitudinal plane.

The complex abdominal US examination is performed by a 3-5 MHz convex ultrasound probe, usually starting with the US imaging of the liver from subcostal direction in deep inspiration. In case of anatomical variations, upward displacement of the diaphragm, unappropriate breathing cooperation and postoperatively (eg., upper abdominal drain), the intercostalis imaging can be very important. The anatomical structural unit of liver, bile ducts and the gallbladder will be adjudged and reported afterwards.

14.1.1.3. CT

Nowadays, CT is a basically important method amongst the modern diagnostic imaging services. (Figure 4) By the application of the multidetector CTs a chance is given to perform multiphase (without contrast, arterial, portal and late phase) CT scans, which provide important additional information because of the different hemodynamics of certain intrahepatic nodules. Multiplanar (sagittal, coronal, oblique) and 3D reconstructions can be adopted from the axial plane CT slices. Due to CT angiographic techniques, excellent spatial resolotional 3D reconstructional images can be performed both on the arterial (hepatic artery) and the venous sides (portal vein, hepatic veins, collateral veins in case of portal hypertension, CT control of transjugular portosystemic shunts)..
14. Imaging of abdominal parenchymal organs

14.1.1.4. MRI

In multiple cases if the exact diagnosis could not be made by US and CT, MRI examination can be necessary. (Figure 5)

MRI can be applied especially in children and young adults – also in order to replace the CT scans due to its unneglectable radiation exposure. Following US examination, in case of a known contrast allergy, pregnancy or denial of intravenous contrast administration additional imaging information can be gained by MRI. However it is important to note that biopsy usually precedes (correctly) the MRI. Nowadays, MRI scans of the abdominal parenchymal organs are infrequently performed only in dedicated cases due to the above mentioned reasons in foreign large diagnostic centres (unless in case of scientific motivation). Good news that MR cholangiopancreatography (MRCP – Figure 6) plays an increasingly more important role in the biliary duct imaging since MRCP provides nearly the same image quality as ERCP. In addition, it is extremely important to note that the non-invasive MRCP does not accompany with complications such as pancreatitis or cholangitis which occur in an unneglectible percentage during the ERCP.
14.1.1.5. Angiography

The CT-angiography and MR-angiography methods take nowadays over from the diagnostic selective catheter hepatic angiographies. The catheter angiographies are performed in case of therapeutic (TAE – Figure 7, TACE, chemoperfusion) interventions and the traumatic liver injuries (selective embolisation) on these fields.

14.1.1.6. Endoscopic retrograde cholangiography, cholangiopancreatography (ERC, ERCP)

This method implies the retrograde contrast filling of the biliary and pancreatic ducts from the papilla of Vater performed usually by gastroenterologists under a fluoroscopy guidance. (Figure 8)
14. Imaging of abdominal parenchymal organs

It is very important to note that bacteria can ascend to the basically sterile biliary ducts from the duodenum during the retrograde contrast administration developing cholangitis, therefore, the intervention must be always performed with antibiotic protection. Following the contrast administration, specific radiographic images must be performed in different projections in order to image the possible filling excesses, filling defects or biliary duct stenoses properly. In 5-15% following the procedure, mild or severe pancreatitis can also develop. Thus, ERCP must be handled as studiously invasive intervention and it should be only performed in case of an established clinical decision. Directly following the diagnostic procedure, therapeutic interventions can be also performed through the working canal of the endoscopic device in necessary situations (papillotomy, stone extraction, mechanic stone comminution, biliary duct stent implantation).

14.1.1.7. Percutaneous transhepatic cholangiography (PTC)

The percutaneous contrast filling of the biliary ducts can be necessary if no reassuring diagnosis was made by US, CT or MRI scans, or the ERCP implementation was unsuccessful due to a technical obstacle (Billroth II. gastric resection, choledochojejunostomy), or the canulation of the papilla of Vater was technically failure. PTC can be only performed in case of appropriate bleeding or coagulation status. (Figure 9).

Figure 8: ERCP (Endoscopic retrograde cholangiopancreatography)

Figure 9: PTC (Percutaneous transhepatic cholangiography)
Significant amount of free abdominal fluid is also a relative contraindication. In the course of PTC, the liver puncture is usually performed in the 9th or 10th rib spaces under fluoroscopic guidance using a 22 G Chiba needle. The puncture should be guided towards the liver hilum. US guidance is helpful in the easier puncture of dilated or even peripherally located biliary ducts. The entire biliary system can be filled through this puncture. Following the diagnostic biliary duct contrast administration – after a previous consultation – bridging of the detected biliary stenosis can be performed (PTC-PTD, biliary duct stenting). Moreover, percutaneous stone extraction can be carried out if necessary.

14.1.1.8. Nuclear medicine

The role of colloid liver scintigraphy (intravenously administrated 99mTc-marked radiocolloid) has been clearly dropped in the past 15-20 years because its spatial resolution can not reach the modern applicable resolution of US and multidetector CT devices. The blood-pool scintigraphy of 99mTc-marked red blood cells helps by planar detection in the non-invasive diagnostic imaging in case of larger and superficial located cavernous hemangiomas (6-9 cm). The 99mTc-marked red blood cell (RBC) SPECT (Figure 10) can also detect the smaller and deeplier located (2-3 cm large) hemangiomas as well.

![Figure 10: SPECT of the liver](image)

In case of the clinically suspicious liver or subphrenic abscess – if the US and CT findings are doubtful – leukocyte scintigraphy may be also helpful in the diagnosis.

14.1.1.9. Hybrid imaging modalities, PET/CT

If the Positron Emission Tomography and Multidetector CT images are performed exactly in the same set and will be superprojected, a quite accurate localisation of metabolically active, pathological liver lesions can be managed. The administrated PET radiopharmacon (fluorodeoxyglucose, FDG) gets stuck in the hypermetabolic (glucose uptaking) cells marking accurately these hypermetabolic areas. (Figure 11)
14. Imaging of abdominal parenchymal organs

Concerning the liver in the oncologic field, PET/CT technique plays a very important role in the detection of metastases.

14.1.2. Diffuse liver diseases

The concept of diffuse liver disease is an ultrasound-morphologic appearance indicating a sort of disease. However, this is non specific, the sort of the illness can only be certified by biopsy. Diffuse liver disease alters the reflection, reduction, homogenicity and vessel structure of the parenchyma. In addition, it can modify the liver's size and shape. The reflection change indicates the modification of the acoustic echo amplitudes in the liver parenchyma, usually the amplitude increases. The diffuse decrease of the reflectivity can also happen rarely (acute hepatitis, leukemia, lymphoma, toxic shock, acute right heart failure). In case of increased beam absorption or distal acoustic weakening, the far liver areas can only be imaged minimally or not at all if the usual amplification is applied. This can be usually corrected partly by the adjustment of the depth amplification. Shape abnormalities include the rounded liver margin, surface incongruences (cirrhosis) and the hypertrophy of the left lobe or caudate lobe as well. Most frequent reasons of diffuse liver diseases:

- fatty liver
- cirrhosis
- chronic hepatitis
- circulation disturbances
- metabolic and storage diseases
- diffuse miliary metastasis
- leukemia, lymphoma

14.1.2.1. Fatty liver (steatosis hepatis)

The triglycerides accumulate in the hepatocytes. The parenchyma reflectivity and the beam absorption increases (Figure 12). The increase of the reflectivity is usually homogeneous, rarely inhomogeneous.
Possible forms of fatty liver: diffuse steatosis or focal steatosis (focal deposition)
The focal forms develop due to the different perfusion statuses. It is characterized by no space
occupying effect (no vessel displacement), and their appearence can change significantly
during the check-up examinations. In the areas of decreased portal circulation (eg., ventral to
the portal vein, next to the gallbladder) less fat is deposited, this area appears focally
hypoechoic - focal sparing (Figure 13). In case of focal deposition, round, nodular or girland
(chart-like) hyperechoic infiltration areas develop in the intact liver.

MR is rarely performed as imaging the diffuse fatty liver. Preferably in case of an imaging of
other reason can come to that the diffuse steatosis of the liver, which was shown to be fatty by
conventional techniques, (higher T1 signal intensity, less T2 signal intensity as usual) will be
imaged by fat suppression.
In addition, differentiation of focal deposits / focal sparrings (next to the gallbladder bed,
portal branches, lig.teres hepatis) is available, too. Essential to note that there is no mass
effect. (The exact extent of steatosis can be shown by proton spectroscopic imaging.)

14.1.2.2. Liver cirrhosis (cirrhosis hepatis)

No direct association among the extent of fibrosis, the degree of the dysfunction and the
ultrasound morphology was detected, normal liver structure can be observed in case of an
extended encephalopathy as well. The right lobe size can decrease, left lobe and caudate lobe
hypertrophy develops. Lateral segment of the left lobe can increase besides the decrease of the
medial segment's size. The fibrosis itself does not change the parenchyma reflectivity.
Increased reflection can be observed if it accompanies with fat deposition as well. On the other hand, rough echostructure, inhomogeneity can be observed in the parenchyma due to the miliary (4-5 mm or smaller) regenerative nodules. Bigger nodules result extensive surface incongruences (Figure 14).

Figure 14: Liver cirrhosis, nodular surface, ascites

The regenerative nodules can appear as moderately hypoechoic lesions, mimicking hepatocellular carcinoma which develops more frequently based on cirrhosis related to B and C viral hepatitis. The nature of the developing nodule can only be clarified by biopsy in some cases. Small amount of free abdominal fluid (ascites) can be imaged well by US. Signs of portal hypertension can be also recognised very well, however, the exact determination of the circulation statuses goes over the possibilities of the routine US examination obviously. In this case, an accessory color duplex US examination using an appropriate top category device is necessary.

US features of portal hypertension:

- portosystemic collaterals can be seen (umbilical vein recanalisation, caput Medusae, splenorenal shunts, gastric veins)
- hepatofugal flow
- pulsatile portal Doppler spectrum
- dilation of the splenoportal veins
- disappearence of caliber change of the splenic vein
- compressed intrahepatic veins
- pathologic Doppler curve of the hepatic vein
- decreased portal flow speed
- decreased portal flow blood volume
- in postprandial situation, loss of portal flow increase
- in postprandial situation, loss of RI increase during the examination of the hepatic artery

MR respects:
The fibrotic conversion weaves around the portal venous sinusoids in cirrhosis, leading to blood redistribution in the liver and in the abdomen by the incapacitation of the flow. The hepatic surface is often irregular, bumpy and characteristically the right lobe is more frequently affected as the left one and the caudate lobe, which ones respond by reactive hyperplasia to the reduction of the right lobar parenchyma.
Because of the fibrosis, the signal intensity is commonly moderately decreased on the T1-weighted images, but not on a constant way. More importantly we can rely on the evaluation of the morphological lesions such as the nodular appearance of the liver parenchyma with the distorted vessels, enlarged caudate lobe and the secondary signs such as: dilatated collateral vessels (which can be imaged exquisitely by MR with signal void), splenomegaly and ascites.

**MR angiography** images the collateral and portal vessels replacing the invasive DSA. MRI is also suitable for the control of the surgically prepared portocaval shunts. Extension and degree of the ascites can be clearly imaged by MRI (T2-weighted images). As a complication of the long-standing portal hypertension or in case of a definitive liver tumor by the formation of a direct tumor thrombus in the portal vein, portal vein thrombosis can develop. Accordingly, further cumulative portal hypertension, ascites and varices of various extent evolves. The thrombotic portal vein can be fairly demonstrated by MR.

**14.1.2.3. Viral hepatites**

In case of acute hepatitis, the diffuse decrease of reflectivity can be observed. Development of the necrosis results inhomogeneity, small liver indicates a bad outcome. In case of chronic hepatitis, importance of the ultrasound examination includes the recognition of cirrhosis and hepatocellular carcinoma.

**14.1.2.4. Haemochromatosis, haemosiderosis**

In case of primary haemochromatosis iron is deposited in the liver (in the hepatocytes) and in various organs, which often leads to cirrhosis and portal hypertension. In the liver of patients suffering from thalassemia and polytransfusion iron is deposited in the hepatic macrophages, the Kupffer cells.

The reason of the very significant MRI signal intensity decline rely on the paramagnetic attribution of the deposited iron which causes the decrease of the relaxation time both in T1 and mainly in T2 (in extreme case the entire liver appears black on T2-weighted images). This effect is independent of whether the iron deposition is hepatocellular or incorporated by the macrophages (the above mentioned phenomenon can be employed for the measurement of the stored iron amount, if the method is well set, otherwise it can be influenced by many other factors: the original status of the liver, fibrosis, steatosis, etc, which cannot be parametrized). Hopefully the liver biopsy will be replaced by it.

**14.1.2.5. Glycogen storage disease**

The glycogen storage diseases are frequently accompanied by the fatty infiltration of the liver parenchyma (and often leading to malignization) resulting very various images on the MRI.

With diffuse liver disease can be associated the

**14.1.2.6. Budd Chiari syndrome**

It is resulted by the intrahepatic obstruction of the main branches of the hepatic vein due to thrombosis (polycythaemia, oral contraceptives) or tumorous invasion of the vessels (hepatocellular carcinoma, renal carcinoma „prefer” to involve vessels).
14. Imaging of abdominal parenchymal organs

In case of obstruction of the smaller branches, regenerative lesions and transformations occur in the liver. Because of the venous supply of the caudate lobe it is less affected compared to the other lobes, therefore it responds by hypertrophy. Thrombosed vessels appear as signal intensity increase in the thrombosed vessels on MRI, in comparison with the open vessels with normal flow with low signal intensity. The consequences of portal vein thrombosis are portal hypertension, ascites and development of varices. MRI images both the thrombosed portal veins and varices.

14.1.3. Appearance of parasites in the liver and the biliary ducts

14.1.3.1. Echinococcosis

Echinococcus granulosus – appearance in the liver as an unilocular cyst, Echinococcus multilocularis – as a multilocular cyst and a bizarre space occupying lesion in the liver.
The plants and drinking water infected by the eggs in the defecation of the definitive and the intermediate hosts (mainly the dog and the sheep) can be consumed by the people. Therefore, embryos will hatch from the eggs in the gastrointestinal tract and can reach the liver and the lung crossing the bowel wall through the portal vein. Very variable appearance forms can be observed by US and CT examinations from the early cyst in active phase to the cyst of the died parasite with a calcified wall (although the calcium appearing in the wall of the cyst does not mean that the parasite has unambiguously consumed) in case of an E. granulosus infection (Figure 15).

![Figure 15: Echinococcus cyst in the liver, contrast enhanced CT](image)

On the other hand, the liver parenchyma affected by E. multilocularis appears as areas with irregular contour and mixed echogenicity (US) or density (CT) including a hypoecholic (US) or hypodens (CT, this is already the necrotic area) necrotic center (multilocular cyst with inner matrix).
14.1.3.2. Schistosomiasis

Depending on the severity of Schistosoma mansoni (endemic areas: Brasil, Venezuela) and S. japonicum (endemic areas: South China and Philippines) infection, periportal fibrosis and liver cirrhosis can develop. US shows portal vein branches with hyperechoic, thickened wall, CT images hypodens, ring-like periportal structures with extensive contrast enhancement.

14.1.3.3. Toxocariasis

Toxocara canis spred by the dogs (rarely the T. cati spred by the cats) results an eosinophilic infiltration or granuloma in the liver and the lung. They perform a small movement in these organs (migrating visceral larvae). These liver lesions appear as multiple, oval lesions measuring 1-1.5 cm in diameter by CT and MRI. Best imaging by CT can be observed in the portal vein phase. Concerning its origin, no endemic areas are known, only sporadic cases are reported worldwide.

14.1.4. Focal liver diseases

The most commonly detected

14.1.4.1. Benign intrahepatic lesions

14.1.4.1.1. Cysta

Typical appearance includes a well defined, anechogenic fluid-containing lesion with sharp margin. Usually thin septa can be included and wall calcification can be observed as well. Their size varies between 3 mm and 10-12 cm.

The simple cyst (Figure 16) indicates a difference from the multicystic liver only in the number of the cysts. Conversely, the polycystic liver (Figure 17) is an autosomal dominant inheritant disorder, in which the cystic conversion can be present in up to 70-80% of the liver parenchyma due to the large number of the cysts. It often accompanies with polycystic kidneys, whilst the entire polycystic syndrome – if also polycystic affection of the pancreas is also associated – occurs very rarely.

![Figure 16: Simple liver cyst, US](image)
14. Imaging of abdominal parenchymal organs

Differential diagnostic difficulty is only given if the liver cysts show atypical appearance (its content becomes more hyperechogenic in US or more hyperdense in CT). In this situation, the differentiation from cystic tumor, metastasis or probably abscess is possible only if taking into account the clinical data and performing US or CT-guided puncture. MRI image shows a smooth contour characteristic to the cysts, which has low signal intensity on T1 and very high signal intensity on T2-weighted images. In case of a complicated cyst (fibrosis, condensation, hemorrhagia) various MRI signal intensities can be observed according to the complications.

Special determination is needed if the clinical features indicate the presence of Echinococcus cyst. In this case, serologic examinations have also an elemental importance. These disorders were discussed already in the parasitic liver diseases paragraph.

### 14.1.4.1.2. Hemangioma

Typical appearance includes a well defined, hyperechoic solide lesion measuring usually less than 2 cm in diameter (Figure 18).

In case of an atypical hemangioma (inhomogeous, mixed echostructure or hypoechoic appearance) additional imaging methods (multiphase MDCT, MRI) can be necessary, in addition in certain cases US guided biopsy can not be avoided in order to achieve the final diagnosis.

Figure 17: Polycystic liver, contrast enhanced CT

Figure 18: Typical US image of a hemangioma in the sixth segment of the liver
MRI is only needed in case of "atypical" hemangiomas, since ultrasound is the best imaging method for diagnosing the hemangioma. If the ultrasound finding is uncertain, dynamic CT (Figure 19, 20), afterwards nuclear imaging and biopsy are the appropriate choices.

Paraarterial or subcapsular localisation, central thrombosis or fibrosis may interfere with the safety of diagnostic evaluation. In this case, MRI can be performed which is very sensitive to hemangiomas (size under 0.5 cm is also indicated – figure 21).
14. Imaging of abdominal parenchymal organs

Hemangiomas appear as a bit lower signal intense lesions compared to the liver parenchyma on the T1-weighted images. A very high signal intensity can be observed on T2-weighted images. T2 relaxation time fluctuation (the strength of signal intensity by T2) is affected mainly by the extent of thrombosis/fibrosis. Dynamic contrast MR study can be also performed, which demonstrates the slowed flow dynamics of the hemangioma (similarly to CT): haemangiomas fill up from outside inward as an iris or wheelspoke form in case of typical appearance.

14.1.4.1.3. Focal Nodular Hyperplasia (FNH)

Significant female dominance can be experienced considering its prevalence (80:20%). FNH frequently occurs in young women who have been taking anticoncipients for a long time. No typical US appearance can be mentioned, because it can be hyperechoic, hypoechoic and even isoechochogenic compared to the intact liver tissue. If it is a bit hyperechoic than the adjacent intact liver parenchyma, it can be reliably detected by US and (not in each case) a hypoechoic central area (central scar) can be also observed. In a typical case, spoke wheel pattern can be shown in the tumor by color Doppler. These tumors are typically arterially hypervascularised and a dominant artery running towards the center of the lesion can be also observed. FNH cannot be differentiated often by US from the adjacent liver parenchyma; only the space occupying effect can be detected (moderate displacement, compression of veins, bile ducts). In these cases, a properly performed multiphase MDCT or MRI can have a diagnostic value (Figure 22). MRI shows on T1-weighted images that the signal intensity is isointense with the liver tissue, and only the vascular distortion is the only sign which can draw attention to the present lesion.

![Figure 22: FNH, contrast enhanced T1 weighted MRI, with intravenous gadolinium](image)

On the T2-weighted sequence, the signal intensity may be slightly increased compared to the normal liver parenchyma. Because of the fibrotic attribute of the "central scar", low signal intensity can be observed on both weighting, but if colliquation necrosis is present inside (some attribute this to the dilated biliary ducts), high T2 signal intensity can be observed.

14.1.4.1.4. Adenoma

Also by these benign liver tumors, a female dominance can be observed concerning its prevalence, but not in as rate as by FNH (60:40 %). Its on-time detection is very important, because they can bleed during their increase resulting serious consequences (parenchymal or intrabdominal bleeding).
No special morphology can be observed by US, however, a hypoechoic, avascular area with irregular contour inside the lesion can draw the attention to the bleeding. In early arterial phase these lesions show an increased contrast enhancement as well, due to their hypervascularised feature from the direction of the hepatic artery, but there is no special sign (eg., central scar) as by FNH.

MRI shows usually a bit low signal intensity on the T1-weighted images. Pseudocapsule, if present, is hypointense on T1. Adenomas have high signal intensity on T2-weighted images. The signal intensity is inhomogeneous because of the contained fat tissue and necrosis. The hemorrhages inside the adenoma provide a very “colorful” image and their signal intensities depend on the age of the hemorrhages on T1 and T2-weighted series.

The following features distinguish the adenoma from FNH: inhomogeneity, fat content, hemorrhages and, if present, pseudocapsule. The same features – except the fat content! - are not suitable to distinguish the adenoma from the hepatocellular carcinoma since the hepatocellular carcinoma can also bleed and pseudocapsule can be also surround it.

14.1.4.1.5. Other benign liver tumors

Lipoma, pseudotumor, intrahepatic splenosis, and other benign liver tumor can be also observed intrahepatically, obviously less frequently compared to the previously mentioned lesions. Diagnostic difficulties may be resulted in these cases, and imaging method guided biopsy can be sometimes necessary in order to draw the conclusions considering the next therapeutic decisions.

The most frequent

14.1.4.2. Malignant intrahepatic lesions:

14.1.4.2.1. Metastasis

The most common malignant intrahepatic lesions are the metastases of various origin. In the oncologic praxis especially in case of a patient with known colorectal, neuroendocrin or breast cancers, focused ultrasound examination of the liver has a special importance during the checkups. US appearence and detectibility of the liver metastases can be very variable depending on the primary tumor. Sensitivity ranges between 53% and 84% according to various large studies. Characteristically hypoechoic liver metastases originate usually from: Breast cancer (Figure 23), pancreatic cancer, testicular cancer, ovarian cancer, malignant lymphoma, carcinoid, gastrointestinal adenocarcinoma.

![Figure 23: Metastases of breast cancer in the liver, contrast enhanced CT](image)
Characteristically hyperechoic liver metastases appear in case of the following primary tumors: Colorectal adenocarcinoma, malignant melanoma, small cell bronchial carcinoma, teratoid carcinoma, gastric adenocarcinoma, certain part of breast cancers.

- Diffuse, infiltrative liver metastases can be observed: In case of anaplastic carcinoma and purely differenciated tumors. Besides these forms, metastases with mixed echostructure (containing both hyperechoic and hypoechoic areas) and cystic metastases with necrotic content can occur relatively often (Figure 24).

The liver metastases of colorectal origin are usually characterised by a bit inhomogeneous hyperechoic structure surrounded by a hypoechoic rim. (Figure 25)

In the central area of bigger (4-6 cm in diameter) metastases necrosis can also develop as so called „target” form (or commonly called as bull’s eye sign).

In the oncological practise, the most often performed imaging modality is nowadays the CT which is appropriate for both searching of liver metastases and the follow-up of the treatment efficacy in case of known liver metastasis. The decreased or increased vascularisation of the metastases can be well documented by appropriately performed three-phase multidetector CT in case of the liver, even from the size of 4-5 mm in most of the cases.

Far before the era of multidetector CT, CT arterioprtography (CTAP) was performed in special cases. The sensitivity and specificity of CTAP in the detection of liver metastases was far better as the conventional spiral CT. In the course of CTAP, a selective catheter was
placed from the arterial side into the superior mesenteric artery or the splenic artery. Following 35-40 sec delay after 80-90 ml contrast administration (by injector) the spiral CT scan was performed in the portal phase. The MRI is very sensitive to the detection of metastases, their surprising multiplicity can be detected by MRI even in case of negative CT and US examinations as well. MRI signal intensity is dependent on their water content. - T1-weighted signal intensity is usually lower - T2-weighted signal intensity is higher compared to the liver parenchyma. The image may be dotted with hemorrhages (according to their age) and calcifications (according to their extent). There are some tumors whose metastases bleed frequently (melanoma). Often, certain metastases can be recognized only after contrast administration.

14.1.4.2.2. Hepatocellular Carcinoma (HCC)

2500-3000 new HCC cases are recognised in the Hungarian population yearly. Its prevalence is more frequent in the Far Eastern population (China, Japan, Korea) and in the South European countries (Italy, Greece, Spain). HCC is the most frequent primary liver tumor originating from the hepatocytes. Chronic viral hepatitis, liver cirrhosis (alcohol or other toxic origin) and other carcinogenous materials (drugs, aflatoxin) can play a role. The blood supply of HCC is received mainly from the hepatic artery, explaining the US, CT and MR image features. Their US apperances include mostly an inhomogeneous, hyperechoic or hypoechoic lesion, which is arterially hypervascularised, and several arteriportal shunts may develop. The demonstration of shunt related portal vein flow disturbance by doppler US has a prominent importance. The adjudication of the cirrhosis related HCC by ultrasound is often a particularly difficult task. HCC appears mostly as low density on the native CT scan, with inhomogeneous structure and a surrounding with a slightly increased density bearing capsule can be also detected. The completion of the three-phase CT scan (arterial, venous, late) is especially important in case of a suspicion of HCC. The appearance of the inhomogeneous lesion in the arterial phase, including sometimes non contrast enhancing necrotic areas inside, bears with a diagnostic value. The capsule can be detected best in the venous phase. The primary hepatic cancers respect usually the liver borders. At the time of death, mainly regional lymph node metastasis is observed in almost half of the cases. Besides that, lung, bone and suprarenal metastasis can occur. MRI findings: - Lower signal intensity can be usually but not necessarily observed compared to the liver parenchyma on the T1-weighted images. The possible capsule appears as even lower ring-like signal intensity. - On T2-weighted images, the hepatocellular carcinoma has a high signal intensity according to the necroses, but in case of no necrosis the tumor can be isointense! Recent haemorrhages, hemosiderin, fat deposition influence the signal intensity characteristically. The differenciation of the foci and the nodular regenerative hyperplasia is very difficult. Concerning the HCC, the knowledge of history is very important for the decision and usually the oncoteams consider the performance of an imaging modality guided biopsy basically important for the further therapeutic decisions (because of the histological validation rather core biopsy should be performed! (Figure 26, 27, 28).
14. Imaging of abdominal parenchymal organs

Figure 26: HCC, verified with FNAB, US

Figure 27: HCC, TAE, angiography

Figure 28: HCC, native CT after TAE

14.1.4.2.3. Less frequent primary liver tumors:

- Rhabdomyosarcoma
- Liposarcoma
- Hepatoblastoma
- Fibrolamellar HCC
Other pathological liver lesions:

14.1.5. Inflammatory processes

There is no specific US sign in case of a hepatitis initially. In a serious case, already a completely inhomogeneous, hypoechoic liver structure can appear. The bacteria may pile up in the biliary ducts due to the bile stasis (either by tumorous or inflammatory choledochus compression) and cholangitis can develop, associated with an abscess development later (Figure 29).

![Figure 29: Abscess in the liver, US](image)

In order to prevent it – by either endoscopically or percutaneously – the primary goal is to ensure the bile flow again, obviously completed with broad-spectrum antibiotics. Liver abscess can develop either following the severe inflammation of the biliary ducts and the gallbladder or following a tumorous necrosis or by the spread of an external inflammation to the liver. By the help of the US, a cystic lesion can be seen with multiple internal echos containing gas bubble frequently as well. In order to determinate the further therapy, contrast enhanced CT examination can be needed, if the US imaging of the entire liver was not possible. An avascular intrahepatic lesion can be seen well on the CT with a contrast enhancing wall (sometimes multifocal as well) (Figure 30). An US or CT guided percutaneous drainage can provide a therapeutic result depending on the lesion's size and location (Figure 31).

![Figure 30: Abscess in the liver, native CT](image)
14. Imaging of abdominal parenchymal organs

14.1.6. Liver injuries

In case of blunt abdominal injuries, polytrauma and stab abdominal injuries, detection of the probable injury of the parenchymal (liver, spleen, pancreas, kidneys) and cavernous organs or the injury of the abdominal large vessels has a crucial importance. In numerous cases the emergency abdominal US performed in the shock room can orientate us about possible abdominal injuries already as „first line” in the traumatology care. If possible, the tiny parenchymal injuries can be detected very sensitively by contrast enhanced US.

In numerous traumatological centres (mostly in case of a polytraumatic patient) a quick whole body MDCT examination is performed in order to achieve a quick diagnosis, ensuring complex information in a short time: intracranial, chest, abdominal and extremital injuries can be identified.

More and more acentuated role is given to the contrast enhanced US examinations in several traumatological centres in the detection of a possible liver and spleen rupture. This technique is especially important in children in order to perform a scan with no ionizing radiation exposure as far as possible.

In case of an uncertain clinical case of a suspicious liver injury detected by US (suspicion of intraparenchymal or subcapsular hemorrhage) depending on the patient's clinical status, a control US several hours later and a contrast enhanced US examination may be helpful to achieve the more appropriate diagnosis. In a portion of the cases, avoiding the multiphase MDCT examination is unpossible of course.

14.2. Gallbladder

14.2.1. Normal anatomy, variations

The normal fullness gallbladder measures 6-8 mm in length, 3-4 cm in diameter, has a thin wall and about a pear shape.

According to the gallbladder's physiological function its role is to store the almost 1 liter bile periodically which is produced every day, hereby is the normal fullness, fluid-containing, superficially located object ideal for the US examination even in case of the moderately obese patients as well.

The arterial circulation of the gallbladder is provided by the cystic artery arising from the right hepatic artery in a normal anatomic situation. The rarely occuring variation of the arterial circulation has extraordinary importance in case of cholecystectomy and selective catheter interventions.
**Radiograph:**
Nowadays the oral cholecystography is no more performed in the radiological practice since the comprehensive spread of the US in the 80's years. Thanks to it, a dangerous examination method often accompanying with serious complications got into the museum of the imaging methods. The porcelain gallbladder with calcificated wall can be observed very rarely on the native abdominal plain film.

**US examination:**
In typical cases, if the gallbladder is located in the region anteriorly to the liver hilum and along the liver margin, fundus, body, neck and cystic duct should be equally circumspectly examined in various planes, possibly both in supine and left lateral positions. As anatomic variation, double gallbladder is a very rare anomaly. The gallbladder agenesis is extremely rare.

One of the main goal of the essential preparation prior to an abdominal US (six-hour-long starvation) is the ability of gallbladder imaging in its uncontracted, normally full status. If the gallbladder is contracted, it cannot be objectively adjudicated. In this case, neither the wall thickness nor the incidental findings (smaller stone, sludge) in the gallbladder lumen should be reported. Therefore, a focused gallbladder US control examination must be performed following 6 hours of starvation at a determinated date.

**14.2.2. Gallbladder wall lesions**

The contraction of the gallbladder (following a fatty meal or chocolate consumption) happens in several minutes in a normal physiological case. The normal gallbladder is 1-2 mm thick and has a wall without stratification (Figure 32).

Adenomyomatosis of the gallbladder: Small hyperechoic particulates can be composed by the solidifacted (dense) bile being deposited in the so-called Aschoff-Rokitansky sinuses in the gallbladder wall, behind them a typical „V”-shape artefact appears.

Cholesterol polyp: In some cases small, hyperechoic (usually 2-4 mm in diameter) lesions can be observed fixed to the thin gallbladder wall (Figure 33), which originate from the excessive accumulation of dense bile essentially, stone development from them is rare.
14. Imaging of abdominal parenchymal organs

Figure 33: Cholesterol polyps with a little stone in the gallbladder

Confusing them with the actual polyps are not recommended, which do have circulation as well (role of contrast enhanced US examination can be helpful!) and may accompany by a prominent oncologic importance, if they have a growing tendency during the 3 month US follow-up.

14.2.3. Gallstones

In the background of epigastric, gallbladder region pains cholelithiasis can turn out, but it can be often detected as incidental finding in asymptomatic cases. In the gallbladder lumen, a freely motionable lesion bearing with an acoustic shadow behind in a typical case (Figure 34), which can measure already a 3-4 cm in diameter in the time of its detection.

Figure 34: Gallstone with typical acoustic shadow

The in the gallbladder neck lodged stone which cannot move out from it can hinder the gallbladder’s motion and cholecystitis can develop later by the piled up bacteria in the stagnant gallbladder content. In an asymptomatic stage detected, smaller (4-8 mm) gallstones expose a potential danger, because they can stick into the main biliary duct by floating down from the gallbladder and besides the development of icterus cholangitis and pancreatitis can be resulted (biliary pancreatitis).
In certain cases it can be difficult to identify the gallbladder itself, because only a large hyperechoic lesion can be seen measuring many centimeters in diameter. In this case the fluent bile can be completely missing from the gallbladder.

### 14.2.4. Cholecystitis

**Acute cholecystitis**
The inflammation is caused by the gallstone-resulted drainage disturbance and the bile stasis in a typical case, which results a compression sensitive, a bit thicker gallbladder which has an edematous wall and it is fuller as the average, after short-time epigastric symptoms lasting for several hours. During the progression of the process, a typical multilayer, „onionleaf-like” wall thickening can develop, increased vascularisation can be detected in its wall by color doppler (Figure 35).

![Figure 35: Acute cholecystitis with thickened, stratified wall](image)

**Acute acalculous cholecystitis**
During a long-time intensive therapy care rarely or in case of immunodeficiency diseases this type of inflammation can develop, which has a very bad prognosis very often unfortunately.

**Chronic cholecystitis**
Following a passed off cholecystitis the gallbladder wall usually remains thicker (3-4 mm), referring to the postinflammatory status.

**Chronic calculous cholecystitis**
This definition is described as a status after gallstone-resulted inflammation(s). According to the literature malignant gallbladder neoplasm can also develop from the cholelithiasis known for many decades in only a small percentage of the cases.

**Gallstone ileus:**
From the inflammatory onto the duodenum or the small intestines „calcined” gallbladder the gallstone can get into the certain bowel lumen following a wall necrosis. Afterwards gallstone ileus can be developed by its migration.

### 14.2.5. Malignant gallbladder tumor

At its discovery the tumor is already inoperable in more than 50% of the cases. It is characterised by a very aggressive growing tendency, which can extend to the liver and the adjacent organs (duodenum, colon) as well. In case of a liver involving tumor, already the identification of the gallbladder can be difficult in many times. Naturally the staging provided by the fast multiphase CT examination (CT examination must be accompanied after the US as quickly as possible) is crucial in these cases in order to decide the operability.
14. Imaging of abdominal parenchymal organs

CT imaging: Due to the gallbladders location and structure, CT imaging turns into an important method only by a gallbladder of a position variation or with a pathologically irregular thickened wall, and a liver-involving gallbladder tumor. In the remarkable part of the cases US examination provides enough information. Concerning the gallstones’ judgement the US has also a primary role.

14.3. Biliary ducts

14.3.1. Normal anatomy, variations

Intrahepatic and extrahepatic biliary ducts
In the left and right lobes collecting biliary ducts form the right and the left hepatic ducts at first, then the main biliary duct (ductus choleductus) develops from their confluences.
In a normal case the intrahepatic biliary ducts cannot be imaged and the diameter of the main biliary duct cannot exceed the 7 mm.
Diverticulum can be also observed on the main biliary duct, which can result symptoms and biliary duct passage disturbance depending on its localisation.
In a case of a postcholecystectomy status the diameter of the main biliary duct can be also 8-10 mm, this is not a pathologic aberration itself.

The significance of biliary MRI:
Investigation of the extrahepatic biliary ducts is an old tradition in radiology, but the intrahepatic biliary ducts can be investigated by ultrasound only approximately. The invasive procedure of ERC (endoscopic retrograde cholangiography) is well known, however, it is slowly forced back to the right place where it fits: to the interventional radiology. Helical CT cholangiography is a more effective way of CT imaging instead of the previously applied cholangiography using iodinated contrast agents. The disadvantage is that the CT cholangiography can be performed only in case of good liver function: in case of icterus there is no excretion and therefore no biliary duct imaging can be performed. In addition, no pancreatic duct(s) can be imaged. However, because of the dependence on the hepatocyte function it is (would be) precisely very beneficial to image the functioning liver areas map-like. Unfortunately, the production of the contrast agent was discontinued (it was toxic, prudence was required).

MR cholangiopancreatography (MRCP) is only the liquid content of the bile inside the biliary ducts, its imaging is possible because of its no flow. However, the biliary duct is gracile – so in many cases the imaging of the normally dilated biliary ducts is doubtful, but even the slightly dilated intrahepatic (and extrahepatic) biliary ducts and the pancreatic duct(s) can be also exquisitely visualized. The fluid-filled gallbladder is also always visualized. The empty stomach and duodenum is helpful in technical point of view, because the extrapolation of especially the duodenum can be difficult from the imaging of the biliary duct by the rotation of the three-dimensional image. Extent ascites may thwart the examination. Less ascites behaves itself as a "curtain", and you can look behind it only by applying „tricks‖. Other fluid-filled cavities do not cause confusion, but the liquor content of the vertebral canal can be deceiving at first glance.
Based on the above mentioned facts, MRCP can be applied in case of biliary duct tumors (malignancy in the liver hilum, Klatskin tumor), intrahepatic or extrahepatic biliary duct strictures or dilatations, investigation of intrahepatic or extrahepatic outflow disorders of unclear origin by other imaging methods, localisation of pancreas head and papilla area
processes.
Above all, important to note and apply: MRCP, which is much less threatening to the patient, must be always the first choice before (in most cases pancreatic enzyme failure causing) ERCP (not a foregone intervention)!

14.3.2. Cholangitis

It does not accompany with a really specific US sign, but the biliary ducts’ wall can be a bit more hyperechoic on the inflammatory intrahepatic sections in case of a long-term clinical existence.

14.3.3. Choledocholithiasis

As mentioned above, the existing smaller stones can migrate down to the main biliary duct and choledocholithiasis can be developed if they stick in there (Figure 36).

The direct US imaging of the main biliary duct stone may need more experience, the proper rotation of the patient and the competent diversion of the duodenal bowel gas can help in the US imaging of the distal segment of the main biliary duct.
In order to solve the choledocholithiasis, endoscopically acute ERCP following by a stone extraction by dormia basket can be performed. If the stone obstructed high in the main biliary duct and it cannot be extracted endoscopically, a percutaneous intervention can be tried. It is important to note, that ERCP is an insecure procedure, very serious pancreatitis can develop as complication, so the indication of the certain procedure must be taken very circumspectly.

14.3.4. Malignant tumor of the biliary duct, cholangiocellular carcinoma (CCC)

Intrahepatic, extrahepatic (perihilar) and distal extrahepatic forms can be distinguished.
The perihilar form of the malignant tumor originating from the biliary ducts is called Klatskin tumor.
This type of malignant tumor is detected in the background of an icterus of unknown origin unfortunately even more frequently. In certain cases ERCP is useful in the cytologic sampling, but sometimes an imaging method guided biopsy is needed for the histological verification. According to the localisation, the following types are known (Bismuth-classification):
Type 1 – localised to the main biliary duct (cystic duct can be also affected),
14. Imaging of abdominal parenchymal organs

Type 2 – localised to the upper portion of the main biliary duct and the distal portion of the two hepatic ducts with itself,
Type 3.a – type 2 + localised to the right sided segmental branches,
Type 3.b – type 2 + localised to the left sided segmental branches,
Type 4 – forms 3.a + /b together, furthermore the distal portion of the main biliary duct can be also affected segmentally with itself.
In case of an inoperable tumor or a high hilar localisated Klatskin tumor (Figure 37), the bridging of the certain stenosis can be tryed by percutaneous intervention from the direction of both lobes (left and right sided double hepatic duct drainage and stent implant).

Figure 37: Klatskin tumor, PTC, punction from left biliary duct of the liver

Additional relevant details can be found in the nonvascular intervention chapter.

14.4. Pancreas

14.4.1. Normal anatomy, variations

The pancreas is a retroperitoneally located, endocrine and exocrine gland.
In the anatomical respect, head, body and tail regions can be distinguished.
Important evolutionary variations:
Pancreas divisum (absence of the fusion of the anterior and posterior pancreatic ducts). – This is a very important variation, since it exists in almost 25% of the patients suffering from recurrent, idiopathic pancreatitis.
Accessory pancreatic duct (Santorini).
Annular pancreas.
Agenesis.
Hypoplasia.
Ectopic pancreas.

Almost twenty-sort of enzyme is produced in the course of the exocrine gland function, which are drained by the pancreatic (Wirsungianus) duct and flow into the duodenum with the bile coming from the main biliary duct. Normally it measures 3 mm in diameter by young adults (measured at the body), whereas 5 mm in the elderly population.
The endocrine gland function consists of the so-called Langerhans islands, which product multifarious hormones and they play a very important role in the glucose metabolism by producing insulin.
Radiograph imaging:
The pancreas can be only observed on the traditional radiograph if multiple bigger
calcifications are located in the gland parenchyma (in case of chronic calcific pancreatitis) or a big space occupying lesion in the pancreas head (tumor or pseudocyst) shifts away the bowel gas-containing duodenal horseshoe. Arising from its location, it is not an ideal organ for an US examination. Its visualisation can be influenced by the gas content of the stomach and the bowels remarkably (Figure 38).

Figure 38: US of the pancreas, disturbing intestinal gas in the body-tail region

Its US examination needs a bigger experience and attention as the average, moreover an effective physical requisition as well (the epigastrically located, disturbing bowel gases can be eliminated only by a compression involving an adequate effort in many cases)!

Because of all these CT and MRI have a primary role as additional imaging methods in the pancreas imaging.

Due to the adaptation of multidetector CT scanners, the adjudication of the pancreas became increasingly more accurate. The sensitivity and specificity has been improved with the three-phase (arterial, venous, late venous) scans.

Favorably, the signal-free MR vessels create better orientation conditions compared to CT scan.

The posterior contour of the pancreas is provided by the splenic vein draining to the portal vein. Anterior to the pancreas, two vessels run in the small bay created by the uncinate process and the body: medially the superior mesenteric vein (in the longitudinal axis of the body), to the left of the superior mesenteric vein the superior mesenteric artery can be identified with smaller caliber. (The artery is always separated by a small fat rim from the parenchyma which is not present by the vein. It is good to know in case of the adjudication of the tumorous infiltration.)

The juvenile pancreas has a glandular solid structure. By aging, the organ becomes adipous because of the fat deposition among the lobules.

The variatious shape of the pancreas can be often identified: pancreas divisum (developmental variation) and the shape and size of uncinate process can be also very altering. It is important to notice it in order to distinguish from the space occupying processes.

The excretory ducts of the pancreatic gland (Wirsung duct, Santorini duct) are frequently variatious. If its size (1-3 mm) is appropriate, the excretory ducts can not be visualized, but 3D technique is able to image them in order to replace ERCP.

**MR imaging of pancreatic diseases:**

The most frequent aim of the examination is to clarify the resecability before surgery: the relationship of pancreatic carcinoma (usually previously clarified by imaging methods) and vascular structures. T1-weighted images are suitable for this purpose.

The T2-weighted images detect the intratumorous necrosis mainly, in addition the relationship
of the tumor and the fluid-filled duodenum (the fluid-filled duodenum has a high signal intensity).
If these examinations are performed by fast techniques, the duration of the examination can be significantly shortened.
MRI with T1-weighted and fat suppression sequences is very suitable for the differentiation of chronic pancreatitis and tumor: the gland parenchyma of the chronic pancreatitis has a low signal intensity, therefore it can be visualized according to its decreased water content. In case of a carcinoma, the normal parenchyma has a high signal intensity according to its water content. (In those cases, however, if chronic pancreatitis preceded the formation of the pancreas carcinoma, the pancreas parenchyma has, of course, a low signal intensity.)
MRI has an important role in the detection of endocrine carcinomas.
The conventional T1-weighted sequences with complementary fat suppression and T2 sequences with dynamic contrast agent administration allow the characterisation of the contrast dynamics of these usually hypervascularized tumors.
The signal intensity of the insulinomas are usually low on T1-weighted and fat suppression images, while the insulinomas have a high and also high contrast enhancing signal intensity on the T2 sequence.

14.4.2. Pancreatitis

14.4.2.1. Acute pancreatitis

Definition of acute pancreatitis:
Acute inflammatory process of the pancreas with the various affection of the peripancreatic tissues, and the far organs, systems.
- Based on the clinical situation and them morphologic criteria (Multidisciplinary International Symposium - Atlanta classification – 11-13 September 1992)
Etiology
- Toxic-metabolic (alcohol, hyperlipidemia, hypercalcemia)
Mechanic (choledocholithiasis, microlithiasis, periampullary obstruction, Oddi sphincter dysfunction, pancreas divisum….)
Vascular (polyarteritis nodosa, embolia of atherosclerotic origin, postoperative status after abdominal vascular and heart operation)
Infectious (viruses – Mumps, Coxackie, hepatitis B, varicella zooster, AIDS…)
Drug-related (Salicylate, sulfonamide, furosemide, tetracycline…..)

