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Benefits of Modern Imaging Techniques in Medicine

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ABSTRACT

Relevance. For more than 100 years, medical practice has used imaging methods to observe pathological changes localized in the human body. The first method was radiography, which became popular among doctors, but later it turned out that high radiation exposure increases the incidence of tumor diseases, which is why standards for permissible radiation doses were developed for patients and radiologists. The introduction of radiocontrast agents also had contraindications that should be taken into account. Ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and angiography methods have significantly increased the diagnostic capabilities of instrumental methods. **The purpose** of this review is to analyze the advantages and disadvantages of modern imaging methods in medicine. **Methods.** To achieve the purpose of the review, a literature search was conducted in Google Scholar and PubMed databases. **Results.** 1) The main indication for the X-ray method is visualization of bone structures. 2) X-ray contrast methods are optimal for studying hollow organs and blood vessels. 3) The advantage of MRI is the ability to visualize soft tissue well. 4) CT helps to reconstruct the spatial architecture of organs. 5) Ultrasound allows you to observe the condition of the embryo and fetus, as well as internal organs.

KEYWORDS: Imaging, radiography, computed tomography, ultrasound.

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Beneficios de las técnicas modernas de imágenes en Medicina

RESUMEN

Relevancia. Durante más de 100 años, la práctica médica ha utilizado métodos de imagen para observar cambios patológicos localizados en el cuerpo humano. El primer método fue la radiografía, que se hizo popular entre los médicos, pero luego resultó que la alta exposición a la radiación aumenta la incidencia de enfermedades tumorales, por lo que se desarrollaron estándares para las dosis de radiación permitidas para pacientes y radiólogos. La introducción de agentes de contraste radiológico también tuvo contraindicaciones que conviene tener en cuenta. La ecografía, la tomografía computarizada (TC), la resonancia magnética (RM) y los métodos de angiografía han aumentado significativamente las capacidades de diagnóstico de los métodos instrumentales. El propósito de esta revisión es analizar las ventajas y desventajas de los métodos modernos de imagen en Medicina. Métodos. Para lograr el propósito de la revisión, se realizó una búsqueda bibliográfica en las bases de datos Google Scholar y PubMed. Resultados. 1) La principal indicación del método de rayos X es la visualización de estructuras óseas. 2) Los métodos de contraste radiológico son óptimos para estudiar órganos huecos y vasos sanguíneos. 3) La ventaja de la resonancia magnética es la capacidad de visualizar bien los tejidos blandos. 4) La TC ayuda a reconstruir la arquitectura espacial de los órganos. 5) La ecografía permite observar el estado del embrión y el feto, así como de los órganos internos.

PALABRAS CLAVE: Imagenología, radiografía, tomografía computarizada, ecografía.

Introduction

Medical imaging methods have been actively developing from the date of their first application 130 years ago (Scatliff, Morris, 2014). Modern doctors can obtain a human body image in minute details with the help of radiography, computer-assisted tomography (CT), magnetic resonance imaging (MRI), positron-emission tomography (PET), ultrasonography (U/S), etc. These technologies allowed significantly improving the diagnostics and monitoring of pathological processes. Many methods are accompanied by significant radiation exposure that enhances the likelihood of cancer formation in future. This once required the revision of radiation tolerance doses and development of new more attenuated technologies. On the other hand, many investigations required the administration of radiopaque substances, having the toxic effect, into the body that is the contraindication for patients with renal disease and intolerance to these compounds (Kaller, An, 2023). Different resolution of imaging methods resulted in the differentiation of their

application field and development of the list of indications and contraindications for different pathologies.

The purpose of this paper is to reveal the advantages of imaging methods most widely spread in medical practice.

1. Materials and methods

To reach the goals set, we conducted the bibliographic search in databases Google Scholar and PubMed. The following search queries were used to find the required articles:

— "history of radiography" – 19988 results (PubMed, 10 years, free full text)

— 11 articles "history of radiography" – 11961 results (PubMed, 5 years, free full text)

— "interventional radiology" – 16998 results (PubMed, 5 years, free full text)

— "ultrasound diagnostics" – 203715 results (PubMed, 5 years, free full text)

— "CT MRI" – 16100 results (Google Scholar, since 2019)

— "U/S application area" – 14700 results (Google Scholar, since 2019).

The maximum search depth was 10 years. The duplicating, close, less informative, unrelated to the topic, and not available as a full text articles were disregarded. We have 41 publications (2 domestic and 39 English-language) in the final list.

2. Results

2.1. Radiography

In 1895 Wilhelm Roentgen saw the hand bone image on the photographic plate from the opposite side of the cathode-ray tube for the first time. This photograph became one of many X-ray photographs made since then. Roentgen's researches were immediately reproduced in other physical laboratories. A 3-hour X-ray photograph demonstrating the non-transparency of metal bullets, rings and pins was made in Davidson College (North Carolina) in January 1896. In a month the X-ray radiation was used for imaging Colles fracture of a student of Darmouth College in Hanover (Scatliff, Morris, 2014). Very soon the doctors appraised the advantages of the new technology and started practicing it, using glass plates for getting the image. Mobile X-ray stations were used during World War I already to diagnose bone injuries, as well as tuberculosis and other pulmonary damages.

