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Cyber attacks on radiological systems

SWOT analysis of the application of artificial intelligence in radiologic technology and radiology

The importance of MRI in determining the stage of cervical cancer

Tumor Hypoxia and Radioresistance

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Riječ urednika

Dragi čitatelji Radiološkog Vjesnika,

Polako smo ušli u novu eru radiološke tehnologije. Sa novom erom su došli novi izazovi, rad u potpuno digitalnom okruženju, kibernetički napadi. Umjetna inteligencija više nije novost, sada se raspravlja o njenim prednostima, nedostacima, prilikama i prijetnjama. Drugi broj Radiološkog vjesnika za 2024. godinu nam donosi upravo takve teme, uz nezaobilazne napredne tehnike slikovnog prikaza u području magnetske rezonancije i kompjutorizirane tomografije te skrb za onkološke pacijente. Pritom konvencionalnu radiografiju i dalje smatramo vrijednom pažnje, a odgovor na pitanje treba li nam sustav za ocjenu kvalitete radiološke slike pronađite ovdje. Jesen 2024. godine je vrijeme događanja Kongresa Dani radiološke tehnologije, sa temom: Jesmo li samostalni? – i 1. Simpozijem studenata radiološke tehnologije. U ovom izdanju Vam donosimo puni program i sve radove koji će biti prezentirani na ovom stručnom događanju. Radujemo se skorom viđenju i novim zajedničkim profesionalnim izazovima.

U ime Uredničkog odbora Radiološkog vjesnika,

Andrija Čop

A word from the Editor

Dear readers of Radiological Journal,

We have slowly entered a new era of radiological technology. With the new era came new challenges, work in a completely digital environment, cyber attacks. Artificial intelligence is no longer a novelty, its advantages, disadvantages, opportunities and threats are now being discussed. The second issue of the Radiological Journal for 2024 brings us precisely such topics, along with indispensable advanced imaging techniques in the field of magnetic resonance and computerised tomography, as well as care for oncology patients. At the same time, we still consider conventional radiography worthy of attention, and the answer to the question of whether we need an evaluation system of the quality of radiological image can be found here. This fall of 2024 is the time for the Days of Radiation Technology Congress, with the topic: Exploring autonomy – and 1st Symposium of students of medical radiation technology. In this edition, we bring you the full program and all the abstracts that will be presented at this professional event. We look forward to seeing each other soon and to new joint professional challenges.

On behalf of the Editorial Board of the Radiological Journal,

Andrija Čop

Hrčak doi EBSCO

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Autori/ce pridržavaju sva prava. Tekstovi u časopisu odražavaju stavove autora/ica i nisu nužno stavovi uredništva niti Hrvatskog društva radiološke tehnologije.

REVIEW PAPER (PREGLEDNI RAD)

Cyber attacks on radiological systems

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Abstract

The base of today's radiological devices are computers and networks. The radiology department has a specific way of working and there are standards such as DICOM for medical image records, PACS for archiving and communication, and HL7 for information exchange in the medical system. As radiology becomes an economically interesting branch, it becomes a target for cyber-attacks. At the same time, radiological systems contain a lot of personal data that are valuable. The reasons for the attacks are often financial gain, political, ideological or personal. The start of an attack can be physical access to radiological devices or network access. DICOM files can be the trigger of an attack. We divide attacks into those that directly affect patients, those that have an indirect impact, and those that affect the infrastructure. Well known types are Denial-Of-Service, malware, cryptographic attacks and making changes of device settings. When defending against cyber-attacks, it is important to secure communication by e-mail and to keep software updated. The IT department of the radiology department should observe accounts of all users and check the authorizations. Networks must have access restrictions according to workplaces and purposes to prevent unwanted access. Web proxy protection restricts access to Internet sites that are potentially dangerous. The basics of the department's network, such as servers, must be physically secured from access. DICOM files should be encrypted with the most secure algorithms available. In response to cyber-attacks, it is necessary to have standard procedures and such a system must always be on standby. Known attacks on radiological systems are Kwampiris, Petja/NotPetya, Ryuk, Wannacry, Conti group and BianLian.

Keywords: cyberattacks, radiological systems, network security

Abbreviations and acronyms: AES (Advanced encryption standard), CD (Compact disc), CT (Computed tomography), DDOS (Distributed denial-of-service), DICOM (Digital Imaging and Communications in Medicine), HL7 (Health Level-7)MRI (Magnetic resonance imaging), PACS (Picture archiving and communication system), RIS (Radiology information system), RSA (Rivest–Shamir–Adleman), URL (Uniform resource locator), USB (Universal serial bus), WEP (Wired equivalent privacy), WPA2 (Wi-Fi protected access 2)

Introduction

Computers today have become an essential part of modern radiology. They allow us to send and receive medical imaging information around the world. With the development of computers and their application in radiology, new challenges have been created, and one of them is cyber security [1]. In recent years, hackers have been able to compromise most medical devices, from infusion pumps to X-ray machines. In the fall of 2013, the Mayo Clinic hired a group of hackers to try to modify 40 different medical devices. After several weeks of looking for security flaws, vulnerabilities were found in all devices, including MRI and ultrasound [2]. Most recent problem is ransomware, which is designed to encrypt data and request ransom. According to a report by the U.S. Department of Justice, in 2016, there were 4,000 such attacks, which is four times more than the year before. The healthcare sector accounts for about 15% of such attacks, which is not negligible, and this type of attack, according to statistics from 2017, accounted for 50% of cyber incidents in hospitals [3].