CT is the most important imaging method in case of pancreatitis.
Because of the exact diagnosis and the staging CT has a crucial importance.
CT classification of the pancreatitis according to Balthazar:
Stage A (0) - normal pancreas
Stage B (1) - focal or diffuse pancreas enlargement (Figure 39)
Stage C (2) - gland structure swelling with peripancreatic inflammatory signs
Stage D (3) - pancreatogeneous fluid content in one localisation (Figure 40)
Stage E (4) - two or more fluid content and/or gas content in the pancreas or in the adjacent area (Figure 41)
In case of an acute pancreatitis, the early flare (swelling) of the gland structure and fluid content formation in various extent can be observed, furthermore the determination of extent of the tissue necrosis is crucial.
In case of acute pancreatitis, additional US, CT, DSA examinations can be performed in order to determine the complications.
Interventional treatment options:
Percutaneous drainage of the pancreas fluid content (Figure 42)
Pancreas abscess drainage (US, CT guidance)
14. Imaging of abdominal parenchymal organs

Figure 42: Pseudocyst of the pancreas, after CT guided drainage

Principally the transcatheter embolisation is recommended for the treatment of the pseudoaneurysm developed by the vessel erosion caused by the disengaged pancreas excretion.

CT indications:

- In case of uncertain diagnosis, suspicion of early pancreatitis.
- In case of serious pancreatitis in order to adjudge the potential serious complications.

CT indications during the course and treatment of a known pancreatitis:

- By sudden, quick progression
- On the 7-10th day of a current pancreatitis
- For the accurate documentation of the result of a surgical or interventional procedure.
- Before the patient’s discharge in order to exclude the possible late complications (pseudocyst, pseudoaneurysm).

14.4.2.2. Chronic calcific pancreatitis:

Following the course and recovery of an acute pancreatitis minor-maior atrophy can be observed in the gland structure with calcifications of various extent, moreover quite rough calcifications can be seen sometimes along the pancreas gland structure. (Figure 43)

Figure 43: Chronic pancreatitis, rough calcifications on the head, contrast enhanced CT
Because of the calcification-related inhomogeneous structure and compression on the one hand Wirsung dilation, on the other hand tumor-suspicious areas can be observed. In case of clinical tumor suspicion and increased tumor marker PET-CT imaging can be necessary for the exact determination.

14.4.3. Pancreatic tumors

14.4.3.1. Pancreatic adenocarcinoma

95% of the pancreas tumors and has a very bad outcome (average one-year survival around 8%). According to its localisation, around 65% of them are localised in the pancreas head. The most informative imaging method is the three-phase MDCT, however the very small, less then 1 cm large tumors can be often observed better by US. The endoscopic US examinations are considered to be the most sensitive method in the investigation of the pancreas head tumors, however they are performed only in few centres. The pancreas head tumors often result a Wirsung and main biliary duct dilatation, however it is caused only by a larger size in case of the tumors arising from the uncinate process. The determination of the tumor’s extension to the surrounding areas (stomach, small intestine, coeliac trunk, superior mesenteric artery - figure 44) is basically important in the judgement of the operability.

Figure 44: Adenocarcinoma in the body of the pancreas, contrast enhanced CT

Because of the more difficult US approach, CT-guided fine needle biopsy can be needed in certain cases for the exact judgement of the tumor suspicious pancreas lesions.

14.4.3.2. Cystic pancreatic tumors

According to the literature these tumors mean only the 15% of all pancreas tumors, however the knowledge of cystic pancreatic tumors have a very important differentialdiagnostic role.

14.4.3.2.1. Mucinous cystic tumor – Potentially malignant

The mucinous cystadenomas are the most frequent cystic pancreatic neoplasms, accounting for up to 50% of all cystic pancreatic tumors. 80% of these cystic pancreatic neoplasms occurs in women and in young age group (average age is 54 years). Without treatment these neoplasms malignize in most of the cases, therefore, their treatment bottoms on surgical resection, unambiguously.
14. Imaging of abdominal parenchymal organs

14.4.3.2.2. Serous microcystic adenoma – Benign

The second most frequent cystic pancreatic neoplasm which is characterized by honeymoon-like tiny cysts on CT scan. Periodic follow-up is recommended, even if considered as a clinically benign tumor.

14.4.3.2.3. Intraductal papillary mucinous neoplasm (IPMT, IPMN)

It is the concluding definition of the mucin producing proliferation of the epithelium. IPMN provokes the progressive dilatation of the Wirsung duct and the cystic dilation of the side branches. It is symptomatic in up to 1/3 of the cases. Most of them is benign. However, the sign of malignancy is the large, intraductally developing wall nodule. Endoscopic US and MRCP has a basic importance in its imaging. According to the literature, temporary control of the branching ductal-type IPMT is recommended because of the basically benign behavior of the tumor.

14.4.3.3. Solid and papillary epithelial tumor

It is a rare, very low malignant tumor, usually among females between 20-30 years of age. At the time of their detection it measures usually already at least 7-8 cm in diameter (Figure 45).

![Figure 45: Solid and papillary epithelial pancreas tumor, contrast enhanced CT](image.png)

US, CT and MR scans indicate a well-defined, moderately vascularised tumor. If the preoperative adjudication is necessary, US guided biopsy can be also performed relatively easily depending on its size. Following its surgical resection, no recurrence has been ever published in the literature.

14.4.3.4. Endocrin type pancreas tumors

Insulinoma: this benign lesion can be certified clearly in the background of a part of the hypoglicemias clinically, which can be detected due to its remarkable hypervascularity by color doppler, CT angiography even if it is 5-6 mm large, however sometimes it occurs that only superselective DSA examination can image it in some cases. Other forms of island cell tumors are the APUDomas (amino precursor uptake and decarboxylation system). 85 % of them is functional, 15 % of them is nonfunctional type. Their clinical adjudgments happen according to their functionalities, undependently of the effective cytologic appearence.
The endoscopic US is the most effective modality here as well (sensitivity is around 80%), according to the localisation naturally (lesions in the tail region are difficultly adjudged). By the help of the intraoperative US 3-4 mm large tumors can be also filtered out.

14.4.4. Pancreatic trauma

The spectrum of the injuries range between the obscure abdominal injury caused pancreatic trauma and those injuries which can penetrate in the gland parenchyma in various extent. Principally CT imaging is the most accurate method in the determination of the extent of the certain pancreas injury.

Degrees of gravity:

- Small hematoma
- Peripancreatic fluid content of various extent
- Total break of the gland parenchyma with pancreas fistula formation
- Pseudoaneurysm formation
- Pseudocyst formation

14.5. Spleen

14.5.1. Anatomy

An intraperitoneal organ located under the left diaphragm contour. Its diameter measured in the spleen hilum is normal until 45 mm, in case of larger diameter minor, moderate or extensive splenomegaly can be noted (Figure 46).

![Figure 46: Splenomegaly, contrast enhanced CT](image)

Variations

Smaller fissures, incongruences near the diaphragmal surface can result diagnostic difficulties in certain appearance forms (eg., by the adjudication of an traumatic spleen rupture US can provide a delusive image in this case, contrast enhanced CT scan can be necessary for the exact determination).

Radiograph:
The spleen turns to be visualized on the radiograph only in cases of possible calcified lesions inside the splenic parenchyma (echinococcus cyst, banal calcifications) and notable calcification of the splenic artery. Above all, the increased splenic shadow can be illustrated in the left hypochondrium in case of remarkable splenomegaly, sometimes displacing the kidney caudally.
14. Imaging of abdominal parenchymal organs

US examination:
The normal splenic parenchyma has the same echogeneity as the liver parenchyma as mildly hyperechoic. Its vascularisation is expressly increased compared to the liver. Accessory spleen tissue can be often visualized as round lesion of 10-15 mm in diameter adjacent to the splenic hilum and the inferior splenic pole. Its increased importance is related to the examination of patients with positive oncological history, since the accessory spleen must be differentiated from lymphadenopathy. In case of portal hypertension, dilated collateral veins can be observed between the splenic hilum and the left kidney (splenorenal shunt).

CT imaging:
By the performance of native and contrast-enhanced CT, the determination of possible circumscribed splenic parenchymal lesions is relevant besides those lesions described above by the radiograph and US examinations (calcifications, accessory spleen). The adjudication of splenic dimensions can be more accurate by CT compared to US. An important artefact concerning the spleen after contrast administration is the so-called „tiger‖ spleen, which is not a real pathologic finding but a very inhomogeneous bizarre contrast uptaking splenic parenchyma in the arterial phase.

MR imaging
Intrasplenic various lesions (infarct, metastasis) usually do not have a high contrast difference with the splenic parenchyma itself. Dynamic sequences taken following contrast bolus administration do not create enough contrast between the lesions and the parenchyma, because the splenic parenchyma shows an inhomogeneous enhancement following the dynamic examination of the contrast bolus in the early arterial phase normally as well. By the help of the in RES cumulating superparamagnetic contrast agents the RES-free regions can be detected within the spleen. (It can refer for example to foreign tissue deposit - tumor metastasis.)

14.5.2. Accessory spleen
A very frequent incidental finding during the US and CT imaging. Its exact adjudgement and its mentioning in the report can be very important during the oncologic staging and control examination.

Splenosis is a special variation, on its course, minor-maior (even several cm large) splenic islands develop because of a past splenic injury in the abdomen around the spleen, moreover in the chest in the lung parenchyma and in the pleura in case of an injury breaking through the diaphragm.

14.5.3. Splenic infarction
Etiologic factors include the dispersion of the endocarditis associated thrombus originating from the left side of the heart. Referring to its morphological appearence, an approximately triangle shaped, a towards the hilum apex-bearing, hypoechoic area is detected, which retracts the splenic surface a bit. The absencse of certain area’s circulation can be imaged by color doppler appropriately. On the course of its recovery, the area becomes inhomogeneous and callused, but an abscess can also develop inside the necrotic area in case of a larger infarction.
14.5.4. Inflammatory intrasplenic lesions

Inhomogeneous areas can be observed with mixed echostructure and irregular contours, which can progress to the development of a circumscribed, avascular, cystic area (abscess) henceforward. In case of a circumscribed abscess percutaneous US or CT-guided drainage can be performed.

14.5.5. Cysts

The spleen cysts occur less frequently than the liver cysts, their morphological appearance is similar to that of the liver cysts (homogeneous, cystic content, sharp contour, thin wall, sometimes some thin septa). Most of them is detected only accidentally. It has a therapeutic consequence if its size increases resulting symptoms for the patient by the compression of the surrounding tissues (Figure 47, 48).

![Figure 47: Spleen cyst, US](image)

![Figure 48: Spleen cyst, contrast enhanced CT](image)

A májcsták alkoholos sclerotisatiojához hasonlóan ezek a panaszt okozó lépcysták is kezelhetők (49. ábra), de nagyobb körültekintést igényelnek, mert a jelentősen vascularisaltabb lépparenchyma miatt a bevérzés esélye jóval nagyobb.
14. Imaging of abdominal parenchymal organs

Similarly to the alcoholic sclerotisation of the liver cysts, these symptomatic splenic cysts can be also treated (Figure 49), but more circumspection is needed, since the chance of hemorrhage is higher because of the notably vascularised splenic parenchyma.

14.5.6. Splenic cancers

14.5.6.1. Benign splenic tumors

As accidental finding, hemangiomas (well defined, hyperechoic, solide lesions) can be detected in the spleen during the abdominal US examination.

14.5.6.1. Malignant tumors of the spleen

Related to the spleen, lymphoma, angiosarcoma, fibrosarcoma, metastases of various origin are the most frequent malignant tumors. US imaging can be enough in certain cases, however, CT scan must be also performed in case of an existent metastasis in order to search for a primary tumor. Furthermore, US guided biopsy can be also necessary.

14.5.7. Splenic injuries

(splenic rupture, intraparenchymal hematoma, biphasic splenic rupture) Following an abdominal trauma especially direct injury under the left diaphragm, an especial attention must be payed to the spleen by imaging methods. Because of the increased circulation of the splenic parenchyma a life-threatening, very serious bleeding can develop from an undetected subcapsular splenic injury. An immediate multiphase CT scan provides enough information on the exact adjudgment of the spleen. In case of clinical worsening, the CT scan provides the quickest, most informative control examination. Following a traumatic splenic rupture, a pricked or shot splenic injury also penetrating through the diaphragm, minor-maior splenic islands adhere in the abdominal cavity or in the chest, which develops as a form of splenosis in case of growth. The appropriate knowledge of traumatic history can avoid several expensive imaging modalities even the US or CT guided biopsy in these patients!

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15. Emergency Radiology

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15.1. Aim

The aim of this chapter is to introduce imaging modalities used in clinical emergency. Well-defined diagnostic strategies are of primordial importance in order to ensure fast and optimal care of the acutely ill patients. In this chapter we discuss abnormalities grouped by symptoms and regions, similarly to real emergency situations, when the radiologist has only these pieces of information.

Definition of medical emergency

A medical emergency is an injury or illness that is acute and poses an immediate risk to a person's life or long term health. Emergency conditions can be classified into the following two major groups: trauma and non-trauma cases.

15.2. Emergencies in trauma

Traumatic injuries can be further classified into the following two major groups: less severe and life-threatening polytrauma injuries. After small traumas the patient is conscious, can talk and respond to questions adequately. In these cases targeted imaging of the injured region is sufficient, for example in fracture of the upper limb, two-view radiography is usually diagnostic. However, in polytrauma patients - especially if the patient is unconscious -, the choice of modality might be more ambiguous.

Treatment of trauma victims consists different levels, in which the acute level means the first hour. This is followed by the primary level, when life-threatening injuries are identified and treated. Secondary level means the treatment of non-life-threatening injuries, while tertiary level is the time for rehabilitation. Acute level has different phases, which are well-known in oxiology. In the first minute, patient’s general condition is evaluated and resuscitation is begun. In the first five minutes vital signs have to be normalized, and in the following hour head-to-toe evaluation of the trauma patient has to be executed for setting all diagnoses and to start adequate therapy. The question arises as to what role radiology has during this process.

In the first minutes – if resuscitation is not needed -, chest film and ultrasonography are useful tools. Chest film provides basic information about the cardio-pulmonary status, while ultrasonography can detect pleural, pericardial and abdominal fluid, and is able to visualize ruptured parenchamal organs. In polytrauma patients – who are unconscious and cannot respond to questions -, the first-line modality has to give answers to all clinical questions very fast. Therefore, in such patients CT plays an important role. Recent multislice spiral technique (MDCT/MSCT) is able to scan the whole body in some minutes. (We have to mention that evaluation of these studies takes more time than that.) Thus, nowadays CT equipment is part of the modern trauma suites.
Many pathologies can be diagnosed and excluded by CT examination, however, it is important to remember of the high ionizing radiation it works with. MRI - the other tomographic modality - is used only in special emergency situations. Before an MRI examination all magnetic items have to be removed from the patient, which otherwise can be rapidly drawn into the magnet of the scanner – known as the missile effect. An important rule is to only bring MR-compatible equipment into the MRI suite. However, the trauma patient might have metallic implants in the body unknown by emergency staff, which contraindicate the study.

15.2.1. Conventional traumatology

To discuss conventional traumatology imaging findings in detail is far beyond of scope of this paper. We mention here only some general rules:

- In less severe cases targeted imaging of the injured region is mostly diagnostic.
• In soft tissue injury (e.g. muscle and tendon rupture) the first-line modality is ultrasonography. If US cannot visualize the given region, MRI is the modality of choice, e.g. in anterior cruciate ligament tear.

• In skull trauma two-view radiographic film is no longer worthwhile. Intracranial injury can be diagnosed only by CT or MRI. In complex fractures, the localization of the bone fragments are necessary for surgery planning, and for this a CT study with 3D reconstructions is needed.

**Choice of modality in conventional traumatology**

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<tbody>
<tr>
<td>Bone fracture (at least two-view)</td>
<td>Soft tissue</td>
<td>Articulation</td>
<td>Bone fragments, fractures</td>
<td>Soft tissue</td>
</tr>
<tr>
<td>Articulation</td>
<td>Vessels</td>
<td>+contrast agent (angiography)</td>
<td>Tendon</td>
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</table>

• In spinal trauma CT is useful for localization of bone fragments, while MRI can visualize soft tissue structures within the spinal canal.

3. Back pain and decreased anal sphincter tone after motor accident. Left panel: Acute fracture of the 12th thoracic vertebra on CT. Right panel: Edema as a sign of acute fracture in the 12th thoracic vertebra on sagittal T2WI.

**Choice of modality in spinal trauma**

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<th>RTG</th>
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<tbody>
<tr>
<td>Bone fracture (at least two-view)</td>
<td>Soft tissue shadow</td>
<td>no</td>
<td>Bone fragments, fractures</td>
<td>assessment of</td>
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<tr>
<td>soft tissue shadow</td>
<td>no</td>
<td>3D reconstructions</td>
<td>structures in the</td>
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<tr>
<td>BUT: spinal cord injury might</td>
<td>indication</td>
<td>3D reconstructions</td>
<td>spinal cord</td>
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<td>present with normal radiography</td>
<td>no</td>
<td>structures in the</td>
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<td>BUT: spinal cord injury might</td>
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<td>present with normal radiography</td>
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<td>BUT: spinal cord injury might</td>
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<td>3D reconstructions</td>
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<tr>
<td>present with normal radiography</td>
<td>no</td>
<td>structures in the</td>
<td>neighbourhood of the spine</td>
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</table>
15. Emergency Radiology

15.2.2. In polytrauma

Patients it is crucial to realize and diagnose internal injuries, which are most commonly rupture of vessels and contusion of parenchymal or hollow organs. We introduce the most frequent injury types by regions, but it is important to remember that usually a polytrauma patient has more than one injured organ.

15.2.2.1. In skull trauma

The key question whether the patient has intracranial hematoma, which causes mass effect and later leads to vasoconstriction. In the presence of open skull fracture signed by liquorrhea severe infection and herniation might occur. To exclude intracranial hemorrhage CT is the modality of choice.

All three types of intracranial hematoma can occur as a result of head trauma:

- Rupture of the meningeal arteries may give rise to an epidural hematoma. At the site of the hematoma skull fracture can be observed.

4. Middle-aged man some days after direct head trauma. On noncontrast CT a lens-shaped, slightly inhomogenous epidural hematoma can be seen, that causes compression of the right lateral ventricle (left panel). In bone window skull fracture without dislocation can be found at the site of the hematoma (right panel).

- Subdural bleeding is caused by injured bridging veins (elongation, tears) ie. when a sudden deceleration occurs. This type of injury generally is not associated with a fracture.
5. A middle aged chronic alcoholic male. On unenhanced CT a typical crescent shape subdural hemorrhage is seen on both sides. Because of its etiology it extends across suture lines.

- Subarachnoid hemorrhage develops after vascular injury or aneurysm rupture.

6. Middle aged female fell of a ladder. On the unenhanced CT scan the basal cisterns are filled corresponding to a subarachnoid hemorrhage.

- Contusion hemorrhage occurs upon sudden deceleration (ie. car accident - collision) when the brain parenchyma due to its inertness keeps moving and hits the cranial bone. Frequently, contusion develops on the opposite side as well, since on an abrupt stop the brain collides with the bone than bounces off and hits the opposite wall of the skull. (coup - contre-coup effect)

7. Elderly female was suffered a direct hit in the parietal region. Coronal reconstruction of a unenhanced CT scan: At the site of the impact on the right side parietally a typical lens shaped epidural hematome is formed. On the opposite side in the temporal lobe at the contrecoup contusion site parenchymal bleeding is seen
- Fractures of the skull base deserve special attention. The classification is based on their close proximity to the intracranial fossae. The fracture can expose the dura, and if the subarachonid space brakes open cerebrospinal fluid can appear outside of the skull. In case of an anterior fossa injury cerebrospinal fluid leaks through the nasal cavity, in middle-posterior fossa fractures it sips through the external auditory canal. When a fracture is suspected special attention should be given to the evaluation of air containing cavities (ie. nasal sinuses, tympanic cavity) on the base of skull.

- Among base of the skull fractures temporal bone, especially pyramidal fracture deserves specific mentioning. The reason for this the potential injury of the many important structures (organs of hearing, and balancing, the facial canal and segments of the internal jugular vein and carotid artery should be specifically mentioned) located in this bone. Due to the primarily bony structure CT is the mandatory method of choice (HRCT).

15.2.2.2. Traumas of the facial bones

They are emergencies as in part of the cases they, although, are not life threatening, can alter quality of life. Preservation of organs of vision, smell and taste sensation as well as the integrity of facial features and mimics have an importance beyond question. The bony environment and reconstructive surgery techniques are necessitating that in this region MDCT is indicated. In the work up post-processing of the primary images can be relevant ie. 3D reconstructions are prepared for surgical planning.

- For routine diagnosis of nasal bone fractures a radiogram is taken only from a lateral projection (PA radiograms have no value due to superimposed shadows of the cranial bones).

8. A young woman was assaulted. She had nose bleeds and a laceration at root of the nose.
Fractures of the facial bones are classified (Le Fort I-III. types) into separate groups based on whether only the alveolar process (dentoalveolar) is interrupted, a pyramid shaped fracture of the maxillary bone below the inferior orbital rim is seen, or the entire viscerocranium is separated from the skull base.

The blunt hit of the orbit and the thin bony wall especially causes burst in the direction of the maxillary sinus it is called blow-out fracture. During this event part of the orbital contents protrudes into the sinus, risking entrapment between the bone layers. It can lead to altered vision. CT is the method of choice to diagnose fractures. (In case of a trauma we could not be certain that there is no ferromagnetic metallic object in the eye socket, that can act as a projectile during the MRI exam). Because of small, non-dislocating fractures x-ray of the orbit is not sufficient. The patient’s age and the radiation protection of the lens should be also considered.

9. Young man in his home worked with a polisher in protection glasses. On the unenhanced CT scan in the medial portion of the right bulbus a metatllic density object can be seen. The strong metallic artifact obstructs the image of the posterior bulbus.

Among the paranasal sinuses burst fracture of the maxillary sinus happens most frequently. A direct blow from the front or from the side hitting thezygomatic bone can lead to a tripod fracture. In this case the zygomatic bone protrudes into the maxillary sinus, and usually the zygomatic arch is also fractured, due to the instability. Typical finding that if the patient blows his nose an orbital and periorbital subcutaneous emphysema develops. It is well seen on the CT images and can be felt as a crepitation on physical exam.

**Choice of modality in skull trauma**

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<th>RTG</th>
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<tbody>
<tr>
<td>Bones – fractures</td>
<td></td>
<td>Unenhanced scan for exclusion of bleeding</td>
<td>Bony structures fractures exact localization</td>
<td>No indication</td>
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<tr>
<td>Soft tissue injury</td>
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<td>No indication + contrast</td>
<td></td>
<td>No indication</td>
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<td>Air shadow</td>
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<td>Two-view</td>
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</table>
15. Emergency Radiology

15.2.2.3. In chest trauma

We discuss two conditions

- Pneumothorax or mediastinal free air means that there is free air in either in the pleural cavity or in the mediastinum. This condition is usually apparent on chest x-ray (In injuries there is also blood in the pleural cavity)

![Pneumothorax on plain film and a skin fold](image)

- Aortic rupture occurs after rapid deceleration it is usually located at the transition of the aortic arch and the descending aorta, as the aortic arch more mobile than the descending aorta, it can be diagnosed with CT angiography.

Choice of modality in chest trauma

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<th>RTG</th>
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<th>CT</th>
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<tbody>
<tr>
<td>Cardiopulmonary survey</td>
<td>Pleural fluid</td>
<td>Unenhanced scan pleural and pericardial fluid, contusion, fracture, radiopaque foreign body and their localization</td>
<td>No indication</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>Mediastinal pathology</td>
<td></td>
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<tr>
<td>Pleural fluid</td>
<td>Diaphragmatic rupture</td>
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<tr>
<td>Contusion</td>
<td>Radiopaque foreign body</td>
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<tr>
<td>Bony structures</td>
<td>Pericardial fluid</td>
<td>IV contrast (angio)</td>
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15.2.2.4. Abdominal and pelvic traumas

- Rupture and contusion of the parenchymal organs. The affected organ is usually already detected on UH however, only CT can give definitive diagnosis, ie when the organs are covered by bowel gases. With UH the liver the spleen the kidneys can be well examined, although the pancreas frequently could not be visualized, as it is covered by meteorism
• Similar to the limbs, neck or chest after a heavy impact abdominal vascular injuries could also develop. They could be detected by UH however CT provides a more reliable diagnosis.

• A knife falling from a kitchen table stuck into the right thigh of an 18 year old young man. Increased femoral circumference and pulsating mass were seen. In the upper image with femoral Duplex sonography pseudoaneurism of the femoral artery is detected

In the middle with a CT angiography the pseudoaneurysm shows contrast enhancement. In the lower image 3D reconstruction of the CTA

11. A knife falling from a kitchen table stuck into the right thigh of an 18 year old young man. Increased femoral circumference and pulsating mass are seen. In the upper image with femoral Duplex sonography pseudoaneurism of the femoral artery is detected. In the middle with a CT angiography the pseudoaneurysm shows contrast enhancement. In the lower image 3D reconstruction of the CTA.

15.2.2.5. Foreign bodies

Foreign bodies could enter the human body in every possible way. The best way to detect them if we are familiar with the application fields of the imaging modalities. With plain radiography radiopaque foreign objects could be identified. Let’s not forget that images always should be taken at least from two directions. Plain radiographs contain summation images of one projection in order to be able to localize the object orthogonal projections are necessary, fluoroscopy and CT can also be helpful in undetermined cases.
15. Emergency Radiology

12 A young dancer was partying in the dressing room with his friends. He suddenly swallowed down an object which on the abdominal radiogram proved to be a cupboard key.

Non radiopaque foreign bodies are more difficult to detect, superficially located objects (ie. impacted sutures) could be identified by UH, deeper located object can be looked up with MRI.

### Choice of modality in abdominal traumas

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<th>RTG</th>
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<tbody>
<tr>
<td>Free air</td>
<td>Abdominal fluid collections</td>
<td>Unenhanced scan free air, fluid collections, rupture, bones, exact location of radiopaque foreign bodies</td>
<td>No indication</td>
<td></td>
</tr>
<tr>
<td>Irregular soft tissue shadow</td>
<td>Rupture of parenchymal organs</td>
<td>CE angiography ruptures (detailed view) injuies of the urinary collecting system</td>
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<tr>
<td>Radiopaque foreign body</td>
<td>Vascular injuies</td>
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<td>Bones</td>
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<tr>
<td>Contrast studies</td>
<td>Free air?</td>
<td></td>
<td>Bony structures farctures detailed view</td>
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15.3. Non trauma emergencies

In this chapter we discuss cases based on the presenting symptoms, thus in emergencies the radiologist only has a limited time frame to come up with the diagnosis. The conscious or cooperating patient generally complains of pain thus differential diagnosis is based on character and localization of the pain, patient history and physical examination. Discussing the findings with other clinicians involved in patient care is especially important. In abdominal emergencies there is no indication of an immediate abdominal CT scan. The examination has to be planned and performed differently in pyelon rupture than in acute pancreatitis. Thus it is imperative to provide the radiologist with the pontential differential diagnoses.
### 15.3.1. Headache

- Selection of adequate imaging modality should be based on whether an intracranial or extracranial localization is suspected. Intracranial diseases are discussed in the neurology chapter. In emergency cases CT (both unenhanced and contrast enhanced) is the primary imaging modality, occasionally MRI is also used to evaluate lesions of the brain.

- In the stroke focal neurological signs might be helpful to establish a diagnosis while headache is less frequently seen. The diagnostic work-up of ischemic stroke is described in more detail in the neurology chapter. Headache, sudden non ceasing pain may indicate hemorrhagic stroke (ie subarachnoideal bleeding, SAH). An unenhanced CT can be diagnostic, it is widely available and fast, even compared to the most advanced MRI sequences. In SAH to guide the therapy site of bleeding has to be identified therefore an MR or CT angiography is usually included in the work-up protocol.

- Sinus thrombosis can occur in any of the intracranial sinuses. However, only cavernous sinus thrombosis constitutes a medical emergency. Facial, orbital, intracranial infections may be associated with sinus thrombosis. If available MRI is the method of choice to diagnose a suspected sinus thrombosis, or similar to other vascular diseases a contrast enhanced CT should be performed (MR and CT venography). Otogenic processes (ie mastoiditis) are frequently complicated with thrombosis of the sigmoid sinus.

13. Old woman with headache and altered mental status. Unenhanced and contrast enhanced CT scans show a hypodens lesion with gyral hyperdensity. The location does not correspond to any arterial territories. On MRI it proved to be a bleeding. Lack of enhancement in the right transverse sinus indicates thrombosis.
• Intracranial infections include meningitis, encephalitis and brain abscess. MRI is superior to CT in diagnosing intracranial infections. If clinical picture is indicative of an infectious lesion CT, although it can exclude an acute bleeding, often can be false negative.

• Hydrocephalus is diagnosed by the radiologist, the site of the obstruction and signs of progression should also be reported. Unenhanced CT is the basic imaging modality in hydrocephalus, nevertheless MRI provides more detailed information on CNS lesions.

• Sinusitis can affect all paranasal sinuses. Detailed description of the diagnostic steps is included in the head and neck chapter. In acute sinusitis the clinical picture is diagnostic thus no immediate imaging is needed. (Usually it associated with lower risk than other emergency conditions). Radiology has a role in differential diagnosis. Sinus view is still widely used in routine clinical practice. It is used to assess air content or presence of exudate in the frontal and maxillary sinuses. Fort he evaluation of the sphenoïd sinus and the ethimoid cells CT or CBCT is recommended. If a soft tissue lesion is suspected MRI should be performed.

• Headache can caused by otological diseases as well, such as acut or chronic middle ear infection or inflammation of the mastoid cells. Imaging is necessary in recurrent or in acute fulminant diseases. Conventional x-ray studies (Schuller, Stenvers, Mayer view) are obsolete. Bony sturctures and air content should be evaluated with CT (high-resolution HRCT). MRI is performed in case of intracranial propagation and to detect complications.

• In acute neck pain, jaw-lock, difficutly with breathing can be caused by a complicated dental or pharyngeal infection. The role of imaging to detect the cause of dyspnoe, and potential mediastinal or spinal spread of the inflammation. UH of the neck is flexible and fast but only can penetrate superficial tissues, and has to be used in combination with other modalities. Its primarily used to detect fluid collections, solid nodules, or to guide image guided interventions such as aspiration or abscess drainage. In the infrahyoid region CT and MRI can be used with similar efficiency as both have certain disadvantages. CT is faster, and less sensitive for motion and metallic artefacts. (Meanwhile, in the supracyoid region MRI provides better soft tissue contrast.)

### Choice of modality in headache

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<th>RTG</th>
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<tbody>
<tr>
<td>Bones</td>
<td></td>
<td>Unenhanced CT to exclude intracranial bleeding, herniations +CE</td>
<td>Stroke Infections Tumors</td>
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<tr>
<td>Soft tissue shadows</td>
<td></td>
<td>Detailed view of bone structures, fracture lines</td>
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<tr>
<td>Air shadows</td>
<td>No indication</td>
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<tr>
<td>Air-fluid levels</td>
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<td>Two-view</td>
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15.3.2. Chest pain

• Pneumothorax usually occurs following thoracic trauma, but it can also happen spontaneously. The same also applies for the appearance of mediastinal air. The most severe form of ptx is tension- pneumothorax that inflates the pleural cavity with each breath, as the air remains trapped due to the valve mechanism of the injury. Conventional chest radiography is sufficient for the diagnosis.
- Hydrothorax occurs as a consequence of certain pathologic states as the pleural cavity fills with fluids and causes compression of the lung and ventilation deficit. At most cases it can already be revealed with chest radiography. Sonographic examination can also be diagnostic, moreover it is able to give further information about the fluid’s characteristics and detect septations. The latter is valuable information for the clinician if drainage is considered.
- ARDS: adult/ (acute) respiratory distress syndrome is a complication of the severely ill, usually ICU patients. It results in the severe loss of lung capacity. Diffuse alveolar injury leads to fluid leakage into the alveolar spaces that first appear as distinct alveolar consolidations. Later, they evolve to confluent patches of opacity (snow storm appearance).

14. Typical appearance of ARDS on chest X-ray: massive, bilateral consolidations with aerobronchograms.

- Pneumonia can also be detected with radiography. However, one must consider that on unidirectional chest radiographs, lung areas behind the heart and the diaphragm are obscured and infiltrates can remain hidden. To overcome this, a lateral radiograph should also be taken. However, as a first step clinicians should indicate the side on which the infiltrate is suspected, since this affects the radiologist’s decision making about which side of the chest should be set closer to the detector for better visualization and diagnosis.
- Pulmonary embolisation should be investigated with pulmonary CT angiography examination. Conventional chest radiography is negative in the majority of the acute cases. Indirect signs, such as pleural effusion, ipsilateral elevated diaphragm, atelectases or infarct pneumonia only appear after a longer period of time. As opposed to this, CTA provides a swift and precise diagnosis.
15. Elderly female with dyspnea. ECG shows abnormalities suggestive of pulmonary embolisation. CTA with bolus-tracking technique reveals a „saddle embolus” causing massive filling defect within the pulmonary trunk.

- Aorta aneurysm rupture – aorta dissection

If the patient is stable, immediate CT angiography is the diagnostic choice. In case of suspected dissection CTA should be performed with ECG gating.

- Esophageal rupture/perforation

In perforation, the esophageal content leaks through the perforation opening into the mediastinum. The consequent inflammation can rapidly result in a life-threatening state. Mediastinal free air is an indirect sign, which is even detectable on chest radiographs if a larger quantity of air is present. Swallow examination can help to reveal the perforation opening in some cases as the contrast material leaks from the lumen. However, it should be noted, that swallow examination in these cases should only be carried out with absorbable contrast materials. The use of non-absorbent Barium contrast is contraindicated since it causes sterile inflammation with necrosis.

**Utility guide of the imaging modalities – chest pain**

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<th>RTG</th>
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<tr>
<td>Cardiopulmonary state</td>
<td>Pleural, pericardial effusion</td>
<td>The same as X-ray, but with precise localization +iv. contrast (angiography) Bone structure, fracture – precise imaging</td>
<td>No emergency indication</td>
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<td>PTX</td>
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<td>Free fluid</td>
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<td>Pneumomediastinum</td>
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<td>Contrast examinations</td>
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15.3.3. Abdominal and pelvic pain

In practice, one can divide the abdominal pain-syndromes according to the affected region a) localized (four quadrants), b) diffuse (whole abdomen) c) periumbilical and d) epigastric area. Therefore, in abdominal pain-syndromes organs/organ group pathologies are investigated.
The clinician – based on a preliminary diagnosis and with regard to the capabilities and limitations of the imaging examination – should be able to choose the most optimal imaging modality. Considering that almost all the abdominal organs share soft tissue characteristics, basically all the imaging methods could be included, least likely MRI examination though. Depending upon the state and compliance of the patient plain abdominal radiography, per os contrast examinations, ultrasonography, non-contrast and contrast enhanced or even dynamic CT examinations (angiography, parenchymal and excretory phase) can be used in the diagnostic assessment. In the following a few general considerations and the specific, quadrant aimed imaging features will be discussed of the most common pathologic processes. At first, one shall consider a few general scenarios that can determine the process of diagnostic imaging.

16. Abdominal regions (right/left upper quadrant, right/left lower quadrant, epigastric, periumbilical region).

- Abdominal distention, the presence of free abdominal fluid or air can be indicative of the generalization of a previously existing problem. Plain abdominal radiography – if possible – should be carried out in an erect position. For those who are unable to stand, a lateral-prone position should be arranged, the so called Friemann-Dahl position. This way abdominal X-ray could inform about the presence of a minimal, 2-3 ml of free air, about the general gas content of the gastrointestinal tract and furthermore about the existence of intra- or extraluminal air-fluid levels. Moreover, the position of radiopaque structures (sclerotic, metallic or other foreign bodies) can also be evaluated. Initial fluoroscopic ingestions with per os contrast material and at later stages, regularly taken abdominal radiographs can reveal the passage function of the whole GI tract.
- US scanning can be used to depict free fluid, abscesses, stone reflections and the general state of the organs. It can also reveal the extent of distention caused by intestinal gas. US Doppler examination is used for the assessment of vascularization; it is capable to differentiate stenosis, obstruction, thrombosis and embolisation. If necessary, US guided interventions can be performed such as puncture, drainage or aspiration.
CT examination provides detailed, summation free images. With contrast administration image detail and tissue characteristics can be further improved.

MRI examination does not play a decisive role in emergency imaging.

Routine imaging algorithm is determined by the preliminary diagnosis based on the main clinical picture and the complaints of the patient. Usually, the first leg of the examination protocol consists of X-ray and US exams, although marked bowel distention can diminish the indication and diagnostic value of sonography. As a third imaging step GI passage examination and CT examination can take place.

Below, an overview is provided of the most important emergency states according to the quadrant-based approach together with their appropriate diagnostic imaging methods.

- **Right upper quadrant** pain usually indicates abnormality of the liver, the biliary tract or the gall bladder. Moreover, right kidney stones, urinary tract dilatation, renal parenchymal damage and the pathologic processes in the perirenal compartment of the retroperitoneum can also localize here. Furthermore, one might also have to consider atypically located appendicitis or duodenal ulcer in the area.
  - Sometimes, the presence of a right subcostal radiopaque stone on a plain abdominal radiograph can confirm the suspicion of cholelithiasis, cholecystitis.

The method of choice however, is ultrasonography. US examination can depict stones located either in the gall bladder or in the biliary tract. They are shown as hyperreflective structures with acoustic shadowing. As a sign of inflammation the bladder wall thickens, becomes multilayered and edematous. Doppler examination can reveal the consequent hypervascularization of the inflammation.

![Ultrasound images of the gall bladder](image)

17. Typical right subcostal colic pain. Ultrasound examination. On the right is a typical picture of a cholelith with acoustic shadowing. The left image shows cholecystitis with multilayered, edematous and hypervascularized gall bladder wall. Note the intraluminal dense sludge and the presence of multiple, small gallstones.

- Because of their similar physical characteristics nephroliths (ureteroliths) can be examined the same way as gall stones. The so called renal radiography is a more direct X-ray examination of the kidney. The use of sonography can be limited by gas filled bowels. At times, only indirect signs such as pyelectasis or the segmental dilation of the ureter can be seen. In some other cases, kidney stones do not cause any urinary dilatation or congestion. “Mobile” stones are missed by the radiologists a lot more frequently – or cannot even be assessed – especially if they are in the middle segment of the ureter. Juxtavesical
nephroliths (if the urinary bladder is well expanded with urine) are often visible due to their acoustic shadowing. In case of uncertainty, after the initial imaging methods (or even as a primary examination) abdominal non contrast enhanced-, or even more importantly, a so called low dose CT examination can be performed. There are further advantages to CT or low dose CT examinations compared to other modalities. They are more objective, imaging is faster with less artefacts. Moreover, other extrarinary structures are more readily assessable (even if the lack of iv. contrast in non contrast enhanced examination has only limited value for tissue characteristics). CT can help to detect other acute processes of the differential diagnostic group. However, one has to note that certain nephroliths (such as oxalate-stones) are not radiopaque therefore even on CT examination they might be missed.

- Duodenal ulcer- or typical prepyloric gastric perforation might result in the appearance of free abdominal air. In the majority of the cases this can be detected with (erect) plain abdominal radiograph. The typical picture of free abdominal air is a thin, crescent-like radiolucent band under the diaphragm. Per os administered contrast media can leak to the abdominal cavity through the perforation opening with a characteristic pattern. In case of atypically located free air, or if there is clinical suspicion but no radiographic evidence, a further CT examination is indicative. In fact, CT can detect much smaller amounts free- or even “hidden” collections of abdominal air.

- Finally, although it is not considered a part of the routine examination protocol, even ultrasonography can suggest the possibility of free air. In highly suspected cases, when the patient is in prone position, typically abdominal air is found between the liver and the right crus of the diaphragm appearing as a hyperreflective streak.

- In the left upper quadrant splenic rupture, gastric perforation, aorta aneurysm, perforated colon and the various lesions of the left kidney need to be considered.
  - Gastric perforation might appear secondary to peptic ulcers. The diagnostic approach is the same as already mentioned earlier.

- Right lower quadrant pain might indicate appendicitis, oophoritis, salpingitis, tubo-ovarian abscess, extra-uterine gravidity, pyelo-urethral stone, strangulated hernia, mesenteric adenitis, Meckel-diverticulitis, Crohn’s disease, perforation of the cecum or psoas abscess.
  - In appendicitis periappendeceal abscess is the most common imaging finding, however – since RLQ is the most common site of abdominal pain – other pathologies are ought to be ruled out. Plain abdominal X-ray might show discrete air-fluid levels in the bowels at the region, which could indicate local peritoneal irritation. Direct visualization of the appendix is possible with ultrasonography, unless hyperreflectivity of the intestinal gas prevents assessment. In practice, the inflamed appendix is easier to detect than the normal one, thus elevating the sensitivity of the method. The typical image of the inflamed appendix is a tubular, non-compressible structure. Doppler exam might be able to detect hypervascularization. At times, a luminal hyperreflective mass is indicative of fecolith. Periappendeceal and ileocecal abscess have a hypoechogetic, inhomogeneous appearance with irregular internal echoes. Pelvic, retrocecal or atypical positions of the appendix might prevent the radiologist from the visualization or the localization with these methods. Equivocal cases can be decided with CT examination, which offers sensitivity over 90%.
15. Emergency Radiology

- Strangulated hernias can be abdominal or inguinal in location. The hernia might contain omentum, mesentery or bowel loops. They can either occur in a preformed, natural canal or after abdominal surgery in the scar of the abdominal incision. Plain abdominal X-ray might show intraluminal air-fluid levels at the site. If the strangulation causes bowel obstruction passage examination might be diagnostic. However, passage follow-up is a time consuming and strenuous examination for gravely ill patients. Hernia can be directly detected by ultrasonography. The herniated bowel in the abdominal wall or the inguinal canal is visualized as a thick, distended intestinal loop, often presenting with perifocal fluid collections.

18. Plain abdominal radiograph shows an inverted U shaped, slightly distended small bowel loop, with thin air-fluid levels. Ultrasonography reveals a herniated intestinal loop with a thick wall, surrounded by a small band of fluid collection. Note the narrow hernia orifice.

- In the left lower quadrant sigmoid diverticulitis, obstetric diseases (similarly to the RLQ) and ulcerative colitis can occur.
  - In average size patients, diverticulitis can be revealed by applying pressure with the ultrasound transducer directly above the painful area. Characteristically, diverticulitis presents as a hypoechoic area connected to the intestinal wall. In its surroundings hypervascularization can be noted with Doppler US. The edematous inflammation is revealed by increased hyperreflectivity in the widened mesenteric fat, which also causes the apparent separation of the bowel loops. In cases where the bowels are lying too deep or when it is necessary to rule out pericolic abscess or progression towards the pelvis, it is more reliable to use CT after the initial US examination has been carried out. CT can also help in the differentiation of the lesion (abscess, tumor), and requires the administration of iv. contrast material. Unfortunately, it can happen that after the inflammation subsides colonoscopy is still necessary for tissue sampling in order to confirm or rule out the malignant nature of the lesion. As a complication of diverticulitis, perforation can also occur, which is indicated by the appearance of extraluminal abdominal air (discussed above).
- In the **periumbilical region** bowel obstruction, acute pancreatitis, early appendicitis, mesenteric thrombosis/embolisation, aorta-aneurysm or diverticulitis can present with pain.
  - The diagnosis of acute pancreatitis has to be based on the complex assessment of the patient. The results of all three: clinical picture, blood results (amylase value, inflammatory parameters) and imaging finding have to be considered. The positivity of at least two examinations can confirm pancreatitis. The role of diagnostic imaging therefore, is to differentiate other processes involving the periumbilical region or to assess the complications of pancreatitis. Peritoneal irritation caused by pancreatitis can create small bowel paralysis and air-fluid levels.

![Plain abdominal X-ray, sentinel loop.](image)

This paralytic, periumbilical bowel loop is also called sentinel-loop. If present, it can lead to the disruption of the ultrasound examination. Any gas filled intestine over the pancreatic region will cause the hyperreflection of the sound waves, thus leaving the middle portion of the retroperitoneum obscured to sonography. If the pancreatic region is still visible with ultrasonography, the pancreas appears widened; its structure shows edematous infiltration. Free fluid is usually detectable in the peripancreatic region, the omental bursa or in other cases there is a diffuse appearance of free fluid in the whole abdomen. CT examination can identify the early phase of acute pancreatitis. In the early, edematous phase the pancreas is widened and the peripancreatic fat appears hyperdense due to the edematous infiltration. Still, the main role of CT scanning remains the assessment of the early and late complications of pancreatitis. Edema, hemorrhage and necrosis each show typical features with CT, which help in the differential diagnostics.
20. Acute pancreatitis. CT examination reveals peripancreatic fluid collection in the anterior pararenal space. The pancreas is edematous.