Later, radiographic contrast studies of gastrointestinal tract with the use of barium meal emerged. The radiation safety events started to be introduced in 1930s: lead aprons, gloves, thereoid shields, safety goggles (for interventional radiologists) got into use. In the late 1940s the specialists began thinking about long-term risks of X-ray radiation. Sharply narrowed X-ray beams and short-range expositions with three-phase generators started to be applied for taking X-ray photographs. It was extremely important to take safety measures with children and babies whose tissues are more sensitive to radiation damages. By 1960s the radiation doses critically decreased, which allowed using radiopaque substances for imaging a beating heart and vessels. This method gave the opportunity to examine the heart noninvasively. In the same period, the X-ray film replaced glass plates. The introduction of digitalization improved the quality of X-ray study even more (Scatliff, Morris, 2014).

Radiography is the gold standard in osteoarthritis diagnostics. The method allows finding the joint space width, which is the indirect marker of the cartilage thickness and meniscus integrity in knees, though the direct imaging of these joint structures is impossible. Besides, marginal osteophytes are found. The radiographically found joint space width is the parameter approved by Federal Food and Drug Administration of the USA to monitor the efficiency of pharmaceutical drugs for osteoarthritis treatment. The joint space disappearance (bone on bone) is the indication for the joint replacement. The severity of radiographic osteoarthritis is found by Kellgren-Lawrence semi-quantitative scoring system. Digital radiography allows precisely measuring the distance between the edges of thigh and shin bones (Hayashi, Roemer, Guermazi, 2016). Nevertheless, the X-ray method does not give an idea about the condition of soft tissues surrounding the joint.

Radiography is widely accessible for outpatients and is often the initial examination to evaluate the condition of patients with acute stomach ache. However, in this case, the method has a limited diagnostic value and its results do not significantly influence the patients' treatment scheme. In case of acute abdomen, the X-ray method is necessary at suspicion on gastrointestinal obstruction, perforation of hollow organs, concretions of urinary tracts, foreign bodies (Cartwright, Knudson, 2015).

Radiography is traditionally used in dentistry and gives a general picture of teeth condition. However, in some cases (for instance, when evaluating root resorption), the diagnostics can be difficult, since ordinary X-ray photographs give only a 2D image and are

not precise when determining the character and localization of the pathological process. In such cases, more accurate methods are applied (cone-beam CT) (Lima, Gamba, Zaia, Soares, 2016).

Such capabilities of the X-ray method, as obtaining of X-ray photographs using protons instead of X-ray beams, should be discussed separately. The change in the density inside a patient's body influences the energy of protons going through it. The protons crossing the region with increased density lose more energy than in less dense tissues. These protons will have a shorter residual range. Measuring the energy of escaping protons and their residual range, it is possible to reproduce inner structures of the body. Coulomb scattering hinders the imaging precision. Another approach is the use of charged nuclei instead of protons. In a series of experiments conducted by Seward and Claire in 1973 the X-ray photographs of different samples were made and it was demonstrated that proton radiography can be used for imaging the anatomy of soft tissues and available anomalies. The introduction of proton CT into clinical practice started in Los Alamos in 1977. Proton X-ray photographs were further used as control images to improve the accuracy of proton beam therapy of patients (Hanson, Schneider, 2022).

In the light of the pandemic all over the world, mobile radiography became widely spread, as well as tele-radiography, which allows distantly examining the picture obtained (Tay, McNulty, 2023).

2.2. Magnetic Resonance Imaging (MRI)

1973 can be considered as the year of magnetic resonance imaging (MRI) emergence, when Prof. Paul Lauterbur published his paper "Image Formation by Induced Local Interactions: Examples of Employing Nuclear Magnetic Resonance" in Nature (Lauterbur, 1973). The clinical use of MRI initially started from the magnetic field intensity in the range of 0.05-0.35 T. However, during the recent 40 years we have been observing the tendency to apply stronger magnetic fields that, on the one hand, resulted in the data improved quality, and on the other – more expensive equipment making it unaffordable for many medical institutions. Nevertheless, in a number of cases, low-field MRI can be used, for example, in diagnostics of congenital hydrocephalus accompanied by elevated intracranial pressure (Marques, Simonis, 2019).

Despite the examination high cost, MRI, in a number of cases, is a valuable diagnostic tool able to evaluate pathology in structures, which are not visualized with radiography, including arthrodial cartilage, meniscuses, ligaments, synovium, capsule. MRI can also detect fluid accumulation, state of bone marrow, organs and soft tissues. MRI allows detecting pathologic changes in joints at the stage when they are not visible on the X-ray image. Sometimes the availability of artefacts can result in wrong conclusions, for example, detection of meniscal tear or cartilage loss. The same way as in the radiographic examination, semi-quantitative scoring of the injury is conducted in MRI: knee joint (WORMS, BLOCKS, MOAKS scales), arm osteoarthritis (OMERACT scale), hip joint (HOAMS system). Composition MRI allows evaluating the cartilage tissue dynamics during treatment. Changes in cartilage matrix are investigated by MRI with delayed gadolinium enhancement (dGEMRIC), T1 rho and T2 mapping. The concentration of sharply negatively charged glycosaminoglucans in hyaline cartilage is used in the first two methods: the loss of these molecules in focal regions can be connected with early stages of the disease and can influence the MRI picture. The concentration of T2 is influenced by the complex combination of collagen orientation and cartilage hydration (Hayashi, Roemer, Guermazi, 2016).