Cyber-attacks on hospital systems have become more popular today. While such attacks were once widespread and random, today they are oriented towards a specific sector in healthcare, depending on the needs and interests of the groups behind them. Radiological devices are targets because they are an essential part of every healthcare facility, and their infrastructure creates many opportunities for cyber-attacks.

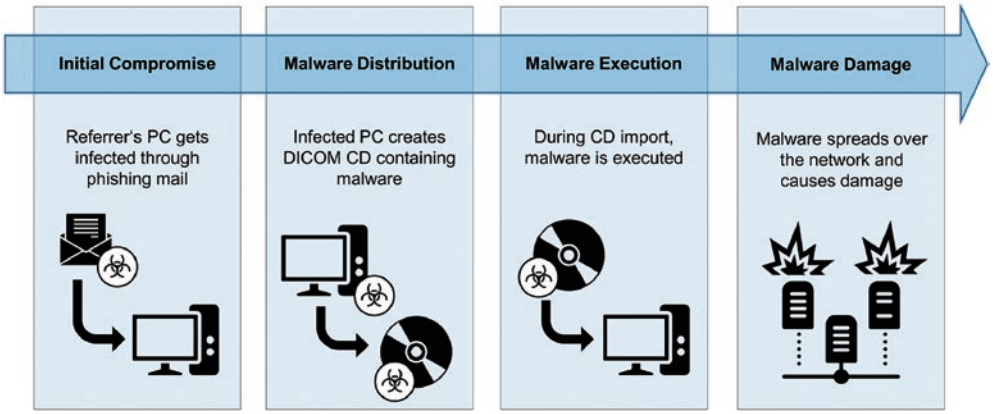


Figure 1. Entering malware from removable media
Source: https://www.sciencedirect.com/science/article/pii/S1076633220301719

Aim of the work

The aim of this review thesis is to show that cyber-attacks on radiological systems are not just occasional harmless incidents but a real threat. Presentations on theory of attacking systems, defense techniques and the application of data recovery can be useful in the daily work of the radiology department. Experience and advice from other radiology departments and hospitals around the world can help prevent repeating the same mistake. Examples of attacks from around the world should motivate us to increase attention to cyber security in radiology.

Discussion

Reason and methods

A negative side effect of wide Internet is the increase in cybersecurity incidents, such as computer viruses, *ransomware* (demanding a ransom to regain access to data) or the theft of patient data. While in the past, cyberattacks were most often caused by curious amateurs, today they are mostly work of organized crime groups. Accordingly, attacks on hospitals are no longer random, but increasingly focus on hospital systems that are becoming primary target.

The most common reasons are: stealing data for financial gain (ransom, selling data or scams), state-level espionage, gaining access to radiological data (political, economic or military purposes) and sabotage (blocking or influencing medical procedures).

Entering patient data from a removable medium

Patients bring their data on storage media to the hospital facility and their media can contain malware. Most systems that burn DICOM CDs add viewer that runs on standard Windows systems which have autorun function included. Malware from the first computer, via DICOM CD, can be copied to the second computer without the need for user action. (Figure 1). It can intercept Internet traffic and send the usernames and passwords to the attacker's device and spread further. [5]. Sometimes an attacker deliberately leaves a USB, external hard drive or CD in the parking lot of hospital expecting that some conscientious employee will find it and connect it to the hospital computer [6]. In an experiment by the US Department of Homeland Security, 60% of their employees who found a device in the parking lot, tried to check the owner at the workplace. If there was an institution label on the same medium, success was 90% [7].

Network Attack

Network attack is when a hacker manages to gain access to a hospital's network system. The first option is access to

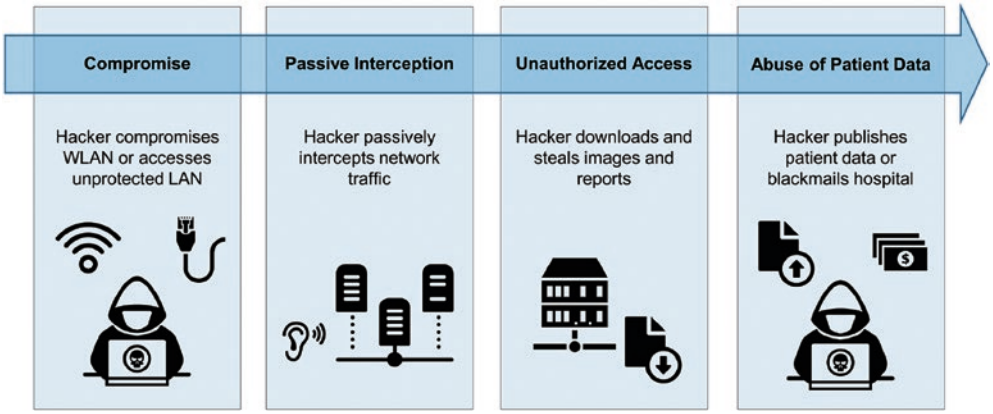


Figure 2. Network Access in a Cyber Attack
Source: https://www.sciencedirect.com/science/article/pii/S1076633220301719