- Plain abdominal radiographs are usually sufficient to raise suspicion for bowel obstruction. In most cases, the radiologic appearance is indicative of the level of the blockage (stomach, small or large bowel). Mechanical obstruction can be incomplete but also it can become complete as the passage function wears off in the strain. Clinical data and patient history (previous abdominal surgery, medication, cancerous state etc.) are all important details in order to help to differentiate the types of obstruction from one another.

21. Right image: plain abdominal X-ray showing distended bowel loops, with wide air-fluid levels. Left image: plain abdominal radiograph showing distended colon until the sigmoid segment, with wide air-fluid levels. The obstruction is most likely to be at the level of the sigmoid or the rectum.

- Abdominal aorta aneurysm or thoracic aorta aneurysm that extends abdominally can both be impending or already completed ruptures. If the patient is stable and is able to cooperate – unless immediately taken to the operation room – has to be assessed with CT angiography. CTA can reveal probable contrast leakage and retroperitoneal hematoma in a matter of a few minutes. In these cases time consuming and non-informative investigations, such as abdominal radiography or ultrasonography can prove to be fatal.
Moreover, the pressure is applied with the transducer during sonography, is feared to induce or increase the probability of rupture or bleeding. On average, however when aneurysm or rupture are not considered as the primary diagnoses, routine abdominal US can also be used. Ultrasonography might depict inhomogeneous periaortic hematoma as a hypoechogenic retroperitoneal mass. In these cases one should not hesitate to order CTA examination, since is the gold standard of abdominal aneurysm.

- Mesenteric thrombosis/ embolism present as continuously increasing, intensive colic-like abdominal pain (mesenteric angina). Plain abdominal radiography can show paralytic obstruction, which in turn, due to the gas filled bowels, can seriously limit the diagnostic use of US. Hence the Sonographic assessment of the retroperitoneum or the Doppler examination of the mesenteric blood vessels cannot be performed. If the there is clinical suspicion of mesenteric thrombosis abdominal CT examination is the method of choice.


22. Colic-like periumbilical pain presents in an elderly patient with generalized atherosclerosis. On the right, CTA examination reveals the occlusion of the superior mesenteric artery about 8 cm from its origin. On the left, 3D reconstruction of CTA examination. Note the extensive aortic sclerosis.

- Epigastric pain can result not only from abdominal, but also from thoracic pathologies. Myocardial infarct, esophageal perforation, hiatus hernia, gastric ulcer should also all be included in the differential diagnostics. On routine chest radiographs only indirect signs might be encountered, but free subdiaphragmatic abdominal air is often detectable as a sign of perforation.

- Any abdominal quadrant pain can begin as upper abdominal or periganglionic (celiac) pain.

- In case of lower abdominal pain, the presence of pelvic fluid collections, cystic or solid pelvic mass all refer to pelvic origin rather than abdominal propagation.
Utility guide of the imaging modalities – abdominal and pelvic pain

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15.4. Summary

During the presentation of various emergency states a regional and symptomatological classification and their primary imaging methods have been discussed. With this knowledge the general practitioner is ought to gain an overview about how to order and obtain the necessary diagnostic imaging information in these acute states. Regarding the narrow time frame provided by many of these emergency situations (acute life threatening states or conditions threatening with permanent damage), clinicians are expected to understand how they can gain the fastest and most relevant information, so that they can initiate adequate therapy within the shortest period of time.

Translated by Pál Kaposi Novák, Balázs Futácsi
16. Diagnostic imaging of the genitourinary tract

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Precise imaging and early detection of genitourinary tract (GU) diseases is a significant challenge for diagnostic radiologists. Advancements in modern radiographic modalities and in particular cross-sectional imaging provide us with diagnostic prospects on a previously unimaginable scale. In addition to the technological aspects personal consultation with the clinician is an equally important part of proper patient management. A significant goal of the present chapter is to better prepare our current and future colleagues for the handling of these challenges. It is important that all involved physicians become familiar with basics of GU imaging as it is essential to achieve a common understanding. We would also like to help our interested readers to obtain deeper knowledge in the selected subspecialty fields.

16.1 Kidneys

16.1.1. Clinical and radiographic anatomy of the kidneys

The kidneys are bean shaped retro-peritoneal organs, located at the level of the twelfth thoracic and first lumbar vertebrae on both sides of the vertebral column. Due to the liver the right kidney is 2-3 cm more caudally situated. The surface of the kidneys is covered by a tightly adherent renal capsule, while outside they are surrounded by a fatty tissue layer (adipose capsule). The renal fascia encapsulates the perinephric fat with a fibrous envelope that is open inferiorly, and accommodates structures of the renal hilum.

The renal hilum contains the renal vasculature, the renal pelvis, which is often described as an irregular shaped sack with a muscular wall, and finally the ureter. The renal pelvis branches into three primary limbs these are the major renal calyces (calyces renales majores). Distally, the major calyces further divide into two to three minor branches, the minor calyces (calyces renales minores). Each renal calyx surrounds one or more renal papillae. The renal papillae constitute the apical portion of the medullar pyramids.

Figure 1. Intravenous CT pyelogram, normal anatomy
The renal cortex extends down between the pyramids in a wedge shape and approximates the renal sinus. This columnar portion of the cortex (columna renalis) is often hypertrophied, and it could lead to a differential diagnostic challenge upon imaging.

The arterial and renal vasculature of the kidneys shows significant individual variations, and may cause pelvic or ureteral compression. In the most common variant the kidney is supplied by a single renal artery which runs posterior to the renal vein in the hilum. The renal arteries are end arteries. They give off arcuate arteries in the interlobular columns of Bertin and on the border of the medullar pyramids. The course of the renal veins is similar to the renal arteries.

**16.1.2. Congenital renal anomalies**

Among the congenital renal anomalies we first have to mention renal agenesis. Usually, it is asymptomatic and a relatively common finding. In 10% of the cases it is also accompanied by an ipsilateral adrenal agenesis.

**Renal hypoplasia** is another common congenital disorder, when the hypoplastic kidney is located at a normal anatomic level while the contra lateral kidney shows compensatory hyperplasia.

Malrotation of the kidneys can also occur. During the normal development the renal hilum first faces anteriorly then, it turns medially; if the rotation is incomplete the hilum stays in an anterior position.

In case of a **horseshoe kidney** the two kidneys fuse at their lower poles. It characteristically accompanied by abnormal arterial configuration and frequently by pelvic retention. It is also frequently associated with nephrolithiasis, and the patients are predisposed to pelvic dilatation.

Many forms of renal **dystopias** can be differentiated, based on the site these could be: lumbal, sacral, pelvic (thoracic). The dystopic kidney can be uni- or bilateral, as well as ipsi- or contra lateral.

**16.2. Kidney tumors**

They constitute 3% of all renal abnormalities in adults. Based on the site of origin and the tissue type we can distinguish between epithelial, mesenchymal and pelvic tumors.

**16.2.1. Epithelial tumors**

**Adenocarcinoma**
The most common type of renal cell carcinoma (RCC) arises from epithelial cells of the proximal convoluted segment of the renal tubules. It is alternatively called: hypernephroma, Grawitz’s tumor, clear cell carcinoma or malignant nephroma. It is twice more common in males than in females. Its incidence is highest in the sixth decade of life. Smokers are more frequently affected.

The classic clinical signs of RCC include the triad of lower back pain, palpable mass and hematuria, which is quite rarely seen. Early symptoms of the patients are often non-specific: weight loss, palor, gastrointestinal or neurologic complaints, fever.

Adenocarcinomas can produce a number of different hormones, which can also lead to miscellaneous symptoms.
The onset of hematuria, the most common sign detected in over 50% of the cases, indicates an advanced process.

**Diagnostics:** with advancement of the cross sectional imaging techniques multi phase contrast enhanced CT became the basic diagnostic modality if a renal neoplasia is suspected. The parenchymal lesion is revealed by its characteristic inhomogeneous contrast enhancement pattern and in certain cases by the presence of focal calcifications. CT has much better sensitivity than intravenous pyelogram, which has been extensively used in earlier times. A properly preformed CT scan can be also considered a staging examination as it could reveal distant metastases and vascular invasion. Additional advantages of CT imaging can be attributed to the various digital elements and post processing features. Multi-plane reconstructions are available and auxiliary 3D or virtual urographic images can also be generated anytime from the primary dataset.

![Figure 2. Extensive right sided kidney tumor on CT](image)

**MR** imaging can be used with similar diagnostic efficacy as CT. In addition to local availability, there are other advantages and disadvantages of this technique that also should be considered, these are discussed in detail in the general radiology section.

**Ultrasonography (US),** which is an extensively used and a widely available method, is often the first step in the diagnostic work up. During a regular abdominal US scan both kidneys are examined. Sensitivity of the US examination is significantly lower than of a CT scan, still important clinical questions can be answered with this technique. When a tumor is visualized, it is usually a hypoechoic, relatively well circumscribed mass. Diagnostics of cystic lesions is based on the Bosniak classification system, which categorizes cystic lesions by their density, calcifications, wall thickness, contrast enhancement, surface lobulation and characteristics of the cyst contents.
Other epithelial tumors

Some other epithelial tumors show similar morphology to non-papillary adenocarcinomas, these include papillary adenocarcinomas, Bellini tumors arising from the collecting ducts, carcinomas and medullary carcinomas. Other, rarely seen variants include Wilms tumor, rhabdoid sarcoma, nephroblastomatosis and mesoblastic nephroma. These tumor types could not be differentiated based solely on the radiology findings. Only typical oncocytomas could be distinguished in this group by their unique morphology, as it shows a slightly enhancing central scar and a spoke wheel like contrast enhancement pattern, which is especially apparent on angiography.

16.2.2. Mesenchymalis

Tumors of mesenchymal origin include: angiomyolipoma, fibroma, fibrosarcoma-osteosarcoma, metaplasia, lipoma, leiomyoma, leiomyosarcoma, hemangioma and juxtaglomerular tumors. Among these angiomyolipomas are the only ones that have characteristic radiologic signs.

Angiomyolipoma is a hamartoma which is primarily composed of fat, vessels and smooth muscle. It is most common in females in their forties. Compared to other renal lesions the fat content is considered specific for this tumor, and it can be easily detected on imaging studies.

On US it characteristically shows up as a well circumscribed, hyperechoic mass in the renal parenchyma. Unfortunately, a small percent of malignant neoplasms has similar appearance, thus depending on the clinical findings frequent follow-ups, or further imaging studies are required.
On the CT scan the fat content is highlighted as a typically hypodense area, where negative HU values can be detected.

On T1 weighted MRI sequences corresponding to the fat containing areas high signal intensity can be seen, while in other non fatty kidney lesions the T1 signal intensity is low.

16.2.3 Pelvic tumors

Malignant pelvic tumors are more common than benign variants, among these the most common is transitional cell carcinoma (TCC). Rarely, squamous cell carcinoma, undifferentiated carcinoma and adenocarcinoma are also found. Papilloma is the most common benign lesions.

In pelvic tumors hematuria is usually the first symptom. Due to the partial urinary retention lower back pain, dysuria and pyuria can occur however, these are less common symptoms. TCCs in 80% of the cases have a polypoid appearance. The lesion causes filling defect on the intravenous pyelogram and on the excretory phase CT scans, when contrast media is being secreted to the renal pelvis.
16. Diagnostic imaging of the genitourinary tract

![CT image of an extensive right pelvic tumor on excretory phase coronal CT scans.](image)

16.2.4. Tumors of extra-renal origin

Non renal tumors of the kidney include: lymphoma, leukemia, myeloma and metastases. The kidney does not contain lymphoid tissue. Nevertheless, it can be infiltrated by lymphomas. Non-Hodgkin lymphomas more frequently involve the kidneys than Hodgkin disease.

On US examination a solitary, hypoechoic, homogenous mass is generally detected however; multiplex lesions can be also frequently seen. The secondary lesion on the CT scan usually appears as a hypodense, slightly contrast enhancing mass. MRI can verify the provisional diagnosis of myeloma if the lesion shows intermediate signal on T1 and high signal on T2 weighted sequences.

Invasion of the leukemia cells involves both kidneys thus, the renal parenchyma shows diffuse symmetrical thickening on both sides.

Myelomas can also present with bilateral kidney masses. In addition to the characteristic nephrocalcinosis moderate volume expansion may also be detected. Importantly, contrast administration should be avoided in myeloma patients because the risk of contrast medium induced nephropathy (CIN) is high.

According to autopsy series metastases frequently (20%) involve the kidneys. Their ratio to primary renal tumors is 4:1. However, the clinical picture is usually dominated by the primary tumor. Meanwhile, renal metastases result in occasional hematuria and peri-renal bleeding. Melanomas, colon, breast, and lung carcinomas are the most frequent to metastasize to the kidneys. Metastatic spread often leads to multiplex lesions.

On CT metastases are characteristically seen as small hypodense lesions. These usually show delayed contrast enhancement compared to primary neoplasms. On US solid, hypoechoic lesions can be detected. With MRI metastases show high signal intensity on T2 weighted sequences.
16.3 Inflammatory kidney diseases

Ascending bacterial infections can propagate to the kidneys, in children this is usually caused by vesico-ureteral reflux, while in adults both acute or chronic pyelonephritis can occur in the absence of reflux.

In addition to occlusion due to various causes, pathogenetic factors of pyelonephritis also include bladder dysfunction and congenital malformations. Dilatation of the renal pelvis during pregnancy, due to physiologic compression of the ureters, is another important risk factor.

Gram negative bacteria such as E. coli, P. mirabilis, P. aeruginosa and certain Klebsiella strains are the primary cause of genitourinary infections. The main clinical symptoms are fever, lower back pain, chills, nausea and vomiting.

The primary goal of the radiologic examination is not verification of the diagnosis, rather to determine the extent of the inflammatory process. When an abscess has already been formed, opposed to the conservative treatment, an invasive therapeutic intervention is necessary.

Currently, CT is the preferred imaging method in acute pyelonephritis. However, the radiologic picture often does not fully correlate with the clinical symptoms.

Intravenous pyelogram and US examinations may give negative results in over two third of the cases.

On the multiphase CT scan the affected parenchymal segment shows delayed contrast enhancement compared to its surroundings, and in the excretory phase it demonstrates a hypodense striated structure.

When abscess formation is suspected a CT scan must be performed. On the CT solitary or multiplex, circumscribed, round defects with a contrast enhancing wall are seen. Corresponding to the secondary perinephric stranding and to the extensive inflammation, abscesses can extend into the perinephric space. In such cases, depending on the severity of clinical symptoms, CT or US guided puncture can be attempted as a therapeutic intervention.

Emphysematous pyelonephritis is a severe condition when in the renal parenchyma and in the perinephric space gas collections can be detected. These are most apparent on CT.

Xantogranulomatous pyelonephritis is a rare inflammatory disease, which develops in the proximity of staghorn type renal calculi. Renal excretion is characteristically decreased in the affected parenchyma.

Regardless of its etiology, in chronic pyelonephritis, due to the recurrent infective episodes, the renal parenchyma shows disseminated structural deformity. Invaginations of the renal contours, thinning and almost complete destruction of the parenchyma as well as distortion and dilatation of the renal calyces are seen.
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16.4. Nephrocalcinosis and nephrolithiasis

*Nephrocalcinosis* is a condition characterized by diffuse calcium deposition in the kidneys involving both the cortex and the medulla. In the background of cortical nephrocalcinosis chronic glomerulonephritis, acute cortical necrosis or oxalosis can be detected. Meanwhile, causes of medullary nephrocalcinosis include renal tubular acidosis, hypercalcemic conditions and renal tubular ectasia, also known as medullary sponge kidney.

Nephrolithiasis is a rather common disease. In addition to various minerals calcium is present in almost 90% of the stones. Therefore, any condition associated with elevated blood calcium levels or with increased calcium excretion can precipitate stone formation. Cystine and urate stones constitute approximately 10% of all cases of nephrolithiasis. In these, calcium could only be detected in traces. Therefore, contrary to calcium containing stones, these stones are especially difficult to detect on abdominal plain films or intravenous pyelograms.

When exceed a certain sizes all stones can be visualized with US, but the reproducibility of this technique heavily depends on the instrument’s specifications and on the examiner’s skills. Stones located in the renal pelvis can be well identified on CT, and with dual-source CT (DSCT) even chemical analysis of the composition is possible. On MRI stones show up as a signal loss on all sequences (occasionally large stones can be directly visualized).

Notably, in majority of the cases renal colic and urinary retention are caused by ureteral stones. The detection rate of these on abdominal plain films and on intravenous pyelogram depends on their size and composition. On US only stones that are located juxtavesically or in the upper third of the ureter or cause concomitant pelvic dilatation can be detected reliably. However, even these stones can be hidden by intestinal air.

In summary, when an ureterolith is suspected a native CT scan should be performed. Considering the patient’s radiation exposure a low dose CT examination is recommended.
16.5 Diseases of the renal vasculature

Regarding the vascular supply of the kidneys it is important to note that in over 40% of the cases, in addition to the main renal artery an accessory or polar artery is also present.

Generally, the accessory artery branches off the aorta distal to the origin of the main renal artery. Horseshoe kidneys, or dystopic kidneys located outside the regular anatomic site almost always supplied by a polar artery, which may arise from the distal aorta or the iliac artery.

Importantly, at the renal pelvis the renal artery bifurcates into ventral and dorsal branches. The ventral branch supplies the ventral and upper part of the parenchyma while, the dorsal branch provides blood to the posterior lower part. At the border of the anterior and dorsal vascular territories a relatively avascular region (Brodel’s line) could be identified, this is the primary target site of percutaneous nephrostomies.

Distally the major renal arteries further divide into segmental, interlobar and arcuate branches.

Configuration of the renal veins follows the arterial architecture. The left renal vein crosses dorsal to the aorta in 2-10% of the patients. A retrocaval ureter is seen in 0.1% of the cases.

Polyarteritis nodosa is a collagen vascular disease, which may affect the intrarenal arteries. It is associated with a pan-arteritis that extends to all layers of the arterial wall with characteristic focal media necrosis. The kidneys are involved in 90% of the patients.

Small aneurysms typically located at the branching of the intralobular arteries could only be detected on angiography.

Nephrosclerosis secondary to hypertension primarily affects the small arterioles. It does not have any specific radiologic signs. However, the diagnosis can be established based on the clinical history, presence of abrupt stenosis, angiography findings and in advanced cases the lack of contrast enhancement.
Renal hypertension can be the result of acute or chronic parenchymal disease that leads to activation of the renin-angiotensin axis. However, the most common etiology is renovascular disease. Noticeably, although renovascular disease constitutes only 1-4% of all hypertension cases, it typically starts in patients under 20 or over 50 years of age, who are less commonly affected by other types of hypertenisons. The pathogenic factor in these cases is ischemia induced renin release secondary to stenosis of the renal artery. The most common etiology of renal artery stenosis is atherosclerosis. Usually, the stenosis is located within 2 cm of the arterial origin.

Fibromuscular dysplasia is observed in approximately 30% of cases. There is pathologic collagen deposition in all layers of the vessel wall. Based on the distribution of the deposits in the intima, media or adventitia multiple forms of the disease can be differentiated.

Radiographic work up starts with a Doppler US, although it is less sensitive than MRI or CTA. A further disadvantage is that its performance is highly dependent on the patient’s body habitus and on the examiner’s skills.

In the detection of stenoses grater than 50% the sensitivity of CTA is 90%, the specificity is 97%. CTA is considered a reliable method integrating all advantages of cross-sectional imaging. MRA is usually performed with gadolinium contrast enhancement; the previously used TOF technique has proved to be less reliable.

In earlier times, angiography used to be the gold standard examination of renal circulation. Nowadays, due to the technological advancements and widespread availability of cross-sectional imaging techniques this could not be universally asserted. Nevertheless, angiography still has an important role in the diagnosis of otherwise indeterminate cases. Its main indication when it is performed as part of a therapeutic procedure (i.e. angioplasty). The most common therapeutic intervention in renal arterial stenosis is percutaneous transluminal angioplasty (PTA), which is always preceded by a diagnostic angiography.

Thrombosis of the renal vein is most frequent in left sided advanced renal carcinomas. Contrast enhanced CT with carefully timed venous phase examination is an excellent method to identify venous thrombosis. In renal vein thrombosis MRI achieves even higher sensitivity than CT. Color Doppler US is a useful method in cases when the full length vein can be visualized.

16.6. Radiologic diagnostics of collecting system diseases, the ureters and the bladder

16.6.1. Ureter

The physiological stenoses of the ureters seen at the pyeloureteral junction and at the juxtavesical segment are also clinically important as ureter stones are most commonly stuck at these sites. Considering their differential diagnostic and surgical significance it is essential that clinicians and radiologists alike familiarize themselves with these crossing sites.

The ureter crosses superficially to the bifurcation of the iliac arteries. Distal to this point it crosses posterior to the testicular artery in men and the ovarian artery in women. The ureter also passes dorsally to the uterine artery and the spermatic duct. Thus, ligation of these vessels may lead to ureteral injury and potential urinary tract obstruction.
Among the developmental disorders the bifid ureter has to be mentioned. In this, two ureters originate from the duplicated renal pelvis and descend towards the bladder where they enter the lumen through separate orifices.

In ureter fissus the two ureters merge proximal to the bladder.

Megaloureter is a condition with extreme dilatation of the ureteral lumen due to innervation defect or chronic stricture. Retrocaval ureter is by definition located on the right side. It may lead to urinary retention thus, its detection is clinically important. Radiologic imaging methods utilize contrast filling of the ureters. In a conventional retrograde pyelogram anterograde or retrograde filling of the ureter is achieved by a catheter insertion. Meanwhile, with cross-sectional imaging techniques (CT, MRI) timed image acquisition is conducted during the excretory phase (approx. 8 min). Both of the above techniques provide good quality images to assess ureteral patency.

With virtual endoluminal reconstructions detailed depiction of the intraluminal lesions is also possible.

For the visualization of intra- or extraluminal ureteral strictures and masses the primary imaging modality is CT with multi-phase contrast enhancement. In addition to detecting nephrolithiasis it is highly sensitive to visualize other GU lesions, congenital and acquired malformations.

Due to its restricted use in meteorism and in heavy set patients, US has limited potential in the examination of the proximal collecting system.

16.6.2. Urinary bladder

The bladder can be anatomically divided into a vertex, corpus and fundus. The position of the later one is fixed by the underlying pelvic fascia. In men the prostate is located right below the fundus, thus prostatic lesions such as prostatic hyperplasia often protrude into the bladder fundus. The ureters enter the bladder through the posterior-caudal part of the fundus. The area bordered by the internal ureteral orifices and origin of the urethra is called the vesical trigone.

Diverticula are the most common congenital malformations of the bladder. These are more frequent in men, and tend to occur around the ureteral os as the trigone has a different embryologic origin than the rest of the bladder. In addition to dysuria, diverticula, due to prolonged urinary retention, may also lead to pyuria. Large diverticula can compress the ureteral os, and cause urinary retention.

Ureterocele is the dilatation of the intramuscular ureter segment, which may pose a differential diagnostic problem as it often protrudes into the vesical lumen.

When the examination is performed with a right technique, and the lumen is fully distended lesions of the bladder wall can be well detected with US. In addition to the diffuse wall thickening seen in cystitis (the normal wall thickness is 3 mm) laboratory tests and the patient’s complaints (abdominal pain, dysuria, urinary frequency and occasional hematuria) may also guide the diagnosis. Detection of dense urine, which contains hyperechoic particles can also help the examiner.
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CT and MRI scans also show diffuse wall thickening without any circumscribed lesions. However, in most of the cases this is an accidental finding as these examinations are not indicated in cystitis, except when an emphysematous cystitis is suspected.

Bladder cancer is the second most common genitourinary neoplasm after prostate cancer. The male to female ratio is 3:1, and 90% develops in patients over 50 years of age.

Etiological factors include smoking, certain occupations, exposure to chemicals used in rubber and plastic manufacturing, irradiation, prior cyclophosphamide use as well as chronic infections.

The primary clinical symptoms are hematuria, urinary frequency and occasional obstructive complications.

Definitive diagnosis can be established with cystoscopy and biopsy. Nevertheless, radiographic imaging plays an essential role in early detection and staging of the disease.

When the patient is well prepared and the bladder is full even the very early papillary lesions can be recognized on US. The papillary form is more common than the muscle invasive type. However, papillary lesions can progress into an invasive type by time.

CT and MRI scans provide information on the extent of the parietal and perivesical propagation while, regional and distant lymph node metastases can be also simultaneously identified. When conventional cystoscopy could not be completed due to urethreal narrowing or prostate hyperplasia, upon clinical request, similar to other parts of the GU tract, virtual endoluminal images can be reconstructed from the excretory phase series.

![Axial CT images show an extensive tumor in the bladder fundus.](image)

16.7. Imaging of prostatic diseases

Familiarity with the “zonal” classification of the prostate (proposed by MacNeal) is essential for the understanding of basic clinical and radiological concepts of prostate diseases. According to MacNeal the glandular prostate can be divided into peripheral, preprostatic and central zones.
The preprostatic zone also includes the zones of transitional and periurethral glands. Meanwhile, the upper fibromuscular stroma shows a non-glandular structure.

The peripheral zone constitutes 70% of the normal gland; it owes its significance to the fact that 70% of prostate cancers arise in this zone.

The transitional zone is a frequent site of benign prostatic hyperplasia. While, the periurethral zone although, only contains 1% of the entire gland, is also important as middle lobe enlargement develops here.

Only 5-10% of prostate cancers originate in the central zone. Importantly, this is the entry point of the ejaculatory duct and the seminal vesicles while, the capsule is absent in this area. Therefore, it is a predilection point where prostate cancer could spread into the periprostatic space.

Prostate cancer is the most common malignant disease in men over 50. Therefore, prostate imaging is an important screening tool. Among the various imaging modalities transrectal US and MRI have a crucial role in primary diagnosis of prostate cancer. CT is used for accurate detection of pelvic and distant metastases.

Transabdominal US is only capable to determine the prostate size or extent of the secondary urinary retention and collective system dilatation. Meanwhile, transrectral US can also be used to guide biopsies from the suspicious hypoechoic areas, which is a significant advancement compared to the blindly performed (sextant) biopsies.

MRI is helpful for the assessment of local invasion and identification of atypical lesions. A highly sensitive MRI technique is spectroscopy, which measures the tissue concentration of metabolites. In prostate carcinomas colin and citrate levels are evaluated. Cancer cells are distinguished by the very low citrate and high colin levels.

Diagnosis of inflammatory diseases of the prostate is fundamentally based on clinical methods. If necessary a transrectal US can be performed, this shows loosened, edematous glandular structure, extracapsular microabscesses and increased flow in the periprostatic veins. Chronic prostatitis is characterized by intraprostatic calcifications although; these can be seen in other conditions as well.

16.8. Imaging of testicular diseases

Disturbances of testicular descent lead to ectopic testes and cryptorchidism. The ectopic testis is found outside the scrotum and the normal migration route. In cryptorchidism descent of the testis begins normally but stops uncompleted. Approximately 10% of the testes do not complete descent until the end of the first year. Chryporchidisim is associated with increased risk of sterility (fibrosing testicular atrophy) and malignant transformation, which still remains elevated if the descent is delayed or following surgical orchidopexy. Risk of malignant transformation in these testes is 30-40 times higher than in the normal population.
In general, testicular imaging consists of US and MRI examinations. For US it is important to use high frequency transducers with color Doppler imaging. MRI is particularly important for visualizing defects of testicular descent. In neoplastic diseases staging as well as detection of enlarged pelvic and abdominal lymph nodes and distant metastases can be equally completed with either MRI or CT.

Acute inflammation of the testis or epididymis is most commonly affects the head or the tail of the epididymis.

US scanning is highly significant in atypical and therapy resistant cases. In addition to abscess formation, epididymal enlargement can compress vascular supply of the testis.

Chronic inflammations are essentially hydroceles and secondary thickening of the tunica vaginalis testis. In a hydrocele fluid is accumulated between the sheets of the tunica vaginalis. When a hydrocele is detected it is important to exclude potential testicular tumors as well.

Testicular cancer is the most common tumor in men aged between 25-34 years, constituting 1-2% of all malignancies. Positive family history, Caucasian descent and cryptorchidism are additional risk factors.

Germ cell tumors comprise 95% of all testicular cancers, among which the portion of seminomas is 60%. Non-seminomas form 40% germ cells tumors, these include embryonic cell tumors, teratomas, choriocarcinomas and yolk sac tumors.

Non-germ-cell stromal tumors are divided into Leydig cell and Sertoli cell variants.

Metastases, lymphomas and leukemias involve the testicles much less frequently than primary tumors.

Seminomas typically occur in 30-40 years of age. They are characteristically hypoechoic, 25% of them have already given metastases at the time of diagnosis, which primarily involve the lungs. The serum alpha-fetoprotein levels are usually normal while, beta human chorionic gonadotropin (beta-hCG) is increased. Seminomas are sensitive for chemo- and radiotherapy. The 10 year survival rate is 75-85%.
Non-seminomas on US have variable echogenicity due to the frequent bleedings, fibrosis and calcifications. Embryonic cell carcinomas arise between 20-30 years as well as below the age of 2 years; these are very aggressive, with fast spread and distant metastases. Meanwhile, teratomas seen in young boys are benign lesions, which in the adulthood could undergo a malignant transformation. Choriocarcinomas are most common between 20-30 years of age. They are typically associated with early metastases to the lungs while, the primary tumor is small. In adults testicular metastases most frequently originate from the prostate, lung, kidney, gastrointestinal tract, bladder, thyroid carcinomas and melanomas. In children neuroblastomas give most commonly testicular metastases. These metastases often show multiplex, bilateral distribution, which are frequently hypoechoic on US.

Hematologic malignancies affect the testicles in 7% of all testicular neoplasias. These are most frequently diagnosed in patients under 50, and they are bilateral in 40% of the cases. Diffuse or focal hypoechoic areas could also be detected. In leukemias the whole testis may be involved.

16.9. Imaging of ovarian diseases

The basic imaging method used for the examination of the female pelvis and the ovaries is transvaginal US. In malignancies CT is essential to detect local invasion as well as distant metastases. MRI is the preferred method in young or pregnant women as it has similar application spectrum and efficacy to CT; it also has a specific advantage in differential diagnosis of ovarian lesions. Furthermore, it has a great importance in the detection of endometrisosis and peritoneal implants.

In addition to clinical and laboratory tests the diagnosis of ovarian inflammatory processes based on US examination.

Volume of the inflamed ovary is expanded, vascularity is increased, around the ovaries and in the pelvis ascites can be detected. In case of a tubo-ovarian abscess a thick walled circumscribed fluid collection could be identified in the surroundings. With US thick fluid layering and gas formation can be observed inside the lesion. In undetermined cases an MRI scan must be performed.
Ovarian tumors often have an insidious onset with no complaints in the early stage of the disease. Hormone producing tumors can present with irregular bleedings or weight loss, later increased abdominal circumference and ascites could be pathogenic signs. The diagnosis is primarily based on US examination, for the staging additional CT and MRI scans are needed. Epithelial lesions constitute around 75% of all ovarian tumors.

16.9.1. Epithelial tumors

"a." Benign tumors: serous cystadenoma, mucinous cystadenoma, Brenner tumor.

Serous cystadenoma is usually a simplex cyst, luminal growths do not show contrast enhancement.

In mucinous cystadenoma the multiplex spaces, which may show differing densities, are separated by vascularized septae. The cystic spaces in the tumor do not enhance contrast, and no luminal growths could be detected.

Brenner tumor is a solid lesion which usually contains calcifications, and does not show contrast enhancement on CT and MRI scans.

"b." Malignant epithelial tumors, which are often bilateral, represent 95% of all ovarian malignancies. Most of the time these present as cystic or solid masses, the later usually show increased echoicity. Typically, a thick wall, solid luminal contents and internal growths are seen on the US examination. On MR a characteristic contrast enhancement pattern is detected.

The three most frequent metastatic sites are the Douglas pouch, the greater omentum and the right subphrenic space. From the lymphatic regions the inguinal, the internal iliac and paraaortic lymph nodes are commonly affected.

16.9.2. Germ cell tumors

Germ cell tumors constitute 15% of all ovarian tumors. In 95% of the cases germinal tumors present as a dermoid cysts, which also alternatively called mature cystic teratoma. Torsion of the teratoma can lead to acute abdominal symptoms.
16.9.3. Sex cord-stromal tumors

Among the sex-cord stromal tumors fibromas frequently show cystic degeneration, while typically no contrast enhancement is seen.

16.9.4. Endocrine tumors

Endocrine tumors are multilocular lesions with pronounced contrast enhancement and with occasional septation.

In endometriosis endometrial tissue islands could be found outside the uterine cavity. The two most frequently involved sites are the ovaries and the peritoneum. Around the endometrial lesions inflammatory reaction could be detected. The most sensitive method to identify endometriosis is MRI. Inside the cyst hemorrhagic contents (the MRI signal is consistent with hemoglobin degradation products), thickened cystic wall and irregular internal wall contours could be identified.

16.10. Imaging of diseases of the uterus

In addition to US, MRI is the best imaging modality for visualizing disorders of uterus and female pelvis. Beyond all the advantages of cross-sectional imaging radiation free examination technique has a special importance in young and pregnant patients. Considering the excellent contrast and spatial resolution it is the preferred examination method even in older patients, when US does not provide an unequivocal diagnosis.

16.10.1. Benign disorders

Based on their location benign disorders of the uterus can be divided into myometral, endometrial and cervical lesions.

"a." Myometrial lesions include uterine fibroids, myomas and leiomyomas. On transvaginal US the different types of fibromas show highly variable echogenicity, they are often hypoechoic but may be isoechoic or hyperechoic as well. The echogenicity pattern can be either homogenous or heterogeneous. Calcifications are very common. Based on their location fibroids can be subserosal, intraluminal or submucosal, the later ones can also have a polypoid shape.

"b." Pathologic lesions of the endometrium include mucosal atrophy, mucosal hyperplasia as well as endometrial polyps formed by circumscribed mucosal thickenings. These all are well noticeable and sizable on both US and MRI scans. MRI is especially important for the identification of uterine wall endometriosis, also known as adenomyosis.

16.10.2. Malignancies

Endometrial carcinoma is the most common gynecologic malignancy. It generally begins in postmenopausal women with dysmenorrhea. The usually polyoid tumor remains superficial for a long period. Myometral infiltration is only seen in a later stage, thus 80% of the lesions are detected in an early form. Diagnosis based on gynecologic examination and biopsy. The role of MRI examination is to assess local and regional invasion.
16. Diagnostic imaging of the genitourinary tract

MRI has an important role in the post therapeutic follow-up of uterine tumors. Cervical carcinoma similar to endometrial carcinoma is diagnosed primarily by clinical means. MRI has a role in tumor staging. MRI can assess myometral and vaginal invasion as well as vesical and rectal spread. With MRI we can also obtain an accurate picture on the involvement of the pelvic wall and the lymphoid system.

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17.1. Anatometric considerations

In skeletal x-ray imaging only calcium containing bone structures are delineated. The cortical bone (cortex) of long bones is seen as thick homogenous band in the diaphysis with a marked thinning in the metaphysis. The epiphysis is covered by a thin lining of dense bone, the corticalis. The medullary or spongy bone is composed of a regular three-dimensional mesh of trabecular bone. The bone is surrounded by the periosteum, which is not depicted radiographically. The epiphysis has a cartilage cover that is not seen in X-ray imaging rendering the radiographic joint space wider than the anatomic joint space. In children the radiographic joint space is wider than in adults since the epiphysis contains mostly radiolucent cartilage and only a small central ossification. At the end of the growth period the epiphysis including the physis (epiphysial growth plate) calcifies completely. The physis is sometimes delineated as a fine calcified linear structure.

17.1.1. Accessory bones

Accessory bones are normal variants. They result from persistent apophysis or additional bone kernels and have to be differentiated from avulsions or fragments. The knowledge of the typical morphology and location of these variants is important to avoid misinterpretations, especially when reading trauma films. Usually clinical symptoms, the typical position and round shape with sclerotic margins and the lack of sharp lines help to differentiate accessory bones from fragments.

Fig. 1. Os tibiale externum a frequent accessory bone medial to the navicular bone in the foot.
17.2. Technical Modalities

17.2.1. Conventional radiography

By far the most frequent modality used in skeletal imaging is conventional x-ray imaging. Radiographs represent x-ray absorption in various shades of black and white. The more calcium present, the whiter (or denser) that part of the radiograph - the less calcium present, the blacker (or lucent) that part of the radiograph.

When looking at x-ray films of bone many aspects have to be assessed:

- Anatomic shape, form and alignment
- Position of articulating structures
- Mineral density
- Cortex and corticalis
- Medullary bone structure
- Joint surface and joint space
- Soft tissue
- Foreign bodies

Fig. 2. Images showing a dislocation of the proximal interphalangeal joint. In the d.v.-projection only a slight sideways displacement of the middle phalanx and missing delineation of the joint space is noted. The lateral projection reveals the full extend of the dislocation showing dorsal displacement of the middle phalanx.
Since x-ray films are projection images of three-dimensional structure a second imaging plane, usually perpendicular to the initial exposure is mandatory to fully assess the three-dimensional structure. In complex anatomic regions additional oblique projections or function tests may be necessary (head of radius, shoulder, pelvis, spine).

Fig. 3. Split fracture of the radial head. The fracture is clearly seen on the oblique image (right image) whereas the fracture is almost invisible on the lateral view (left image). The displaced fat pad (white arrow) indicates joint effusion and is an indirect sign of significant trauma.

17.2.1.1. Stress films:

Joint relationships can frequently be evaluated better with the aid of stress films. Stress may be applied either by weight bearing (evaluation of the acromioclavicular joint) or by external stress applied to alter the at-rest relationship (evaluation of ankle ligaments). Stress films are used to test joint stability in suspected ligament injury. Images are taken under defined conditions with weight or pressure applied. Subluxation or joint space widening indicates partial or complete rupture of the ligaments tested. Before ordering stress images a set of conventional images in mandatory to exclude fracture.

Fig. 4. Stress test of acromioclavicular joint instability. The patient is holding 10 kg weight in each hand. Note the step in the right acromioclavicular joint indicating injury to the ACG capsule and the coracoclavicular ligament.
17.2.1.2. X-ray tomography

Conventional x-ray tomography has been used in skeletal imaging to better assess fractures or infections especially in the tibial head, dens or spine. Today these indications are better covered by computed tomography and magnetic resonance imaging.

17.2.2. Computed Tomography

CT is a very important imaging modality in skeletal imaging especially in assessing trauma and complex bone lesions. CT offers excellent spatial resolution and allows detailed assessment of bone and surrounding soft tissue due to its good contrast resolution. CT is the standard technique to assess facial bones and skullbase in trauma and is frequently used to image spine, pelvis, shoulder and feet in complex injuries. With the use of submillimeter slice thickness and fast data acquisition high resolution two-dimensional and three-dimensional images reformations have become standard when assessing trauma cases. CT is also used to guide therapeutic interventions like bone biopsy, vertebroplasty or radiofrequency ablation of certain bone tumors.

![CT Image](image)

Fig. 5. Osteoid osteoma of the acetabulum in a 14 year old girl with persistent hip pain. A radiofrequency needle is positioned in the nidus of the osteoma. The patient was painfree immediately after successful thermoablation.

17.2.3. Magnetic resonance Imaging

MRI is the currently the most sensitive noninvasive imaging modality to visualize joints, cartilage and ligaments in inflammatory joint disease and trauma. MR imaging has a high soft tissue contrast and can be used to characterize lesions, describe the exact extend of a lesion and depict extrasosseous involvement of bone tumors. Furthermore, MRI is able to detect subtle changes, e.g. in occult fractures or transitory osteoporosis, since signal intensity changes in MRI can be observed even if conventional films do not show any abnormality. The excellent soft tissue contrast allows to delineate articular and periarticular soft tissues, like tendons, menisci, and synovia.
17.2.4. Ultrasound

The role ultrasound sonography in musculoskeletal imaging is limited. Bone causes total reflection of ultrasound waves; therefore only the bone surface and not the bone structure can be assessed. Bone destruction, erosions and sometimes fractures can be depicted. In rib fractures and fractures of the sternum sonography is superior to conventional x-ray. The main role of ultrasound, however, is the visualization of ligaments, joint effusion, and periarticular soft tissues.

17.2.5. Nuclear medicine

A nuclear bone scan visualizes bone metabolism, not bone morphology, and is mainly used to detect bone metastases or infection. $^{99m} \text{Tc-MDP}$ ($^{99m} \text{Tc}$ biphosphonate) is partly absorbed in bone and represents bone metabolism. In areas of increased bone turnover, an increased uptake is seen. Bone perfusion, thickness of bone and osteoblastic activity determine uptake levels. Bone scans are performed as single phase scintigraphy (bone scan for exclusion of metastases) where imaging is performed 2 – 3 hours after nuclide injection, or as three phase exam with images acquired during injection and in an early phase as well as the late phase (perfusion, bloodpool, and bone phase). For more details refer to the chapter on nuclear medicine.

17.3. Trauma

By far the majority of bone films are exposed because of a history of trauma to rule out or document skeletal involvement. In evaluating these films a precise clinical history, including the location of point of tenderness is helpful if not mandatory to correctly interpret the image.

17.3.1 Soft tissue

In viewing the trauma film, soft tissue swelling or foreign bodies have to be assessed. If foreign bodies are more dense than soft tissue (more radiopaque) they will be easily recognized (e.g. metal fragments or gravel). If they are less dense (e.g. gas) they will be seen only with close observation. Most exposures will require either a bright light or appropriate windowing on digital images to evaluate the soft tissues properly. If foreign bodies are not seen, they cannot be excluded as many types of glass, wood splinters or plastic have approximately soft tissue density.

Soft tissue swelling may be discerned not only by the apparent increase in the soft tissue but also by the interruption of normal fat planes. If subcutaneous fat or fat between muscle planes is infiltrated by edema (water density), the fat plane will no longer be visible since it looses its sharp contrast with water density structures like tendons or muscle.
Fig. 6. Patient with knee trauma. Plain films reveal significant suprapatellar joint effusion (white arrows). A fracture is not seen. MR imaging reveals a torn anterior cruciate ligament (white arrow head).

**17.3.2. Fractures**

Fractures can be easily seen when displaced, distracted or severely comminuted, but frequently fractures are missed when they are subtle and have not been carefully searched for. Evaluation of bone films means that every cortical margin has to be followed on every projection and searched for minute areas of irregularity to detect cortical discontinuity.

In assessing trauma two perpendicular planes are mandatory. In anatomic areas where this is not possible or helpful (pelvis, shoulder) additional oblique projections are produced. If initial films do not show a fracture despite strong clinical suspicion, the affected extremity should be immobilized and a repeat study performed after 8 – 10 days. These delayed images will usually depict fracture lines better due to bone absorption during fracture healing. MR images can also be obtained to detect occult trauma early.

Fig. 7. Patent with suspected scaphoid fracture. The wrist film and the scapoid series did not show a definite fracture line. A faint line is seen in the proximal third of the scaphoid. MR imaging of the wrist reveals a bone marrow edema and fracture indicated by a low signal area on a T1 weighted image.

There are many ways of classifying fractures. The sometimes complex classification systems used by orthopedic surgeons will not be discussed in this text in favor of a more simple approach.
A **linear fracture** is a radiolucent fracture line traversing a bone. The fracture is described according to the orientation of the fracture line and the number of fragments (see figure 8). If the fracture line extends only partway through the bone, it is an **incomplete fracture**. If the fracture consists of a single line separating two fragments, it is a simple fracture. If there are more than two fragments at the fracture site, it is a **comminuted fracture**. In a simple fracture there is a proximal fragment (closest to the center of the body) and a distal fragment (farthest from the center of the body).

![Fig. 8. Diagram showing different types of fractures: fissure or incomplete fracture, transverse simple fracture, oblique simple fracture, spiral fracture, simple and complex comminuted fracture. The x-ray example shows a severely comminuted fracture of the proximal humerus. Note that the angulation of the facture with 30 degree dorsal tilt of the distal fragment is fully seen only on the transscapular view (second plane).](image1)

Fractures may be described as displaced or in anatomical position. If they are displaced they are described in terms of position and alignment of the fragments. The distal fragment is seen in relation to the proximal fragment. In order to describe alignment the angulation or tilt of the distal fragment is assessed in relation (dorsally, volarly, inferiorly, medially, etc.) to the proximal fragment. If the fragments are parallel the displacement is described in terms of shaft width or cortical width and direction of displacement. If the fragments are displaced distally they are distracted as opposed to a contracted (overriding) fracture.

![Fig. 9. Diagram showing displaced fractures: 1 sideways displacement, 2 sideways with contraction, 3 angulated, 4 distracted with rotation.](image2)
**Impacted fractures** present with an area of increased density rather than a fracture line. This is because proximal and distal fragments have telescoped into each other and twice as much bone occupies the same space, which in turn results in an increased x-ray absorption.