Imaging at strokes can be obtained by MRI and CT methods. MRI has higher sensitivity at acute ischemic injuries. Besides, MRI detects strokes in the system of posterior cerebral arteries better than CT. Nevertheless, MRI is contraindicative if implanted devices or claustrophobia are available. MRI is also more sensitive and specific than CT and U/S in the diagnostics of vertebral artery stenosis. Cervical and intracranial stenosis, intraplaque hemorrhage, vertebra wall hematoma, cervical arteriopathies, atherosclerosis, vasculitis can be visualized with the help of MRI (Salerno et al., 2022).

MRI can be useful to evaluate acute cholecystitis with the sensitivity of 85% and specificity of 81%, similar to U/S method. MRI is prescribed for the patients with unclear U/S results for imaging diseases of liver and bile ducts not detected by U/S. MRI has high sensitivity and specificity when diagnosing appendicitis with pregnant women (Cartwright, Knudson, 2015).

MRI together with CT is widely used for gallbladder cancer diagnostics revealing the mass occupying the bladder lumen and frequently invading into the liver parenchyma. MRI can show the hypointense and hyperintense signal on T1-suspended images of the

gallbladder and hyperintense signal on T2-suspended images. MRI, the same as CT, reveals the uneven intensive enhancement on the periphery to the early arterial phase, which is preserved in fibroid components of the initial affection to the portal venous phase of the disease (Fine, Smith, Stein, Madoff, 2019).

Different inflammatory anomalies of pancreas are able to imitate the adenocarcinoma of its ducts when visualizing their cross-section. The incorrect diagnosis can result in the unnecessary surgical interference. MRI and CT methods are able to differentiate the adenocarcinoma of pancreas ducts (APD) and mass-forming chronic pancreatitis (MCP). The combination of perfusion MRI and diffuse-suspended imaging allowed achieving good results in differential diagnostics. The mean value of apparent diffusion coefficient (ADC) was much lower at APD than at MCP (1.17±0.23 vs. 1.47±0.18, $p<0.01$, obtained at 3.0-T MRI). The slow diffusion coefficient and perfusion fraction were much lower at MCP than at APD. The intravoxel coherent motion at diffuse-suspended imaging also allowed differentiating these two pathologies (Schima el al., 2020).

MRI is an effective technique for diagnosing thrombi. Imaging using fluorine[19], trace superparamagnetic iron oxide (RGD-USPIO), magnetic-powder suspension is applied to obtain the thrombus image. MRI can be also used to study the thrombus magnetic properties using the magnetization method and diffusion imaging. The former better characterizes old, dense thrombi, and the latter is more effective to detect new thrombi sensitive to lysis (Lanza et al., 2019). MRI method, the same as CT with U/S, is effective in diagnosing liver portal vein thrombosis (Ju et al., 2019).

MRI (and CT) method was recommended by European Society of Cardiovascular Radiology (ESCR) when planning the surgery of aortic valve transcatheter replacement. The diagnosis and classification of aortic valve severe syndrome were based on the symptoms and imaging data related to the aortic valve anatomy and hemodynamics. It is suggested to use MRI for quantitative evaluation of the aortic valve coverage area and transvalvular rates using the planimetry and phase-contrast image with simultaneous calculation of the left ventricle ejection fraction (Francone, 2020).

MRI has significantly improved during the recent 20 years that resulted in the emergence of safe, universal, noninvasive alternative to coronagraphy not requiring the administration of iodine-containing contrast agent. MRI is considered the clinical gold standard for evaluating cardiac structure, volume, function, tissue characteristic, presence

and condition of cardiac muscle scar, and myocardial perfusion (Mangla, Oliveros, Williams, Kalra, 2017). Nevertheless, the quality of MRI-angiography is lower than of CT-angiography and X-ray angiography, since the resolution is 1 mm vs. 0.4-0.6 and 0.1 mm, respectively. Besides, MRI-angiography differs in longer procedure duration, high cost, complicated planning of stenting and deteriorated image quality due to the heart motion and the patient's breath. All this results in low sensitivity and specificity in comparison with other angiographic methods. The application of MRI-angiography is mainly limited by the assumption of the anomaly of coronary vessels, aneurysm and evaluation of proximal segments of coronary rami. The innovations recently introduced into MRI technology allow overcoming many of the indicated drawbacks. The main techniques are as follows: imaging acceleration, motion and reconstruction structure correction, simplified scanning planning, higher magnetic field intensity, use of opaque substances based on gadolinium and nitrates. MRI ability to characterize vessel plaques is of research and clinical interest for early diagnostics and treatment of atherosclerotic diseases (Hajhosseiny et al., 2020).

2.3. Computed Tomography (CT)

The idea of laminography of human organs was initially proposed by American doctor William Odendorf in 1959. In contrast to flat X-ray photographs the new method allowed evaluating a 3D structure of anatomic formations. The first brain tomogram was made in 1971 on the scanner developed by A. Cormac and G. Hounsfield, for which they were awarded the Nobel Prize in 1979. The technology has been significantly improved since then – the image is more clear, it is possible to evaluate the organ work in dynamics (heart) (Klarov, Platonov, 2018)

CT allows imaging the bone and soft tissue calcification well, and evaluating the condition of spinal column facet joints in osteoarthritis. The limitations for CT are the radiation exposure and limited ability to evaluate soft tissues (Hayashi, Roemer, Guermazi, 2016).

CT prescription can be relevant at acute stomach ache. American College of Radiology recommends using CT to evaluate the pain in the stomach right and left lower quadrants. The broad CT application is accompanied by the worries about the ionizing radiation resulting in the attempts to use CT with decreased radiation doses. CT is

recommended in abscesses, pancreatitis, appendicitis, Crohn disease, diverticulitis, mesenteric ischemia, nephrolithiasis, intestinal blockage. The contrast medium is used in many cases. In acute appendicitis CT has better sensitivity and specificity (91% and 90%) than U/S (78% and 83%). The routine use of CT for appendicitis diagnostics resulted in reduced frequency of appendectomies with the negative result from 24% to 3%, as well as reduced treatment costs (Cartwright, Knudson, 2015). With the gallbladder cancer, CT reveals the hypodense formation, and the contrast agent intravenous administration demonstrates the hypervascular focus enhancement in 40% of cases (Fine, Smith, Stein, Madoff, 2019).

The investigations of perfusion CT efficiency in APD and MCP differential diagnostics demonstrated the promising results. The perfusion CT allowed clearly distinguishing the normal parenchyma from the tumorous and inflammatory ones, as well as distinguishing between the latter two. The average blood flow, blood volume and the product of permeability and the surface area were much higher at MCP than at adenocarcinoma. The combination of the indicated parameters demonstrated high sensitivity and specificity in differential diagnostics of adenocarcinoma of pancreas ducts and mass-forming chronic pancreatitis (Schima et al., 2020).

SPECT (single-photon emission CT) with the use of opaque substances is applied for detecting thrombi. The main targets (for radiopharmaceutical agents) for imaging are thrombocytes and fibrin. An acute thrombus is easily detected with the help of SPECT, however, it is difficult to visualize an old one. Besides, the intake of anticoagulants also decreases SPECT diagnostic value (Lanza et al., 2029). Low-dose spiral CT can be an effective tool for the pulmonary cancer screening, revealing small tumors well (Hajdu, Vadmal, Tang, 2015).

The cone-beam computer-assisted tomography (CBCT) has been actively applied in dentistry in recent years. It generates images in axial, coronary and sagittal directions that allows performing 3D imaging of tooth structures. CBCT has become a valuable method of studying periapical lesions and traumas of teeth, as well as the complications (fractures, perforations, root resorptions). The CBCT image quality depends on the field of vision (FOV) and voxel size. Images with smaller voxels have better resolution and visualize endodontal lesions more accurately. The comparison between radiologic method (periapical R) and CBCT when evaluating the root resorption revealed the increased CBCT

accuracy in diagnosing the external (p=0.0144) and internal (p=0.0038) resorptions. The accuracy of both methods was the same in replacing resorption (Lima, Gamba, Zaia, Soares, 2016).

CT method appeared to be very highly-demanded during COVID-19 pandemic. CT was recommended for patients with positive laboratory tests for the virus and with moderate-to-severe disease progression, as well as for patients with negative test results. The method was more effective than the ordinary X-ray photograph at the early stages of the disease (Toussie, Voutsinas, Chung, Bernheim, 2022).

European Society of Cardiovascular Radiology recommends CT examination before the transcatheter replacement of aortic valve for the quantitative evaluation of the aortic valve calcification load based on CT for diagnostic purposes. Nevertheless, this examination is recommended only for the patients with contradicting results of Doppler echocardiography (Francone et al., 2020).

Computer-assisted coronary angiography (CTA) has come the considerable way of evolution due to the innovation in the production of X-ray tubes, accelerated gantry rotation, multiple parallel detector rings in tomographic scanner and decreased slice thickness connected with it. The spatial resolution is 0.4 mm, the negative prognostic value of the method is 90%. The examination is noninvasive and is distinguished by low cost compared to invasive coronary angiography. CTA is recommended as a method for selecting patients with IHD stable symptoms and low-to-average risks of ischemia. During CTA, the fractional blood flow reserve is evaluated and the plaques are characterized (total mass of the plaques, lesion calcification, suppression character of the plaques and remodeling positive index). The application of CTA method is limited by the radiation exposure and necessity to administer an iodine-containing contrast agent. The availability of artefacts connected with vast calcification of coronary arteries handicaps the stenosis accurate evaluation. There are contraindications for patients with renal disease, resistant tachycardia/arrhythmia, hypersensitiveness to iodine-containing contrast agents, pregnancy, and incapability to follow the instructions on holding breath (Hajhosseiny et at., 2020).