**Stress fractures** may occur when a bone is stressed by physical activity well above the patient’s usual activity level. Initially, there may be no x-ray findings, but after a few weeks increased bone density or callus formation may be seen as healing progresses.

**Chip fractures** are minute pieces of bone, which may be chipped off a bone by trauma.

**Avulsion fractures** are small pieces of bone, which may be pulled off a larger piece by the forceful pull of a muscle, tendon or ligament.

A **pathologic fracture** is a fracture through a preexisting bone lesion, frequently a tumor or sometimes an infection or area of aseptic necrosis. The pathologic fracture is characterized by a history of no trauma or minor trauma not anticipated to be sufficient to fracture the bone.

An **articular fracture** is a fracture through a joint surface. When a fracture line crosses a joint surface, that fact should be mentioned in the report.

**Greenstick fractures** are seen only in children. Rather than a fracture line there is buckle or bend in the bone. Another type of fractures seen in children is an epiphyseal separation. This is a fracture through the physis (epiphyseal growth plate). There may be only minimal widening of the plate or considerable displacement of the epiphysis from the metaphysis.

### Table 1: Fractures involving the growth plate classified according to Salter-Harris or Aitken.

<table>
<thead>
<tr>
<th>Salter-Harris</th>
<th>Aitken</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>I</td>
<td>Transverse fracture through the physis</td>
</tr>
<tr>
<td>II</td>
<td>II</td>
<td>Fracture through the physis and metaphysis</td>
</tr>
<tr>
<td>III</td>
<td>III</td>
<td>Fracture through the physis and epiphysis</td>
</tr>
<tr>
<td>IV</td>
<td>IV</td>
<td>Fracture through physis, metaphysis and epiphysis</td>
</tr>
<tr>
<td>V</td>
<td>V</td>
<td>Compression fracture of the physis</td>
</tr>
</tbody>
</table>

Fig. 10. Diagram showing the growth plate fracture types according to the classification by Salter and Harris (from Wikipedia).
17.3.3. Dislocation and Subluxation

When the range of normal relationships for a particular joint is slightly exceeded, it is called a subluxation. When it is grossly exceeded and the articulating structures are not in contact any more, it is called a dislocation. Joints most frequently affected by a luxation are shoulder, elbow, ankle, hip, and interphalangeal joints. Luxations will usually cause capsule and ligament disruption with soft tissue swelling and loss of fat planes. Associated avulsion fractures are frequently seen. As in fracture imaging exposure in two perpendicular planes are required to correctly visualize and describe a luxation or dislocated fracture.

Fig. 12. A) Complete dislocation with contraction in the elbow joint. Ulna and radius are both dislocated and dorsally displaced. B.) Anterior and inferior dislocation of the humerus.

17.4. Degenerative Joint disease

Primary osteoarthritis involves weight bearing joints such as the knee, where changes are seen especially in the medial compartment and the patellofemoral compartment. In the hip changes are seen superolaterally. The tibiotalar joint is rarely significantly involved, except for changes along the anterior margin of the distal articular surface of the tibia. These are most likely posttraumatic in origin.
Fig. 13. A) Knee joint with degenerative changes. Note the sclerotic medial tibial plateau and joint space narrowing. A small osteophyte is seen on the medial femoral condyle. B.) Pelvis with marked degeneration of both hip joints. The right femoral head shows lateral osteophyte formation and is deformed. The joint space is narrow with increased subchondral sclerosis of the acetabular roof. The left hip has a marked joint space narrowing and lateral osteophyte formation. The femoral head shows increased density due to sclerotic areas and irregularity.

In the hand there is typically involvement of the trapezium-scaphoidal joint and the first carpal-metacarpal joint. In addition, there is involvement of the distal interphalangeal joints of the fingers with lesser changes at the proximal interphalangeal joints and the metacarpal-phalangeal joints.

Fig. 14. Typical degenerative changes in the hand: A) Joint space narrowing and subchondral sclerosis of the trapezoidum-scaphoidal joint and the first carpal-metacarpal joint. B.) Degenerative arthritis of the distal interphalangeal joint showing typical osteophyte formation, joint space narrowing and increased sclerosis.
In the foot there is often involvement of the first metatarsal-phalangeal joint. In addition to joint space narrowing and subchondral sclerosis there is subchondral degenerative cyst formation and osteophyte formation along joint margins. Osteophytes are the sine qua non of osteoarthritis. In degenerative joint disease new bone formation is seen as a response or repair reaction. In inflammatory arthritis there usually is a destruction of bone and osteophytes are not seen.

In the spine, changes are seen in the facet joints throughout and at the uncovertebral joints in the cervical region. Degenerative disc disease is also seen with associated osteophyte formation. The traction osteophytes of degenerative annular disease begin several millimeters from the edge of the vertebral body, and tend to be initially oriented horizontally at their attachment to the vertebral bodies. They then often curve slightly and may even form a complete bony bridge across the disc space.

Sacroiliac joint involvement is common. The sclerotic joint margins are sharply defined as opposed to changes seen in inflammatory arthritides.

Degenerative osteoarthritis may be secondary to previous infection or trauma. In these cases there is more degenerative change in the particular joint than may be found in corresponding regions elsewhere in the body. Osteophytes can be seen in both primary and secondary osteoarthritis. They can also be seen at various entheses, often due to altered or increased stress at the entheses (traction osteophytes).

17.5. Arthritis

17.5.1. Rheumatoid arthritis

Rheumatoid arthritis may involve any synovial joint. The sacroiliac joints are involved only infrequently. The greatest involvement is in the small joints of the hands, wrists and feet with sparing of the distal interphalangeal joints. In early stages there may be only soft tissue swelling and juxta-articular osteoporosis. Next joint space narrowing and early erosive changes are seen.

In general, the presence of erosions bespeaks some type of inflammatory disease, whether the erosions are due to synovial hypertrophy, crystalline deposits, or infection. In rheumatoid arthritis, the erosions follow the development of an inflammatory proliferation of the synovium, called pannus. As this pannus increases in amount, it begins to cause erosions of the chondral surface. As the pannus increases further in amount, one begins to see erosions at the periarticular "bare" areas. These "bare" areas refer to bone within the synovial space which is not covered by articular cartilage. The articular cartilage tends to protect the bone that it covers. The marginal "bare" areas are not covered by cartilage, and the earliest erosions of rheumatoid arthritis are seen here.
Rheumatoid arthritis also involves the cervical spine, with apophyseal joint erosion and malalignment, intervertebral disc space narrowing with endplate sclerosis and without osteophytes, and with multiple subluxations, especially at the atlanto-axial junction. Abnormalities of the thoracolumbar spine and sacroiliac joints are infrequent and less prominent than those of ankylosing spondylitis.

### 17.5.2. Ankylosing Spondylitis

Ankylosing spondylitis affects synovial and cartilaginous joints as well as sites of tendon and ligament attachment to bone (entheses). An overwhelming predilection exists for involvement of the axial skeleton, especially the sacroiliac, apophyseal, discovertebral, and costovertebral articulations. Early in ankylosing spondylitis there is sacroiliac joint involvement with blurring of the joint margins and some reactive sclerosis. Then changes appear at the thoracolumbar and lumbosacral junctions.

Therefore, sacroilitis is the hallmark of ankylosing spondylitis. Although an asymmetric or unilateral distribution can be evident on initial radiographic examination, roentgenographic changes at later stages of the disease are almost invariably bilateral and symmetric in distribution. This symmetric pattern is an important diagnostic clue in this disease and may permit it differentiation from other disorders that affect the sacroiliac articulation, such as RA, psoriasis, Reiter's syndrome, and infection. Changes in the SI joint occur in both the synovial and ligamentous (superior) portions, and predominate on the iliac side.

Inflammatory synovial changes and subchondral edema are well seen on MRI. MRI is more sensitive and is being used with increased frequency to detect and stage inflammatory involvement of the sacroiliac joint in patients with ankylosing spondylitis.
Fig. 16. T1 weighted and STIR images of the sacroiliac joints in a young patient with low back pain. Low signal areas on T1 correspond with edema seen on STIR. Note the joint space narrowing and the more pronounced subchondral changes in the iliac bone as compared to the sacrum.

There is squaring of the vertebral bodies and syndesmophyte formation. Osteoporosis is generally prominent. Syndesmophytes are generally seen only in the seronegative spondyloarthopathies. These are due to inflammation and ossification of the outer fibers of the annulus fibrosus, known as the Sharpey's fibers. This is classically seen in ankylosing spondylitis. In the other seronegative spondyloarthopathies, one usually sees paravertebral ossification, which forms in the paravertebral connective tissue at some distance from the spine.

17.5.3. Psoriatic arthritis

While many of the changes are similar to those seen in rheumatoid arthritis, the changes in psoriatic arthritis are not always symmetrical. There is greater involvement of the distal interphalangeal joints and joint fusion occurs with higher frequency. About 30 to 50% of patients with psoriatic arthritis develop sacroiliac joint changes. Sacroiliac joint involvement may be bilateral or unilateral. Radiographic sacroiliac joint changes include erosions and sclerosis, predominantly on the iliac side, and widening of the articular space. Although significant joint space diminution and bony ankylosis can occur, the incidence of these findings, particularly ankylosis, is less than that of classic ankylosing spondylitis or the spondylitis associated with inflammatory bowel disease.

17.5.4. Reiter's syndrome

Reiter's syndrome is associated with an asymmetric arthritis of the lower extremity, sacroiliitis, and, less commonly, spondylitis. Although its general features resemble those of ankylosing spondylitis and psoriatic arthritis, Reiter's syndrome has a greater tendency to affect the feet and lower extremity with relative sparing of the upper extremities. A history of urethral and eye complaints helps with the diagnosis.
17.6. Osteomyelitis

Osteomyelitis may occur anywhere, as direct extension of a soft tissue infection or from an open fracture. Hematogenous osteomyelitis usually begins in the metaphyseal region of long bones because of their blood supply. The infectious process may spread through the subperiosteal region, through the marrow cavity, or both. Osteomyelitis most frequently affects children due to their specific vascular supply of the metaphyseal region and in immune deficient adults.

In early osteomyelitis the x-ray may be completely normal or just show slight soft tissue swelling. A nuclear bone scan or MRI exam will allow much earlier detection of osteomyelitis. Faint demineralization of the area bone involvement may be seen after two weeks progressing to changes of permeative demineralization. Other signs are periosteal new bone formation and loss of sharpness of cortical margins. The more aggressive the infection the more bone destruction and radiolucency will be seen. Periosteal new bone formation and sclerotic changes relate to the tissues attempt to reconstruct normal bone.

If an osteomyelitis becomes chronic there will be an altered architecture with multiple areas of lucency surrounded by areas of sclerosis and areas of irregular cortical thickening.

17.7. Metabolic bone diseases

Metabolic bone disease is one of the most fascinating and complex subjects in radiology. There are many subtle interactions occurring among diverse mechanisms, some of which are not well understood. To stay in the scope of this text only a few entities will be mentioned.

One of the most common findings in skeletal radiology is increased radiolucency of bone, most properly termed osteopenia. This term is preferred over "demineralization", since the exact mineral status of the patient's bone cannot be determined from the radiograph alone. The most common cause of osteopenia is osteoporosis. However, there are many disease entities that can cause osteopenia, so the mere finding of radiolucent bone does not make this an automatic diagnosis.

17.7.1. Osteoporosis

Osteoporosis results from a loss of bone. On conventional film a 30 – 50 % loss of bone mass is required before osteoporosis can be recognized.

Senile osteoporosis refers to the gradual loss of skeletal mass that is seen with advancing age. Postmenopausal osteoporosis refers to the increased bone loss seen in women following menopause. Both of these processes are very common, and both commonly occur in the same individuals. The pathogenesis of both of these states is not clear, but probably involves a combination of decreased bone production and increased resorption. In general, the gradual loss of skeletal mass begins in women in the fourth decade and in the fifth or sixth decade of life for men. This bone loss accelerates in women following the menopause.

Clinically, the loss of spongy bone in osteoporosis causes a predisposition to fractures, especially compression fractures of the vertebral bodies, fractures of the distal radius and fractures of the femoral neck and trochanteric regions. In addition of anterior wedging of vertebral bodies there is increased concavity of the vertebral endplates.
Inadequate dietary calcium intake may lead to osteoporosis. Patients receiving large doses (> 15,000 units/day) of heparin may develop a reversible osteoporosis. Alcoholic patients may also develop reduced bone mass and increased bone fragility, for reasons that are not well understood.

The osteoporosis occurring during Cushing's syndrome or following exogenous steroid administration is well known. Histologic studies of this process reveal a combination of decreased bone production as well as increased bone resorption.

Hyperthyroidism, acromegaly, pregnancy, idiopathic juvenile osteoporosis and osteogenesis imperfecta are other entities that present with osteoporosis during their course. These are fairly rare causes of osteoporosis, but should be kept in mind when one is faced with unexplained osteoporosis, particularly in younger patients.

17.7.1.1. Disuse osteoporosis

Generally, disuse osteoporosis presents as a diffuse osteopenia seen throughout the disused body part. Lucent bands of osteopenia may be seen just proximal to the physeal line. Following an extremity injury and immobilization, the injured extremity experiences a lack of normal stresses to the bone which can result in a pronounced osteoporosis distal to and including the area of injury.

17.7.2. Reflex sympathetic dystrophy syndrome

Reflex sympathetic dystrophy syndrome (RSDS, Sudeck atrophy) is a disorder of unclear etiology. It is characterized clinically by pain, vasomotor disturbances (vasospasm or vasodilatation) and trophic skin changes (skin atrophy, pigmentation abnormalities, hypertrichosis, hyperhidrosis and nail changes) and radiographically by regional osteoporosis in the affected area. The diagnosis of RSDS relies on the recognition of the classical clinical findings. The main radiographic findings are soft tissue swelling and regional osteoporosis.

17.7.3. Osteomalacia

Osteomalacia is the term used to describe inadequate mineralization of the osteoid, which is present. In children this presents as rickets, and in adults as osteomalacia. The two important differential diagnosis include disturbances of vitamin D metabolism and renal tubular phosphate loss. The classic findings of osteomalacia include decreased bone density, coarsening of the trabecular pattern and cortical striations, followed by cortical thinning as the disease progresses. In some cases of osteomalacia, collections of osteoid may build up to the point that these "seams" of osteoid may be seen on plain radiographs as linear luencies oriented perpendicular to the cortical margin. If large enough, these "Looser's zones" or pseudofractures may help lead one to the diagnosis of osteomalacia.
17. Musculoskeletal Radiology

17.7.4. Hyperparathyroidism

The primary form is due to a hyperfunctioning parathyroid gland, usually an adenoma. However, since the advent of hemodialysis, a far more common cause for hyperparathyroidism is the secondary form, due to chronic kidney disease, especially glomerular disease. The skeletal disease seen in these patients is usually referred to as renal osteodystrophy.

Once enough bone has been resorbed from the skeleton due to elevated parathormone levels, one may see diffuse skeletal osteopenia. This finding is extremely nonspecific. A far more specific finding is the presence of subperiosteal resorption, which is practically pathognomonic for hyperparathyroidism.

17.8. Bone tumors

The most important thing to determine about a primary bone tumor is whether it is benign or malignant. Benign tumors do not have an aggressive appearance. They are slow growing lesions with a definite geographic appearance, well defined sclerotic margin or no sclerosis at the margin but clear cut definition of the interface between the lesion and the normal bone. Benign lesions tend to respect the normal bone architecture. Nonaggressive lesions may expand and thin the cortical bone but usually stay confined to the host bone.

In more aggressive lesions the margins become poorly defined, lesions may show a moth eaten pattern or even a permeative, diffuse bone destruction and lesions will take a more spherical shape and will not respect bone architecture. Some tumor will permeate through the cortex and periosteum and will have a large soft tissue component. Metastatic lesions are often multiple and present in a patient with an already known malignancy elsewhere. Nevertheless, when a solitary aggressive lesion with ill defined margins and permeative appearance is seen in a middle age or older individual is seen, metastatic malignancy must be considered more likely than a primary bone tumor. Most metastatic tumors are osteolytic, however adenocarcinoma of the prostate most frequently manifests as osteoblastic. Breast cancer metastasis will sometimes present as blastic lesions as will some lymphomas, particularly Hodgkin’s disease. An initially osteolytic lesion may convert to osteoblastic under the influence of radiation or chemotherapy.

A nuclear medicine bone scan is the method of choice in evaluating for the presence of bone metastasis in a patient with a known primary such as bronchogenic or breast carcinoma. A bone scan has a greater sensitivity and areas which are “hot” on the nuclear study can then be evaluated with conventional x-ray examinations.

Differential Diagnosis of Solitary Lucent Bone Lesions

- Metastasis / Myeloma
- Eosinophilic Granuloma / Enchondroma
- Solitary Bone Cyst
- Aneurysmal Bone Cyst
- Giant Cell Tumor
- Non-ossifying Fibroma
- Fibrous Dysplasia
- Osteoblastoma
- Chondroblastoma / Chondromyxoid Fibroma
- Hyperparathyroidism (brown tumors) / Hemangioma
- Infection
Patient age is important to narrow the potential differential diagnosis of a bone tumor. The table gives a rough scheme relating bone tumors with patient age. Table: Typical bone tumors and age groups.

<table>
<thead>
<tr>
<th>Age</th>
<th>Tumor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – 10 év</td>
<td>Ewing’s sarcoma</td>
</tr>
<tr>
<td>10 – 30 év</td>
<td>Osteo sarcoma, Ewing’s sarcoma</td>
</tr>
<tr>
<td>30 – 40 év</td>
<td>Fibrosarcoma, parosteal osteosarcoma, malignant giant cell tumor, lymphoma</td>
</tr>
<tr>
<td>&gt; 40 év</td>
<td>metastatic carcinoma, multiple myeloma, chondrosarcoma</td>
</tr>
</tbody>
</table>

If a lesion is growing slowly then the bone will retreat from the lesion but new bone around the margins of the lesion will be created producing a sclerotic and usually distinct margin around the lesion. If the process grows more rapidly surrounding bone may only have time to retreat without building this sclerotic rim. Solitary lucent lesions in bone with a distinct margin are generally called "geographic" lesions, whether or not they have a sclerotic rim. If the process grows more rapidly the boundary between normal and abnormal bone may be lost with only a very ill-defined pattern of lucency, caused by small, irregular holes in the bone. This indicates an extremely aggressive growth pattern, also called a "permeative" pattern. The most common malignancies that display a permeative pattern are metastases, myeloma, primary histiocytic lymphoma, and Ewing's sarcoma.

Fig. 17. Lodwick classification for description of solitary lucent bone lesions. 
IA - slowly growing tumor - sharp lesion with sclerotic margin, usually benign. 
IB – slowly growing tumor – geographic lesion without sclerotic margin, thinning of cortex possible. 
IC – faster growing tumor – ill defined but geographic lesion, cortex destruction possible. 
II – fast growing lesion – no geographic pattern but rather a moth eaten appearance with infiltrative pattern, malignant tumor. 
III – very fast expanding tumor – tumor does not respect bone structure or margins, the infiltration has an aggressive “permeative” pattern.
Fig. 18. An osteosarcoma is seen as an ill defined lesion with a permeative pattern of bone destruction with cortex involvement in the distal metaphysis of the femur.

Most expansile, lucent lesions are located in the medullary space of the bone. A good way to further describe a lesion is noting its relationship to the physis. Many lesions have predisposition in specific parts of the bone, which reflects their “original tissue”. For example, a chondroblastoma will arise in the epiphysis whereas an osteosarcoma usually originates from the metaphysis. Round cell lesions like Ewing’s sarcoma are typically seen in the diaphysis.

Another way to further characterize bone tumors is to search is looking at tumor associated matrix. Matrix is produced by osteoblasts and chondroblasts and usually is the basis for new bone or cartilage formation. Matrix produced by tumors is usually quite abnormal and does not ossify properly. The matrix produced by bone tumors may help to classify a lesion as cartilage producing tumor (enchondroma, chondrosarcoma, chondromyxoid fibroma, etc.) or bone-producing tumor (osteoma, osteoblastoma, osteosarcoma, etc.). Chondroid matrix tends to produce small punctate or swirled areas of calcification. Osseous matrix is dense and confluent. Some lesions show little or no calcification in their matrix (fibrous dysplasia, fibrosarcoma, malignant fibrous histiocytoma, solitary bone cyst, etc.).
Fig. 19. Chondrobastoma: An expansile lesion involving the epiphysis, physis and metaphysis of the humerus is depicted. The lucent lesion shows cortex destruction and spotty matrix calcifications.

As opposed to lucent lesions with we have to consider sclerotic lesions.

A lesion is called sclerotic if it is more dense or radiopaque than surrounding bone. These lesions generally indicate a slow-growing process. Bone reacts to its environment in two ways — either by removing some of itself (usually in rapidly progression lesions) or by creating more bone (bone has time to form a sclerotic area around the lesion).

Differential Diagnosis of Sclerotic Bone Lesions

- hemangiomas
- infarct
- stress fracture
- chronic osteomyelitis
- osteoma
- osteosarcoma
- prostate cancer
- breast cancer
- Vitamin D toxicity
- Fluoride toxicity
- hyperparathyroidism
- osteopoikilosis
- osteopetrosis
- Paget's disease
17.8.1. Plasmacytoma

Plasmacytoma is a malignant plasma cell tumor predominantly growing from the red bone marrow. Plasmacytoma is the most frequent malignant bone tumor. The primary solitary plasmacytoma is less frequent than the multilocular disseminated form (multiple myeloma). Most frequent locations involved by multiple myeloma reflect the distribution of red blood cells: spine, pelvis, skull, ribs and proximal long bones. The diagnosis is made by immunoglobulin electrophoresis and bone marrow biopsy. Bone involvement is searched for by imaging the axial skeleton, skull and proximal long bones. This can be done by conventional x-ray films, however, low dose CT has replaced conventional radiography in the initial staging of plasmacytoma in recent years due to its better performance. Especially the detection and characterization lesions in spine and pelvis is much more reliable when it is based on cross sectional imaging.

Nuclear bone scan will usually not show an increased uptake. If a lucent bone is seen on conventional x-ray with uptake in bone scintigraphy then plasmacytoma will be the most likely diagnosis. MR imaging is quite sensitive in detecting bone marrow involvement on T1 weighted and STIR sequences.

17.8.2. Fibrous dysplasia

This idiopathic disorder is due to excessive proliferation of the spindle cell fibrous tissues in bones. Although this process may occur rarely in the cortical bone, the vast majority of cases originate in the medullary space. Therefore, most cases present as bony enlargement with the process seeming to arise from an expanded medullary space.

The main clinical significance of this entity depends upon exactly which bones are affected. These bones will exhibit deformity, enlargement, and pain. Occasionally, pathological fractures will develop, and malignant transformation to osteosarcoma is seen rarely (< 0.5 %).

Two forms of fibrous dysplasia are seen in general radiologic practice: the conventional form (Jaffe-Lichtenstein syndrome) which may be monostotic or polyostotic, and a polyostotic form associated with precocious puberty and café au lait spots (McCune-Albright syndrome).

17.9. Vascular disorders

17.9.1. Osteonecrosis

Osteonecrosis represent non-vital bone. Synonyms include aseptic necrosis, avascular necrosis, bone infarction and ischemic necrosis. The terms "aseptic" or "avascular" necrosis is used when juxtaarticular areas are involved or entire bone necrosis is discovered. The term bone infarct is usually applied to metaphyseal or diaphyseal involvement.

Osteonecrosis is multifactorial in etiology and can involve different areas and bones. Some predilections do exist.
Osteonecrosis needs to be present for some time before it can be detected on plain radiographs. Early in development an ill-defined mottling of the trabecular pattern is seen. The late findings of osteonecrosis depend upon its location within the bone. If the lesion occurs in the medullary space well away from the joint, one eventually may see the classic pattern of dense, serpiginous calcification. However, if the necrosis occurs in the subchondral bone, a different pattern usually emerges. Once the osteonecrosis has been present for months, microfractures will accumulate in the dead bone to the point that one may see developing subchondral fractures. This may lead to a discontinuity in the subchondral line, or in some cases, to the "crescent sign", which represents a fracture between the subchondral line and adjacent necrotic bone. As living bone reacts to the presence of adjacent dead bone, a thick sclerotic zone may develop along the "no-man's land" between the living and necrotic bone.

17.10. Developmental disorders

17.10.1. Achondroplasia

Classic achondroplasia is an autosomal dominant disorder, and is compatible with a long life span. Most cases of achondroplasia are due to new mutations, rather than inheritance from a parent.

Achondroplasia is a disproportionate type of dwarfism characterized by shortened extremities and rather unaffected spine and skull. The primary problem is a generalized defect in enchondral bone formation resulting in significantly impaired growth in length. The characteristic shape of the skull and face in achondroplasia reflects this fact. The calvarium is modelled on membranous bone, and its size is a reflection of brain size. These people have brains of normal size, so their calvaria are likewise of normal size. The face and skull base, on the other hand, come from enchondral bone and end up relatively small, in comparison to the skull. The foramina of the skull base and spine and the spinal canal are often small, which may lead to prominent neurological problems and spinal stenosis. The metaphysis of long bones are broadened and diaphysis is shortened and deformed.

17.10.2. Osteogenesis imperfecta

This inherited, generalized disorder of connective tissue is characterized by abnormal maturation of collagen. It affects the skeleton, ligaments, skin, sclera, and teeth. Clinical signs are blue sclera and odontogenesis imperfecta. Furthermore, impaired periosteal and endosteal new bone formation results in generalized osteoporosis with skeletal fragility. Growth retardation occurs in most cases. The patient’s short stature, however, does not only reflect impaired bone growth but also deformities secondary to multiple fractures in the fragile bones. Excess callus formation and pseudarthroses may also be seen. Despite increasing numbers of patients with renal failure, the incidence of renal dystrophy is decreasing due to better understanding of the underlying metabolic process and preventive treatment.
18. The fundamentals of pediatric radiology

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18.1. Differences between pediatric and adult radiology

The child is not a small adult – it might seem as a cliché, but in fact it is the basic truth. Children and adolescent suffer from different diseases than adults and require different therapies as well as altered imaging approaches.

The strategies for diagnostic imaging are different, although the modalities are the same or similar to those used in adult radiology. The sequence of modality choice, some of the technical parameters and the follow-up protocols are different in pediatric radiology.

The number one difference is radiation safety. Children are especially sensitive to ionizing radiation. Immature tissues are extremely sensitive to radiation and there is no minimal safety dosage that is considered absolutely harmless. Tissues in growth and the red bone marrow – that takes up most of the bone marrow tissue – at this age group are especially sensitive to radiation. Because of the smaller body size, the gonads are closer to the irradiated zones. Moreover, because of the longer life expectancy in children, the cumulative dose of natural and artificial radiation mean higher risk for the development of malignant diseases. The best protection is to minimize or to completely avoid the use of ionizing radiation in children.

This, on one hand means strict control and supervision of the indications of X-ray and CT examinations, on the other hand, when possible, the use of non-ionizing examinations such as ultrasound or MRI are preferred. The other perspective of radiation safety is to decrease the number of X-ray expositions to the bare minimum, meaning that unnecessary repetitions, comparative or multi-angular examinations should be avoided. CT examinations should only be performed if they are absolutely necessary and if so with the use of special, low-dose protocols.

The so called ALARA acronym stands for – As Low As Reasonably Achievable -., therefore it means that one should use the lowest dosage of radiation possible. This point of view can never be neglected in pediatric radiology.

This chapter is meant to introduce the most important radiologic modalities in children and adolescent care differing from the adult radiology, as well as to give an overview of the most common diseases in a short and basic manner.

18.2. Radiologic diagnostics of the chest

18.2.1. The normal newborn chest

*Normal newborn lungs:* a newborn’s chest goes through some fundamental changes during the first days of extra-uterine life. The heart is relatively rounded, characterized by the dominance of the right side. The cardio-thoracic index taken in a mid-inspiratory state is between 0.55-0.62. Expiratory state can lead to diagnostic mistakes.

*Thymus:* is usually made up of two asymmetrical lobes, situated in the anterior-superior mediastinum and shows a great variability of both size and shape. It does not cause any compression on the neighboring organs. On ultrasound examination it appears as a homogenous solid tissue, relatively more hypo-echoic than the thyroid gland. The diaphragm is a bit more elevated in mid-inspiratory state its arch is between the 8-9th rib on the back and at the 6th rib in the front.
Bony thorax: the ribs are horizontal and the sagittal and horizontal diameters of the chest are very close to each other.

1. a. Expiratory state: the transparency of the lung is diffusely decreased.
1. b. Inspiratory state, the lung is transparent, the heart is normal sized. Ribs run horizontally in infants.
2. Thymus has a contour on both sides. Healthy newborn.

18.2.2. A few diseases of the newborns

Wet lung, transitoricus tachypnoe. Fetal liquids in the lung are not properly drained by the venous and lymphatic vessels; the newborn will show signs of dyspnea and tachypnea. On X-ray, the chest appears hyperinflated, with decreased transparency and with a relative cardiomegaly. These signs usually disappear within 72 hours.

IRDS (Idiopathic respiratory distress syndrome). Preterm infants, younger than 34 weeks, have immature lungs with surfactant shortage that leads to alveolar insufficiency. The breathing disorder progresses with time as tachypnea, dyspnea, cyanosis and grunting occur. On X-ray images the respiratory volume will regress and a diffuse reticular-nodular pattern can be observed, also wide air-bronchograms will appear running to the peripheries. The contours of the heart will be blurred or even a complete loss of transparency is visible (stages I-IV). Surfactant administered in time will result in improved radiologic picture.

Meconium aspiration syndrome (MAS). It is frequently the disease of term and post-term newborns. The fetus defecates meconium to the amniotic fluid that is aspirated at birth, and it causes chemical pneumonitis. On the radiograph this is depicted with coarse patchy and streaky alveolar shadows.

Bronchopulmonary dysplasia (BPD). It is the pulmonary damage that occurs in immature newborns due to prolonged perspiration. Its radiologic picture depends on the stage of the disease, early signs of BPD are undistinguishable form IRDS. In later stages, the lung is hyperexpanded with pronounced central reticular pattern. Atelectasis is a frequent complication that promotes the appearance of infectious diseases.
Congenital diaphragm hernias. It is the result of abnormal diaphragm development. Its radiologic picture is influenced by its severity, localization, and time of duration. Left sided hernias are more frequent (also called Bochdalek hernias). The newborn suffers from respiratory insufficiency, intestinal and dislocated heart sounds can be heard above the chest, the abdomen is collapsed. The right sided diaphragm hernia is also called the hernia of Morgagni and causes a less severe clinical picture, many times discovered accidentally on the X-ray. On ultrasound the missing diaphragm and a herniated portion of the liver is seen.

18.2.3. Pneumonia

In case of characteristic clinical, auditory and percussion examination results (crepitation, bronchial breathing sounds, dullness at percussion) a radiologic examination is not even necessary.

Radiography: for the majority of pneumonias a single PA chest X-ray is enough for the diagnosis. The initial examination within the first 24 hours of onset is generally negative, if its clinically necessary, control exam is to be performed. However, if the treatment for bronchopneumonia improves the clinical symptoms X-ray can be neglected. The final confirmation that the infiltrate has been resolved is always documented on a radiograph. In case of pleuro-pneumonias ultrasonography is capable to control, to analyze and to follow the course of the pleural effusion. Therefore, many control X-ray exams can be substituted with US.

X-ray in general is not appropriate to fully determine the etiology of pneumonia, but can be indicative in some cases.

Streptococcus B pneumonia: is an acquired infection after birth of mature newborns and it can mimic IRDS. The difference to IRDS is the coarser reticular-nodular appearance accompanied by pleural effusion at many times. Sometimes scattered or confluent perihilar pattern can be recognized.
Staphylococcus aureus pneumonia: is a common bacterial pneumonia in small babies. Its clinical picture on X-ray is accompanied by coarse nodular or confluent infiltrations, with frequent pleural effusions. The pneumatic nodules consolidate fast and form pneumatoceles that can grow further and persist for a longer time. Healing usually lasts for months.

Round pneumonia: is a characteristic pediatric disease. The round shaped infiltration mimics a tumor on the X-ray image (neuroblastoma, bronchogenic cyst). Acute development, a feverish state, and air-bronchogram appearance within the infiltrate help with the differentiation, as well as the regression of the infiltrate by the end of the therapy. The most common bacterium is Streptococcus pneumoniae. Further imaging (CT) is rarely necessary.

18.2.4. Airway foreign body

Children put anything in their mouth and, therefore from time to time accidental aspirations tend to occur. The symptoms of acute aspiration are very apparent. A pneumonia recurring at certain localization is highly suggestive of chronic aspiration of a foreign body. Hence, the role of radiology is more important in chronic cases of aspiration, where patient history does not necessarily indicate foreign body aspiration.

X-ray examination: aspirated foreign bodies are rarely X-ray absorbing, and therefore rarely appear on the radiographs. A negative inspiratory chest X-ray does not exclude the possibility of a FB aspiration. Most FBs cause occlusion on the level of the bronchi, which means that in inspiration air can get further than the FB but at expiration it will block the airway. Thus, on expiratory chest X-ray, the affected lung segment will be pneumatic; the diaphragm will be pushed lower on the ipsilateral side, while at inhalation the midline will be shifted towards the affected side (Holzknecht sign). In suspicion of FB aspiration (even if chest radiograph is negative) bronchoscopy is compulsory.

18.3. Gastrointestinal (GI) tract

18.3.1. Examination methods:

Preparation: When performing a passage examination in newborns or small infants the last feeding is skipped. A starting abdominal plain film radiograph is mandatory before each passage examination (to identify the distribution of intestinal gas, to rule out free abdominal air, or intestinal wall pneumatization and to locate the level of obstruction.) Plain abdominal x-ray is in many cases informative, whether contrast administration is really necessary, and if
18. The fundamentals of pediatric radiology

an immediate surgery is unavoidable (e.g.: free abdominal air, or in case of a proximal atresia in newborns). In cases of contrast examinations (passage exam or colon enema) the preferred contrast agent has a low osmolality and is absorbable.

18.3.2. A few important diseases

**Esophageal atresia:** is commonly located at the level of the upper/middle esophageal border and is sometimes associated with tracheo-esophageal fistulas. Newborns are unable to swallow their saliva and the diagnostic tube gets stuck in the esophagus. The most common form is atresia with a lower fistula. In 50% of the cases other abnormalities are present; as part of the so called VACTERL syndrome (vertebral, anal, cardiac, tracheo-esophageal fistula, renal and limb) various additional abnormalities can be observed.

X-ray examination: an X-ray absorbent tube is visible in the obstructed diverticula of the esophagus. In cases of a lower fistula, the intestines are aerated, the accompanying costal and vertebral abnormalities can also be observed.

**Hypertrophic pyloric stenosis (HPS).** As a result of the hypertrophy and hyperplasia of the pyloric musculature a secondary stenosis can occur, that usually leads to symptomatic states in 3-6 weeks old infants. It primarily occurs in boys as frequent, progressive, nonbilious, projectile vomiting. On ultrasonography an enlarged (15mm or more), thick walled (3mm or more) pylorus can be seen in both longitudinal and in axial cross section.

**Duodenal obstruction.** The cause of proximal obstruction is primarily duodenal atresia or stenosis. Usually US is able to depict the distended stomach and duodenum during intrauterine US examination as a cystic mass, while other intestines are completely free of fluids. Vomiting occurs in the first hours of extra-uterine life. Plain abdominal radiograph in cases of atresia will reveal the so called “double bubble” sign, where the stomach and the duodenum are distended but on distal segments, the intestines are gas free. In cases of
stenosis, the distal intestinal loops will also show some air content. Other examinations are unnecessary and air can be used as a negative contrast material.

**Malrotation-volvulus.** During the normal development of the intestinal tract, the intestinal loops make three 90 degree clockwise rotations around the mesenteric superior artery (MSA.) If this rotation only partially occurs during the embryonic development the intestines remain in a non-rotational or malrotational position, the mesenteric root will be shorter and the cecum will be weakly attached. This anatomic positioning can be symptom free throughout a lifetime, but it predisposes for volvulus. Volvulus can occur at any age, but it is most frequent in the first months of life, when it abruptly occurs with acute bilious vomiting. In this state the intestines around the mesenteric root twist, end up in a complete obstruction that can lead to a rapid death of the intestines. Ultrasonography can depict the mesenteric superior vein (MSV) coiled up around the MSA, so called “whirlpool”-sign. During X-ray examination the contrast material does not progress to the jejunal loops or it shows a “corkscrew” sign on the right side of the vertebrae as it piles up in the twisted intestinal loops.

![Image](image1.png)

**13. Distended stomach and duodenal bulbus, “Double bubble” sign. Duodenal atresia.**

![Image](image2.png)

**14. “Whirlpool” sign The mesentery and the superior mesenteric vein, as it coils around the superior mesenteric artery. Volvulus. US exam.**

![Image](image3.png)

**15. Contrast material empties the stomach slowly, small intestines are found on the right side of the abdomen. Malrotation-volvulus.**

![Image](image4.png)

**16. “Non-used”, narrow colon. Newborn, meconium ileus**

**Meconium ileus** occurs in 10% of children with cystic fibrosis (CF), and almost all of meconium ileus cases are a result of CF disease. It is characterized by vomiting and abdominal distention, as the meconium cannot be defecated. On plain abdominal radiograph the intestines are distended without any air-fluid levels due to the adhesive nature of meconium. Colon enema examination with water soluble contrast material will show a micro-colon in which the meconium will cause contrast filling defects resembling small pearls. Contrast material that reaches the terminal ileum, and the repetition of the enemas can sometimes solve the ileus.

**Invagination.** A distal intestinal loop invaginating to a proximal intestinal loop can result in a mechanical intestinal obstruction, and cause ischemic damage. It most frequently occurs in infants (3-24 months) with recurring, colic-like complaints, distended intestines, a palpable mass and with frequent vomiting and bloody stool. Invagination requires immediate diagnosis and desinvagination. US exam reveals the invaginated intestines as a “target” sign in axial cross section and looks like a “pseudokidney” in longitudinal cross section. The therapy is
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Hydrostatic or pneumatic desinvagination. Perforation and/or peritonitis are absolute contraindications to these procedures. Hydrostatic desinvagination can be performed under fluoroscopy or with US guidance and is considered successful if air or the contrast material appears in the terminal ileum and the invaginated loop disappears. If these efforts do not succeed, surgical desinvagination is needed.

**Necrotizing enterocolitis (NEC).** It is a severe intestinal necrotizing disease of the newborns. It usually occurs as early as the first 10 days of life, but can happen in the first few months after birth. Vomiting, distended intestines, bloody stool, acidosis, peritonitis and perforation are frequent findings. Plain abdominal X-ray can be non-informative in the early stages of the disease; later distension indicates the separation of loops due to wall thickening. Often, air bubbles appear in the intestinal subserosal or submucosal layers, as characteristic signs of “intestinal pneumatosis”. The intramural air can diffuse to the mesenteric veins and appear in the portal circulation in the projection of the liver. Free abdominal air is indicative of perforation and requires surgical intervention. US examination can reveal these characteristics of the disease before X-ray is indicative. US can depict thickened intestinal wall, portal and intramural air, abdominal free fluid or abscesses.

**Hirschsprung-disease.** In this disease the ganglions of the distal colon are missing. The lack of innervation of the colonic smooth muscle results in spastic functional obstruction. The symptoms can appear right after birth with the lack of meconium defecation and signs of obstruction. On plain abdominal X-ray the proximal intestines are distended with or without air-fluid levels, the distal loops are gas free. With contrast enema the distal, irregular, spastic, non-innervated segments and the proximal prestenotic dilatation of the colon can be visualized.
19. Distended bowel loops. Air is seen in the intestinal wall, intestinal pneumatosis. Necrotizing enterocolitis.


21. The distal segment of the colon is narrow, irregular (aganglionar segment). Transitional zone (arrow) and compensatory prestenotic dilatation. Hirschspring-disease.

18.4. Urogenital system

18.4.1. Diagnostic methods

Ultrasound is the method of choice, provides detailed information of the morphology of the kidneys and the urinary tract. Prenatal examinations can readily diagnose most of the lesions at the intrauterine age.

Miction cystourethrography (MCU). Is the gold standard for the imaging of the bladder and the distal urinary tracts as well as the investigation of vesico-ureteral reflux. A urinary catheter is inserted and contrast agent is administered with fluoroscopic control.

Sonocystography. Ultrasonographic contrast material is administered to the bladder through a catheter. The contrast material increases the echogenity of the urine (fluid) and in cases of reflux this change can be detected in the ureter and the pyelon. This method in most cases can substitute MCU, however, the urinary catheter still remains an invasive step of the examination.

Nuclear medicine examinations (see there)

MR urography (see there)

18.4.2. Some important diseases

Congenital obstructive uropathies. Congenital abnormalities of kidney development can occur at any level of the urinary tract. Its most common sig is urinary tract dilatation. The role of imaging is in: diagnosing the cause, the level and the stage of dilatation and differentiating the obstructive cases form non-obstructive ones.

Uretropelvic obstruction (UPO). Uretropelvic junction stenosis can be an acquired or an innate state, with different degrees that lead to the dysfunction of excretion of urine from the pyelon to the proximal ureter. It is the most frequent form of obstructive uropathy. US examination even at prenatal states can diagnose the urinary tract dilatation that can be uni- or bilateral, always without ureter dilatation.

Isotope examination: the isotope (Tc-99m-MAG3) injected with diuretics can be used to analyze renal function.

Distal urethral valve (subvesical obstruction). It is the most severe form of obstructive uropathy. In newborn boys the valve dysfunction can lead to bilateral obstruction with
hydronephrosis and hydroureter. Urination can only occur intermittently. The bladder wall is thickened, trabecular and reflux is frequent. The proximal urethra is distended as well.

22. The calices and the pyelon of the kidney are markedly dilated, the parenchyma is thinner. Severe hydronephrosis. The ureter is not visible. Pyelouretral stenosis.

23. Miction cystourethrography. A small diverticula is seen on the right side, the proximal urethra is dilated, beneath is a filling defect. Subvesical obstruction, dorsal urethral valve.

**Vesicouretral (VU) reflux.** Reflux stands for the reentry of urine from the bladder to the ureter and the collecting system of the kidneys due to the insufficiency of the uretrovesical valve. This can lead to a transient or a permanent dilatation of the urinary tracts. US can only raise suspicion for UV reflux through indirect signs such as thickened pyelon wall, small kidney, thinner and blurry cortico medullary junction, uneven parenchyma, thickened bladder wall. Reflux can be depicted with MCU or sonocystography. Reflux is internationally categorized in 5 levels (I-V). Its special form is the intrarenal reflux that appears in the upper or lower pole of the kidney.

24.a. b. c. d. e. ábra

Miction cystourethrography. a. Reflux in the left normal diameter ureter. VUR l.s. Gr.I. b. Both ureters have a normal diameter as they refill with the contrast material refluxing from the bladder. VUR l.u. Gr.II. c. There is a slightly dilated right ureter and collecting system in the right kidney, the calices are widened. VUR l.s. Gr.III. d. Dilated ureter and collecting system can be seen on the left side. VUR l.s. Gr. IV. e. The right ureter is markedly dilated and elongated the pelvicalyceal system is also markedly dilated, the calices are rounded, contrast material appears in the tubules as well. VUR l.d. Gr.5. with intra-renal reflux.
18.5. Abdominal masses

**Neuroblastoma.** is a tumor that develops at any part of the sympathetic nervous system. Therefore, in over 90% of the cases the urinary catecholamine levels are elevated. It is the most frequent extra cranial, solid tumor in children and has its highest malignancy rate within the first year. It is most common in children aged 1-5 years, appears as a palpable abdominal mass, with fever, hypertension, and anemia; in cases of bone metastases, bone pain and limping are common. US examination reveals a well circumscribed, echogenic mass usually crossing the midline, dislocating the kidney; it is frequently calcified, highly vascular, surrounding and compressing the abdominal vessels. In progressive cases liver and nodal metastases can be found. The tumor can also be solid, homogenous and with a smooth margin. The adrenal region in newborns is well visualizeable with US, but at older ages only major lesions can be depicted. CT/MRI examination: can depict a large sized, irregular shaped, extrarenal mass, with frequent necrosis, hemorrhage and calcifications. The lesions show a heterogeneous contrast enhancement.

*Nuclear medicine examination: MIBG scintigraphy is basically a 100% specific but its sensitivity is lower, because non-MIBG uptaking tumors exist as well.*

25. US examination, longitudinal view. Above the right kidney, in the adrenal region a solid, slightly inhomogeneous mass can be seen. Neuroblastoma.

26. MRI examination, axial T2 weighted image. Irregular, large solid, inhomogeneous retroperitoneal tumor is seen. Neuroblastoma. (with the courtesy of Dr. Gábor Rudas)

**Wilms tumor.** It is the most common kidney tumor in childhood that appears between 2-5 years of age. It is usually only noted when the tumor is palpable as an abdominal mass. Hematuria, hypertension, vomiting and abdominal pain are also part of the clinical picture. US examination is a basic method in both the diagnostics and the follow-up of the tumor. The tumor is normally seen as a homogenous or an inhomogeneous mass, dislocating the pyelon and the surrounding retroperitoneal blood vessels. It is important to rule out any lesion in the other kidney. MRI examination: gives a picture of the entire abdomen, kidneys included. Nodal metastases, tumor thrombus are well depictable. CT-examination: is to be chosen if MRI is not available. The tumor shows an inhomogeneous contrast enhancement and pulmonary metastases (invisible to x-ray examination) are also depictable.
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27. A solid, echogenic mass arising from the right kidney. Wilms tumor. Abdominal US.

28. MRI examination axial, T2-weighted sequence. A solid mass arising from the right kidney and filling out the right side of the abdomen, with peripheral follicular cystic components. Wilms tumor. (with the courtesy of Dr. Gábor Rudas)

29. CT-examination after iv. contrast administration. Mostly hypodense mass arising from the left kidney. Wilms tumor. (with the courtesy of Dr. Z. Karádi)

18.6. Central nervous system (CNS)

Due to the vastness of this field, in this segment we can only consider some fundamentally different diagnostic methods and a few CNS diseases typical to newborns and infants. The most important diagnostic method of the CNS of infants and children is MRI. (see there)

18.6.1. Special imaging methods of newborns and infants

Cranial ultrasonography: is the first method of choice in brain parenchyma examinations. It can only be performed until the closure of the fontanelles (8-10 months) (anterior and posterior fontanelles, mastoidal and temporal region). Examinations require a high frequency convex transducer as well as a linear one. Vertebral ultrasound: can only be performed in the first 2-3 months of life until the closure of the vertebral arch, with a linear transducer.

US examination is also capable of diagnosing and following-up cerebral complications of premature infants e.g.: germinal matrix hemorrhage, periventricular leukomalacia (PVL), hydrocephalus and for the screening of certain developmental disorders (corpus callosum agenesis, Galeni vein aneurysm, Dandy-Walker syndrome). However, we have to remember that US is not sensitive to all abnormalities or more sophisticated lesions. Metabolic diseases and some hemorrhages etc. are not always detectable with US. It is a very useful method but its limitations have to be kept in mind and when necessary MRI is to be used.

31. Normal spinal US, longitudinal view (long arrow: medullar cone, small arrow vertebral body.) Newborn.


33 a-b. Cerebral infarct, newborn. a. US examination, coronal view. On the right temporal lobe a small echogenic area can be seen.
b. MRI, axial view, diffusion sequence. Right sided, 3.5 cm area with restricted diffusion. Acute infarct in the parieto-temporal region. (SE, MRKK, with the courtesy of dr. György Várallyai).

18.6.2. Some diseases of preterm infants

Germinal matrix hemorrhage. It is a hemorrhage typically occurring in premature infants. There are 4 stages distinguished (subependymal bleeding, ventricular hemorrhage, ventricular bleeding with hydrocephalus, and the latter + parenchyma bleeding).

Hydrocephalus can be a frequent complication after germinal matrix hemorrhage, but at about half of the cases it resolves spontaneously. US examination is a method for its diagnostics and also for its follow-up.

Periventricular leukomalacia (PVL). It is usually a bilateral porencephalic cystic disease in the periventricular white matter that develops due to ischemic damage in preterm infants.
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34. Cranial US, coronal view. Moderate ventricular dilatation with inhomogeneous bleeding in the ventral horn of the right lateral ventricle. Grade III hemorrhage.

35. Cranial US, coronal view. The posterior horns are dilated, hemorrhage is present in all ventricles. Left sided periventricular parenchyma bleeding. Grade IV hemorrhage.

36. Cranial US, sagittal view. Dilated ventricle, periventricular cysts. PVI.

18.6.3. Mature newborns

Hypoxic-ischemic encephalopathy (HIE). Hypoxic ischemia, or perinatal asphyxia is the most common cause for severe neurologic abnormalities of the newborns. The role of imaging is to determine the grade and extent of the damage and to monitor the damaged lesion as early as possible. Ultrasonography: in some cases in the acute stages of the disease can visualize focal or diffuse hyper-echogenic periventricular or basal ganglia lesions. In chronic stages periventricular cysts, encephalopathy, hydrocephalus and widened subarachnoid space can be detected. MRI-examination is the most sensitive method, as it can depict changes undetectable by US. In the acute stage MR spectroscopy is very sensitive to the damage that is indicated by lactate peak and a decrease in other metabolites. Diffusion weighed imaging is the most sensitive way to detect cytotoxic edema right after the ischemic insult.

18.6.4. Developmental disorders of the CNS

They are amongst the most common developmental disorders (1:100 births). The spectrum is broad, covering small, focal cortical dysplasia as well as complex syndromes. The early detection of these developmental diseases helps in determining the degree of the lesion and might help in the therapy, as well as in the prognostics. It plays a fundamental role in the planning of future pregnancies. US examination is only good for partial diagnostics; MRI is the best choice for the detection of cortical malformations, migrational anomalies and myelination disorders.

18.6.5. Supra- and infratentorial brain tumors in children

Brain neoplasms are the second most common tumors in children, after leukemia. Their symptoms differ from the ones of adulthood, on one hand because we encounter different types of tumors in children and on the other because the bony sutures are still not closed in this age group. Brain tumors below the age of 2 tend to be primarily supratentorial in localization, while in ages between 2 and 10 years they are mostly infratentorial. Above 10 years of age the supra- and infratentorial tumor ratio is basically the same. Before brain surgery MRI examination is performed with various sequences and iv. contrast administration, moreover functional MRI exams might be used as complementary techniques.
to help the correct diagnosis and surgical decision making. Early phase (24 hours) postoperative MRI is capable to show residual tumors. US examination is of limited value, it can be used in the follow-up of consequential hydrocephalus.

18.7. Musculoskeletal system

18.7.1. Diagnostic methods (see there)

18.7.2. Some important disorders.

**Osteomyelitis.** Osteomyelitis stands for the inflammation of the bone and the bone marrow. Its most important symptoms are fever, pain, erythema, swelling and elevated inflammatory lab parameters. In newborns and preterm infants it is often symptom free and multifocal. Early diagnostics and therapy are extremely crucial, since the developing bones might suffer a permanent damage. Under 1 year of age the epi- and metaphysis are rich in blood vessel anastomoses that provide a spreading route for the inflammation towards the epiphysis or even to the joints or the adjacent bone. After 1 year of age the anastomotic connections disappear and the disease is characteristically metaphyseal. Rarely, but primary diaphyseal and epiphyseal osteomyelitis can also occur.

X-ray: does not show any changes within the first 7-14 days. The first sign is focal, uneven porosis. In further stages soft tissue swelling, bony destruction, osteolysis, bone necrosis can occur and even later, sequestration and periosteal reaction takes place. Radiologic healing takes months. Ultrasonography: detects early signs before X-ray examination does. It can quickly depict soft tissue edema, periosteal reaction and subperiosteal fluids.

Nuclear medicine: offers a method with a 90% and up sensitivity and specificity to osteomyelitis, however within the first 6 months of life is only partially reliable in the diagnostics. It shows a characteristic activity increase in all 3 stages of the examination.

MRI: can detect osteomyelitis in early stages, and with great reliability. Its rate for identification and the detection of the extent of the disease is between 88-100%. MRI is able to provide a good picture of the physis, epiphysis and the relation of the inflammation to the joint as well (edema, exudates, abscess).

37. a-d) X-ray of the right humerus. a. Rarefaction in the proximal-medial part of metaphysis of the right humerus – early osteomyelitis. b. Two weeks after the lytic area has grown. c. 1 month later sclerotic regeneration has begun. d. 4 months after almost complete healing. Osteomyelitis, infant.
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38. US, longitudinal. On the proximal part of the right femur, the periosteal soft tissue is hypoechoic, the flow is increased. Osteomyelitis

39. a-b. MRI, T2 weighted and T1 weighted, postcontrast axial images. Signal intensity increase and increased contrast enhancement in the bone marrow of the left femoral neck. 2 years old child, osteomyelitis. (with the courtesy of dr. Gábor Rudas).

**Transitory coxitis.** It is a transitional inflammatory disease of the hip joint that causes pain and limping. The pain is many times localized elsewhere; on the limb or the knee, leaving limping as an only symptom. US examination: can depict small amounts of fluid. Either a 4 mm wide fluid collection or 2 mm difference compared to the other leg are indicative of inflammation. The synovium is often thickened.

**Rachitis.** Rachitis can be caused by insufficient vitamin D alimentation, a decrease in mineral uptake (e.g.: premature infants) and vitamin D shortage due to malabsorption (coeliakia, cystic fibrosis) or a disorder in vitamin D production process. Its clinical symptoms are very characteristic: the wrist is swollen, a palpable mass or strain is often found on the anterior ach of the ribs, the skull is compressible like a ping-pong ball. X-ray examination: the typical signs of rachitis can always be found in the transitional ossification zone. On wrist radiograph the distal metaphysis of the ulna and the radius have an irregular contour, they are hollowed, the distance between the bone and the epiphyseal core is widened.
Hip dysplasia. Congenital hip dysplasia is a multifactorial disease that occurs more in girls (1:9) and causes the dislocation of the head of the femur. Acetabular rim development and configuration abnormalities, ligament looseness, muscle contracture, family history of hip dysplasia, or intrauterine breech position have all been mentioned as possible factors causing hip dysplasia. US examination is capable to diagnose infant hip dysplasia. It is indicated if the clinical examination raises suspicion or if risk factors (breech position, twin pregnancy, family history, oligohydramnion, deformed limb, neuromuscular disease) persist. US can be used as a screening tool. Due to the physiologic looseness of the ligaments before 4 weeks of age the hip is immature, therefore screening exam should take place after 4 weeks and can be performed until 4-6 months. X-ray exam: can only detect indirect signs of hip dysplasia until the appearance of the ossification centers of the femoral head.

Battered child, child abuse, shaken baby syndrome, non-accidental injury. These are all synonyms describing the syndrome of child abuse (usually of newborns and infants). At many times only the radiologist can identify these cases. There are some characteristic injuries that are not in relation with the story the parents tell. Fractures of multiple numbers, or in various healing stages are indicative of child abuse. Complex skull fractures are rare in simple cases of falling. The most characteristic sags are metaphyseal or corner fractures on the metaphyses of the tubular bones.

Violent shaking causes rib fractures and the to-and fro motion of the head leads to subdural hematomas, hypoxi-edematous contusion. X-ray examination: chest, bidirectional skull, vertebral and limb radiographs are necessary. US examination: both cranial and abdominal US are performed in infants. CT-examination can be required if the abdominal or the vertebral injuries are severe. MRI is unavoidable if neurologic symptoms persist.
43. Comparison Radiograph of the knees. On the distal-lateral epiphysis of the right femur “corner” fracture is seen, lytic area, periosteal reaction. Both proximal tibia, on the visible part of the picture show periosteal reaction. Battered child.

Summary

1. ALARA – As Low As Reasonably Achievable -, a term for the use of as low radiation dose as possible. It is a fundamental and primary point of view in pediatric radiology.
2. Diseases of the chest can most commonly be diagnosed with X-ray, and complementary US examinations. CT/MRI is rarely necessary.
3. Air in the imaging of gastrointestinal developmental disease can often be used as a negative contrast material on plain abdominal x-rays, and is sufficient for diagnosis.
4. The investigation of the GI tract of the newborns is carried out by low osmolality, absorbable contrast materials. US examinations are important part of the diagnostic toolkit.
5. US, miction cystourethrography, nuclear medicine and rarely MRI are needed in the diagnostics of urinary tract disorders.
6. Cranial and vertebral US examinations have some limitations, but are useful diagnostic methods while the fontanellas and the vertebral arch are open. If the US examination is not satisfactory the CNS should be examined with MRI.

Translated by Balázs Futácsi
19. Non-vascular interventions

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19.1. Historical introduction

Out of the numerous and many times groundbreaking innovations of interventional radiology, the one probably with the utmost importance and impact is still considered the work published by Seldinger - a Swedish radiologist - in 1953 about a percutaneous catheter technique. This technique is not only successfully implementable in the field of vascular interventions but it is also useful in the field of non-vascular interventions. Besides its obvious vascular use, biliary tracts, urinary tracts, fluid collections, abscesses can also be successfully and safely reached with this technique.

With X-ray fluoroscopy interventions of the biliary tract have already been performed since the beginning of the 1960s and by then various types of biopsies have been performed already world-wide in growing numbers.

The development of the imaging methods during the 1970s and 1980s gave a tremendous push to the improvement of more delicate non-vascular interventional techniques (X-ray, US and CT guided interventions). With regard to biopsies, the more precise image guiding and the development of finer needles, automatic biopsy guns have all lead to the improvements in precision of tissue sampling as well as they have reduced complications significantly.

19.2. Image guided biopsies and drainage

These procedures are amongst the most widely performed non-vascular interventions, their understanding and their practical knowledge is fundamental for any healthcare professional. The diameter of biopsy needles is given in Gauge (G) where 19.8 G = 1 mm (the smaller G value represents a wider needle, i.e.: 14G = 2.03 mm).

Biopsies in the majority of the cases should be performed with local (Lidocain 1%) anesthesia. Fine needle biopsy of more superficially located lesions can be performed without local anesthesia though. In case of known Lidocain sensitivity other local analgetics (i.e.: Marcain, Bucaïn) should be used.

19.2.1. Types of biopsies according to needle diameter

19.2.1.1. Fine Needle Aspiration Biopsy (FNAB)

With 20G or thinner needles one can obtain cytological samples, thus smaller groups of cells can be aspirated from a certain area. (Figure 1.)
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Figure 1. - Fine needle, core biopsy needle – pictures (A: 22G and 14 G biopsy needle, B: 22G fine needle with US transducer)

These needles with a diameter of less than 1 mm can even puncture intestines without the risk of causing perforation. Therefore retroperitoneal- and lesions behind the stomach can also be sampled.

After aspiration, the collected sample is squeezed on a glass plate and one quickly has to produce a smear and chemically fixate it.

19.2.1.2. Core biopsy

Most often we use 14-18 G needles for these tissue samplings. With the help of an automatic biopsy gun one (or more) tissue columns are acquired of the desired area. (Figure 2.) This sample already provides histological information.

Figure 2. – Core biopsy needle – pictures (A: 14G needle in the biopsy gun, B: 14G biopsy needle with UH transducer)

A special biopsy method; mammotome (8G needles!) can be used with smaller breast cancers which are able to completely remove the lesion (at certain cases multiple biopsies need to be performed).
19.2.2. Types of biopsies according to image guidance

19.2.2.1 US guiding

Nowadays it is the most commonly used method. Both superficial (figure 3.) and deep (figure 4.) lesions can be biopsied.

There are two basic technical approaches:

1. With the help of a special needle guider
2. Free hand method

The free hand method requires more experience from the operator. The needle should not move out of the transducer’s field of view, not to lose sight of its tip. Lesions lying 10-12cm deep in the body, with a diameter equal to or less than 10mm should all be approached with needle guiders for biopsy.
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Advantages:

1. Real time control of the procedure during the whole examination.
2. No ionizing radiation is used.
4. Easy to perform.
5. Bed-side biopsy can also be performed on immobile, ICU patients.

Disadvantages:

1. Operator-dependent, requires practical skills and experience.
2. Significant obesity, bones, intestinal gas, postoperative drains can hinder or disable the possibility of biopsy due to low image quality.

19.2.2.2. CT guided biopsy

Ideal method if the lesion is located either in the chest (figure 5.), mediastinum, retroperitoneum (figure 6.) or the pelvis.

Figure 5. – CT guided thoracic biopsy

Figure 6. – CT guided pancreatic biopsy
Advantages:

1. Excellent spatial resolution.
2. Bone and intestinal gas do not hinder sampling.
3. Less operator dependent than US guided biopsy.

Disadvantages:

1. Uses ionizing radiation.
2. No real time control.
3. Less available, relatively more expensive.
4. Can only be performed in the CT lab.
5. More time consuming.

19.2.2.3. X-ray guiding

Decades ago renal core biopsies used to be performed after iv. urography with fluoroscopic guidance. These procedures nowadays are performed with US guiding. A special mammographic stereotaxic biopsy method is still preserved for some cases of breast cancer, which are not (or only poorly visible) with US. However, this method can only be performed in some specialized centers.

19.2.2.4. MR guiding

In special cases the use of MR guidance can be considered. Its disadvantage is its expensive price and its availability is lot less than that of CT. Moreover it requires special, non-magnetizable equipment. Today it is used to biopsy intracranial tumors.

19.2.2.5. Hybrid imaging methods

With recent developments, nowadays it is possible to fuse MR/CT examinations of a patient with US images in real time, when the proper imaging region and plane are set. This method is useful in the biopsy of lesions that are otherwise hard to visualize with US alone.
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19.2.3. Drainage techniques

These methods are helpful for the percutaneous treatment or drainage of fluid collections and abscesses (figure 8.).

Figure 8. – UH guided drainage, abdominal wall seroma (drainage of 400 ml)

The diameter of drainage catheters is given in French (F), 1F = 1/3 mm. These interventions can be basically performed in two ways:

19.2.3.1. Seldinger technique drainage

As a first step US or CT guided puncture of the lesion is performed with a correct needle size. (Figure 9.)

Figure 9. – Hepatic cyst CT guided puncture (guide wire in the cyst)

After, a guide wire of 0.035” diameter is placed through the needle to the lesion, and the needle is removed. The guide wire is used to assist the insertion of a carefully selected, correct sized (6-14F) drainage catheter.
19.2.3.2. *Trocar method drainage*

During the trocar method both the puncture cannula and the trocar sheath (drain) are inserted together to the lesion with the proper image guidance. After the desired positioning of the trocar the cannula is removed and the sheath stays in the lesion to drain the fluid collection or the abscess. (Figure 10.) The drain is usually attached to the skin with a stitch.

Abscess healing can be accelerated by repeated drainage and lavage of the contents of the abscess. (Figure 11.)

![Figure 10. – Hepatic cyst before alcoholic sclerotization, cyst is filled with diluted contrast material.](image1)

![Figure 11. – US guided hepatic abscess drainage control (day 13, after several rounds of lavage and cleaning of the abscess)](image2)

The length of the percutaneous drainage is influenced by the washout of the contents and the reduction of its size.
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19.2.4. Contraindications of biopsies and drainage

Biopsy and drainage are contraindicated:
- if no proper blood clotting parameters are met (it can be temporarily corrected for the time of the puncture with fresh frozen plasma (FFP),
- if there is an unavoidable blood vessel (aorta, IVC) in the way to the lesion,
- if there is a lack of sufficient cooperation from the patient (anesthesia might be necessary).

19.2.5. Complications of biopsy and drainage

There are various complications of each procedure:
- Hemorrhage (subcapsular (figure 12.), parenchymal, intraabdominal (figure 13.), intrathoracic, pseudoaneurysm),
- Ptx (thoracic (figure 14.), mediastinal, infraclavicular, in case of subdiaphragmatic intervention),
- Perforation (it is FORBIDDEN to use core biopsy needle for lesions lying behind intestines),
- Tumor spread in the cutaneous biopsy canal (the same risk factor applies in case of all guiding modalities.)

Figure 12. – US guided renal biopsy, subcapsular hemorrhage (5 minute control)

Figure 13. – US guided renal biopsy, serious retroperitoneal and intraabdominal hemorrhage, with active bleeding (20 hour control)
19.3. Complex interventional radiological treatment of hepatic tumors

The gold standard of malignant hepatic tumors is still considered surgical resection. However, in some cases when the tumor is inoperable or the surgical procedure is with too much risk for the patient, interventional radiological methods can be considered. These methods can also be performed if the patient rejects surgery.

There are various types of interventional methods in the treatment of primary and secondary liver tumors, which can either be applied as a stand alone procedure or in combination with each other.

19.3.1. Percutaneous tumor destruction

It is necessary to note that various materials (hot physiologic saline solution, acetic acid) have also been used for the percutaneous destruction of hepatic tumors in the 1980s. However, stable long term results could only be achieved with ethanol.

The following therapeutic methods can only be considered successful if the surrounding – few millimeter wide tumor free margin (safety zone) – is also affected by the therapy.

19.3.1.1. PEIT (Percutaneous Ethanol Injection Therapy)

It is the most commonly used and cheapest percutaneous method for the treatment of primary hepatic cancer (HCC). Sterile, 95%, absolute alcohol is injected with US guidance to the tumor.

Ethanol causes dehydration and coagulation necrosis of the tumor cells, followed by fibrotic degeneration. After alcohol injection, a typical “snow storm like”, hyperechogenic area can be seen in the treated area (figure 15.).
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The special (end and side pins) biopsy needle, the syringe and ethanol together cost about 40-50USD.

19.3.1.2. Radiofrequency tumor ablation (RFA)

During RF ablation an electrode is positioned in the tumor. The end of the electrode will produce extensive heat as ionizing current is generated at 460 kHz frequency, with alternating polarities. In a given (50-200 Watt) energy range it is possible to produce 50-90C degree heat under set circumstances. (Figure 16.)

With the use of a special RF equipment and electrode (Berthold or Radionics equipment) the internal cooling of the needle is possible with physiologic saline solution, therefore carbonization is avoidable.

The complete RF ablation in the vicinity of large venous branches (hepatic vein, portal vein, IVC) is difficult to achieve, since the flowing blood of the veins cools the nearby tumor tissues. Another difficulty is presented with lesions lying too close to the choledochal duct or the hepatic duct, since they poise the possibility of a serious biliary injury. The treatment of subcapsular tumors can lead to persisting pain, therefore in these cases combined methods are usually preferred (RF + chemoembolization, RF + PEI).
Considering the above mentioned anomalies, the most ideal scenario for RF ablation of liver tumors are the following:

1. There are 4 or less lesions,
2. lesions are equal to or less than 3cm,
3. they are each located at least 1cm below the hepatic capsule and
4. any larger vein is located at minimum 2cm of a distance from them.

Therapeutic success can only be hoped to achieve with a tumor of maximum 5cm diameter, however at this size multiple interventions are needed. With the help of hybrid guiding methods, larger lesions might be successfully treated in one session. Superficial lesions might be intraoperatively performed to avoid damage to the surrounding organs (diaphragm, gall bladder, large and small bowel).

Percutaneous RF ablation should only be performed with strong analgesia or in anesthesia. After treatment a 24 h clinical observation is necessary.

The average time for the ablation of a lesion of 3cm is 8-10 minutes long. In case of 3-4 lesions the procedure can last up to 40-50 minutes.

The effectiveness of the RF ablation is usually controlled by PET-CT examination, properly adjusted MR/CT protocols or with contrast enhanced US examination (figure 17.)

![Figure 17. – Control CT after liver RF ablation](image)

The price of the RF machine is between 12 000 - 30 000 USD, while the single use electrodes are worth 500-1000 USD.

19.3.1.4. Microwave tumor ablation

Microwaves at a wavelength at 2450 MHz- create a very fast rotation in the water molecules of the targeted lesion. This leads to the heating up of the tissues and the coagulation necrosis in a volume with elliptic crossection. The technique is performed with a 25cm long, 18G electrode (14G cannule).

The microwave machine is 45 000 USD, while each electrode is 500 USD.
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19.3.1.5. Laser tumor ablation

After the development of laser ablation technique, it became possible to create reproducible tissue destruction with Nd YAG (Neodymium yttrium aluminium garnet) laser. After the first published results in 1993, Lees and colleagues published their own results about comparing the effectiveness of percutaneous colorectal liver tumors interventions with ILP (Interstitial laser photocoagulation) and with PAI (Percutaneous Alcohol Injection). The newly developed portable laser equipment can use up to 30W of energy and with a 10m long optical cable (possible MR application) the destructive Nd YAG laser can be directed even to specially cooled territories. The portable system is 20 000 - 50 000 USD and the laser cable for about 50 patients is 2000 USD.

19.3.1.6. Cryoablation

Cryoablation methods in larger series could only be used in the 1990s in oncologic interventions. Cold under -20, -30 C degrees produces irreversible tissue destruction. The criteria for the treatment are basically the same as for RF ablation. In the vast majority of the cases cryoablation is performed during open surgery, and less than 10% are performed with laparoscopy. The cryoablation machine is 130 000 – 160 000 USD, while needles are around 1200 USD.

19.3.2. Chemoembolization

TAE (Transcatheter Arterial Embolization) and TACE (Transcatheter Arterial ChemoEmbolization) are methods with which the supplying artery/arteries of the tumor are selectively approached through the branches of the hepatic artery. When the catheter is in position the tumor branches are injected with a special, oily contrast material, Lipiodol (TAE). The injected material is used as an embolization material (figure 18.), other chemotherapeutical drugs (5-Fluoro-Uracil, Epirubicin, Cisplatin, Mytomicin-C) can also be used (TACE) (figure 19.).

![Image of Lipiodol uptake in HCC, selective catheterization, injection of 10 ml Lipiodol (DSA)](image)

Figure 18. – Lipiodol uptake in HCC, selective catheterization, injection of 10 ml Lipiodol (DSA)
Compared to systemic chemotherapy, with these methods 10 or even 100 times greater drug concentrations can be delivered to the tumor tissue. Moreover, due to the effects of Lipiodol, the drug effects persist longer, while normal liver parenchyma will wash out the chemicals faster leaving little or no harm. This can be successfully combined with the other percutaneous methods, especially during the treatment of multiplex primary and secondary tumors. An important factor is the cost-benefit question with regard to these tumors. The given prices are from the literature and they intend to reflect how each therapeutic method compares to another (i.e.: the cryoablation equipment is 4-5 times more expensive than the RF equipment). Ethanol injection costs only a fraction compared to the other methods and can be considered relative cheap. RF ablation is considered a method with well determinable tumor destruction effect, for a “competitive” expense.

19.4. RF ablation in other organs (lung, renal and bone tumors)

19.4.1. Lung

Many teams have published remarkable results in cases of the RF treatment of inoperable pulmonary tumors. Well accessible, peripherally localized tumors that otherwise would carry significant surgical risk can be successfully treated with this alternative method. In the vicinity of larger blood vessels (branches of the pulmonary artery, SVC) the cooling effect of the flowing blood decreases the effectiveness of the RF procedure.

19.4.2. Kidney

In cases of malignant renal cancer RF ablation can be applied in the following scenarios:

1. Elderly patient, with relatively large surgical risks.
2. Unilateral, solitary RCC.
3. Palliative treatment in case of a centrally located tumor.
5. According to the latest recommendations tumors up to 5cm in diameter can be treated successfully with RF.

Figure 19. – TACE, CT control (2 weeks after treatment)
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19.4.3. Bone

The RF treatment of primary bone tumors and bone metastases have been the topic of several large scale studies from various centers. RF ablation is especially useful technique and has a good outcome in the direct treatment of osteoid osteomas (figure 20.) The invasiveness of the method is several folds smaller than orthopedic surgery.

![Figure 20. – RFA treatment of osteoid osteoma in the right tibia (A: CT exam before the treatment, B: RFA)](image)

Patients treated with RFA only require 1-2 days of hospitalization as opposed to the ones undergoing open surgery, who need to stay in the hospital for 7-10 days.

19.5. Percutaneous (biliary) choledochal, cholecystic interventions (PTC, PTD, stent implant, choledochal stone removal, cholecystostomy)

Percutaneous interventions are usually necessary in case of malignant, inoperable pancreatic head tumors, if enlarged lymph nodes in the hepatic hilum compress the choledochal duct, or in case of the various types of cholangiocellular tumors (Klatskin tumor). Amongst the benign lesions, primarily biliary strictures, inflammatory stenoses, and sclerotizing cholangitis cause indication for intervention.

In case of the failure of endoscopic biliary interventions or if there is a persisting Bilroth II resection, percutaneous biliary intervention needs to be considered.

It is important to note that due to the congestion of bile – which might serve as fertile ground for bacteria – one needs to provide prophylactic antibiotic therapy before the intervention.

19.5.1. Percutaneous transhepatic cholangiography (PTC)

During this procedure X-ray or US is used to guide the insertion of a 22G (Chiba needle) from a right IX. or X. intercostals position into a dilated intrahepatic biliary branch. After the Chiba needle is well positioned the intra and extrahepatic biliary tree is filled with contrast material. (Figure 21.)
Under special circumstances – when the left side of the biliary branches is affected primarily - PTC can be performed from an epigastric entry towards the left lobe of the liver. (Figure 22.)

![Figure 21. – PTC (Percutaneous transhepatic cholangiography)](image)

Figure 22. – PTC the puncture of the biliary branches of the left lobe

**19.5.2. Percutaneous transhepatic drainage (PTD)**

After a diagnostic PTC is successfully performed and a guide wire is positioned over the stenotic or occluded segment of the choledochal duct an external-internal drain (PTD) can be installed. (Figure 23.) If desired, a self expanding metallic stent could be used to override the stricture (Figure 24.)
If one cannot pass the biliary stenosis in the initial attempts, the placement of a temporary external drainage is advisory to control the biliary congestion and cholangitis. Later during a second session the insertion of an external-internal drain will be possible.
In special cases separate catheter insertion and stenting of both the left and right hepatic ducts might be necessary. This depends on the extent of the pathologic lesion (tumor or inflammation).
In case of a malignant stenosis the use of covered stents can prolong the passage in the tumor bound segment of the choledochal duct.

19.5.3. Percutaneous choledochal stone removal

After an unsuccessful endoscopic attempt, stones can be removed percutaneously if they are centrally localized (at the junction of the hepatic ducts) or in some rare instances, if they are located even more peripherally in a hepatic duct. Depending on the size of the stone, it can be percutaneously removed with the help of a special stone removing set (dormia basket). If the percutaneous removal is not possible, then one can try to push the stone to a more distal position “rendezvous technique” for endoscopic removal.
19.5.4. Percutaneous cholecystostomy

Usually in case of elderly patients and in case of certain types of acalculous cholecystitis US guided precutaneous drainage of the gall bladder proves to be a very effective technique. (Figure 25.)

Figure 25. – Percutaneous cholecystostomy (85 years old, female patient in poor general condition. Percutaneous intervention due to acute cholecystitis.)

During the procedure one needs to carry out the puncture or the insertion of the drain from the parenchymal side of the cholecyst. Puncture on the free side of the colecyst can lead to serious complications, intraabdominal bile leakage, bile peritonitis.

19.6. Gastrointestinal interventions, endoluminal stent implantations

19.6.1. Balloon expansion of benign enteral strictures

Benign esophageal strictures can be expanded with an inflatable balloon with fluoroscopic guidance or endoscopically.

Indications for the balloon expansion are achalasia, postoperative scarring, stenosis, scarring after irradiation.

The results of the expansion are controlled by swallowing examination or with endoscopy.

19.6.2. Interventional radiological methods of malignant gastrointestinal stenosis

In case of inoperable esophageal, gastric or duodenal cancer, large (15-20mm wide) endoluminal stents can be applied. Moreover obstructive tumors on the descending colon or on the sigma can also be treated with these endoluminal stents. The length of the stent has to be chosen so that its proximal and distal ends reach beyond the stenosis by about 2-3cm.
19. Non-vascular interventions

There are five indications when distal colon tumors can be treated with stents:
A/ acute, large bowel obstruction can be temporarily decompressed with a stent, and used as a “bridge” until the elective surgery.
B/ palliative care of inoperable colon cancer.
C/ decompression of the colon due to post-surgical fibrosis or radiation caused benign stenosis.
D/ to overcome the obstruction caused by diverticulitis and inflammation, so that until surgery the colon can be kept clean and empty.
E/ palliative care of coloenteric or colovesical fistulas.
Stent positioning can be performed with fluoroscopic control or with colonoscopic support.

19.6.3. Percutaneous gastrostomy

In case of swallowing impairment (usually as a result of neurological cause: severe stroke, brain damage, amyotrophic lateral sclerosis) percutaneous gastrotomy is used to temporarily decompress the esophagus segment, to alleviate gastric emptying disorder or to cease intestinal obstruction.
Usually with mild sedation and local anesthesia PEG is inserted with endoscopic assistance with the use of a special catheter set.

19.7. Percutaneous ethanol cyst treatments

19.7.1. Percutaneous ethanol cyst sclerotherapy (liver, spleen, kidney)

During US and CT examinations simplex cystic lesions are often accidentally encountered that do not cause any pain for the patient. Cysts of the liver, spleen or the kidneys cause discomfort or pain for the patients need to be therapeutically addressed.

Compared to the surgical methods of past, nowadays these cystic lesions can be successfully treated percutaneously with alcoholic cyst sclerotherapy. (Figures 26., 27.).

![Figure 26. – Percutaneous ethanol cyst sclerotherapy (filling up of the cyst before the sclerotherapy)](image-url)
The puncture of the cyst is usually guided with US (rarely with CT). The puncturing needs to take place from the parenchymal side of the cyst. When its contents are removed the empty cavity is filled up with diluted contrast material to ensure that there is no contrast leakage to the surroundings. The 96% ethanol is only injected after the contrast material has been removed and no leakage was found. (The volume of the alcohol should not exceed 50-60% of the cyst or 100 ml.)

The injected ethanol is left in the cyst for 20 minutes. Following this, the alcohol is drained as well. Cystic regression is then regularly controlled with US or CT examinations. (Figures 28., 29.) Patient complaints usually cease within 4-6 weeks after the treatment.
19. Non-vascular interventions

Figure 29. – Percutaneous ethanol hepatic cyst sclerotization, CT examinations (A: before treatment, B: 6 months after treatment) – pronounced regression

19.7.2. Percutaneous interventional treatment of Echinococcus cyst

The treatment of larger Echinococcus cysts in the liver is possible with percutaneous interventional methods. The method is described best by its acronym PAIR (Puncture, Aspiration, Injection, Reaspiration). Hyperosmogenic saline solution (15%) and/or absolute alcohol can be both successfully applied to treat the Echinococcus cysts. Therapeutic efficacy can also be controlled with US or CT exams.

19.8. Urinary tract interventions

The most commonly performed intervention is US guided percutaneous nephrostomy. In special cases (obesity, visualization difficulties with US) CT guidance can also be chosen to create percutaneous nephrostomy. (Figure 30.)

Figure 30. – Percutaneous nephrostomy contrast X-ray examination (CT guided catheter insertion)
In case the insertion of the catheter is not possible through the bladder in a retrograde manner, then the benign or malignant stenosis can be both overcome by inserting a hydrophilic – so called double J catheter – percutaneatously. In selected cases biodegradable stents can also be applied to treat certain benign strictures or stenoses of the ureter.

19.9. Percutaneous interventional methods of the musculoskeletal system

19.9.1. Vertebroplasty

Elderly patients, especially women frequently suffer osteoporotic vertebral collapse. In malignant states imminent or definite vertebral collapse can also occur due to osteolytic vertebral bone metastases at various locations. In both etiologies the goal is to stabilize the vertebral column and to prevent further destruction or collapse. Vertebroplasty is a CT guided procedure (CT-fluoroscopy method) where a special, 10G thick needle is applied. It is inserted transpedicularly in case of the lumbar vertebra, while in case of thoracic vertebrae insertion is through the intercostal space. During the procedure the injection of bone cement is continuously controlled with CT-fluoroscopy and a final control CT examintation is performed to stage the status of the patient.

19.9.2. Interventional treatment option for lytic bone metastases (extravertebral localizations)

The main goal of these interventions is to provide palliative care, besides the other, non-operative treatment options (pain killers, radiotherapy, hormone therapy, chemotherapy):

1. Pain relief caused by the bone metastasis.
2. Preventing pathological fractures.
3. The correction of the function of the affected limb or joint to an optimal level. Thus improving the standard of living.

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20. Catheter angiography and vascular interventional radiology

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20.1. Introduction

Vascular interventional radiological techniques mean that patients undergo image-guided, minimal invasive therapeutic procedures. Medical students should be aware of these techniques and diseases in which they are used; students should also know the basic methodology of such procedures.

The advantages of these minimal invasive techniques compared to surgery are: local anesthetia – no need of general anesthesia and its complications; lack of surgical dissection and surgical complication (e.g. inflammation, nerve injury, suture-insufficiency); negligible amount of blood loss; can be done in elderly, ill-conditioned patients with medical contraindication to anesthesia; can be repeated numerous occasions; in case of technical failure, surgery is still possible. Disadvantages include that not all surgical procedures can be substituted by interventional procedures; there are less data in the literature for interventional radiological procedures than for surgical procedures; interventional radiological procedures may also carry serious complications despite its minimal invasive nature, however, this is usually considerably lower than that of surgical procedures.

Tasks before the intervention
Patient history and physical examination – with a special emphasis of pulse palpation - should be performed. Relevant laboratory values, including renal function (GFR) to prevent contrast medium induced nephropathy; hemostatic parameters (thrombocyte number and INR rate) to prevent arterial access complications should be checked. Consent by the patient – including risks, benefits, alternative therapies - should be done by the interventional radiologist, informed consent form should be signed and dated by the patient.

20.2. Catheter angiography

For many decades, catheter angiography has been the gold standard method. In recent years, CTA and MRA gradually replaces a large proportion of diagnostic angiography in more and more centers. US is used mostly to answer specific clinical questions, i.e. significant stenosis at a certain vascular territory, e.g. common femoral artery; existence of pseudoaneurysm at a former puncture site; patency of a femoropopliteal graft. Catheter angiography is mostly used for final, precise planning and performing an interventional procedure. Assessment of crural arteries (anterior tibial artery, posterior tibial artery, peroneal artery) by catheter angiography is often more precise than CTA or MRA.

Seldinger technique is used for vascular access. Arterial puncture by a Seldinger needle (Fig 1, Upper row, left panel) is most often pulse-directed (by palpation), but can be accessed by ultrasound guidance. Most commonly used access sites are common femoral and brachial arteries, radial arteries are used mostly by cardiologists, popliteal artery can be rarely punctured in special cases (retrograde recanalisation of superficial femoral artery occlusion).
A guidewire is inserted into the needle (Fig 1, Upper row, right panel), the needle is withdrawn (Lower row - left panel) (at this point the puncture site should be compressed to prevent bleeding); a few mm dissection may be done by a scalpel, the introducer sheath and then a catheter is fed onto the guidewire (Lower row - right panel); then the guidewire can be withdrawn and contrast medium can be inserted through the catheter. More information on contrast medium is available in chapter 7.

Figure 1.: Seldinger technique. Upper row – left panel: one-part Seldinger needle; Upper row – right panel: the femoral pulse was well palpable, the right common femoral artery was punctured using the Seldinger needle, then the guidewire was inserted into the needle. Lower row- left panel: the needle was withdrawn, manual compression was performed to prevent puncture site hematoma; Lower row - right panel: a 4F introducer sheath was inserted onto the guidewire. Contrast medium can be injected through the sheath.
20. Catheter angiography and vascular interventional radiology

Digital subtractive angiography (DSA) (Fig. 2) means that the computer subtracts the contrast-enhanced image from the pre-contrast image (mask), resulting in an image where the bones and other background structures are not visible, therefore less amount of contrast medium is necessary with a much higher image quality.

20.3. Arterial interventional radiological procedures

20.3.1. Percutaneous transluminal angioplasty (PTA) and stent implantation

Theory of angioplasty: Balloon angioplasty and/or stent implantation elicits a dramatic decrease in the rate of stenosis (e.g. from 70-95% to 0-20%); in case of occlusion, recanalisation is achieved. PTA causes a controlled injury at the site of angioplasty. This results in reendotheliasation of the ballooned segment of the artery, a process that takes place in 30-40 days. In case of overreaction of the reendothelisation, restenosis may occur which is more frequent in smaller diameter arteries (e.g. crural arteries) than larger diameter arteries (e.g. iliac arteries). The 5-year patency rate is 60-70% for the larger arteries, and 30-50% in smaller arteries.

PTA can be done only if the targeted stenosis and/or occlusion can be negotiated with the guidewire. Therefore, manipulation with the guidewire is one of the most important and difficult part of radiological interventions. Balloon-catheters have two channels, the inner, thicker channel for the guidewire, and the outer, thin channel for balloon inflation (using a mixture of saline and contrast medium on 6-20 atm pressure).
Stents are elastic metal meshes (Fig. 3, middle and right panel), which remains permanently in the artery. In terms of mounting and delivery, there are two major types: balloon-expandable and self-expanding. Studies indicate that stents decrease the rate of restenosis and also the risk of distal embolisation. Covered stent (or stent-graft) is a bare stent covered with prosthesis material, therefore it is a tube, rather than a mesh. Covered stents are used for minimal invasive treatment for aneurysms (e.g. thoracic or abdominal aortic or popliteal aneurysm), but arterial injury, rupture or pseudoaneurysm can also be treated using covered stents.

Potential complications of PTA and stent implantation include: thrombosis, dissection, peripheral embolisation at or distally from the PTA site; hematoma and pseudoaneurysm at the puncture site. Major complications – such as arterial rupture - are rare. Complications can be often managed by interventional radiological techniques, however, acute vascular surgery may be necessary to treat some of the complications.

20.3.1.1. Percutaneous transluminal angioplasty and stent implantation in lower limb arterial disease (peripheral arterial disease, PAD)

Atherosclerosis is a very common disease, therefore lower limb arterial angioplasty provides the largest fraction of workload for most interventional radiological laboratories. In case of lower limb symptoms, its vascular origin should be assessed. Differential diagnosis include musculoskeletal diseases and neuropathy in diabetes mellitus. Physical examination (pulse palpation) and measurement of ABPI (ankle-brachial pressure index; a quotient of lower limb and upper limb systolic pressure) is the first step. The anatomy of the lower limb arteries is expected to be known by the fourth year medical students. If the symptoms are of vascular origin, the next step is to decide whether or not the symptoms indicate operative treatment (either interventional radiological or surgical). Operative treatment, and therefore diagnostic angiography (CTA, MRA, DSA) is necessary only in Fontaine stage IIb (intermittent claudication <200 m), III (rest pain), and IV (gangrene or ulcer). Indication for operative
treatment at mild claudication (>200 m) should be considered only if the claudication distance is insufficient for the patient’s lifestyle. The patient, not the morphology, should be treated! Even significant stenoses should not be treated in asymptomatic limb (Fontaine stage I). Exceptions may include a significant stenosis on a femoropopliteal bypass graft (because occlusion of the graft elicits higher risk than the risk of endovascular therapy) and in the presence of popliteal artery aneurysm (for prevention of embolisation to the crural arteries).

Due to technical reasons (antegrade or retrograde puncture, contralateral or ipsilateral puncture, femoral or brachial puncture), prognosis and risks, three types of levels are distinguished: iliac (Figure 4), femoro-popliteal (Figure 5) and crural (infrainguinal) (Figure 6) endovascular therapy. The latter two compose the infrainguinal group. PTA and stent placement are usually technically easier (with the exception of long occlusions), have a longer patency and carry lower risk in the iliac group compared to the other two groups. Crural patency is the worse and carries the highest risk, therefore, it is usually indicated only in Fontaine stages III and IV. The number of amputation in Hungary is larger than that in most other European countries. In patients with gangrene and diabetes, crural PTA may save a large number of amputations. In case of successful PTA, limb salvage rate is considerably higher than patency rate, since perfusion needed for a healing ulcer or gangrene is considerably higher than for the basic functions (collateral arteries may be sufficient for such purpose). Subintimal PTA is performed more and more frequently: when luminal recanalisation is technically not possible, intentional dissection is done using the hydrophilic guidewire along the occluded segment; then, distally to the occlusion, the guidewire is directed back to the normal lumen and a new channel is formed along the normal lumen—dissected channel—normal lumen route (Figure 5).
Figure 5. Subintimal percutaneous transluminal angioplasty (PTA). Panel A: Superficial femoral artery has been occluded from its origin with a stump (upper arrow). Refilling occurs at the distal SFA (lower arrow), total length of the occlusion is approximately 18 cm. Panel B: The white background („roadmap“) shows the profunda femoral artery. The guidewire (in black on the white background; arrow) is at the beginning of the occluded segment. Panel C: the guidewire forms a loop (arrow), and gradually proceeds into the subintimal space. Panel D: the tip of the guidewire reached the normal popliteal artery lumen, there is no loop formation any longer. Panel E: Following balloon dilation of the whole segment, SFA shows quick flow in its entire length.

The efficiency of interventional radiology can be improved by multidisciplinary consultations (vascular surgeon, angiologist, interventional radiologist) in order to find the best indication, medication and operative treatment.

Figure 6. Crural PTA. Left panel: the only crural vessel filling is the peroneal artery; the posterior tibial artery is filled only in the proximal segment; the plantar arch in its continuation is also filled. Middle panel: successful recanalisation of the posterior tibial artery was performed using the guidewire (dashed arrow). Right panel: following balloon dilation, posterior tibial artery is well filled (arrows).
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20.3.1.2. Percutaneous transluminal angioplasty and stent implantation in upper limb arterial diseases

In the upper limb arterial system, the most frequent site of atherosclerotic stenosis or occlusion is by far the proximal part of the subclavian artery (proximal to the origin of the vertebral artery). It occurs on the left side four times more frequently than on the right side. This entity can be diagnosed by duplex sonography: the stenosis/occlusion may be directly visualised, but mostly, indirect signs (retrograde flow in the ipsilateral vertebral artery; poststenotic, monophasic flow distal to the stenosis, i.e. distal subclavian artery, brachial artery) may be identified. Physical examination reveals weak ipsilateral radial pulse, therefore, it is recommended to palpate at the beginning of the ultrasound examination. Blood pressure is typically 20-30 mmHg lower compared to the normal, contralateral pressure. In asymptomatic patients, subclavian artery stenosis or occlusion may be unidentified, however, it is of crucial importance, that for assessing blood pressure of the body, measurements should be performed on the contralateral (non-stenotic) upper limb to assess.