2.4. Positron Emission Tomography (PET), scintigraphy

Scintigraphy with 99Tc-hydroxymethanediphosphonate (HDP) and positron-emission tomography (PET) with 2-^{18}fluorine-2-deoxy-D-glucose (^{18}FDG) or ^{18}fluoride is successfully applied to diagnose the condition of joints. With the help of scintigraphy it is possible to completely examine the body, carry out the differential diagnostics between the bone and soft tissue pain and localize the pain source at complex symptomatology. FDG-PET reveals synovitis and bone marrow damages. Inferior anatomic resolution is the limitation for radioisotopic methods, however, it is overcome with the help of hybrid technologies (PET-CT, PET-MRI) (Hayashi, Roemer, Guermazi, 2016). Cholescintigraphy has better sensitivity and specificity (96% and 90%, respectively) than U/S (81% and 83%) when diagnosing acute cholecystitis, although U/S is more accessible and can detect the accompanying abdominal pathology (Cartwright, Knudson, 2015). With gallbladder cancer (GBC) PET-CT demonstrates high hypermetabolic activity of fluorinedeoxyglucose in the place of tumor and metastases localization. In the beginning of the disease the diffuse, focal or asymmetric wall thickening is observed in 20-30% of cases. The initial detection of GBC can define the polypoid lesion in 15-25% of cases: malignant polyps are over 1 cm and should provoke cancer alertness (Fine, Smith, Stein, Madoff, 2019).

PET based on Gu^{64} can be used for thrombi imaging. It is proposed to use peptide FBP8 for binding as a fibrin-specific probe, however, its efficiency is higher in respect of an acute thrombus and it goes down with the thrombus ageing due to gradual decrease in the fibrin content (Lanza et al., 2019).

At present, the diagnostics based on positron-emission tomography is widely applied in inflammatory diseases of bones, joints, heart, sarcoidosis, diabetic foot, query fevers, oncological diseases of varied localization, metastases, when planning radiation therapy. As a rule, the enhancement by gadolinium or fluorinedeoxyglucose is used (Casali et al.,, 2021; Chen, Chen, Wang, 2022; Kocher, Ruge, Galldiks, Lohmann, 2020; Kratochwil et al., 2019; Pu et al., 2021; Rischpler et al.,, 2019; Yang et al., 2022).

2.5. Intervention radiology

Intervention radiology started developing in 1960s and its initial narrow directedness has expanded and today it comprises the diagnostics and treatment of diseases in many body systems. At the moment, a lot of treatment procedures, including

percutaneous biopsy, are carried out under the control of radiologic methods (Arnold, Keung, McCarragher, 2019).

Technical achievements in radiology made it possible to implement the improved imaging and intervention radiology. The most noticeable diagnostic contribution was made by such methods as percutaneous cholangiography, endoscopic retrograde cholangiopancreatography, angiography, percutaneous transthoracic biopsy under CT's control, intravenous or intraperitoneal administration of radioisotopes I^{131} and Tc^{99} to localize tumors, diagnostic use of radiolabelled antibodies, etc. (Hajdu, Vadmal, Tang, 2015).

Invasive X-ray angiography and coronary computer-assisted tomography are the recognized gold standards in coronary angiography. Nevertheless, they are connected with certain contraindications, ionizing radiation and necessity to administer iodine-containing contrast agents. This prompts seeking new techniques for imaging vessels. Among a number of imaging methods, coronary cardiovascular magnetic resonance angiography can be applied to seek and monitor the stenosis of coronary arteries. The method advantage is in its universality, lack of radiation exposure, perfect imaging quality of soft tissues, lack of necessity to administer iodine-containing contrast agents. The comparison between unenhanced MRI-angiography and X-ray angiography demonstrated that sensitivity and specificity of the first method are about 88-92% and 42-72%, respectively (Hajhosseiny et al., 2020).

Quantitative invasive X-ray coronography gives good visualization of vessels at IHD. Due to spatial resolution of up to 0.1 mm, the method is second to none in evaluating the distal coronary anatomy. X-ray coronography is used during percutaneous coronary intervention (PCI) required in emergency cases and it provides the precision of manipulations and economic efficiency of the surgery. With patients with symptomatic stable IHD the invasive evaluation of the physiology of coronary arteries and PCI with functional control (with defining the fractional flow reserve) and pressure provision has a good forecast and is the established gold standard of the approach to revascularization at stable angina. Nevertheless, the complications connected with invasive radiology (death, stroke, myocardial and vessel injury, pain, bleeding) long-term accumulated risk from ionizing radiation and short-term risk of nephropathy conditioned by the administration of iodine-containing contrast agents limit the application of this method as a screening tool at

suspicion on stable IHD. This method poorly characterizes intravascular plaques, especially during the remodeling keeping the vessel lumen (Hajhosseiny et al., 2020).