Asymptomatic subclavian artery stenosis/occlusion needs conservative (medical) treatment. In case of upper limb symptoms or vertigo, endovascular treatment (PTA/stent) is the primary option. Vascular surgery may be performed if endovascular therapy failed.

20.3.1.3. Carotid stent implantation

Significant stenosis in the extracranial part of the carotid arteries occurs most frequently at the level of the carotid bifurcation. Carotid duplex scan is one of the most frequent vascular ultrasound examination; its clinical relevance and therapeutic consequence should be well known by the investigator. In the presence of atherosclerotic plaque, internists may prescribe acetyl salisylic acid for stroke-prevention. In case of 50-69% stenosis, more frequent (3-6 months) controll duplex should be recommended or CTA or MRA may be considered to verify the exact degree of the stenosis. If the stenosis is >70%, depending whether or not it is symptomatic, operative treatment (surgical, e.g. eversion endarterectomy or endovascular, primary stenting) may be considered.

Figure 7. Carotid stenting: DSA angiography image before and after stenting (courtesy of prof. K. Hüttl, Semmelweis University).
The major goal of primary carotid stenting is stroke prevention (not symptom relief, this is quite a different mechanism and goal described for the upper and lower limb PTA and stenting). The Willis circle normally provides sufficient circulation in the carotid territory even in case of 80-90% stenosis, very often carotid occlusion is totally symptomfree. The cause of ischemic stroke is very often distal embolisation of small debris from the carotid plaques. At the stented region, a controlled injury elicits the formation of a new endothelial layer in 30-40 days, after which the risk of distal embolisation is considerably smaller. Therefore, studies assessing risk and effectiveness of carotid stenting always cite not only the perioperative but also the 30-day stroke/mortality ratio.

Distal embolisation of the smallest particle during carotid stenting or carotid surgery may cause stroke, the risk is 1-3%. For prevention, dual platelet aggregation inhibitor therapy and often the use of filters during stenting is used. The patient should be clearly informed about the potential benefit (decreased risk of stroke) and risk (appr. 1-3% stroke within 30 days of the operative treatment) when indication is decided and informed consent is gained.

20.3.1.4. Renal angioplasty

Stenoses in renal arteries are mostly of atherosclerotic origin, however, fibromuscular dysplasia may also be causal factor. There is no consensus for the indication on endovascular therapy. Most important indications include severe hypertension despite best medical therapy, deteriorating renal function, flush pulmonary oedema, acute renal insufficiency in the presence of normal kidney size, severe stenosis on the renal artery following contralateral nephrectomy.

20.3.1.5. Mesenteric stent placement

Among the mesenteric arteries, atherosclerotic lesion may occur at the origin of the superior mesenteric artery; PTA or stent placement may be indicated in symptomatic cases (e.g. abdominal angina or postprandial abdominal pain). It is performed rarely.

20.3.1.6. Dialysis fistula PTA

Stenoses on arterio-venous dialysis fistulas (either at the site of the fistula or in case of central venous stenosis) can easily be treated by PTA. Consequently, the number of surgical operations on these fistulas will decrease, which provides a longer patency time for a particular fistula.

20.3.1.7. Stent-grafts, covered stents

Covered stents are tubes, rather than meshes, since the bare stents are covered with a graft material. It is widely used to exclude thoracic or abdominal aortic aneurysm from the circulation to prevent rupture; in the abdominal aorta, the size for indicating operative treatment (open surgery or stent-graft) is 5.0-5.5 cm. Popliteal aneurysms are one of the rare exceptions when lower limb arterial disease is treated operatively in asymptomatic patients, covered stent placement prevents distal embolisation to the crural arteries.

Covered stents are used in cases of arterial rupture (trauma, post-PTA rupture), or in patients with pseudoaneurysm, e.g. on the lienal artery caused by chronic pancreatitis.
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20.3.2. Thrombolysis, thrombus aspiration

In acute thromboembolic diseases, vascular surgical treatment is the most common treatment. In case of relative or absolute contraindication of vascular surgery, selective arterial lysis is an option. Most commonly, tissue plasminogen activator (tPA) is given in a bolus and then in an arterial infusion for 4-24 hours. To prevent further clot formation, heparin is also administered intraarterially. Control angiograms during the lysis usually shows the underlying stenosis responsible for the occlusion, which can be treated by PTA or stenting in the same session.

Thrombolysis may have severe, life-threatening complications, e.g. gastrointestinal or intracerebral hemorrhage. Thrombolysis is contraindicated if patient history includes intracranial or gastrointestinal hemorrhage, or there was any kind of operation within 6 weeks. Relative contraindications include coagulopathy, gastric or duodenal ulcer, liver diseases, portal hypertension, severe arterial hypertension, gravidity, incompliance of the patient.

Due to the above mentioned potential serious complications, whenever possible, thrombus aspiration or mechanical thrombectomy devices are used. Thrombus aspiration can be used in case of distal embolisation of thromboembolic material as a complication of PTA and stenting, typically occurring in SFA or popliteal PTA. Mechanical thrombectomy devices are of extremely high cost, in Hungary, these are seldomly used.

20.3.3. Embolisation

Embolisation provides intentional temporary or permanent closure of arterial branches by using occlusive materials. These include gelfoam (temporary effect); or metal coils, beads made of synthetic materials (e.g. PVA – polyvinylalcohol) (permanent effect), lipiodol and absolute alcohol (scleroembolic material). Embolisation can be used in any type of arterial bleeding (e.g. trauma, gastrointestinal, malignant tumor), vascular malformations, aneurysms, and malignant or benign tumors for curative, palliative or preoperative purpose. Potential complications of embolisations include non-target embolisation (embolic material reaches an arterial bed different from the one intended to be treated) which may result in negligible clinical consequence but may also cause ischemia, infarction, necrosis, pain, paraplegia and a number of other serious complications. Therefore, complete and thorough planning of embolisation procedures are very important. Severe complications are fortunately rare.

Transarterial chemoembolisation (TACE) combines intraarterial chemotherapy and embolisation for treating malignant tumors. These techniques may be used separately also (TAC – transarterial chemotherapy, TAE – transarterial embolisation). Typical postembolisation syndrome consists of pain, subfebrility/fever, nausea, vomiting, leucocytosis. Antiinflammatory drugs, antiemetics and prophylactic antibiotics usually solves these problems. TACE is most often performed in the liver. The liver has dual arterial system, namely the hepatic arteries and the portal system. Normal liver tissue gains its arterial supply predominantly from the portal system, however, arterial supply for hepatocellular carcinoma (HCC) cells are mainly from the hepatic artery, which makes arterial TACE more effective. In order to prevent liver insufficiency, portal vein should be patent when TACE is indicated. Most frequent indication of TACE include irresecable liver tumor (HCC, colorectal carcinoma or other metastasis). The interventional radiological treatment is mostly palliative, increased survival time has been proved in case of HCC. Embolisation may be performed on any hypervascularised metastasis (e.g. neuroendocrine tumor, renal carcinoma metastasis).
Figure 8. A 55-year old male patient has resection of a 2.5 cm tumor from the left kidney. Two days earlier, macroscopic hematuria developed, which was repeatedly present. In the lower third of the left kidney, at the site of the former operation, contrast enhancement shows severe intraparenchymal bleeding (Panel A: catheter in the proximal position, Panel B: catheter in the distalis position). The small arterial branches responsible for the bleeding was occluded using two metallic coils (Vortx-35, 3x7x67 mm, Boston Scientific) (Panel C). Urine was clear of blood within a few days, other treatment was not necessary. The only other alternative treatment would have been nephrectomy.

Embolisation may be required in benign hepatic tumors also (e.g. ruptured adenoma, huge hemangioma) for volume reduction and decreased risk of hemorrhage. Renal tumor embolisation is also performed both in benign (e.g. angiomyolipoma) and in malignant tumors (for preoperative or palliative care). Embolisation of benign bone tumors (e.g. aneurysmal bone cyst) may also reduce symptoms considerably, operative care may be postponed for years. Malignant bone tumors and bone metastasis are also occasionally treated by embolisation for palliative or preoperative care. Embolisation 1-2 days before an extent bone operation may decrease blood loss during the operation. Severe hemorrhage may occur at any part of the body due to malignant tumors; rapid intraarterial angiography and embolisation may serve as a life-saving measure in these cases.

Figure 9. Uterine artery embolisation due to symptomatic fibroid. Panel A and B: angiography before (A) and after (B) embolisation; arrows point to the catheter. Panel C and D: T1 weighted, contrast enhanced axial MR image before (C, myometrium and fibroid are both enhancing) and 5 months after embolisation (D, myometrium is enhancing, fibroid is no longer enhancing contrast medium; fibroid is considerably smaller in size).
Fibroids are among the most frequent benign tumors, it occurs up to 30% among the 35-55 year old females. However, it causes symptoms only in every 5th patient. Embolisation is indicated in symptomatic fibroids or symptomatic adenomyosis. Bilateral uterine artery embolisation elicits significant symptom reduction in 80-90% of the patients while the size of the fibroid is decreased by 20-25% in diameter and by 50-60% in volume at 6 months. Due to the embolisation, hysterectomy is not necessary in the vast majority of the patients.

20.4. Interventional radiological procedures in the venous system

Access for venous interventions are usually the common femoral vein, internal jugular vein or subclavian vein. US guided puncture is recommended to reduce the number of complications. PTA or stenting is most frequently done in the venous system in the brachiocephalic veins or superior vena cava for treating stenosis caused by external compression of lung tumor or for central stenosis in patients with dialysis fistula.

In case of portal hypertension and consequent oesophageal varicosity, an artificial connection between the portal vein and the hepatic veins can be created, i.e. transjugular intrahepatic portosystemic shunt (TIPS) can be performed; access is from the internal jugular vein, the catheter is directed to the hepatic vein branches, the portal brach is reached through a liver parenchyma puncture. A stent is placed within the liver parenchyma between the portal vein branch and the hepatic vein branch.

Selective venous catheter-directed thrombolysis can be performed in upper or lower limb deep vein thrombosis resulting in quicker therapeutic effect than in systemic thrombolysis. Chronic deep venous thrombosis may result in venous valve dysfunction, selective catheter-directed thrombolysis may prevent the development of valve dysfunction.

Varicocele embolisation is a procedure where the internal spermatic vein is occluded using coils and sclerotic agents (instead of surgical operation); in Hungary, there are very few centers providing such a procedure.

Placement of chronic venous lines and ports in Hungary are usually done by anesthesiologists, whereas in many countries in Europe and in a few centers in Hungary it is performed by interventional radiologists; image-guidance (US-guided puncture, fluoroscopy guided placement of the catheter tip) reduces the risk of complications. Chronic venous access is necessary when chemotherapy, antibiotic therapy or total parenteral nutrition is needed for a number of weeks or months. The advantage of port is that it is placed into a subcutaneous pouch (as opposed to the Hickman line, which has a large portion of the catheters outside the skin) thus the quality of life of the patient is much better, the port is (almost) not visible, regular lifestyle including showers and swimming is possible; the catheter is tunneled from this pouch to the internal jugular vein or the subclavian vein; the tip of this catheter is in the distal portion of the superior vena cava (Figure 10). Most important immediate complications at these procedures are PTX, inadvertent arterial puncture, venous wall perforation, air-embolism, catheter malposition; delayed complications include infection, venous stenosis, formation of thrombus or fibrin sheath.
Figure 10. Port implantation. The port chamber is indicated by the solid arrow. The plastic catheter from the port chamber is directed through a subcutaneous tunnel into the internal jugular vein and the superior vena cava (dashed arrows). Internal jugular vein was punctured using ultrasound guidance.

From lower limb or pelvic deep venous thrombosis, smaller or larger clots may escape and cause pulmonary embolism that even may be fatal. Primary treatment is anticoagulation; if it is contraindicated, or despite of adequate anticoagulation, repeated thromboembolic complications occur; anticoagulation therapy caused serious adverse event; or the patient is not compliant for anticoagulation therapy, than IVC filter placement is indicated. Filter is placed normally from the common femoral vein access and is placed distal to the renal veins. The filter itself may cause complications in the long term (1-2 years) (e.g. increased risk of deep venous thrombosis, inferior vena cava thrombosis, caval perforation of filter struts), therefore retrievable filters (retrieved few weeks or few months following placement) are more and more often indicated (few years ago, only permanent filters were available).

Foreign body retrieval (e.g. a few cm long piece of chronic venous catheter or pacemaker wire broken and stuck into the brachiocephalic vein or superior vena cava) is also possible using snares.

20.5. Summary

Vascular interventional radiological procedures are image-guided, minimal invasive, therapeutic procedures, by which stenotic arterial segments may be dilated, occluded vascular segments can be recanalised; occluded segments may be reopened by selective arterial thrombolysis; or vessels may be intentionally occluded in case of bleeding, benign or malignant tumors. In the venous system, stenotic segments may be treated; new channel may be created between the cava and portal system; selective lysis may be performed; inferior vena cava filter may be placed to prevent pulmonary embolism; foreign body retrieval is also possible using snares.

Translated by the author
21. Nuclear Medicine

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21.1. Introduction

Nuclear medicine is an independent medical field; it uses unsealed radioactive isotopes (radionuclides) for diagnostic or therapeutic purposes. The basic concepts of nuclear medicine use were laid down by a Hungarian descendant scientist, György Hevesy (1885-1966) who was awarded the Nobel Price for the invention of tracer and radioisotope labeling methods with which very small amounts and concentrations of matter can be tracked.

21.1.1. Methods in nuclear medicine

In the diagnostic use (isotope studies) we differentiate in vitro and in vivo examinations. In vitro diagnostics mean that samples of the patient (blood, body fluids, tissues) are analyzed for various materials (e.g.: tumor markers, hormone and medicine concentrations) with radi-isotopic laboratory methods such as radioimmunoassay (RIA). (In vitro methods with the emergence of non-isotopic laboratory examinations have lost much of their significance nowadays.)

During in vivo examinations radiopharmaceuticals (radiotracers) are delivered to the patient’s body in various ways. Administration is usually done intravenously, sometimes orally, at other times with inhalation or with direct injection to the tissues. The radiotracers are made of an organ-, tissue-, or function specific compound combined with the radioactive isotope. The latter is regarded as a tracer and its radioactive radiation is detected from outside while it shows different distribution patterns in the human body.

For the treatment of some pathologic processes it is possible to use tracers that accumulate in tissues over a longer period of time. Therefore, the attached radionuclides can be delivered to a targeted location and therapeutic radiation can take place locally with the preservation or with minimal impact on surrounding organs (isotope therapy).

The majority of in vivo examinations is an imaging method (scintigraphy). Since the dynamics of radiopharmacon enrichment and excretion are always related to some type of biochemical process and function, isotope examinations – as opposed to the other, so called morphological, structural imaging methods (X-ray, US, CT and to some extent MRI) – innately provide functional information. They are many times referred to as functional imaging techniques. Scintigraphy, as one of these methods, provides complementary data to radiological procedures. On the other hand, nuclear medicine techniques can also be regarded as emission methods, since they rely on the detection of radiation emitted from the patient.

Gamma radiation, including the gamma photons produced at the annihilation process of positron decay, and characteristic X-ray radiation are all electromagnetic radiation. They can be used for diagnostic imaging, because as a form of radioactive radiation, they show a great penetration capacity through the patient’s body. On the contrary, the corpuscular radiation of beta and alpha particles has a very little penetration ability and is absorbed after a short travel within the tissues. Therefore, isotopes that show beta and alpha decay are useful for therapeutic purposes.
21.1.2. Imaging in isotope diagnostics

The imaging equipment of nuclear medicine are gamma camera (also called Anger-, or scintillation camera) and positron emission tomography (PET) scanner. Scintigraphy detects single photon radionuclides, while PET is able to detect the positron emission of certain isotopes.

Gamma camera can produce two dimensional, planar images, while in case of SPECT (Single Photon Emission Computed Tomography) acquisition operates in a way that tomographic slices can be obtained with it. With SPECT the distribution of radiotracers can be visualized in a 3D volume. PET is a modality with which only tomographic images (and their 3D reconstructions) can be produced, while it is incapable of creating planar images. For non-imaging examinations, with the use of properly adjusted, collimated scintigraphic detectors radioactivity over a specific organ (e.g.: iodine transport of the thyroid gland, intraoperative radionuclide detection with gamma probe in certain surgical procedures) can also be measured.

Gamma camera can cover a limited area of the patient’s body (field of view) to produce planar images. If the patient is moved along the longitudinal axis of the detector, it can obtain a so called whole-body image in one picture. In SPECT mode the detector(s) are rotated around the body and tomographic images can be made of certain body parts (their size is consistent with the camera’s field of view). Beside general purpose gamma cameras, specially optimized, organ dedicated cameras can also be used (thyroid camera, brain or heart dedicated SPCET cameras). Pinhole collimators differ from the regularly used parallel hole collimators, because they are able to produce magnified, high resolution and highly detailed images even of smaller organs or lesions (e.g.: thyroid gland, infant hip). The camera in the PET machine can visualize a 20 cm long segment of the body at once, and if the table is moved along the longitudinal direction to make images in several sections, it is also capable of making whole-body examinations.

In nuclear medicine one can also distinguish static and dynamic examinations.

In static examinations the injected radiotracer can be accumulated in normal tissues, pathologic lesions or in some distribution spaces of the patient. If adequate incorporation time is allowed, an equilibrium state occurs in the dispersion of the radiotracer. Images taken at this point reflect the regional distribution of radiotracers and therefore a tissue/organ’s regional activity.

Dynamic examinations, on the other hand, are not only able to produce images of spatial activity, but they can follow the course of certain processes over the time. For instance, urine excretion in the kidney can be followed dynamically if appropriate time adjustments are made for the imaging. Even if some functional processes are faster than the time resolution of the image acquisition, they can be adjusted with gated methods (ECG, breathing gated imaging) to allow a chance to capture processes. However, it has to be noted, that in static isotope examinations, in order to minimize radiation dosage to the patient and to achieve the best signal-to-noise ratio, acquisition usually takes up to several minutes.

Gamma cameras with multiple detectors are more favorable, because they can produce better quality images and/or faster imaging without needing to increase the necessary radiation dosage.

A special feature of the isotope examination and image production is that both gamma cameras and the PET machine produce better quality images of regions closer to the detectors. This is because gamma photons that are emitted further from the detector suffer a greater absorption rate in the patient’s body than the ones emitted closer to it.
This is the reason why bone scans have to be made from at least an anterior and a posterior direction, while the kidneys are typically imaged from the posterior direction. When abnormalities are detected, for a more precise spatial localization, lateral or oblique images are acquired or in distinguished cases (for instance a more complex anatomic structure) SPECT examination might be required.

### 21.1.3. Radionuclides and radiotracers

Radioisotopes used for diagnostic purposes preferably have a reasonably short half-life, a pure gamma or X-ray radiation and a chemically simple way to bind various pharmaceuticals. They should not be too expensive to produce and be widely available. For single photon examinations, 99mTc isotope is a match for all the above mentioned requirements; it can be locally produced at the nuclear medicine department with an isotope generator, has a 6 hours long half-life, and solely emits gamma rays. It can be used in most of the gamma camera examinations as a radioactive tracer.

The characteristics of the pharmaceutical will determine what function and what clinical question can be investigated with it. Pharmaceuticals are available in their unlabelled form before being mixed together with the isotope. After a certain incubation time, their resulting product is the radiotracer. Besides 99mTc other tracer isotopes, such as 123I, 131I, 111In, 67Ga and 201Tl, are also used.

During more expensive PET examinations positron emitting isotopes are used. When these decay they produce a pair of high energy gamma photons, detected at tomographic image acquisition.

The development of PET examination method relies on the fact that the building blocks of organic materials: carbon, nitrogen and oxygen – only have positron emitting radioactive isotopes (11C, 13N, 15O). With the use of these isotopes labeled tracing compounds can be produced that are chemically identical to the naturally occurring molecules. Thus, with the help of PET, various physiologic/pathologic biochemical and metabolic processes can be analyzed in an in vivo, completely non invasive way. A major back-draw of these isotopes is that their half-life is extra short (2-20 minutes), and they require a cyclotron available at the site for their production. Nevertheless, these isotopes have an invaluable role in research.

For routine clinical PET examinations, an isotope with longer half-life is necessary, one that allows it to be transported within a few hundred kilometers. The 18F isotope and especially the fluorine labeled glucose analogue 18F-Fluoro-Dezoxi-Glucose (FDG) have become the widespread radiotracer of PET examinations with a relatively long, 110 minutes half-life. Another characteristic of FDG making it more favorable to use, is the phenomenon of “metabolic trapping”. This means that processes involving intense glucose metabolism show higher enrichment, therefore on single static images local metabolic levels can be represented. This happens in a way that FDG competes for glucose transporting channels with glucose molecules to get inside the cells. Intracellularly a hexokinase transforms it into FDG-6 phosphate, however as opposed to simple glucose, this molecule will not be a substrate of the following enzyme in the chain (glucose 6 phosphatase) and does not participate in further metabolic steps. Hence, FDG levels accumulate inside the cells over the time. Equilibrium will eventually occur and if PET image production is adjusted to this (usually 60 minutes after iv. injection) the locally detectable FDG levels will represent the intensity of glucose metabolism.
Since most of PET examinations are connected to the glucose metabolic activity of the organism, they are best used for organs that already have a high level of glucose activity (heart, brain) and the changes in glucose metabolism indicate a high diagnostic relevance. In most of the malignant tissues, a high increase of metabolic activity can be observed; this is the reason why PET studies have earned such a high significance in oncology. The above mentioned characteristics determine that FDG radiotracers are used in most cases (85%) with oncologic indications world-wide. Neuropsychiatric and cardiac indications constitute only a smaller part of FDG use (10% and 5% respectively). FDG is also useful in inflammatory diseases, since it accumulates in activated macrophages.

Obviously, in PET diagnostics beside glucose metabolism, with the use of appropriate radiopharmaceuticals several other specific biological functions can be studied in both, the clinical field and also in research.

21.1.4. Hybrid imaging

Functional imaging examinations are lagging behind in terms of structural and anatomic representation ability compared to the morphologic modalities. However, there is an obvious need for the precise localization of functional abnormalities both for diagnostic and therapeutic purposes. Therefore, it is important that results of functional and morphologic imaging are made available for comparison. Comparison is either possible directly (images from one modality is analyzed with the other next to it) or with software guided image registration (the fusion of image sets of two independently and separately performed examinations). Spatial registration means the process with which the imaging results of two modalities, or two separate examinations of the same modality are, after appropriate transformation, registered in a common 3 dimensional coordinate system. This way, two examinations can be fused with one another. The resulting fusion image is a real-time superimposition of the previously registered data sets of these modalities.

The greatest precision of image registration is achievable if the patient experiences minimal motion differences (the patient lies in the same position and imaging takes place almost at the same time) during both examinations. These requirements are met in hybrid imaging methods, with the implementation of the so called hardware registration. PET-CT, SPECT-CT or the newly emerging PET-MR examinations are all able to utilize hardware registration. The integrated PET/SPECT-CT method represents the latest technical developments of both PET and CT scanners, combined in one machine. It is capable to represent structural and metabolic information simultaneously and identically. The machine’s PET/SPECT and CT components are aligned along the common axial axis, and as the patient table moves along their longitudinal axis, the two examinations are carried out only minutes apart from each other, minimizing any movement or change in the patient’s position. During evaluation the identical slices of CT and PET can be matched with each other and they can be analyzed independently or represented in a fusion image. (Figure 1.)
Another advantage of hybrid imaging is that CT can be used for the attenuation correction (AC) of the PET images. Photons arriving from deeper lying tissues have a smaller chance of reaching the detector, due to greater scattering and absorption. The decrease in signal intensity is directly proportional with the local tissue densities. Thus, the activity-maps detected by PET and SPECT cameras are not the real tissue dependent radiopharmacon distributions. Real activity distribution maps are only detectable with the knowledge of tissue densities that are calculated from the attenuation corrected maps, registered during the CT examination. For anatomic localization and attenuation correction, a non-diagnostic quality, low-dose CT scan is appropriate.

21.1.5. The general characteristics of isotope examinations

Functional information is a characteristic property of isotope examination; another is related to the tracer principle, which makes it highly sensitive. This means that pathologic processes can be detected at an early stage. SPECT is able to detect nano-molar radiotracer concentrations, while PET pick-up signals coming from pico-molar radiopharmaceutical quantities. The higher sensitivity is due to the fact that functional alterations of metabolism usually precede detectable morphological changes of the tissues. Therefore, functional studies allow earlier and more precise diagnostics. Another aspect of higher sensitivity is that in an optimal scenario, the biologic contrast between normal and pathologic function is very high. Therefore, signal intensity of a normal tissue process will be much lower than that of a pathologic one, making them easily distinguishable on the image. (Figure 2.)
2. FDG PET Maximum Intensity Projection (MIP) image. There is a large biological contrast between the normal and the pathologic tissues. Right sided breast cancer, ipsilateral metastatic lymph nodes and multiplex metastases in the lung. Physiologically elevated FDG uptake is seen in the brain, salivary glands, tonsils, liver and the spleen as well as in the bone marrow and at certain segments of the intestines. Also, there is increased FDG activity in the kidneys and the urinary bladder due to excretion.

If a radiopharmaceutical accumulates in a pathologic process itself (tumor, inflammation, receptor), it makes specific, non-invasive, tissue characterization possible. If radiotracers, that display normal function are used, then pathologic processes as opposes to normal ones will appear different (either as an increase or a decrease in activity) independent from the type of pathology. Consequently, these examinations will be non-specific in nature (e.g.: thyroid gland-, bone/marrow-, liver- or renal scintigraphy).

A further advantage of isotope examinations is their non-invasive nature. The levels of chemical material use are so low that they usually do not have any side effects or complications. Allergic reactions are rare, however the use of certain protein products (e.g.: monoclonal antibodies) are contraindicated in known cases of hypersensitivity. Many of the isotope diagnostic methods provide quantitative, numerical data. Regional functional participation of the organs can be determined as percentage ratios. Dynamic processes can be represented with time-activity curves. PET is capable to produce results with absolute quantification, which is very useful in scientific studies. In routine clinical PET diagnostics tissue radiotracer distribution can also be quantified by the so called standardized uptake value (SUV). To determine SUV of a region, local radiopharmaceutical activity concentration needs to be divided with total activity of the injected radiopharmaceutical and the patient’s weight. SUV values gained by this equation represent how many times a region’s tracer concentration is greater, than the value it would give if all the injected concentration was equally distributed in the whole body weight of the patient.

The disadvantage of isotope examination compared to morphologic examinations is that they have a lower spatial resolution. Characteristically, a planar examination’s resolution is from 1-several cm, while SPECT has a 7-8 mm resolution, and PET can discriminate lesions of the size of 5-6 mm. However, one has to remember, that detectability is also influenced by the state of local activity—uptake values; if a lesion in question is very intensive in radiotracer uptake and the surrounding tissue is very limited, even smaller lesions can be detected than the ones indicated above.
Nuclear medicine examinations all exert a radiation burden on the patient of usually low doses. Even in case of technetium and PET exams the effective doses are not greater than 10mSv. Due to the radiation burden, most isotope exams are contraindicated in pregnancy and have to be indicated with care in lactating women and children. One method, to decrease a patient’s dose is achieved by good hydration. Most of the radiopharmaceuticals are excreted through the kidneys, therefore non-participating, useless activity can be faster excreted if the patient is well hydrated and micturates frequently.

21.2. Musculoskeletal system and bone scintigraphy

21.2.1. Diagnostic methods

The most important and most commonly used isotope examination of the musculoskeletal system is bone scintigraphy. During the examination composites of the normal bone, technetium labeled phosphate analogues are used. The radiotracer after iv. injection binds to the hydroxyapatite crystals of the bone. Its uptake in the bones is influenced by blood supply and osteoblast activity. The unnecessary, unbound radiotracers are excreted through the kidneys after about 2-3 hours, scintigraphy is performed during this late metabolic phase. This method consistently depicts bone structure and areas where increased or decreased metabolic activity persist. Usually, whole-body planar images are obtained from an anterior and a posterior direction and additional, optional lateral and oblique measurements can also be performed of targeted lesions if necessary. (Figure 3.)

3. Whole body bone scintigraphy, anterior (a) and posterior (b) acquisitions. Normal findings.

More complex anatomic structures (spine, the base of the skull, facial and hip bones) can only be imaged confidently with SPECT scans. On the one hand, they provide a more accurate spatial localization and on the other, with their superior contrast resolution, they are able to differentiate lesions even if planar exams are negative or uncertain. SPECT-CT can characterize the CT morphology of the lesions with pathologic uptake. Thus, it is capable to provide definitive diagnosis. (Figure 4.)
Bone scintigraphy, prostate cancer. The image set shows the characterization of multiplex increased activity uptake. Posterior whole body scan (a). SPECT-CT coronal fusion images (b,d), CT examination (c,e). Sclerotic lesions in the pelvic bones are suggestive of osteoplastic metastases (b,c), small joint arthrosis at LIII-IV segments, more expressed on the left side (b,c), spondylosis on the right side at LIV-V segments (d,e). (The increased activity spot on the whole body scan, at the left cubital region, is correspondent to the paravasation of the iv. radiopharmaceutical.)

With the use of pinhole collimators more detailed or magnified images can be acquired of even the smaller structures (hip bones of small infants or children, the bones of the hands and the feet.)

In case of localized complaints or known bone lesions a three phase scan needs be obtained. The three phase exam begins with a usually one minute long scan at the time of the injection of the isotope (first or perfusion phase). It is acquired in dynamic imaging mode and is used to analyze the blood perfusion of the lesion. The second, (early blood content) phase shows tissue perfusion. Here scanning is performed right after the end of the first phase and after 5-10 minutes of injection. Images are made of either the region of interest or a whole body scan is performed. The third, late phase scan, even in cases of targeted regional examination has to be performed as part of the whole body scan, in order to rule out multiplicity.

The examination does not require any special preparation. Within 2-3 hours of injection 50% of the injected activity is excreted through the kidneys. Excretion of the unnecessary radiation can be enhanced with increased fluid intake and frequent micturations, thus reducing unnecessary exposure of the bladder and the gonads. Bone scintigraphy depicts changes in metabolic activity, hence it is very sensitive. Compared to X-ray imaging it predicts pathologic processes at an earlier stage and provides information of the whole skeletal system. Most of the pathologic bone lesions, independent from their etiology, are associated with increased osteoblast activity, therefore scintigraphy is aspecific. Usually, even in lesions that
appear lytic radiologically, an increased activity can be observed with scintigraphy. This is due to the fact that around the lytic zone, a neighboring reparative process (increased osteoblast activity) is also occurring at the same time. A three phase examination however, is still relevant for the final diagnosis because malignant processes and inflammations are also positive in the first phase of the exam. Moreover, in the early phase some relevant information can be gained about the accompanying soft-tissue lesions and about the soft-tissue abnormalities occurring independently from the bone lesions. On a normal bone scintigraphy, the bony structure is well visible, and activity uptake intensity is basically proportional to the volume of the bones. Symmetric bones show identical activity uptake levels. Soft tissues show only small levels of activity uptake, the kidneys and the bladder are distinguishable from other organs. In children, active growth zones both in long tubular bones and in the apophyseal region of flat or irregular bones show an increased activity content. In cases of inflammatory disorders specific, inflammation sensitive radiotracers can also be used (e.g.: gallium scintigraphy, or labeled leukocyte scintigraphy).

In neoplastic diseases, direct identification of the lesion is possible with the use of tumor specific radiopharmaceuticals and methods (e.g.: FDG-PET, or PET-CT, MIBG scintigraphy.)

21.2.2. Bone metastasis

The most common indication of bone scintigraphy is the evaluation of bone metastasis. (Figure 5.)

5. Multiplex bone metastases. Bone scintigraphy, anterior (a) and posterior (b) whole body scans. SPECT-CT sagittal plane, fusion image (c) and CT image (d). CT examination at this stage is yet unable to identify structural changes in the bone.
The examination is appropriate for staging a malignant process and following-up bone metastases. It is clinically most suitable for lesions that frequently present bone metastasis, primarily in case of prostate-, breast-, lung cancer and neuroblastoma. It is, however only indicated in cases where the soft tissue involvement of the tumor is big enough to suggest a higher incidence of bone metastasis; before radical surgeries and for the selection of patients who would benefit form a palliative radionuclide therapy. Otherwise, scintigraphy is advisable in case of any primary tumor, if the suspicion for metastasis is raised, e.g.: bone pain, pathologic radiological or lab results (elevated serum ALP and tumor marker levels). Bone metastases in most cases are located in bones that contain red bone marrow (skull, vertebrae, ribs, sternum, pelvic bones and the proximal bone segments of the limb) and usually show a multiplex appearance. Usually activity increase can be seen. Metastases that cause activity decrease are rare; they could occur in cases of thyroid gland tumor, renal carcinoma, lymphoma and multiple myeloma. Solitary lesions or a few lesions only, due to the aspecific nature of the examination, cause a differential diagnostic problem in many cases, for example vertebral degenerative processes can mimic metastatic activity. Equivocal lesions usually require further, targeted radiological investigations. A negative X-ray examination does not rule out the possibility of a metastatic lesion, since the isotope scan is more sensitive. Therefore, it is possible that it could already be detecting an existing metastasis, while X-ray is still insensitive and unable to show the lesion. (Figure 5.)

SPECT examination of the spine can help in the precise lesion localization within a single vertebra. It is especially useful, since the different pathologic bone processes occur in different predilection sites of the vertebral bone. Bone metastases are commonly located in the dorsal aspect of the vertebral body. Degenerative processes involve mostly the vertebral edge as in the case of spondylophytes in spondylosis. Finally, spondolyathrosis is usually located at the intervertebral facet joints.

In cases of diffuse metastatic lesions of the bone marrow (most common in prostate cancer) a so called superscan can be observed. This means that the bone structure can accumulate in such an intensive manner, that the background activity, the renal uptake is completely inhibited.

21.2.3. Primary bone tumors

In cases of primary bone tumors, three phase scintigraphy can help to determine the dignity of equivocal bone lesions. Benign lesions do not show typically increased activity in the early phases, and even if there is a detectable late phase activity, it is moderate (except for osteoid osteoma, osteoblastoma, fibrotic dysplasia and aggressively growing bone cysts, or lesions that are associated with pathologic fractures.) Malignant tumors (osteosarcoma, Ewing sarcoma) as opposed to benign tumors, have an increased blood supply and a more intense osteoblast activity. (Figure 6.)
6. Osteosarcoma in the right femur. Three phase bone scintigraphy, planar anterior images. Perfusion phase acquisitions (a), summation (b), early blood pool phase (c), late phase (d), whole body scan (e).

Scintigraphy is also helpful to determine any skip lesion and bone metastases that are normally associated with malignant tumors. It is also useful in monitoring preoperative chemotherapy, and tumor recurrence. In osteosarcoma, because of the tumor’s osteoid production, it is also possible to detect soft-tissue metastases (e.g.: lung metastases). Tumor-specific nuclear medicine examinations, such as FDG-PET are useful for the staging and re-staging of the tumors and in monitoring chemotherapy. Uncertain processes can be differentiated by FDG-PET. Low grade sarcomas show no or minimal glucotic activity. High grade sarcomas demonstrate high glucose metabolism. Scintigraphy is basically 100% sensitive for osteoid osteoma. Its nidus shows an intensive, dot-like activity increase in all three phases of the examination. Since the activity accumulation in osteoid osteoma is so intense, isotopic methods (intraoperative scintigraphy or gamma probe) can be used as a guiding tool during surgery.

21.2.4. Inflammatory and degenerative bone and joint diseases

Scintigraphy is helpful in the early diagnosis of osteomyelitis. Both the sensitivity and specificity of the exam are above 90%. The scans are positive within 24-72 hours after initial symptoms occur. A characteristic, well circumscribed increased uptake is detectable in all three phases of the examination, however, sometimes, especially in infants, decreased activity might be observed (cold osteomyelitis). This phenomenon is due to regional ischemic changes. If there is a strong clinical suspicion but the scintigraphy is negative or there are other preexisting bone lesions (and the scan cannot differentiate osteomyelitis from the preexisting bone lesion), as an alternate we can use isotopes capable to directly identify inflammatory processes. These are combined Gallium- and bone scintigraphy exams or the combined exams of labeled white blood cell and bone marrow scintigraphy. In cases of subacute or chronic osteomyelitis on the one hand the radiologic picture should be indicative. On the other hand, an activity increase is notable mostly in the late phase of scintigraphy. In infectious diseases of the spine, scintigraphy is more sensitive for discitis and vertebral osteomyelitis than X-ray examination. However, in osteomyelitis scintigraphy of the long, tubular or flat bones only becomes indicative later, usually after symptoms persisting for more than a week. Complementary SPECT examination is able to detect lesions in case of negative scintigraphy or equivocal planar imaging. Although scintigraphy is usually unnecessary for the diagnostics of inflammatory joint diseases it might be used for non-diagnosed cases. When clinical symptoms are suggesting joint
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inflammation, scintigraphy could also be used for ruling out accompanying bone involvement. In the three phase bone scan articular and periarticular soft-tissues show early phase activity, while in bones a diffuse, late phase activity increase can be observed. Still, the exam can end with negative results, especially in transient synovitis. A well-defined spot of increased uptake in the bone might be indicative of other bone processes, especially osteomyelitis. (Figure 7.)

7. Right sided subacute coxitis. Three phase bone scintigraphy. Anterior (a) and posterior (b) whole body scans. Summation of the perfusion phase acquisitions (c), early blood pool phase (d), late phase (e), anterior view. Increased blood content and osteoblast activity in the right hip.

If degenerative arthritic joint lesions are in an active phase, they might also show elevated activity, but usually only in the later metabolic phase and – only in greater joints – only at certain parts of the articles.

The loosening of joint prosthetics can be diagnosed sensitively with scintigraphy. If there is a suspicion for septic loosening, the fact of inflammation can also be investigated.

Three phase scan shows intensive tracer accumulation in myositis ossificans. The exam can already be indicative when other methods still cannot depict any calcification. Scintigraphy is also useful in determining optimal timing of the surgery. Surgical resection should only be performed, when the activity of the lesion has ceased, so in the early phase it is not showing any increased activity, while the late phase has already started to show less intensive radiotracer accumulation. Timing is essential because too early resection is associated with greater recurrence rate.

21.2.5. Trauma

Traumatic bone lesions can readily be detected after a few hours of injury with scintigraphy. It is very helpful in the diagnosis of radiologically occult fractures, i.e. stress fracture, trauma of the scapula, fractures of the hand and feet and injuries of the sacrum have to be considered. It is especially useful for the detection of fractures related to child abuse.
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21.2.6. Aseptic necrosis

Bone scintigraphy is usually performed after radiologic exams are negative and in cases of uncertain symptom localization. Scintigraphy is able to detect lesions, even 6 weeks before they would become apparent with X-ray imaging. Scintigraphy, just like MRI has its sensitivity over 90%. Avascular necrosis most commonly presents at predilection sites, in Perthes disease at the proximal epiphysis of the femur. Scintigraphy can identify a lack of tracer accumulation. However, in order to appreciate the imaging findings, magnified pictures are necessary to be taken with the use of a pinhole collimator. On these images in the surrounding growth zone an activity increase can be noted compared to the other side. In the follow-up of the disease, as sign of revascularization, a gradually increasing activity uptake is noticeable. It either starts from the lateral side or from the epiphyseal base, of which, the first one indicates better prognosis.

21.3. Neuropsychiatry

21.3.1. Introduction

Functional brain imaging provides information based on biochemical, metabolic signs and changes in other processes of both the normal and the pathologic activity of the human brain. Functional imaging methods – besides MR spectroscopy and functional MRI – are SPECT and PET exams that employ radioisotopic tracer methods. PET compared to SPECT has a greater functional sensitivity and currently a better spatial resolution.

21.3.2. Functional brain mapping

During functional brain mapping regional cerebral blood flow (rcbf) or glucose metabolism indicates neuronal activity. In rcbf SPECT measurements, the so called diffusible radiotracers are used. These pass through the blood-brain barrier. (They are either 99mTc labeled hexamethylpropyleneamine oxime, HMPAO or ethyl cysteinate dimer, ECD). The radiotracers accumulate in the brain tissue proportionally to the blood flow, through an entrapment mechanism. The sole energy source of the brain is glucose. Its metabolism can be depicted with FDG-PET examinations. Because of the entrapment mechanism, FDG accumulation is going to be proportional to the local glucose metabolism and it will be indicative of the local brain activity. Since functional neuronal activity, regional cerebral blood flow and glucose metabolism are parallel changing events, these examinations are capable to visualize vascular lesions or to map brain functions. (Figure 8.)
One advantage of rcbf SPECT examination is that the radiotracer distribution occurs right after the intravenous injection and is not followed by significant redistribution. Therefore, at the time of the injection, the functional pattern of brain activity can be visualized as a “snapshot” although imaging can take place later. It is especially useful if sedation is necessary before imaging; the “frozen” image can still be recalled even a few hours later, in late phases. Thanks to this, beside normal resting examinations, psychomotor or pharmacological stress examinations can also be carried out. Ictal examinations can be performed to preoperatively detect focal epileptic lesions. For the imaging of regional involvement and for the organization of specific brain functions, the so called activation methods are available. This way a signal induced activity pattern can be revealed. SPECT imaging can be used in preoperative brain mapping even in patients who are otherwise unsuitable for functional MRI examination. Therefore, the localization of important brain areas (e.g.: speech center) is possible. Vasodilatation induction examinations with acetazolamide or CO2 show the reserve capacity of brain arteries. These are used in the preoperative mapping of blood supply disorders (Moyamoya disease).

Multimodal imaging, image registration, image fusion techniques combine morphologic (CT, MRI) and functional (SPECT, PET) methods. Usually, when these techniques are combined, they allow us to gain complementary and more complex information on brain function. However, the wide-spread availability of the hybrid method, PET-CT, had a more significant effect on whole-body imaging than on the imaging of the central nervous system. Nuclear medical examinations can be combined beside CT also with MRI or with one another (e.g.: SPECT-MRI, SPECT-PET, PET-MRI, SPECT-SPECT). Data set registration is carried out for the fusion, or in certain cases for the subtraction of imaging data sets.

In clinical practice, these methods are suitable for the examination of cerebrovascular diseases. One of their main indication is the differential diagnostics of dementia, or the early diagnosis of Alzheimer’s disease (possibly with FDG-PET). (Figure 9.)

In Alzheimer’s disease the posterior parietotemporal areas show typically decreased uptake. In frontotemporal dementia, the frontal and temporal areas are involved. In multi-infarct vascular dementia, a decrease in perfusion/metabolism can be shown at the corresponding areas of supplied brain regions. Pseudodementia in depression either demonstrates normal activity values or prefrontal hypoperfusion parameters. Preoperative lesion localization with isotope scans can be helpful in cases of therapy resistant focal epilepsy. At the beginning of the seizure, increased activity can be revealed at the site of the epileptic source. In the interictal state, the epileptic source is represented as a region with decreased activity. These functional changes are best captured with the combined use of ictal and interictal rcbf SPECT scans. If only a single interictal examination is considered, FDG-PET is more sensitive than rcbf SPECT. The above mentioned techniques are also useful for the diagnostics of brain death. However, usually it is enough to perform a planar brain scintigraphy with 99mTc-DTPA (diethylene triamine pentaacetic acid), during which the visualization of intracranial arteries and venous sinuses does not occur.

21.3.3. Neurotransmitter imaging, receptor scintigraphy

Neurotransmitter imaging or receptor scintigraphy is used for the investigation of specific radiotracer accumulation and binding. In the latter, neuropharmaceuticals show various parts of the neurotransmission: presynaptic, synaptic or postsynaptic functions. Neuropharmaceuticals either enter the synthesis of a neurotransmitter or they show specific binding to enzymes, receptors, transporters and reuptake sites. SPECT and PET examinations can visualize dopaminergic, serotonergic, cholinergic and GABA-ergic systems of the brain. However, these are mostly performed in an experimental setting. For clinical imaging purposes, the investigation of the dopaminergic system is available and provides relevant information. Presynaptic dopamine transporter molecule (DAT) can bind certain radiotracers (such as 123I-FP-CIT); the decrease of its striatal accumulation is indicative of a nigrostriatal degenerative process. Thus, this method is capable to diagnose Parkinson’s disease also in early stages. It can also be used to rule out Parkinson’s disease or to differentiate it from essential tremor. The differentiation of idiopathic Parkinson’s disease from atypical Parkinson’s syndrome is possible with the use of a postsynaptic D2 dopaminergic receptor binding radiotracer (123I-iodine-benzamid, IBZM). In atypical Parkinson’s syndromes the postsynaptic sites show a pathologic injury, while in idiopathic Parkinson’s disease they do not.
21.3.4. Neurooncology

In neurooncology PET radiotracers that show increased uptake in tumors (metabolic and amino acid metabolite tracers) provide complementary information that is otherwise irreplaceable with other imaging modalities. FDG radiopharmaceuticals depict increased glucose metabolism and their uptake levels are proportional to the grade of malignancy. In case of heterogeneous tumors, FDG is even capable to show which regions of the tumor are more active, making targeting of the more malignant parts possible. However, physiologically high tracer uptake of the gray matter can represent differential diagnostic problems. False positive results can also be encountered due to occurrence of inflammatory processes after a treatment.

With FDG, low grade tumors appear hypo-metabolic (their activity uptake does not exceed the levels seen in the white matter). High grade tumors are hyper-metabolic their FDG uptake may surpass the levels of gray matter accumulation. Radiotracers that are capable to indicate increased amino acid transport in malignant neoplasms (11C-methionine, 18F-ethyl-tyrosin: FET) only show a minimal uptake in normal brain tissue. These are useful indicators of low grade tumors. They also enrich in inflammatory processes to a smaller extent, consequently they can be used to sensitively and precisely locate the extent of viable tumor tissue.

PET studies have various roles in the diagnostics of brain malignancies (determining the grade, guiding stereotaxic biopsy), estimating the prognosis (the more intensive FDG uptake the worse the outcome), planning therapy (can determine the extent of the tumor), following-up the disease (the effectiveness of the therapy can be measured with the functional changes, low grade gliomas can transform anaplastically, which can be diagnosed non-invasively).

PET has an outstanding role in residual tumor detection or in the imaging of recurrence, after surgical and/or irradiation therapy. PET can be used for the differentiation between postirradiation necrosis and tumor reappearance, while most imaging modalities in these cases are less reliable.

21.3.5. Liquor scintigraphy

During liquor scintigraphy radiopharmaceuticals are injected to the subarachnoid space (99mTc-DTPA). This is used to study various liquor circulation and absorption dysfunctions. It can also reassure suspected cases of traumatic liquor fistulae.

21.4. Nuclear medicine in oncologic diagnostics

21.4.1. Direct methods

Nuclear medicine methods that visualize tumors directly, have an outstanding role in cancer imaging. The applied radiotracers are taken up in malignant processes. The most important role and a unique ability of FDG-PET and PET-CT is to provide information about viable tumor tissue. This characteristic is unmatched by other non-invasive modalities.

21.4.1.1. PET

The most common clinical use of FDG-PET is in the form of whole-body scan, with oncologic indications. The majority of malignant tumors operate with higher energy consumption and show an increased glucotic activity, consequently an increased uptake of
FDG. The grade of malignancy is usually proportional to the rate of uptake. This method is useful in oncologic diagnostics, since it is capable to differentiate benign lesions from malignant ones. Whole-body PET imaging is capable to detect the primary tumor with local nodal metastases as well as distant metastatic lesions (staging) in one examination. (Figure 10.)

10. Ewing’s sarcoma in the right humerus. Staging FDG PET-CT. PET Maximum Intensity Projection (MIP) image (a), transversal (b,c) and coronal (d) plane fused PET-CT images. Multiplex metastatic process with nodal, lung and bone involvement.

In the staging of malignant diseases FDG-PET is extremely important, since it has a greater sensitivity and specificity than the morphologic imaging modalities. This is most certainly true in case of imaging metastatic lymph nodes. Morphological imaging methods utilize size as the only reliable criteria for the differentiation of a metastatic lymph node. FDG-PET detects metabolic changes in the metastatic lesions independently from their actual size. This way, also normal sized metastatic lymph nodes can be identified. Larger lymph nodes that are non-metastatic in nature, but for other reasons show abnormal enlargement can also be differentiated. (Figure 11.)
11. FDG PET-CT. Transversal plane fused (a) and CT (b) image. Small (normal sized) metastatic lymph node on the right side retrocrurally showing increased radiopharmaceutical uptake.

It provides a great help for determining lesions for biopsy, planning surgery or planning irradiation volumes. Oncologic PET examinations, based on a wide data of scientific literature, lead to a relevant modification of disease staging in approximately 30% of various oncologic diseases. Thus, the results of PET exams can significantly change the therapy planning of a patient. This change in about 2/3rds of the cases leads to restaging the disease to a higher level (upstaging), in 1/3rd of the cases PET results are able to restage the disease to a lower level (downstaging). According to reliable international studies, the use of this method in many indicated cases has proved to be cost-effective. Upstaging could mean that any further, unnecessary and expensive treatment options could become avoidable. Downstaging can help in therapy decision making, particularly in making various other and possibly more expensive therapeutic options unnecessary.

In most cases the real cost effectiveness of a single examination cannot even be estimated. However, it is important to consider if a previously incorrect diagnosis could lead up to unnecessary and dangerous interventions. But with a reliable diagnostic tool effective therapy can be sought, and this can have an impact on patient improvement and quality of life. PET examination is suitable for patient follow-up and for the monitoring of therapy effectiveness. When compared to morphologic imaging modalities, the therapeutic effectiveness can be better monitored and response evaluation can be made sooner after the initiation of a therapy. This is based on the fact that the examination measures functional changes of the tumor that tend to precede morphological/structural changes (size) of the tumor.

With the functional methods residual tumors or recurrence (restaging) can be diagnosed earlier or ruled out even when other modalities are uncertain. For example, it can be determined whether a post-therapeutic residual mass contains any viable tumor tissue or if it is just scar tissue.

In the early phases of oncologic treatment (so called interim phase) PET examinations seem to be able to differentiate patients that respond well to the therapy, from the ones that are resistant to it. (Figure 12.)
12. Diffuse large B-cell lymphoma. Neoadjuvant staging (a-c) and after 3 cycles of immunochemotherapy, interim (d-f) FDG PET-CT. Maximum Intensity Projection (MIP) PET images (a,d), transversal fusion images (b,e) and CT images (c,f). During staging extended supra- and infradiaphragmatic nodal involvement was found. At the interim examination a good therapeutic response can be seen through the complete metabolic remission. A residual soft tissue mass can still be noted with considerable parailiac extension. (e-f).

In resistant cases this would provide valuable information, and non-reacting patients would not necessarily have to be exposed to ineffective, but expensive and toxic treatments. Their option would either be the early suspension of the therapy or the switching for another one. In addition, the intensity of FDG uptake and the level of early therapy response can also be useful in assessing the prognostics of a tumor. Finally, PET imaging due to its high sensitivity may be able to detect tumors of unknown origin (occult tumors). Considering the principles of evidence based medicine, the PET examinations which are proven to be cost-effective and able to provide information with relevant therapeutic consequences and - even if slight national differences exist between the countries – can routinely be indicated for a list of malignant diseases.

PET imaging has a proved effectiveness in the following cancer types:
- the differential diagnostics of a solitary pulmonary nodule
- it is valuable in staging and restaging of lung cancer,
- lymphomas,
- colorectal cancer,
- esophageal cancer,
- head and neck cancers,
- malignant melanoma,
- breast cancer
and uterine cervical cancer.
In case of thyroid cancer restaging, it is valuable if the tumor is dedifferentiated, i.e. it does not accumulate the iodine isotope.
However, FDG-PET can lead to false negative results if the tumor is too small and/or its glucose metabolism has not or only slightly increased (for example: well differentiated neuroendocrine tumors, bronchoalveolar carcinoma, many types of renal or prostate cancer and hepatocellular carcinoma.)

Since FDG is not a tumor specific tracer, some false positive results have to be considered with its use. These usually occur in processes with elevated glucose metabolism or excretion. Certain inflammatory processes — early postoperative and postirradiation phenomena, activated brown fatty tissue, urine excretion in the kidneys and in the urinary tract, aspecific intestinal activity, bone marrow hyperplasia following chemotherapeutic treatment and - especially in younger patients - thymus hyperplasia can all have false positive results.

21.4.1.1.1. PET-CT

The rapid spread of clinically available PET-CT devices is continuous since the beginning of the third millennium. So much so, that nowadays standalone PET machines are not even sold by the manufacturers. Its usefulness is underlined by a wide range of data from the oncologic field. The results show that integrated PET-CT is more sensitive and specific than if its individual modality units are used separately. The most important effect of PET-CT compared to stand alone PET machine is that various lesions on PET are more precisely localized. With the rendering of the morphologic data the differentiation of various benign and physiologic processes from malignant lesions makes this technique more reliable. These all lead to the reduction in the number of uncertain or false negative results, while they are increasing specificity. Furthermore, the functional information from PET imaging also helps in the characterization of equivocal CT lesions (as in the case of lymph nodes). The increasing effect of PET, regarding the value of CT examination looks obvious, because the PET radiotracer can be considered as a new type of “contrast material” with a very high functional sensitivity and specificity. In some cases, like in disseminated pulmonary metastatic lesions, when the lesion size is too small to be detectable with PET examination alone, CT can increase the sensitivity of PET-CT. Therefore, it has become a widely accepted fact that in the filed of tumor staging PET-CT is more sensitive than CT or PET alone, (or even if the two modalities are analyzed side by side.)

It is also an emerging trend that PET-CT examination, with its capability of whole-body imaging and with both functional and structural information on the organ systems, should be performed at the initial phase of the diagnostic process. An adequate diagnosis could be reached faster, the use of other modalities, would become unnecessary, and examination costs could be decreased. It is also diagnostically beneficial, if intravenous dynamic contrast enhanced CT exam is performed as a part of PET-CT examination. Nonetheless, this algorithm would decrease the radiation exposure that patients experience during each of these exams.

In oncologic PET diagnostics, beside FDG other radiopharmaceuticals can also be used:
- perfusion tracers;
- labeled amino acids that depict amino-acid transport;
- nucleotides that indicate tumor proliferation;
- labeled choline that provides information of cell membrane synthesis;
- DOPA or somatostatin analogues for the examination of neuroendocrine tumors;
- and special tracers that can depict tumor oxygenation or hypoxia.
21.4.1.2. Iodine scintigraphy

Whole-body iodine scintigraphy is usually performed in cases of iodine uptaking well differentiated thyroid cancer. It can detect recurrent tumors or its metastases.

21.4.1.3. Receptor scintigraphy

Receptor scintigraphy is also a direct and a very specific technique.

21.4.1.3.1. Adrenerg receptor scintigraphy

Neuroectodermal tumors that are rich in adrenergic receptors (neuroblastoma in children, pheochromocytoma in adults) can be targeted with radiotracers that are analogues of noradrenaline, and concentrate in the secretory granules of catecholamine producing cells (metaiodobenzylguanidine, MIBG). Radioactive labeling is performed with 123I isotope, and less frequently with 131I isotope. In cases of pheochromocytoma the method is useful in preoperative localization, which is usually necessary if the tumor is ectopic or multiplex (various MEN syndromes), or if it is malignant and has metastases. For neuroblastoma MIBG scintigraphy basically has a 100% specificity, while its sensitivity is smaller, since there are tumors that do not take up MIBG. The exam is useful for the detection of local recurrence and distant metastases, thus it is important in tumor staging and early detection. Moreover it reflects about the effectiveness of the therapy.

21.4.1.3.2. Somatostatin receptor scintigraphy

Many tumors express somatostatin receptors, especially the various types of neuroendocrine tumors (for example carcinoid, meningeoma, medulloblastoma and neuroblastoma). These can be investigated with somatostation analogue peptides, most commonly with pentetreotide, an 111In isotope labeled peptide (OctreoScan). This examination is primarily significant in carcinoid and GEP (gastroenteropancreatic) tumor (gastrinoma, insulinoma, glucagonoma, VIPoma) diagnostics. Although GEP tumors present with a severe clinical picture, they are usually small and their detection with other imaging modalities is difficult. For this reason, somatostatin receptor scintigraphy is the method of choice. If the carcinoid is well differentiated, it is able to detect the lesion and possible metastases. Furthermore, it is useful in therapy monitoring and in cases of planned liver transplantation to rule out extrahepatic metastases. (Figure 13.)
13. Somatostatin receptor scintigraphy (Octreoscan). Planar anterior (a), transversal (b) and coronal (c) fusion SPECT-CT images. Multiplex liver metastases, the primary neuroendocrine tumor is in the head of the pancreas.

Pharmaceuticals that bind these receptors or their analogues can be labeled also with beta emitting radionuclides. Thus, even radioisotopic therapy can be performed. In case of radiotherapy a diagnostic examination should precede every time, in order to determine whether the targeted lesion shows pharmaceutical uptake, thus indicating it is applicable for radioisotopic therapy.

21.4.2. Indirect methods

Among the indirect methods (depicting normal function as well as their abnormalities) scintigraphy can be performed with pharmaceuticals, that for instance, compete with bilirubin extraction (HIDA, BrIDA) for hepato-biliary scintigraphy, or with colloids that are taken up by Kupffer cells for static liver scintigraphy. These techniques are both able to determine the benign origin of focal liver lesions.

Bone scintigraphy is used in the imaging of bone metastases of malignant tumors. Bone marrow scintigraphy is a less significant method; however it can also be used in bone metastasis diagnostics.

A three phase blood-pool scintigraphy is available in the diagnostics of liver hemangiomas.

21.4.3. Radionuclid-guided surgery

Primarily occult, non palpable lesions that are to be surgically removed can be targeted with radioisotopes and, during surgery, located with a hand held gamma probe. Radiotracers are either enriched in the lesion (e.g. surgery of the parathyroid gland, sentinel lymph node localization) or injected directly to a lesion, e.g. non-palpable breast cancer can be located with the Radioguided Occult Lesion Localization (ROLL) method as an alternative to the radiologic wire guide technique.

21.5. Urogenital system

21.5.1. Introduccion

Renal scintigraphy and urinary tract imaging have high significance because, for instance scintigraphy can express numerically (percentage) the split renal function which information is otherwise immeasurable with other methods.
21.5.2. Dynamic renal scintigraphy (camera renography)

During this examination technetium labeled radiopharmaceuticals are used that are excreted rapidly through the kidneys either by glomerular filtration (DTPA= diethylenetamine pentaacetic acid), or by tubular secretion (MAG-3= mercaptoacetyltriglycine, EC= ethylenedicysteine). Normally, because of the dorsal position of the kidneys, posterior measurements are taken. In case of a transplanted or ventrally localized kidney, images are obtained from an anterior direction. A series of images are acquired after the start of intravenous injection of the radiopharmaceutical. The imaging is performed at least up to 20 minutes, so that the excretory mechanism can be depicted. In these series the intensive excretion of the renal parenchyma can be well recognized, then in a transitory period the collecting system is visualized and after, parallel with the emptying of the kidneys, the filling up of the bladder can be seen. On these image series the so called ROI (region of interest) technique can be applied, in order to circumscribe the projections of the kidney and then to calculate time-activity curves (renograms). The renogram normally consists of three phases
the first one is a rapid elevation due to the blood flow;
in the second phase the elevation slows down, the parenchymal function dominates;
then in the third phase, the curve decreases exponentially following the washout from the pyelon.
With the help of the computed data sets, the relative renal contribution of each kidney can be determined in percentages to the total functional load. (Figure 14.)

14. Dynamic renal scintigraphy, normal state. Posterior planar sequence (1 min/image) (a). Results of the semiquantitative evaluation (b).
Dynamic renal scintigraphy is useful in determining the nature of acute anuric states (prerenal, renal or postrenal).
In case of unilateral kidney diseases, it is important to see how much is the relative functional share of the damaged kidney. If a surgery is planned, it is also valuable to know the functional state of the contralateral kidney.
Obstructive uropathies also make up a significant indication group for renal scintigraphy. The examination can answer whether the uropathy has caused any nephropathy, i.e. is there any secondary parenchyma lesion. Moreover it is possible to see whether there is any real obstruction or stenosis behind the dilatation of the collecting system requiring future intervention to prevent progression. In these cases, when parenchyma function is preserved, the activity excreted by the kidney is either retained, or its excretion is very prolonged. Obstructive and non-obstructive dilatations are differentiated by giving the patient a diuretic
(diuretic renography). If there is no obstruction, as an effect of the diuretics the previously stagnating urine quickly washes out from the collecting system, while in real obstruction this effect is not seen. (Figure 15.)

15. Diuresis renography. Iv. diuretics were given to the patient in the 15th minute of the exam. Case 1: Posterior planar sequence (1 min/image) (a). Case 2: Representative images, time-activity curves, ROIs (b). Left sided functional dysfunction of the urethral system in both cases at the pyelo-urethral junction.

The first case is regarded as a functional problem, the latter as an organic abnormality. To determine the renovascular cause of hypertension (the existence of a renin mediated process), the captopril challenge test is required. In case of a persisting renal artery stenosis, the production of renin is enhanced, that with the help of angiotensin convertase enzyme (ACE) will consequently lead to the elevation of the most potent vasoconstrictor, angiotensin II. In the glomeruli, Angiotenzin II constricts the efferent vessels more than the afferent ones. Consequently, this effect increases glomerular pressure and compensates for the decreased GFR, caused by the stenosis of the renal artery. Captopril (ACE-inhibitor) ceases the previously described chain. Thus, the kidney with a stenotic artery will not show the effect and its function decreases.

For a transplanted kidney dynamic renal scintigraphy can be a valuable tool to detect various complications (blood supply abnormalities, rejection, urine excretion impairment, urine leakage) at an early time. Scintigraphy is also helpful in the differentiation of tubular necrosis from rejection and in the follow-up of kidney function.

21.5.3. Static renal scintigraphy

With the use of 99mTc-DMSA (Technetium-99m-dimercaptosuccinic acid), a radiopharmacon that is excreted by the kidney (proximal tubules) and that persists within the tubules for a longer time, static renal imaging can be performed. Imaging is performed after a certain incorporation time of the radiopharmaceutical (3-4 hours after iv. injection) to depict the regional renal function in high detail static images.

This is primarily useful in the diagnostics of pyelonephritis. In uncertain cases it can verify acute inflammation. In chronic processes, static renal scintigraphy can identify scar lesions sensitively (chronic pyelonephritis, reflux nephropathy). The above mentioned lesions present themselves as decreased activity. Since the exam is not specific, the detailed morphology of the lesion is also necessary, and it is usually obtained with a complementary US examination. US exam helps the differentiation of pyelonephritis from lesions with a mass effect that also present as an activity defect on scintigraphy. (Figure 16.)

With multiangular static imaging the abnormalities of kidney shape, size and position can be also depicted. Especially, in cases of renal disposition disorders, (e.g.: dystopia) the kidney’s relative involvement in the total renal function can be better calculated than with dynamic examinations. It is because in the static exam, the mean count rate measured in the anterior and posterior images are used for calculation.

21.5.4. Radionuclide cystography

Radionuclide cystography can be used in children for the diagnostics of vesicoureteral reflux (VUR) and also for the measurement of bladder retention.

In case of a direct cystography, just like in X-ray micturation cystography, the isotope is delivered through a catheter into the bladder. The use of the indirect method is more widespread and has the advantage that it does not require the placement of a urinary catheter. VUR can be observed in physiologic conditions; at the end of dynamic renal scintigraphy, when the kidneys are completely emptied, the patient is asked to micturate while a dynamic acquisition is obtained by the gamma camera. The process is recorded with high frame rate image series. If VUR exists, then during micturation activity can be detected again in the ureter and the renal collecting system. (Figure 17.)

17. Indirect radionuclide cystography. Dynamic examination (5 sec/image), posterior view. Left isded uretral and urinary tract reflux at filled bladder and during micturation. This method is useful for the follow-up of previously diagnosed cases of VUR.
21.6. Gastroenterology

21.6.1. Examination of the liver and the biliary system

There are three imaging methods for the liver.

21.6.1.1. Colloid liver-spleen scintigraphy (static liver scintigraphy)

During colloid liver-spleen scintigraphy a technetium labeled colloid is used, that is taken up by the elements of RES and the Kuppfer cells. At imaging, most solid lesions of the liver, except for focal nodular hyperplasia and the regenerative nodules in cirrhosis will appear as well-circumscribed activity defects.

21.6.1.2. Cholescintigraphy

Cholescintigraphy is a method to assess hepatocellular function, bile secretion and biliary drainage. The radiotracer is 99mTc labeled iminodiacetate (IDA), it is similar to bilirubin, and it is secreted by hepatocytes. During cholescintigraphy dynamic series of images of the liver and the abdominal region are produced for an hour. This will show the excretion of the radiopharmacon in the liver, then its appearance in the biliary tree, gall bladder and finally its duodenal secretion. The examination is excellent for the assessment of gall bladder emptying. (Figure 18.)


Gall bladder contraction is either provoked pharmacologically (iv. injection of cholecystokinin) or with the consumption of fatty meal. For the identification of biliary obstruction, this is the most sensitive method. In case of obstruction, in the biliary tracts proximal to the obstructing lesion a retention of the radiopharmaceutical occurs. Duodenal-gastric reflux of the bile can only be detected with this examination in physiologic circumstances. It is also sensitive for the diagnosis of postoperative biliary fistulas. If there is a preexisting parenchymal liver disease, the radiotracer excretion decreases and intrahepatic transport is prolonged. Biliary atresia in infants can also be ruled out or confirmed by the appearance or the complete absence of intestinal activity.

21.6.1.3. Focal nodular hyperplasia

Isotope examinations are also available for the detection of focal liver lesions, for instance focal nodular hyperplasia (FNH). In the majority of FNH, the Kupffer cells are active, therefore in static liver scintigraphy (SPECT) the labeled colloid activity will be increased in the lesion, which is characteristic for the lesion. During cholescintigraphy a characteristic
image is seen; a three phase examination is required with a perfusion scan of the liver included. During the perfusion phase a mass with arterial supply is visible, then the radiotracer is secreted in the FNH, but due to the lack of normal biliary tracts within the lesion, the activity appears to be trapped. (Figure 19.)

19. Focal nodular hyperplasia (FNH). Three phase scintigraphy, anterior view (a-d), perfusion sequence (a), summation image of the arterial phase (b), early parenchymal phase (c) and late phase (d) static images. Static liver scintigraphy anterior plane (e). During chole-scintigraphy a well defined increased arterial inflow (a,b), hepatocellular excretion (c) and late activity retention (d). Static liver scintigraphy reveals preserved Kupffer cell activity at the site of the lesion (e).

However, well differentiated HCC and hepatoblastoma can both appear very similarly as well.

21.6.1.4. Three phase blood pool scintigraphy

The three phase blood pool scintigraphy is a specific examination for cavernous hemangiomas. Blood pool scintigraphy can be performed with two techniques. In the first one red blood cells (rbc) are labeled in vivo (within the blood vessels) and in the second case an in vitro labeling can be carried out in two steps. The first step of the in vitro technique is the sensitization of rbc with an inactive component, then they are labeled with 99mTc-pertechnetate.

In the perfusion phase decreased activity can be noted according to the cavernous hemangioma, due to its decreased blood supply. Following, in the early blood content phase, this decrease persists, since the labeled blood can only gradually fill up the cavernous spaces of the hemangioma and its dilution with the unlabeled blood takes some time. In the late phase scans (at about 2 hours after the start of the exam) the lesion appears with higher blood content compared to the surrounding parenchyma. (Figure 20.)
20. Cavernous hemangioma in the liver. Three phase blood pool scintigraphy in posterior view. Summation image of the perfusion phase (a), early (5 min.) phase (b) and late (2 hours) phase (c) static images. There is a steadily growing blood pool activity increase in the dorsal lesion of the right lobe of the liver.

21.6.2. Gastrointestinal bleeding

Blood pool scintigraphy is also used for the localization of gastrointestinal bleeding. In case of an active bleeding, the labeled rbcs exit to the intestinal lumen. In typical cases the hemorrhage is apparent as a circumscribed activity pool, which by following the intestinal peristalsis, will appear at different locations over the time, while its extension grows. The exam is only sensitive if the rate of bleeding is equal or greater than 0.1-0.4 ml/min.

21.6.2.1. Meckel’s diverticule

In infants GI bleeding can also occur from the ectopic gastric mucosa in Meckel’s diverticule. The diverticule’s mucosal membrane can be identified with 99mTc-pertechnetate scintigraphy. The isotope is accumulated in both normal and ectopic mucosal membrane and the ectopic mucosa will appear as a circumscribed activity increase outside the stomach’s area. (Figure 21.)

21. Meckel-dierticule with ectopic ventricular epithelium. Anterior image was taken of the abdomen after 60 minutes of iv. injection of 99mTc-pertechnete. In the right lower quadrant of the abdomen there is a pathological activity increase, while at the projection of the stomach the activity uptake is normal. (Urine activity in the bladder.)
21.6.3. Inflammatory bowel diseases

Inflammatory bowel diseases can also be assessed with scintigraphy for their extent and their state of activity. In IBD isotope labeled white blood cells are used. The advantage of scintigraphy is, that as opposed to other techniques, it is completely non-invasive.

21.6.4. Gastrointestinal motility

The motility examinations of the GI tract, esophagus, stomach, small and large bowels are carried out with functional isotope examinations. The radioactive isotope labeled liquid, semi-solid and solid food is ingested orally. Their most important advantage is sensitivity and their physiologic nature, which means that these results can be quantified. Gastro-esophageal reflux is well assessable with these orally ingested foods. Scintigraphy due to its non-invasive manner and low radiation burden is especially useful in infants and small children.

21.7. Endocrinology

21.7.1. Thyroid scintigraphy

Thyroid scintigraphy is carried out with 99mTc-pertechnetate. The examination is capable to assess regional thyroid activity and the pharmaceutical is taken up by the iodine pumps of the gland. Pertechnetate as opposed to iodine does not participate in the consequent steps of hormone production and empties the thyroid gland rapidly. (Figure 22.)

![Thyroid gland scintigraphy (planar anterior image). Normal thyroid gland scintigram.](image)

22. Thyroid gland scintigraphy (planar anterior image). Normal thyroid gland scintigram.

The exam is able to depict the shape, size, location and the activity levels of the lobes and moreover it can visualize ectopic thyroid tissue. The thyroid nodules are usually identified by palpation or US examination while their activity is assessed by scintigraphy scans. When the level of activity in a nodule is low or there is no activity at all it is regarded as a “cold” nodule. In cases when activity levels are equal to the normal thyroid tissue they are called “warm” nodules, and in case of increased activity “hot” nodules are differentiated. The carcinomas of the thyroid gland appear as cold nodules, however the examination is aspecific. Other lesions cause also cold nodules, such as colloid nodule, focal thyreoiditis or hemorrhage. (Figure 23.)
23. Thyroid gland scintigraphy (planar anterior image). Cold nodule in the lower pole of the left lobe of the thyroid gland.

(It is to be noted here, that due to the limited spatial resolution, cold nodules smaller than 1 cm routinely do not appear on the scan.) Scintigraphy is very valuable in the differentials of hyperthyreosis. Autonomic adenomas can be readily identified as they appear as hot spots. While the normal thyroid tissue is suppressed and it shows decreased radiopharmaceutical uptake. (Figure 24.)

24. Thyroid gland scintigraphy (planar anterior image) in hyperthyroidism. Hot nodule in the lower pole of the right lobe. Other parts of the thyroid gland show a suppressed activity uptake, autonomic adenoma (a). Enlarged thyroid gland showing a homogeneous activity uptake, diffuse struma, Basedow-disease (b).

Differentiated –iodine uptaking – recurrent tumors and metastases of thyroid cancer (papillary and follicular carcinoma) can be detected with a whole body iodine scintigraphy using 131I-NaI.

21.7.2. Parathyroid scintigraphy

Parathyroid adenoma is the typical cause of primary hyperparathyroidism. The over-producing lesion can be preoperatively localized, and is gaining significance with the spreading of minimally invasive (endoscopic) surgical methods. The increased and overproducing gland does not show any affinity for a specific radiopharmaceutical. Due to increased cellular density and increased metabolism, adenomas can be identified with so
21. Nuclear Medicine

called perfusion radiotracers such as 201Tl-cloride or 99mTc-sestamibi (commonly used in cardiac scintigraphy). Parathyroid adenomas are either located on the neck or in 6-10% of the cases in the upper mediastinum as ectopic adenomas. It is slightly problematic that the hypercellular thyroid gland also accumulates the radiotracers. However, sestamibi washes out rather quickly. The differentiation of adenomas from the thyroid gland is done with a two phase (wash-out) sestamibi scan. In early pictures both the adenoma and thyroid glands show increased activity, while in the late phase thyroid activity decreases compared to the adenoma. (Figure 25.)

25. Two phase parathyroid gland scintigraphy with 99mTc-sestamibi. Early (a) and late (b) planar anterior images, SPECT examination in the early phase (c). Behind the lower pole of the right lobe of the thyroid gland there is increased activity uptake of the radiopharmaceutical with decreased wash-out phase. Parathyroid adenoma.

Another method used, is the subtraction method, in which functional thyroid gland is depicted with 99mTc-pertechnetane (just like in the thyroid scans) and in the next step this image is subtracted from the scan taken with the perfusion radiotracer. Precise localization is possible with SPECT or even with SPECT-CT imaging.

21.7.3. Adrenal cortical scintigraphy

Cholesterol derivatives labeled with radioisotope are used for the imaging of the functioning adrenal cortex. The method is used in the differential diagnostics of hormone overproducing syndromes and in the characterization of incidentalomas.

21.7.4. Adrenal medullar scintigraphy

Pheochromocytoma originating from the adrenal medulla and hormone producing neuroendocrine tumors (carcinoid, GEP tumors) are investigated by adrenergic and somatostatin receptor scintigraphy methods discussed previously in the oncologic section. (see there)

21.8. Isotope diagnostics of inflammatory processes

Gallium scintigraphy, white blood cell scintigraphy and FDG-PET examinations are the most commonly used techniques for the characterization of inflammatory diseases. Gallium (67Ga-citrate) enrichment is the result of a complex process in the inflamed tissue. (Increased activity can also be detected in certain tumors such as lymphomas, in which it used to have a high diagnostic value before the FDG-PET era.)
White blood cell labeling can be performed in vitro. A leukocyte suspension is derived from the patient’s white blood cells in the laboratory, which in turn for the labeling process, is mixed either with 99mTc-HMPAO (hexamethylpropyleneamine oxime), or rarely with 111In-oxin. At the end the produced white blood cells are reinjected to the patient. During in vivo labeling, technetium labeled monoclonal antigranulocyte antibodies, or its fragments are injected (immune-scintigraphy). The labeling of the granulocytes happens within the blood vessels. (Figure 26.)

26. Hepatic abscess in a polycystic liver. SPECT examination with in vivo antigranulocyte antibody labeled white blood cells. Maximum Intensity Projection (MIP) image, anterior view (a), transversal and coronal planes (b). Increased enrichment in the subdiaphragmatic, large cystic lesion’s wall in the enlarged liver. (Normal spleen and bone marrow.)

(The antigen used for the labeling process, is actually expressed on all elements of the granulocyte chain, including promyelocytes. Thus the in vivo technique can also be used to visualize the bone marrow.) Considering that activated leucocytes and macrophages accumulate FDG; FDG-PET is also capable to sensitively depict inflammatory processes.

White blood cell scintigraphy is also popularly used for acute and subacute states of inflammatory processes that are usually caused by bacterial infections. In chronic and non-bacterial inflammations – especially chest, pulmonary – processes, the preferred examination technique is Gallium scintigraphy. FDG-PET is a technique, preferred in cases of fever of unknown origin (FUO) syndromes, and it is also important for the detection of vertebral osteomyelitis, and for the identification of inflammatory processes of vascular prosthetics as well as large vessel arteritis examinations. (Figure 27.)
27. Vasculitis, FDG PET-CT. PET Maximum Intensity Projection (MIP) sequence (a), fusion sagittal (b) and transversal (c,d) plane images. Increased FDG uptake in the aortic and the large vessel arterial wall.

FDG-PET is also able to detect Hodgkin and aggressive non-Hodgkin lymphomas, colorectal cancer and sarcomas as the cause of tumor related fever. FDG-PET can potentially replace other imaging methods in cases of FUO syndromes, because compared to white blood cell scintigraphy it is able to assess a wider range of patients.

21.9. Isotope therapy

Nuclear medicine includes therapeutic procedures carried out with unsealed radioactive isotopes. The main principle is, that after local injection or after systemic (iv. or per os) administration, the beta emitting isotope labeled pharmaceuticals create a selective radiotherapeutic effect. They are enriched in the targeted lesions and due to the locally acting radiation the damage on the normal surrounding tissues is minimised. Their advantage is that they barely have any side effects, and their effect is long lasting. The most commonly used isotopes are 131I, 90Y, 153Sm, 89Sr and 186Re. Clinically, the most widely available methods are the following:
- radiodine therapy of benign and malignant thyroid diseases;
- palliative, pain relief therapies of bone metastases with bone affine pharmaceuticals;
- radiation synovectomy with the injection of metallic colloids to the articular space in chronic joint inflammations;
- palliative therapy of neuroectodermal and neuroendocrine tumors with 131I-MIBG or other isotope labeled somatostatin analogues;
- radioimmunotherapy (labeled monoclonal antibody) primarily of B-cell lymphomas.

Translated by Balázs Futácsi
22. Cardiovascular nuclear medicine examinations

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The imaging of cardiac and central circulatory functions is possible with cardiac nuclear imaging methods. Myocardial perfusion and pump function, the metabolic processes of the heart, the distribution of myocardial receptors and molecular level processes are all part of the imaging spectra of cardiac nuclear medicine. In the diagnostics of ischemic heart disease (IHD), their use is part of the modern clinical cardiologic practice. Cardiac studies are able to assess the severity of heart disease, estimate risks, determine therapeutic principles and to follow-up patients.

1. Basic cardiologic examinations (routine clinical exams)
   1. Myocardial perfusion studies
   2. Myocardial viability assessment
   3. Central circulation examination

2. Further examination possibilities
   1. Metabolic tests: glucose, lipid, amino acid, oxidative metabolism
   2. Receptor examinations: adrenergic, cholinergic, muscarinic, angiotensin, endothelin, opiate etc.
   3. Apoptosis, molecular level imaging

22.1.1 Myocardial perfusion studies (SPECT / Gated SPECT, in special cases PET)

This is one of the most commonly performed routine examinations in clinical nuclear medicine for suspected or known cases of IHD. The method is based on the imaging of perfusion radiotracers as they are taken up by the normal myocytes. The rate of accumulation is determined by regional perfusion and tissue extraction. Hence, it shows a homogenous distribution in normal circumstances. In stress tests the work and oxygen consumption of the myocardium elevates. The dilatation of the coronary arteriolar system is responsible to match the increased perfusion needs - coronary reserve capacity. If tissue perfusion needs are unmatched with the perfusion increase perfusion disturbances /ischemia occur. This is the first step of the ischemic cascade. The most common etiologic factor is IHD related stenosis in the epicardial coronary system. In order to assess perfusion abnormalities, the radiotracer is injected at the peak of the stress exam and its result is compared to the resting state. The examination gives valuable information about the perfusion defects of the left ventricle, their extension, ratio, distribution and type, which in turn will be relevant for prognostics and therapeutic planning. If a necessary stress level is unachievable with physical exercise, a drug mediated coronary vasodilatation can be applied, in order to perform a stress perfusion examination (direct vasodilator: Adenosine, Dipyridamole stress, or beta receptor agonists: Dobutamine stress).
22. Cardiovascular nuclear medicine examinations

Perfusion radiotracers:
**Gamma ray emitters (SPECT imaging – clinical routine)**

99mTc – labeled: sestaMIBI (Methoxyisobutyl Isonitrile) and Tetrofosmin

It accumulates in the mitochondria and it requires intact myocardial metabolism for enrichment. After injection its distribution reflects the current state of the perfusion, and does not experience any further redistribution. Stress and resting states need to be investigated with two separate portions of the radiopharmaceutical. It can also be used for ECG gated SPECT examination. Its use is normally connected to a diagnostic protocol, and its diagnostic and prognostic value is equal to the examination carried out with 201Thallium.

**201Thallium: 201Tl (K analogue ion)**

It is actively transported intracellularly with Na/K ATP-ase enzyme. If injected at the peak of the stress exam it reflects tissue stress perfusion for about 30 minutes. Then redistribution follows between the myocardium and the blood pool and TI is washed out of the tissues. Accumulation and wash-out is smaller in regions with decreased perfusion and ischemia. Therefore, compared to the normal regions a more pronounced equilibrium can be seen. If redistribution happens within 3-4 hours after injection, then it can be considered complete for an ischemic lesion (reversible defect). In cases of necrosis no equilibrium is seen (fix defect). The different properties of the perfusion radiotracers can be used for different diagnostic purposes.

**Positron emitters (PET)**

$^{13}$N Ammonium, $^{15}$O Water, $^{82}$Rb (Rubidium: K analogue ion).

They are significant in quantitative characterization of perfusion: ml/gram of tissue/minute. They are primarily useful in experimental research. PET radiotracers are applied to detect early perfusion abnormalities, endothelial dysfunction or drug effect. SPECT and PET provide clinically equally relevant information. Since PET is less available and more expensive, normally SPECT is the preferred modality in routine diagnostics.

**Imaging modalities:** SPECT, PET, hybrid machines: SPECT/CT, PET/CT

Development directions: specially optimized and built SPECT machines for cardiologic examinations. SPECT scanners are available with traditional detectors, but recently semiconductor detectors are also used. Their recently developed hybrid systems are with a joined CT machine. The role and importance of hybrid imaging

**Imaging and analyzing methods** Both SPECT and PET measure the spatial (3D) distribution of the isotope. If the left ventricle is being investigated, the heart can be depicted in its “own geometry” short-axis, vertical and horizontal cross-sections. Identical imaging planes are comparable with each other. Short-axis slices of the heart of an actual patient can be represented in a polar coordinate system as a sum image and it is possible to compare that to a normal reference database (expert systems)(Fig.:2) The severity of ischemia either according to a score system or according to the percentage ratio of the ischemic myocardial mass of the left ventricle can be evaluated and used to determine the diagnosis and the prognosis of the disease. Then further therapeutic options can be decided according to the gained results. (Fig.:1)
Combined myocardium perfusion + function assessment: ECG gated SPECT and PET

$^{99m}$Tc labeled radiotracers can be used in ECG gated SPECT examinations. The ECG gated data acquisition makes the differentiation of the phases of the cardiac cycle possible. In this procedure global and regional left ventricle ejection fraction (EF), end-systolic-, end-diastolic volumes, ventricular wall motion and wall thickening can be determined. (Fig.:4) Ventricular functional parameters provide independent prognostic information about IHD. Combined perfusion and functional parameters detail all components of the ischemic process. (Table)

<table>
<thead>
<tr>
<th></th>
<th>transient ischemia</th>
<th>stunned</th>
<th>hibernated</th>
<th>necrosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>perfusion</td>
<td>normalizes after ischemia</td>
<td>normalizes after ischemia</td>
<td>decreased</td>
<td>decreased</td>
</tr>
<tr>
<td>function</td>
<td>decreased during ischemia</td>
<td>remains decreased after ischemia (hours-days)</td>
<td>decreased (improvement is only seen weeks-months after revascularization)</td>
<td>decreased, no improvement</td>
</tr>
<tr>
<td>glucose(18FDG)</td>
<td>normal</td>
<td>preserved</td>
<td>preserved (mismatch)</td>
<td>decreased</td>
</tr>
<tr>
<td>uptake</td>
<td>present</td>
<td>present</td>
<td>present</td>
<td>none</td>
</tr>
<tr>
<td>inotropic reserve</td>
<td>present</td>
<td>present</td>
<td>present</td>
<td>none</td>
</tr>
</tbody>
</table>

22.1.2 Myocardial viability assesment

The high risk of IHD in case of decreased left ventricular function (most commonly after heart attack, if left ventricle EF <35 %). can be lowered if there is a possibility for the revascularization of a considerable volume of hibernated myocardium with the possible elimination of residual ischemia. The identification of hibernated myocardium is possible with PET through the representation of perfusion and glucose metabolism. In SPECT examination both types of perfusion radiotracers can be used. The basis of imaging is that perfusion radiotracers only accumulate in living myocytes (glucose metabolism is also preserved)(Fig.:3). For routine clinical imaging SPECT is the recommended examination, if any uncertainty arises, PET is considered the gold standard compared to all the other cardiac imaging modalities (Echocardiography, MRI).

22.1.3 Central circulation examinations - Radionuclide angiography ( RNA )

First-pass examination: FP-RNA

is carried out with planar imaging. The activity of iv. injected bolus of gamma emitting $^{99m}$Tc is measured as it travels with the central circulation (central veins-right atrium-right ventricle-pulmonary flow-left atrium-left ventricle–aorta). Time-activity curves can be created to determine cardiac output and stroke volume indices and transit times. Global and regional right and left ventricular functions and volumetric assessment can all be made in resting state or in a stress examination (physical exercise or pharmacologic stress).
ECG gated blood-pool scintigraphy
PLANAR: ECG gated RNA – ERNA
SPECT: ECG gated blood-pool SPECT or G-SPECT - ( 3D ERNA )

After adequate preparation the iv. injected gamma emitting $^{99m}$Tc remains in the bloodstream (e.g.: red blood cell labeling), with which cardiac chambers and the main vessels (aorta, pulmonary arteries) can all be depicted.

Planar imaging is used for the ventricles. Left ventricle is imaged with multi-planar ECG gated acquisition. During acquisition, several hundred cardiac cycles can be acquired and their average gives a representative cardiac cycle. Besides the calculation of the left ventricular EF, visual assessment of the wall motion and further global and regional left and right ventricular functional data can be computed. (Ventricular activity represent volumes in planar representation )( Fig.:5)

Parametric imaging ( imaging of various calculated parameters of the function e.g.: phase and amplitude imaging) is able to depict dysfunctional regions more pronounced and numerically characterize them. ECG gated SPECT technique makes the real-time, spatial representations of all these parameters possible, with a better imaging quality of the right ventricle. (. Fig.:6., Fig.:7 ) Combined with stress examination the technique is used to assess regional dysfunctions due to ischemia (ischemic cascade). With parametric imaging the degree of inter and intra ventricular asynchrony is also computable

Myocardial infarct detection

The detection of myocardial infarct in its late, chronic phase is possible with perfusion radiotracers (fix defect) or with functional examination, with the detection of wall motion and thickening abnormalities. ECG gated SPECT techniques with perfusion radiotracers can depict both abnormalities simultaneously during the same examination.

Acute myocardial infarct: rarely investigated with nuclear medicine techniques, only in special cases with perfusion radiopharmaceuticals or with radiopharmaceuticals accumulating in the necrotic tissue.

Indications of nuclear cardiologic exams in IHD

I

- In case of stable angina to determine the extent and severity of ischemia, or if symptoms of ischemia/silent ischemia are present with medium risk IHD

*Prognostic evaluation after myocardial infarcts
*Ischemia assessment in unstable angina in stabilized acute coronary syndrome

- Percutaneous coronary intervention (PCI) planning – identification of the ischemic lesion

*Perioperative risk assessment before high risk (non-cardiac) surgeries
*Ischemia – restenosis – identification in symptomatic cases after PCI/GABG

- Examination of certain symptom free patients after PCI/CABG, if there is suspicion for myocardial ischemia (e.g.: ECG)
- Ventricular function assessment (not only in cases of IHD)
II/A
- Pharmacologically treated (stable) patients for the assessment of ischemia
- Coronary – circulatory anomaly detection in adult congenital heart diseases
- In valvular heart diseases to assess accompanying coronary disease and functional assessment

II/B
- Pharmacological therapy effectiveness measurements for myocardium – perfusion
- Coronary arteriopathy verification after heart transplant

III
- Low risk, non-symptomatic IHD patients – not recommended

22.2.1 Myocardial metabolic tests (used in clinical practice)
Glucose: 18-FDG (PET)
Fat metabolism: $^{123}$I labeled fatty acids. The fatty-acid chain determines the possible functional examination (partially able to assess perfusion parameters with SPECT)

22.2.2 Myocardial receptor imaging (used in clinical practice)
Adrenergic receptors: $^{123}$I MIBG (metoxi-iodobenzyl-guanidin). Presynaptic receptor density assessment with SPECT.
In cases of decreased left ventricular function, the results correlate with the rate of enrichment (heart-mediastinum ratio), the kinetics of enrichment and wash-out. Results are also informative of the regional left ventricle distribution with the prognostics of the disease and the appearance of malignant arrhythmic disorders.

The previously described radiotracers/methods are used in clinical cardiology practice. The most commonly performed examination is ECG gated myocardium perfusion stress examination with SPECT. It is used in order to diagnose, give the prognostics, to determine therapeutic interventions and to follow-up of IHD. There are several radiotracers in their experimental phase that could be used to depict molecular level processes. Further myocardial receptors, cell-level metabolic processes and genetic markers are also in their research phase. The development of imaging technologies and methods (semiconductor detector cameras, hybrid systems) and the results of radiopharmacological research are all aiming to provide earlier detection, genetic background assessment and the understanding of molecular origin of the cardiologic diseases.
22.3 Appendix

22.3.1. Multivessel disease

Interpretation
Moderate to severe reduction of perfusion in the posterolateral and apical region. Moderate reduction in the anterior, anterolateral segments and mild reduction in the lateral wall. Reversibility in the anterior wall and partial reversibility in the lateral, anterolateral and apical region. No significant change in the size of the left ventricular cavity and wall thickness to the normal case.