2.6. Ultrasonic Signal (U/S)

For the first time, the ultrasonic signal captured on the photographic plate to determine the cerebral ventricle anomaly was used by an Austrian neurologist (psychiatrist) Karl Dusik and his brother Friedrich Dusik. Moving the transmitter around the scull and registering the energy of the beam having passed, the brothers received the image of dark and light spots, something like a TV picture, which was put onto the photographic plate and was initially called "hyperphonogram". The physical principle of the new method was based on sound attenuation when it was going through the head structure. The researchers' conclusions were published in 1942 and 1947. Sound waves, the same way as X-rays, lose energy when going through tissues, however, the ultrasound is easily reflected, deflected and diffracted changing the wave direction and amplitude. In later hardware developments it became possible to neutralize the number of reflections and backscattering (Dietrich et al., 2022).

Due to low radiation exposure and good resolution U/S is widely used to diagnose endocrine, gynecologic, oncologic, kidney diseases, pathology of abdominal cavity, heart and lungs (Grani et al., 2020; Martire et al., 2020; Nicolau, Antunes, Paño, Sebastia, 2021; Oskovi Kaplan, Ozgu-Erdinc, 2018;_Radzina, Biederer ,2019; Riddell, Corallo, Albazaz, Foley, 2023; Salzman, Collins, Hersh, 2019). Ultrasonography of heart and vessels allows defining the myocardium stiffness, its functional consistency, and (application of echocardiography with speckle tracing) gives the possibility to identify nearly invisible myocardial injuries, find the ischemia regions with the creation of clear picture of affection zone for differential diagnostics and treatment (Pastore et al., 2021; Pedreira et al., 2022). The application of short focused U/S protocols helps to diagnose diseases of lower extremities, aorta, pulmonary arteries, atherosclerotic changes in vessels (Balakhonova et al., 2022). The development of supplementary reproductive technologies made U/S a key method in the evaluation of ovarian syndrome, as well as the control method in ovary paracentesis with ovum collection for IFV and monitoring of the patient's condition after the embryo transfer into the uterine cavity (Cortés-Vazquez et al., 2021). The absence of radiation exposure resulted in the fact that U/S method is the most sought-after for

diagnosing pregnancy and fetus pathology. Apart from the endometrium state, U/S helps in defining the fetus dimensions, growth rate, uteroplacental Doppler indices, carrying out cardiotocography, revealing indications of the mother's arterial hypertension, etc. (Lees et al., 2022). U/S today is an accessible, safe and inexpensive method to reveal the pathology of different organs and systems.

Conclusion

The information analysis in the literature references demonstrated that imaging methods have been continuously developing and improving for nearly 130 years. Despite the expectations, the very first X-ray imaging method has still been actively used, being, among others, a mandatory component of the population's general preventive medical examination. Although initially it was used for diagnosing bone fractures, the diagnostic range has gradually broadened and comprised pulmonary diseases, acute abdomen, scull images (Turkish saddle), etc. The possibility to administer radiopaque substances made X-ray a valuable tool for diagnosing diseases of gastrointestinal tract and vessels. The limitation comprised high radiation exposure, intolerance to radiopaque substances with renal disease. U/S and MRI methods, which emerged later, were not accompanied by radiation and had high information value and good resolution of the picture obtained. MRI advantage is excellent imaging of soft tissues, tendons, ligaments, vessels, internal organs. CT and its derivatives (PET-CT, CTA) refer to the methods of the best imaging of internal structure, however, the influence of artefacts is possible here. Besides, CT-angiography has lower resolution than X-ray and MRI-angiography, therefore, it is recommended to be used only to evaluate the proximal part of coronary vessels. X-ray angiography is still considered to be the best.

Therefore:

1. X-ray method provides clear imaging of bone structures but does not allow evaluating soft tissues. Besides, the method is accompanied by considerable radiation exposure.

2. Radiographic contrast studies allow defining the structure of hollow organs and vessels well, however, the intolerance to radiopaque substances and enhancement of renal disease are possible.

3. MRI advantage is expressed in good imaging of soft tissues and absence of radiation exposure, however, MRI-angiography has lower resolution in contrast to X-ray and CT-angiography.

4. CT allows recreating an organ spatial structure, however, radiation exposure and insufficiently sharp imaging of soft tissues are the limitations.

5. U/S method is widely used in diagnosing pathology of soft tissues, conducting supplementary reproductive technologies and evaluating embryo and fetus condition due to the absence of radiation exposure.

References

Arnold M.J., Keung J.J., McCarragher B. (2019) Interventional Radiology: Indications and Best Practices. *Am Fam Physician.* 99(9): 547-556.

Balakhonova T.V., Ershova A.I., Ezhov M.V., Barabash O.L., Bershtein L.L., Bogachev V.Yu., et al. (2022) Focused ultrasound investigation of vessels. *Cardiovascular Therapy and Preventive Care.* 21(7): 105-126. doi: 10.15829/1728-8800-2022-3333.

Cartwright S.L., Knudson M.P. (2015) Diagnostic imaging of acute abdominal pain in adults. *Am Fam Physician.* 91(7): 452-9.