Diagnostic Impression
Posterolateral infarction with moderate to severe perfusion defect. Severe and extended transient ischemia in the anterior and lateral wall and in the apex. Mild necrosis could not be excluded in the apex.

Summary:
High risk multivessel disease. Coronagraphy and possible revascularization is recommended.

22.3.2. Normal perfusion

Interpretation:
there is no significant stable or reversible perfusion defect
Perfusion defect: stable: similar significant perfusion defect in the stress and in the rest slices according to decreased activity level and localisation. It is characteristic for myocardial necrosis.
(It can be false positiv finding due to gamma ray absorption in the anterior segments in females because of large breasts. The same is in the inferior segments in males because of diaphragmatic attenuation.
Decreased function – eg ECG gated study – can help to verify necrosis. ) reversible defect: significant perfuxios defect at stress that is totally - or partially - reversible at rest. It is characteristic for transient ischemia

**Diagnostic impression:** Myocardial necrosis and transient ischemia can be excluded.

**Summary:** The probability of ischemic event is low. Further invsiv evaluation is not indicated.

22.3.3. Myocardial perfusion SPECT stress + rest. EKG gated rest perfusion SPECT Apical + inferior necrosis . Viable myocardium .

![Myocardial perfusion SPECT stress + rest. EKG gated rest perfusion SPECT Apical + inferior necrosis . Viable myocardium .](image)


**Interpretation**


b.: Function: Moderate reduction of LV function. EF: 38%. Akinesis in the apical and infero-apical, inferolateral-apical segments. Wall motion and thickening can be detected in some extent in the distal-inferior and posteroinferior + posterolateral segments in the region of moderate level defect.

**Diagnostic Impression**

Extensive apical, inferior and posteroinferior infarction. Minimal transient ischemia in the lateral segments.

Moderate reduction of LV function. Viable myocardium can be supposed in the distal-inferior, posteroinferior + posterolateral segments. based on functional data and on the moderate level of perfusion defect.

**Summary:**

High risk IHD. Revascularisation is recommended.
22. Cardiovascular nuclear medicine examinations

22.3.4. One vessel disease: anterior ischemia + small apical necrosis.

Interpretation:
Perfusion: Moderate reversible anterior perfusions defect. Moderate apical perfusions defect with partial reversibility. The volume of the left ventricle is a bit larger after stress: transient ischemic dilatation (TID) (moderate fix defect in the posterosepal region probably due to the gamma ray absorption by the diaphragm).
Function: Good global left ventricular systolic function, ejection fraction (EF)
Minimal hypokinesia in the apical region with decreased wall thickening due to necrosis. (no functional deficit in the posteroseptal region - it reinforces the diaphragmatic attenuation)

Diagnostic impression: Moderate transient ischemia in the anterior region and in the apex with small necrosis in the apical region.

Summary: Ischemic heart disease verified. The probability of ischemic events is moderate. Revascularisation is indicated.

22.3.5. Radionuclid angiocardiography (RNA) Planar projection movies + quantitativ evaluation

5. Radionuclid angiocardiography (RNA) Planar projection movies + quantitativ evaluation
Apical-inferior + inferior necrosis, enlarged left ventricle, decreased left ventricular function

5.a LAO 70 projection
5.b LAO OPT projection (perpendicular to the septum, enables separation of the left ventricle. It makes possible the quantitative functional evaluation)
5.c Quantitative evaluation: functional parameters and parametric images showing decreased apical-inferior amplitude and delayed phase

22.3.6. EKG gated blood-pool SPECT. Extensive apical necrosis – aneurysm

Moving slices, parametric evaluation, 3D movie, left and right ventricular functional data (the method separates the left end right ventricles, so the functional data can be calculated for both ventricles properly)

22.3.7. EKG gated blood-pool SPECT. Right ventricular dysfunction. Arrhythmogenic right ventricular dysplasia (ARVD)

7. EKG gated blood-pool SPECT. Right ventricular dysfunction. Arrhythmogenic right ventricular dysplasia (ARVD)
22. **Cardiovascular** nuclear medicine examinations

Segmental movie, parametric images, 3D movie, functional parameters
(Enlarged right ventricle, decreased right ventricular function, regional dysfunction in the anteroseptal region of the right ventricle with phase delay)

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Translated by Balázs Futácsi
23. The biological effects of radiation
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This brief sketch delineates some important statements of radiobiology. In nowadays radiology can’t be done without radiobiology, and as well these are the principles of radiation protection. The importance of this subject is emphasized by: 1./ the increasing number of ionizing sources; 2./ the opportunity of environmental contamination; 3./ the human life span along with the time of exposure is extended. /Th.M.Flizdner, 1972./. We live in a radiation space. This space divided two parts: 1./ natural background radiation; 2./ artificial radiation. The world average in our days, after Chernobyl, is about 3.0 mSv/year.

Radiobiology examines the response of the ionizing radiation in living material. It is an interdisciplinary field of science, so the development depends on these interdisciplinary sciences’ advancing. The main directions of development are: general, experimental, clinical, military (cosmic) and environmental radiobiology.

The Grotthus /1815/– Draper /1895/’s law states that the primary effect of radiation is the absorption of energy. Biological effect redeemed by only absorbed radiation. The time elapsed between the absorption and the biological effect called primary radiation effect period. /Th.Herrmann, 1990./. This effect can be divided three parts:

a./ physical
b./ physical-chemical
c./ chemical-biochemical
d./ biological part.

The length of these periods is growing the same sequence (nanosec, msec, minute, hour, day, month, year).

In medicine, it is appropriate to think that the effect of ionizing radiation is biologically and cumulative. (But it’s true, that Lucky wrote down biopositive effect, the hormesis, but only in plant cell cultures. The plant cell contains less DNS than human cell. In other aspects there are many differences in radiobiological properties between plants and mammal cells. Because of this, an independent field of science is plant radiobiology.)

Regularly direct and indirect radiation distinguished. At the direct effect, the physical and the biological process occurs in the same medium, and at the indirect effect, the energy transferred by water. At the indirect effect the formation and the influence of free radicals are very important. These radicals are short-lived due their reactivity. Recent theories states the radical formation exists not only in water, but also in dry systems. In nowadays, direct and indirect radiation effects can’t be differentiated.

The discovery of direct and indirect radiation led to the development of the target theory. This theory assumes that: 1./ the absorption of the energy occurs in sensitive volume, 2./ the energy releases in this volume. This release called hit. The graphic representations of the direct biological radiation effect are the dose-response curves, which have two types: 1./ exponential or single-hit curves, when only one hit required to the inactivation, 2./ non-exponential curves. The non-exponential curves divided to two groups: 1./ multi target curves, 2./ multi hit
Another important classification is the deterministic /non-stochastic/ and the stochastic radiation. The deterministic effect has a limit-dose and the severity depends of dose. The stochastic effect has no limit-dose, and only the probability of the effect increases with dose. The acute radiation poisoning is a deterministic, the cancer with radiation origin is a stochastic process. The modern radiation protection is aiming to decrease the stochastic effects to tolerable range of the community. /Sztanyik, 1983./.

Somatic and genetic radiation effect also can be distinguished. /V.P.Bond, Th.M.Fliedner és J.O.Archambeau, 1965., Köteles, 2002./. The first effect important to the person, the second is to the descendants. Since the discovery of the X-ray mutagenity /H.G.Mueller, 1923./, research of the genetic radiation effects became the most developing field of radiobiology /N.Y.Timoféeff-Ressovszky, 1931./. Meantime it found that the genetic radiation effect has no limit-dose, and the gametes are very sensitive to radiation.

The biological radiosensitivity is relative. The susceptibility orders of tissues are described by H.Holthusen /1921/. From the most sensitive to the most resistant: the bone marrow, the mucosa of bowels, the lymphatic tissue, the testicle, stratum germinativum in the skin, the ovary, the lungs, the kidneys, the muscles, bones and connective tissues, the cartilage, the nerves, and the cells containing melanin. In practice, this order accepted till nowadays. The species-dependent radiosensitivity in acute radiation were shown by Jacobson, Marks and Lorentz /1949/. They found the whole animal radiation sensitivity in growing order: rabbit, rat, mouse, chicken, human, goat, guinea pig, dog /whole animal radiation sensitivity/.

The specific tissue tumors’ radiation sensitivity follows the normal specific tissues sensitivity. /Borak, 1938/.

Bacteria and viruses are very resistant compared to other biological objects. The doses used to sterilization are adjusted this.

The LET (Linear Energy Transfer, keV/μm) is very important physical factor in biological radiation effect. It describes the density of the ionization caused. This density can be high (alpha decay, n, p) or low (X-ray, gamma-ray, beta-decay or electron beam). Another factor, the relative biological effectiveness is also used to qualify the biological effect /RBE and RBW values: X-, gamma ray, beta decay: 1, neutron emission: 5-10, alpha decay: 20/. Oxygen improves the biological effect (oxygen enhancement ratio, OER). In case of gamma ray, OER is between 2 - 3. In hypoxia, low LET, the radiation resistance increases.

The effect of ionizing radiation can increased by: 1./ radiosensitizers (e.g. Misonidazole), 2./ membrane specific pharmacons (e.g. I-acetamide), 3./ DNA precursor analogues, 4./ cytotoxic substances (e.g. Cu 2++) 5./ reparation inhibitors (Actinomycin-D) 6./ thiols, 7./ scavengers. The effect can decreased by: 1./ amino acids with sulfur compound (e.g. cysteine, glutathione, cysteamine) 2./ some enzymes (catalase, superoxide dismutase, glutathione peroxidase), 3./ hypoxia.

The primary target of ionizing radiation is the DNA, and the G2 phase in the interphase (W.K.Sinclair, 1968.). The major damage types are: single or double-strand breaks, damage of the bases or the sugar component, DNA-protein cross-link, bulky lesion. The damage of the linear macromolecules in mammal cells and its results can be understood with this sketch:
DNA → m-DNA → polypeptides → structure → function
↓
genotype phenotype

The quantum chemistry enables the modern interpretation of the radiation damage in DNA. The delocalized electron system and the structure make the DNA to an inhomogeneous electric semiconductor. The conductive electrons came from the intramolecular impurities (e.g. iron strain). The electron drift in the axis of the helix enabled by the base pair’s \( \pi \)-electron overlaps and the exciton interaction. After radiation the intramolecular electron system changes: excitation and \( \pi \)-electron emission (positive hole formation) occurs. These lead to the tautomeric rearrangement of the base pairs, and the formation of abnormal pairs. These abnormal pairs can’t fulfill the Chagaff-Watson-Crick’s rules about the base correlation, and they don’t fit in the DNA-helix’s spatial structure, so the hydrogen bonds break. It has a chance that abnormal m-RNS, polypeptide chain, structure or function formed. In radio- and chemotherapy, this malformation provoked exactly. It’s expected to became an universal tumor treatment theory by the results of quantum chemistry /A. és B. Pullman, 1959., P.-O. Löwdin, 1961., Ladik J., 1967./.

The radiation effect will be specific to a biological system itself, because radiation specific biological answer doesn’t known. The programmed cell death (apoptosis) researches became a new direction of radiobiology. The discovery of stem cells and cell reproduction systems (differon-correlaton models) made a brand new approach. In radiobiology stem cells and the tissue-systems based on differon function (bone marrow, the mucosa of bowels, skin, testicles, etc.) are very important. The outcome of an effect depends on how the radiosensitive stem cells can restore the oscillating peripheral cellular equilibrium (e.g. the number of red blood cells in veins) through the differon function. The differons loaded by four fields: 1./ physical, 2./ chemical, 3./ gas, and 4./ microbiological field. If the load goes higher than the limit of physiological adaptation, the pathophysiological base of radiation poisoning evolves. The modern clinical radiobiology and radiation protection is the question of the physiology and pathophysiology of stem cells and differons.

Maybe the most important principle of radiobiology is the Bergonié-Tribondeau’s law /1903/: The more a cell or tissue dedifferentiated and immature, closer to embryonic stage, and faster it’s division, the more it’s sensitive to radiation, and vice versa. The radiobiology and radiation protection are mainly based on this law.

The symptoms of acute radiation syndrome (early deterministic injuries) are very diverse (erythema, ulcer, pigmentation or depigmentation, epilation, fibrosis, cytopения, infections, diarrhea, infections caused by cytopenia, bleeding caused by thrombocytopenia). Nowadays the opinion is 6-8 Sv full body exposure causes death in 100% in humans. The classification of radiation sickness based on:
1./ latency,
2./ leading symptoms, and
3./ the organ system leads to death.
According this, we can talk about 1./ hematologic, 2./ gastrointestinal, 3./ skin and 4./ neurologic radiation syndrome.
All of this cases four prognostic category exist: 1./ the recovery is certain, 2./ likely, 3./ probable 4./ improbable (Th. M. Fliedner, 1965.).
The prolonged injuries are: decrease of life expectation, cataract, leucosis, degenerative diseases, tumors, malformations. The prolonged injuries can be deterministic or stochastic.

Very early shown, the ionizing radiation not only mutagenic but also teratogenic /Th.Herrmann, 1990., Farkas, 1995., Köteles, 2002./.

Clinical obsevations show the blastogenesis can damage on the 1-10th days in utero. Some sources assume that embryonic death can occur by 0.05 Sv of radiation. Else the pregnancy advances without any disorder. Beside the mutagenic and the teratogenic effects, the carcinogen effects also proved. Between the 10-60th days of pregnancy, we have to count on organ malformations, if the radiation dose higher than 0.05 Sv. It’s not expected at lesser doses. It’s observed that influence of 0.2 SV, the frequency of malformations double. In point of the fetus, the risk of radiation occurred after the 60th day in utero is slightly decreases (except the development of brain vesicles) (Th.Herrmann, 1990.).

The laboratory diagnostics of clinical radiation syndrome is a part of internal medicine. It’s complemented by modern methods of marker diagnostics (cytogenetics, micronucleus, comet assay, in situ hybridization, gel electrophoresis with denaturation, DNA sequence analysis, etc.). It’s necessary to take care of the collect, the store and the administration of biological materials (saliva, sweat, sputum, CSF, blood, urine, defeocation, hair, vomit, etc.).

In the treatment of radiation sickness, the important principles are:
1./ strict indication
2./ individual therapeutic plans;
3./ the main task according to clear radiobiological bases to eliminate cytopenias (infection, bleed, critical period) and the reasons of sickness. The clinical classification and the treatment have not only to be based on the exact dose but also the leading symptoms (symptom groups) and the knowledge of their latency (Th.M.Fliedner, 1972., Th.Herrmann, 1990.).

Recommended reading

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Translated by János Norbert Gyebnár
24. Radiation Therapy

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24.1. Introduction

Radiation therapy is applied to destroy the malignant tissue, so the damage of the healthy parts (like the skin) should to be minimized. We can ensure that with the physical and geometric properties of the beam. The most important of these are the crossfire-technique, the selection of energy, the utilization of the build-up region, the well-defined range of charged particles (and the Bragg-Gray peak), and the use of inverse-square law. The use of these possibilities (or a part of them) is guaranteed by the radiation sources below.

In radiotherapy, the sources can be grouped in many ways. The properties of the source (radioactive isotope, Bremsstrahlung radiation, charged particles, etc.), dose rate, the type of the irradiation facility (60Co unit, linear accelerator, afterloading, etc.), the source-surface distance (teletherapy, brachytherapy) can be the basis of grouping. In this chapter, the last grouping is used. Because of space limits obsolete devices, which are no longer or only rarely used, are only mentioned but not discussed in detail.

The most important devices are: teletherapy equipments, brachytherapy units, special imaging devices and treatment planning systems.

24.2. Teletherapy equipment

X-ray therapy. In the order of invention, the first device was the therapeutic X-ray machine. The high voltage is between 10 and 300 kV (can be changed), the tube current is variable between 6 - 25 mA, or fixed. This depends on the type of the device and the application. The 10 -50 kV range is used in soft X-ray therapy, with Be-window (beryllium) tubes, using usually fixed high voltage-filter combinations and constant current.

Another special X-ray device used in Europe is the Chaoul. It works with special anode, constant high voltage and tube current, fixed filtration and 1.5 - 5 cm focus-skin distance. The machines operated in 50-300 kV range with different filtering are called orthovoltage or deep X-ray therapy units (focus-skin distance: 30-50 cm). Their importance is strongly reduced in nowadays.
Cobalt unit. Almost for 40 years the most important external beam radiotherapy device of tumour therapy was the cobalt unit. It’s true, that the Cs-137 source seemed hopeful, but that’s proved to be a dead end.

A suitable artificial radioactive source should be relatively small having a $\gamma$-energy above 1 MeV (skin sparing effect), and a sufficiently long half-time. The average energy of the two $\gamma$-lines of a Co-60 source is 1.25 MeV, it has a 5.28 year half-life, a source can be made with 1-2 cm diameter and 3-400 TBq activity, which can result in about 3Gy/min dose rate at 80 cm source-surface distance. It’s enough to replace the source in 5-8 year intervals, depending on patient’s number.

The unit consists of a stand, a moving C-arm with the head, and a (at least rotating and moving in 3 axis) treatment couch. Because of the head’s heavy weight, it’s advisable to apply a counterweight on the opposite end of the C-arm. The head contains the source, the field-limiting system and the field projection system. The machine is operated from an external operator room. The modern heads can be moving also around the long axis of the head.

The source is stored usually in the head, when it is in beam off position. The source movement from beam on to beam off (storage) position can be done with mechanic devices (pushing rod, sliding clutch, etc.), pneumatic way, or the source isn’t moving, only the beam is broken by a metallic block. The machine is supplemented with many latches to improve the safety of the staff and the patient.

Linear accelerator. Accelerating electrons is theoretically easy, but in practice, it became only available when high-power (above 2 MW), high frequency devices were developed. During the Second World War in Europe the high-power high frequency oscillator, the magnetron has been developed, and in the USA, the klystron invented, which is suitable for high-frequency amplifying. Both were a military secret, so until the end of the war, the medical application was out of question. The medical accelerators are working on 2.97GHz.

In the magnetron the central cylindrical cathode is surrounded by the anode block made of copper, with a cylindrical cavity between them. In the anode block, the resonant cavities have a circular layout. The magnetron is placed in a homogenous magnetic field, perpendicular to the plane of the figure. The electrons, emitted from the central hot cathode, are moving to the anode on a complex way by the effect of DC pulses and the magnetic field. In case of resonance, high power, high frequency oscillation created, which can be coupled to the accelerator tube through the waveguide with the appropriate antenna. Usually a few hundred 2-5 $\mu$s wide pulses/second are created.
The klystron is not a high frequency generator, it is a microwave amplifier. It has two cavities (buncher and catcher) connected by a tube. The low level microwave to be amplified enters on the cathode side, and it modulates the electron beam velocity, so the electrons arrive to the second cavity sorted in compact bunches. In the second cavity the electron bunches are decelerated resulting in a high-power microwave, which has the same frequency as the input signal. 5-30 MW power can be reached with this unit.

In radiotherapy linear accelerators requiring lower power, operated only at 6 MV or below, exclusively magnetrons are used, and above 15 MV, almost all companies are using a klystron.

The most important units of the linear accelerator are illustrated on the block diagram: 1. pulsed power supply, 2. control console, 3. klystron, 4. wave guide, 5. circulator, 6. electron gun, 7.accelerator structure, 8. magnet and treatment head, 9. vacuum system, 10. automatic frequency control (AFC) system, 11. pressure system, 12. cooling water system (upper left modulator = modulator cabinet; middle: állórész = stand; right: C kar = gantry). The injection system is the source of electrons (electron gun) and the accelerated electrons are drifting through the anode into the accelerating wave guide. The electrons arrive in bunches in the proper time, and accelerated in the waveguide by the transmission of RF power. The length of the waveguide depends on the technique of acceleration. In the travelling wave devices, an electric field parallel to the waveguide is used. The slow bunches only take a short way in unit time, and the cavities close to the electron gun are relatively short. Later as the bunches are accelerating practically to the speed of light, longer cavities are required. At the end of the tube, the energy has to be absorbed or fed back to the input end of the waveguide. The well-defined electron beam energy is the advantage of this system. The disadvantages are the long waveguide, which makes the keeping of the bunch’s convergence more complicated, and only rotating drum suspension available.

Modern radiotherapy accelerators are usually standing-wave type (except one manufacturer’s devices) equipments. In these machines, the accelerator guide is about 1.7 times shorter than in the moving wave types. Further significant decreasing of length was possible by moving of the non-accelerating coupling cavities to side. To these, only a little more decreasing factor is the energy attached form the side in the wave guide. The result is a short accelerating tube (with the electron source), which can be directed to the isocenter using 6 MV, and a bending magnet is not necessary, in the 10-25 MV range it fits into a C-arm. The disadvantage is a wider electron spectrum.
The direction of the electron beam (as it exits the window of the accelerator tube) to the isocenter (if necessary) is possible in two ways. In moving-wave devices several magnets required to use the “slalom technique”. The electron beam is “slaloming” in the field of the first two magnets while the third one, which is hardly more than 90° bending magnet (the 90° magnet is not for focusing the beam, but spreading it), is directing the properly focused beam to the isocenter. In standing-wave machines achromatic, 270° magnet is applied, which has an appropriate magnetic field and it can focus and direct also a wider spectrum to the isocenter. The beam can be used in two ways. If we want to apply it in an electron therapy, than the narrow beam is usually spread by two scattering foils. If bremsstrahlung radiation is required, then suitable target (e.g. tungsten target) is used. The target is not designed to produce a homogenous irradiation on the body surface, but at a depth of 10 cm and in a large (40x40 cm²) field. On the surface we observe the effect of the “overflattening” filter.

The accelerator is supported with a very complex latch system. Besides the direct safety latches, this is controlling the stability of the accelerator’s physical parameters. The ionisation chamber system is the most important of these. This controls not only the beam’s symmetry, homogeneity, dose rate, but also the dose delivery. The collimator system is added to form the proper field size.

The field shape can be modified with shielding materials (e.g. blocks), and the dose distribution can be changed with wedges. The latter is replaced in modern accelerators by a software: the collimator is moving (dynamic wedge), or an appropriate combination of 60° wedged field and an open field are resulting in the required wedged field. The following figure shows an X-ray unit (with EPID) combined with a linac.

Developing the Multi Leaf Collimator (MLC) was a significant improvement. With this, a conformal shaping can be provided. The MLC can be an independent beam limiting device, or it replaces one of the collimator pairs. On modern accelerators two types of MLC are used. One type is used in the conventional radiotherapy (52-120 leaves, large fields, up to 40 cm), and the other type is the γMLC, used in fields below 10 cm, but in fine steps (stereotactic irradiation). The MLC is an essential device of conformal irradiation and intensity-modulated radiotherapy (IMRT).

**Other types of accelerators.** In the following section, some other machines are presented.
They are used only for treating a few percent of patients. We don’t pay attention to machines no longer used (betatron, e.g.), or not expected to be important in the future.

**Cyberknife.** Practically, it’s a combination of a linac and a robotic arm, the system being supported by imaging devices. The doubled frequency compared to standard linacs leads to the size reduction of resonating cavities and the waveguide.

**Microtron.** The microtron is a circular accelerator with only one resonating cavity. Electrons passing through this cavity are forced to an orbit in a homogenous magnetic field, and they are passing through the cavity repeatedly. The radius of the orbit is increasing with the speed of the electrons, and if appropriate energy is reached, the beam extracted by using a deflection tube. The beam can be used as electron beam with appropriate energy, or with appropriate target (Bremsstrahlung) an X-ray beam is produced. The improved version uses a multiple cavity system (race track microtron), with the same principles of operation. Its significance can be best characterized with the figures: while about 500 linacs are installed, only 1-2 microtrons are produced in a year.

**Tomotherapy:** The principle of operation is the same as that of the spiral-CT; the radiation source is a low energy linear accelerator. It is adjusted with a binary MLC.

**Gamma knife.** Several number of Co-60 sources are applied on a spherical heavy metal segment containing radial boring for each source thereby collimating the individual beams.
(Leksell) or a limited number of radial collimated sources are mounted on a movable arch (Chinese solution). Both systems permit the exact irradiation of small volumes.

Ciklotron. In medical practice the most important circular accelerators are the cyclotrons. They are used for the production of radioisotopes with short half-life (used in nuclear medicine, positron emission tomography, PET) and in radiation therapy (proton therapy and neutron therapy). For the latter purpose nuclear reactions of accelerated heavy ionizing particles (proton, deuteron, α) are used.

The device contains two semicircular direct current magnets, and a short metallic cylinder divided in two sections (high frequency field connected between them). The particles injected from a source in the device’s centre, are accelerated by the electric field only between the magnets, and the magnetic field is forcing them onto a circular orbit. In the gap, they will receive again an increment of energy, and so on. The particles radius increases with the speed, and after an appropriate energy reached, the particles are deflected. If neutrons are required, then deuterons are accelerated to 15-50 MeV, and collided to some type of a low atomic number target, for example, beryllium. The peak of the energy-spectrum of neutrons generated in a nuclear reaction is between 6-20 MeV, depending on the energy of the colliding deuterium. The beam’s depth-dose curve looks like that of the cobalt sources. The only radiobiological advantage of neutrons is the oxygen effect is practically missing. (See in the radiobiology chapter).

The mono-energy particles’ depth-dose curve seems to be very attractive: Near to the surface only quarter of the maximum value, and (depending on energy) it increases suddenly at a greater depth (Bragg peak), and it falls to zero immediately. The problem is that the peak’s FWHM (full-width half-max) is 2-3 cm, so in clinical practice, it’s significantly less than the linear size of the irradiating area. So several beams have to be superimposed to raise the Bragg peak (e.g. replacing human tissue with filters), and with this, the benefits of the low surface dose can be completely lost.

### 24.3 Radiation sources and devices in brachytherapy

The radiation sources in brachytherapy are also classified by the isotope’s type, half-life, the application’s aim, repeatability or by the devices using the isotopes. In this chapter, we discuss only the closed sources, not talking about the former, reusable sources developed to manual treatment, or the 226Ra, which is no longer used. The table below summarizes the parameters of some sources used in brachytherapy. The data are only informatory, because depending on the material of the case, fluorescent X-ray is also formed, but the unnecessary electrons and low energy photons are absorbed by the case.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>T_{1/2}</th>
<th>E_{av}</th>
<th>Application</th>
<th>Comment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>^{60}\text{Co}</td>
<td>5.28 year</td>
<td>1,25 MeV</td>
<td>afterloading</td>
<td></td>
</tr>
<tr>
<td>^{192}\text{Ir}</td>
<td>74,2 day</td>
<td>0,38 MeV</td>
<td>afterloading, interstitial</td>
<td></td>
</tr>
<tr>
<td>^{125}\text{I}</td>
<td>60,2 day</td>
<td>35,5 keV</td>
<td>interstitial</td>
<td>patient remains consider: permanent</td>
</tr>
<tr>
<td>^{103}\text{Pd}</td>
<td>17 day</td>
<td>20,8 keV</td>
<td>interstitial</td>
<td>patient remains consider: permanent</td>
</tr>
<tr>
<td>^{106}\text{Ru}</td>
<td>374 day</td>
<td>354 keV</td>
<td>$\beta^-$, ophthalmology</td>
<td></td>
</tr>
</tbody>
</table>

*Permanent brachytherapy, or seed implantation.* The sources left in the patient, called seeds, exactly about 0.8-1 mm diameter, 4-5 mm long rods, and their build are diverse, depending by the isotope type, and the application. For example, the ^{125}\text{I} is placed on a carrier in a thin Ti
case, because of the low energy. The $^{103}\text{Pd}$ source isn’t seen in the X-ray, that’s why a lead marker put in the centre of the seed, etc. The seeds can inserted to the target place with a special tool, through the puncture channel.

**Manual Afterloading.** The essence of this method is in its name. Inactive devices, lead wires, hollow needles, templates punctured in the patient properly to the treatment plan, to decrease the staff’s radiation exposure. After the setting of this complex setup, which proved appropriate in inactive phase, the sources are placed manually into it. The usually $^{192}\text{Ir}$ wire could be made from Ir-Pt alloy, what can be cut to proper size with special, radiation protected tools. The other usual process is to put $3\,\text{mm}$ size $^{192}\text{Ir}$ sources with $1\,\text{cm}$ distance into a plastic tube, and the necessary length is reached by cutting the inactive part to the appropriate size.

**Afterloading.** In this method, first the inactive applicators placed into the patient’s body and after the fitting setup controlled by imaging, the required dose rate reached with moving only one point source.

The main parts of the afterloading machines are: The source-moving device, the channel selector, source container, source-leading tubes and applicators and the computerized controlling device. The installed system, in addition to locking mechanisms, is completed by security devices. The inactive (dummy) source is also a part of the modern afterloading machine’s security system, which is used to verify all sources moving before the irradiation. Moving the point source, arbitrary source can be created, only the stepping times have to planned by an irradiation planning program. The common source is $^{192}\text{Ir}$ and $^{60}\text{Co}$ (less common). The Iridium source’s initial activity is usually $370\,\text{GBq}$, that of the cobalt source is $37\,\text{GBq}$. Greater specific activity can be reached with iridium, and therefore it can used with many types of applicators including needles. The disadvantage of this type is that in an institution with larger patient throughput a source replacement required in every 3 months. Because of the cobalt source’s lower specific activity, the charge’s size is bigger, that’s why it is not suitable to prickling, but it is suitable for intracavitary therapies (oesophagus, rectum, gynaecological treatment) The frequency of the charge’s replacement is only specified by the quality of the fixation on the mover cables.
24.4. Special imaging devices

**Simulator.** The simulator is a machine that emulates the geometry and the movements of the treatment unit but diagnostic quality x-rays instead of high-energy treatment rays. **CT-simulator.** The CT-simulator is a dedicated CT scanner for use in radiotherapy treatment simulation and planning. The CT scanner has large bore (opening up to 85 cm), room lasers, including a movable sagittal laser for patient positioning and marking and flat table top and special software for virtual simulation.

24.5. Treatment planning in teletherapy

The whole process begins with patient positioning and body fixation and the creation of individualized 3D digital data sets of patient tumours and normal adjacent anatomy in CT. These data sets are then used to generate 3D computer images. Radiation oncologists make a contouring for tumour and organs of risks. Sometimes it is necessary to fusion the images, combining of MRI and PET-images into CT slices. The next steps are dose planning with a treatment planning system, acceptance of treatment plan and transporting of information into the treatment and simulating equipment through a computer network. After that the patient is placed on the simulator table and the final treatment position of the patient is verified using the fluoroscopic capabilities of the simulator. The images from simulator are compared with digitally reconstructed radiographs (DRRs) from treatment planning system. The clinical aspects of treatment simulation, be it with a conventional or CT simulator, rely on the positioning and immobilization of the patient as well as on the data acquisition and beam geometry determination. Treatment evaluation consists of verifying the treatment portals (through port films or on-line portal imaging methods) and comparing these with simulator radiographs or DRRs and/or performing in vivo dosimetry through the use of diodes, thermoluminescent dosimeters (TLDs) and other detectors.

Workflow in teletherapy:

- a. patient fixation using the different type of devices
- b. acquisition of CT data for treatment planning
- c. definition of the critical structures
- d. definition of the target volumes
- e. treatment planning (determination of field geometry and shielding, dose calculation)
- f. dosimetric control of the dose distribution for the treatment plan
- g. analyse the dose distribution a point of view to planning target volume and region of interest
- h. treatment simulation (conventional or CT-simulator)
- i. treatment verification with portal imaging or cone-beam CT.
Three different types of calculation algorithms are used for treatment planning systems:
1. Measurement based algorithm (i.e. Clarkson).
2. Model based algorithms which use a pencil beam convolution model and primarily equivalent path length corrections to account for inhomogeneities. Changes in lateral electron and photon transport are not modelled (no lateral transport).
3. Model based algorithms which primarily use a point kernel convolution/superposition model and account for density variations in 3D. Changes in lateral electron and photon transport are approximately modelled (with lateral transport).

All of the systems are commercially available and it is assumed that all of the TPSs and algorithms have been previously evaluated and commissioned for clinical use.
Recommended literature for further reading:
4. Perez, C. A., Brady, L. W.: Principles and Practice of Radiation Oncology. 3rd ed. on CD-

Translated by János Norbert Gyebnár
25. Exam images

1. [Image of CT scan]

- Nativ CT / Nonenhanced CT
- Szubakut ischaemia a jobb a. cerebri media területén / Subacute ischaemia in territory of right middle cerebral artery
- Elmosódott cortex-fehérállomány határ az ödema miatt / Cortical-subcortical border disappeared due to oedema
- Hiperdenzmedia jel (Gács jelzések) / (Gács') hyperdense media sign (arrow)
• CT (natív), agyi ablakolás (ablakközép: 40 HU, ablakszélesség: 80 HU) / CT (unenhanced), brain window setting (window center: 40 HU; window width: 80 HU)
• Régi ischaemia jobb oldalon / Ischaemic lesion in chronic phase on the right side
• Az a. cerebri media területén / In territory of middle cerebral aretry
CT (nativ) / CT (nonenhanced)
Acute parenchymal & intraventricular haemorrhage
Midline shift to the right
CT (nativ) / CT (unenhanced)
Haemorrhagia subarachnoidale acutum
Friss vérzés a bazális cisternákban, sulcusokban
Acute bleeding in basal cisterns and sulci
25. Exam images

- CT (natív) / CT (nonenhanced)
- Haemorrhagia subdurale subacutum (kétoldali) / Subacute subdural haemorrhage (bilateral)
- Félhold alakú / Crescent-shaped
CT (natív) / CT (unenhanced)

Epidurális haematoma jobb oldalon / Epidural haematoma on the right

Lencse alakú / Lens-shaped

Bal oldalt köp: agyi ablak, jobb oldalt: csontablak / Image on the left: brain window, right: bone window

Boltozati térés / Skull vault fracture
25. Exam images

- *Bala*: natív CT; *jobb*: T1-súlyozott posztraktrasztos MR
  *Left*: nonenhanced CT; *right*: T1-weighted contrast-enhanced MRI
- *Fent*: paraszaggittális metszet, *lent*: axiális metszet
  *Above*: parasagittal plane, *below*: axial plane
- Glioblastoma multiforme
CT (natív), ép viszonyok / CT (nonenhanced), normal
Felhasi lágyrészek, csigolya, bordák /
Upper abdomen, vertebra, ribs

CT (kontrasztos), ép viszonyok / CT (contrast-enhanced), normal
Máj, pancreas, lép, bal vesc, mellékvesek, v. cava inf., aorta / Liver, pancreas, spleen, left kidney, inferior vena cava, aorta
Többfázisú CT: natív, 35, 70 másodperces és késői fázis / Multiphasic CT: nonenhanced, 35-sec, 70-sec, and late phase

- Maj 8. szegmentum / Liver 8th segment
- A kontrasztelődés haemangiomiára jellegzetes / Contrast enhancement typical of haemangioma
10.

- CT (IV. kontrasztidúsított) / CT (contrast-enhanced)
- Metastasis hepatitis multiplex / Multiple liver metastases
- A lép szabályos / Normal spleen

- Májultrahang, konvex transzducer (3.5–5 MHz) / Liver ultrasound with convex probe (3.5–5 MHz)
- Multiplex echószegény lézió / Multiple hypoechoogenic foci
- CT (kontrasztált) / CT (contrast-enhanced)
- Pancreatitis acuta
- Pancreatitis szövődményeinek vizsgálata: CT / Assessment of pancreatitis complications: CT
- Fej és test hipodenz = nekrotizált; cauda halmoz = élő szövet / Head & body hypodense = necrotic; cauda enhancing = viable
• *Bal o.: CT-topogram* / *Left: CT scout view*
• *Jobb o. lent: natív CT-kép* / *Right side above: nonenhanced CT scan*
• *Jobb o. lent: kontrasztos CT-kép* / *Right side below: contrast-enhanced CT scan*

*On nonenhanced scans: calcification in pancreas (ellipses)*

*A ductus pancreaticus major egyenlő tágulata (nyilak) / Beaded dilatation of the pancreatic duct (arrows)*

*Pancreatitis chronica*
14.

- Epehólyag ultrahangképe / Sonogram of gallbladder
- Vastag, rétegzett fál, ődema / Thick, stratified wall, oedematous

- Fekszott Doppler-jel a falban = hipervaszkulrizáció / Increased Doppler signal in the wall = hypervascularisation
- Cholecystitis ACUTA
15. Eppholyag ultrahangkepe konvex fejel (3,5–5 MHz) / Ultrasound of gallbladder with convex probe (3.5–5 MHz)
Echódenz (hangárnyék ot adó) képlet a lumenben / Hyperechoic structure in the lumen with acoustic shadowing
Cholelithiasis / Gallstone disease
• Appendix ultrahangképe lineáris fejjel (7.5–10 MHz) / Sonogram of the appendix with linear probe (7.5–10 MHz)
• Tubuláris képlet, megvastagodott, echőszegény fal / Tubular structure with thickened hypoechoogenic wall
• Appendicitis acuta
• Nyilrúnyú mellkasi röntgenfelvétel (álló vagy ülő helyzetben) / Chest radiograph, frontal projection (in upright position)
• Transzparens sáv a rekeszkupolák alatt / Crescent of radiolucency under both hemidiaphragms
• Hasi szabad levegő → üreges szerv perforációja / Free abdominal gas → perforation of luminal organ
• Follow-through examination (X-ray study with oral contrast agent)
• Contrast agent in small-bowel loops with air-fluid levels (arrows)
• Small-bowel obstruction (‘small-bowel ileus’)

Passzázskövetés – hasi röntgenfelvételek per os kontrasztanyagadás után / Follow-through examination (X-ray study with oral contrast agent)

Kontrasztanyag a vékonybélakkal, nívók (nyálak) / Contrast agent in small-bowel loops with air-fluid levels (arrows)

Vékonybélileus / Small-bowel obstruction (‘small-bowel ileus’)

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19. Exam images

- Nativ hasi röntgenfelvétel / Abdominal plain radiograph
- Álló helyzet / Standing posture
- Disztedált colon, széles nívók / Distended colon, large air–fluid levels
- Vastagbélileus / Large-bowel obstruction ("large-bowel ileus")

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Irrigoscopy, kettős kontrasztos technika / Barium enema study, double-contrast method

Számos borsónyi telődés többlet a sigmából / Numerous small barium-filled protrusions from the lumen of the sigmoid colon

Diverticulosis
• Irgoscopy, kettős kontrasztos technika / Barium enema study, double-contrast method
• Átvilágítás / Fluoroscopy image
• Körkörös szabálytalan lúmenszűkítet / Annular irregular stenosis (apple-core sign)
• Carcinoma coli / Colon cancer
• CT (nativ, alacsony dózisú) / CT (nnonenhanced, low-dose)
• Jobb vesében hiperdenz képlet / Hyperdensity in the right kidney
• Nephrolithiasis
25. Exam images

23. 

- CT (posztikontrasztos) / CT (contrast-enhanced)
- Jobb vese nagyobb, szabálytalan szerkezetű / Enlarged right kidney with irregular structure
- Pyelonephritis acuta

- Vesoultrasound convex probe (3.5–5 MHz), B-mode & colour Doppler / Kidney ultrasound with convex probe (3.5–5 MHz), B mode & colour Doppler
- Elmosódott határral centrális échócsoport / Ill-marginated central echo group
- Pyelonephritis acuta
24. CT (natív) / CT (unenhanced)

• Per os kontrasztanyag nélkül / Without oral contrast medium

CT-angiography (1st series: nonenhanced, 2nd: contrast-enhanced in arterial phase)

• Hasi aortaaneurysma környező haematomával / Abdominal aortic aneurysm with adjacent haematoma

• Szívárgás vagy ruptura / Leakage or rupture
25. Exam images

- Percutaneous transhepatic drainage (PTD)
- Fluoroscopy spot films
- Drain (and guide wire) in bile ducts and jejunum (previous hepaticojejunostomy)
26.

Nyilrányú mellkasi röntgenfelvétel álló helyzetben / Upright chest radiograph in frontal projection

Keménysugár-technika (120–140 keV) / Hard-beam technique (120–140 keV)

Szabályos morfológia / Normal morphology
- Nativ mellkas-CT-kép / Nonenhanced CT scan of the chest
- Tudóablak / Lung window setting (WC: −500 HU; WW: 1500 HU)
- Szabályos kép / Normal appearance
• Nyilványú mellkas-röntgenfelvétel külégésben / Expiratory chest radiograph in frontal projection
• Keménysugár-technika / Hard-beam technique
• Pneumothorax a jobb oldalon / Right-sided pneumothorax
25. Exam images


29. Hard-beam technique

- Bal oldali parakardialis infiltratív transzparenciasszökkéntés: pneumonia / Left paracardial infiltrative opacity (loss of transparency): pneumonia
**Fen**t: nyílirányú mellkas-röntgenfelvétel / Above: upright chest X-ray in frontal projection

**Balra lent:** natív mellkas-CT, tüdőablak / Below, left: nonenhanced CT of the chest, lung window

**Jobbra lent:** lágyrészablak / Below, right: soft tissue window

**Spikulált lágyrészárnyék a jobb felső tüdőmezőben:** carcinoma / Speculated soft tissue mass in right upper lung area: cancer
Pulmonális CT-angiográfia (először natív, majd pulmonális artériás fázisú poszikontrasztos) / Pulmonary CT-angiography (1st step: nonenhanced series, 2nd step: contrast-enhanced series in pulmonary arterial phase)

Masszív telődéskiesés a jobb a. pulmonalis-főtörzsben és bal a. pulmonalis ágaiban / Large filling defects in the right pulmonary artery and in branches of the left one
- Digital szubtrakciós angiography (DSA) / Digital subtraction angiography (DSA)
- Carotisrendszer / Carotid system
- Szignifikáns szénőzis az a. carotis internán / Significant stenosis on internal carotid artery

- Célzott röntgenfelvétel és DSA / Spot film and DSA
- PTA (percutan transziluminális angioplastika) / PTA (percutaneous transluminal angioplasty)
- A. carotis interna-tágítás és stentbehezéssel / Dilatation of the internal carotid artery with stenting
25. Exam images

**33.**

- DSA
- A. poplitea / Popliteal artery
- Szignifikáns sztenózis a jobb a. popliteán / Significant stenosis on the right popliteal artery

**33.**

- DSA
- Jobb a. poplitea PTA után / Right popliteal artery after PTA
• Az V. metatarsuscsont célzott réntgenfelvétele / Posteroanterior radiograph centered on fifth metatarsal

• Az V. metatarsusbázis haránttörése / Transverse fracture on the base of the 5th metatarsal
25. Exam images

- A bal hallux kétrányú röntgenfelvétele / Radiograph of the left hallux in two projections
- A tuberositas distalis (= processus unguicularis) csontállománia elmosódott határral nagyrészt felszívódott / Marked ill-defined bone resorption in distal tuberosity (= ungual process)
- Lágyrész-kiszéledés / Soft tissue swelling
- Osteomyelitis
Kontrasztos fej–nyaki CT / Contrast-enhanced head-and-neck CT

Nyaki lágyrész-kiszélesedés a jobb oldalon / Soft-tissue widening on the right side of the neck

Gyüres, szeptált kontraszthalmozás centrális hipodenzitással / Ring-like septated enhancement with central hypodensities

(Gyulladásra utaló klinikai kép esetén) abscessus / Abscess (provided a clinical presentation suggesting inflammation)
- Pajzsmirigyszcinigram / Thyroid gland scintigram
- Megnagyobbodott jobb lebeny / Right lobe enlargement
- Aktivitáskiesés a jobb lebeny közepén: hideg göb / Loss of activity in the centre of the right lobe: cold nodule
Mammografía, jobb emlő, ferde felvétel / Mammography of right breast, oblique view
Lágysugár-technika (30 keV) / Soft-beam technique (30 keV)
Spíkulált lágyrészámék / Soft tissue mass with spiculated contour
Emlőcarcinoma / Breast cancer
25. Exam images

- Emlőultrahang lineáris fejel (7.5–10 MHz; max. 4 cm-es vizsgálati mélység) / Breast sonography with linear probe (7.5–10 MHz; imaging depth of 4 cm maximum)

- Bal oldalon: echőmentes, jól körüli képlet mögöttes hangërősítéssel = cistva / On the left: well-defined anechoic lesion with acoustic enhancement behind = cyst

- Jobb oldalon: elmosódott kontúru echőszegény képlet részleges hangámyékelással; szohdum, carcinomára gyanús / On the right: ill-defined hypoechogetic lesion with partial acoustic shadowing; solid structure, suspicious of cancer
PET-CT (hybrid imaging method)
CT: detailed morphology + PET: metabolic information (glucose uptake rate)
Increased fluorodeoxyglucose (F-18-FDG) uptake in liver and pubic bone
Normal excretion in urinary bladder
Metastatic disease