Casali M., Lauri C., Altini C., Bertagna F., Cassarino G., Cistaro A., et al. (2021) State of the art of ^{18}F-FDG PET/CT application in inflammation and infection: a guide for image acquisition and interpretation. *Clin Transl Imaging.* 9(4): 299-339. doi: 10.1007/s40336-021-00445-w.

Chen Z., Chen X., Wang R. (2022) Application of SPECT and PET / CT with computer-aided diagnosis in bone metastasis of prostate cancer: a review. *Cancer Imaging.* 22(1): 18. doi: 10.1186/s40644-022-00456-4.

Cortés-Vazquez A., Goitia-Landeros G.A., Regalado M.A., León-Hernández S.R., Cortés-Algara A.L., Bandala C., et al. (2021) Prediction of ovarian response in IVF/ICSI cycles. *JBRA Assist Reprod.* 25(3): 422-427. doi: 10.5935/1518-0557.20210003.

Dietrich C.F., Bolondi L., Duck F., Evans D.H., Ewertsen C., Fraser A.G., et al. (2022) History of Ultrasound in Medicine from its birth to date (2022), on occasion of the 50 Years Anniversary of EFSUMB. A publication of the European Federation of Societies for Ultrasound In Medicine and Biology (ERSUMB), designed to record the historical development of medical ultrasound. *Med Ultrason.* 24(4): 434-450. doi: 10.11152/mu-3757.

Fine G.C., Smith T.A., Stein S.I., Madoff D.C. (2019) Interventional radiology's role in the diagnosis and management of patients with gallbladder carcinoma. *Chin Clin Oncol.* 8(4): 40. doi: 10.21037/cco.2019.07.09.

Francone M., Budde R.P.J., Bremerich J., Dacher J.N., Loewe C., Wolf F., Natale L., Pontone G., Redheuil A., Vliegenthart R., Nikolaou K., Gutberlet M., Salgado R. (2020) CT and MR imaging prior to transcatheter aortic valve implantation: standardization of scanning protocols, measurements and reporting-a consensus document by the European Society of Cardiovascular Radiology (ESCR). *Eur Radiol.* 30(5): 2627-2650. doi: 10.1007/s00330-019-06357-8.

Grani G., Sponziello M., Pecce V., Ramundo V., Durante C. (2020) Contemprorary Thyroid Nodule Evaluation and Management. *J Clin Endocrinol Metab.* 105(9): 2869-83. doi: 10.1210/clinem/dgaa322.

Hajdu S.I., Vadmal M., Tang P. (2015) A note from history: Landmarks in history of cancer, part 7. *Cancer.* 121(15): 2480-513. doi: 10.1002/cncr.29365.

Hajhosseiny R., Bustin A., Munoz C., Rashid I., Cruz G., Manning W.J., Prieto C., Botnar R.M. (2020) Coronary Magnetic Resonance Angiography: Technical Innovation Leading Us to the Promised Land? *JACC Cardiovasc Imaging.* 13(12): 2653-2672. doi: 10.1016/j.jcmg.2020.01.006.

Hanson K., Schneider U. (2022) History of proton radiography and tomography. *Z. Med Phys.* 32(1): 2-4. doi: 10.1016/j.zemedi.2021.11.005.

Hayashi D., Roemer F.W., Guermazi A. (2016) Imaging for osteoarthtitis. A*nn Phys Rehabil Med.* 59(3): 161-169. doi: 10.1016/j.rehab.2015.12.003.

Ju C., Li X., Gadani S., Kapoor B., Partovi S. (2022) Portal Vein Thrombosis: Diagnosis and Endovascular Management. *Rofo.* 194(2): 169-180. doi: 10.1055/a-1642-0990.

Kaller M.O., An J. (2023) Contrast Agent Toxicity. 2023 May 1. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; https://www.ncbi.nlm.nih.gov/books/NBK537159/ [Access date: 21.06.2023].

Klarov L.A., Platonov F.A. (2017) Computer tomography (CT) or magnetic resonance imaging (MRI)? *Science and Engineering in Yakutia.* 1(32): 28-31.

Kocher M., Ruge M.I., Galldiks N., Lohmann P. (2020) Applications of radiomics and machine learning for radiotherapy of malignant brain tumors. *Strahlenther Onkol.* 196(10): 856-867. doi: 10.1007/s00066-020-01626-8.

Kratochwil C., Flechsig P., Lindner T., Abderrahim L., Altmann A., Mier W., et al. (2019) ^{68}Ga-FAPI PET/CT: Tracer Uptake in 28 Different Kinds of Cancer.*J Nucl Med.* 60(6): 801-805. doi: 10.2967/jnumed.119.227967.

Lanza G.M., Cui G., Schmieder A.H., Zhang H., Allen J.S., Scott M.J., et al. (2019) An unmet clinical need: The history of thrombus imaging. *J Nucl Cardiol.* 26(3): 986-997. doi: 10.1007/s12350-017-0942-8.

Lauterbur P.C. (1973) Image Formation by Induced Local Interactions: Examples of Employing Nuclear Magnetic Resonanse. *Nature.* 242: 190-191. doi: 10.1038/242190a0.

Lees C.C., Romero R., Stampalija T., Dall'Asta A., DeVore G.A., Prefumo F., et al. (2022) Clinical Opinion: The diagnosis and management of suspected fetal growth restriction: an evidence-based approach. Am *J Obstet Gynecol.* 226(3): 366-378. doi: 10.1016/j.ajog.2021.11.1357.

Lima T.F., Gamba T.O., Zaia A.A., Soares A. (2016) Evaluation of cone beam computed tomography and periapical radiography in the diagnosis of root resorption. *J. Aust Dent J.* 61(4): 425-431. doi: 10.1111/adj.12407.

Mangla A., Oliveros E. , Williams K.A. , Kalra D.K. (2017) Cardiac imaging in the diagnosis of coronary artery disease. *Curr Probl Cardiol*, 42 , pp. 316-366. https://doi.org/10.1016/j.cpcardiol.2017.04.005.

Marques J.P., Simonis F.F.J., Webb A.G. (2019) Low-field MRI: An MR physics perspective. *J Magn Reson Imaging.* 49(6): 1528-1542. doi: 10.1002/jmri.26637.

Martire F.G., Lazzeri L., Conway F., Siciliano T., Pietropolli A., Piccione E., et al. (2020) Adolescence and endometriosis: symptoms, ultrasound signs and early diagnosis. *Fertil Steril.* 114(5): 1049-1057. doi: 10.1016/j.fertnstert.2020.06.012.

Nicolau C., Antunes N., Paño B., Sebastia C. (2021) Imaging Characterization of Renal Masses. *Medicina (Kaunas)*. 57(1): 51. doi: 10.3390/medicina57010051.

Oskovi Kaplan Z.A., Ozgu-Erdinc A.S. (2018) Prediction of Preterm Birth: Maternal Characteristics, Ultrasound Markers, and Biomarkers: An Updated Overiew. *J Pregnancy*. 2018: 8367571. doi: 10.1155/2018/8367571.

Pastore M.C., Mandoli G.E., Contorni F., Cavigli L., Focardi M., D'Ascenzi F., et al. (2021) Speckle Tracking Echocardiography: Early Predictor of Diagnosis and Prognosis in Coronary Artery Disease. *Biomed Res Int.* 2021: 6685378. doi: 10.1155/2021/6685378.

Pedreira O., Correia M., Chatelin S., Villemain O., Goudot G., Thiebaut S., et al. (2022) Smart Ultrasound Device for Non-Invasive Real-Time Myocardial Stiffness Quantification of the Human Heart. *IEEE Trans Biomed Eng.* 69(1): 42-52. doi: 10.1109/TBME.2021.3087039.

Pu Y., Wang C., Zhao S., Xie R., Zhao L., Li K., Yang C., et al. (2021) The clinical application of ^{18}F-FDG PET/CT in pancreatic cancer: a narrative review. *Transl Cancer Res.* 10(7): 3560-3575. doi: 10.21037/tcr-21-169.

Radzina M., Biederer J. (2019) Ultrasonography of the Lung. *Rofo.* 191(10): 909-923. doi: 10.1055/a-0881-3179.

Riddell Z.C., Corallo C,. Albazaz R., Foley K.G. (2023) Gallbladder polyps and adenomyomatosis. Br *J Radiol.* 96(1142): 20220115. doi: 10.1259/bjr.20220115.

Rischpler C., Nekolla S.G., Heusch G., Umutlu L., Rassaf T., Heusch P., et al. (2019) Cardiac PET/MRI-an update. *Eur J Hybrid Imaging.* 3(1): 2. doi: 10.1186/s41824-018-0050-2.

Salerno A., Strambo D., Nannoni S., Dunet V., Michel P. (2022) Patterns of ischemic posterior circulation strokes: A clinical, anatomical, and radiological review. *Int J Stroke.* 17(7): 714-722. doi: 10.1177/17474930211046758.

Salzman B., Collins E., Hersh L. (2019) Common Breast Problems. *Am Fam Physician.* 99(8): 505-514.

Scatliff J.H., Morris P.J. (2014) From Roentgen to magnetic resonance imaging: the history of medical imaging. *N C Med J.* 75(2): 111-113. doi: 10.18043/ncm.75.2.111.

Schima W., Böhm G., Rösch C.S., Klaus A., Függer R., Kopf H. (2020) Mass-forming pancreatitis versus pancreatic ductal adenocarcinoma: CT and MR imaging for differentiation. *Cancer Imaging.* 20(1): 52. doi: 10.1186/s40644-020-00324-z.

Tay Y.X., McNulty J.P. (2023) Radiography education in 2022 and beyond – Writing the history of the present: A narrative review. *Radiography* (Lond). 29(2): 391-397. doi: 10.1016/j.radi.2023.01.014.

Toussie D., Voutsinas N., Chung M., Bernheim A. (2022) Imaging of COVID-19. *Semin Roentgenol.* 57(1): 40-52. doi: 10.1053/j.ro.2021.10.002.

Yang T., Ma L., Hou H., Gao F., Tao W. (2022) FAPI PET/CT in the Diagnosis of Abdominal and Pelvic Tumors. *Front Oncol.* 11: 797960. doi: 10.3389/fonc.2021.797960.