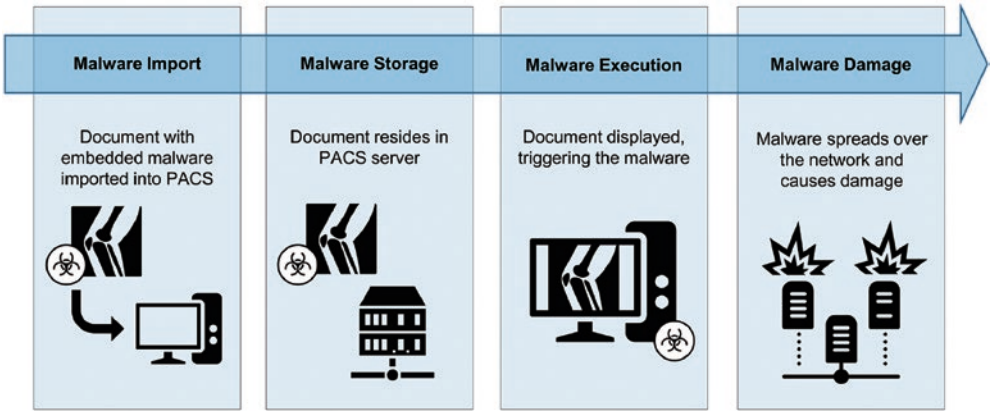


Figure 3. Malware cloaking and DICOM format
Source: https://www.sciencedirect.com/science/article/pii/S1076633220301719

an unprotected network connection via cable. The second is when he manages to decrypt the password for wireless access (Figure 2). Over time, weaknesses in all wireless network protection mechanisms have been discovered, from the original WEP to WPA2, which is used today. [8]. The final stage is downloading images and patient reports.

A new method of attacking the network is the use of drones. This allows the attacker to access any hospital network within 10 meters distance [9]. In two experiments, drones were guided to hard-to-reach places above hospitals and managed to connect. Drones initially use the logout method, where users are forced to disconnect from the hospital network and then set new fake access. [10].

Malware in DICOM format

Malware can be injected into DICOM files where it can operate in the PACS behind the firewall. Malware inserted into a DICOM image or report will not activate on the user device but on the workstation or server. (Figure 3). When activated, it can access the entire PACS archive. There are three main ways to inject malware into the DICOM format [5].

File format in the first 128 *bytes* contains nothing of the DICOM standard but arbitrary information. This can be a place for malware insertion. [5]. Today's DICOM standard supports adding other file types to a DICOM file which have their own security holes. DICOM can be compressed, so attacker can create a file that, when unpacked, will run a malicious script [11].

Interception of communication

Hacker installs small computer into the connection between the radiological device itself (e.g. CT, MRI...) and the workstation, server or network in general (Figure 4). It is also called *a man-in-the-middle* attack. This requires physical access [5]. It can change data packets, display false displays on screens and take full control [2].



Figure 4. Man-in-the-middle attack
Source: https://www.veracode.com/security/man-middle-attack

Network Infiltration with Wrong HL7 Messages

By passively monitoring HL7 data over the network, the attacker can obtain patient data. (Figure 5). In the same way, it can add or modify existing HL7 messages. [5].

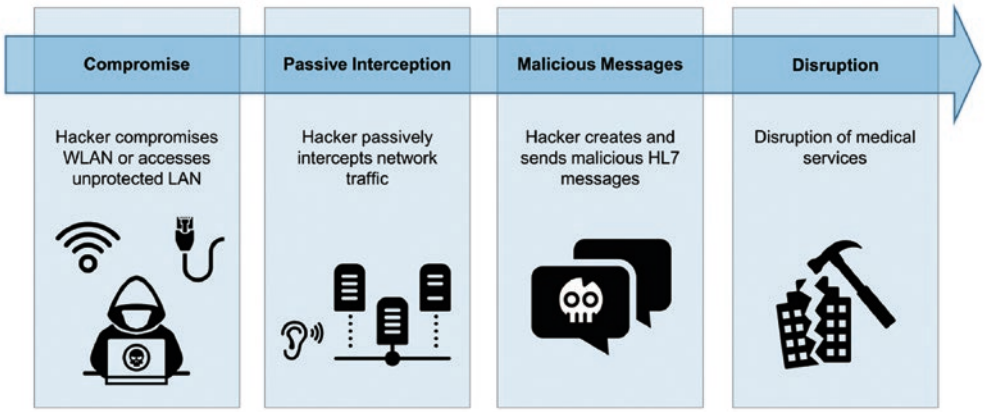


Figure 5. Inserting Wrong HL7 Messages
Source: https://www.sciencedirect.com/science/article/pii/S1076633220301719

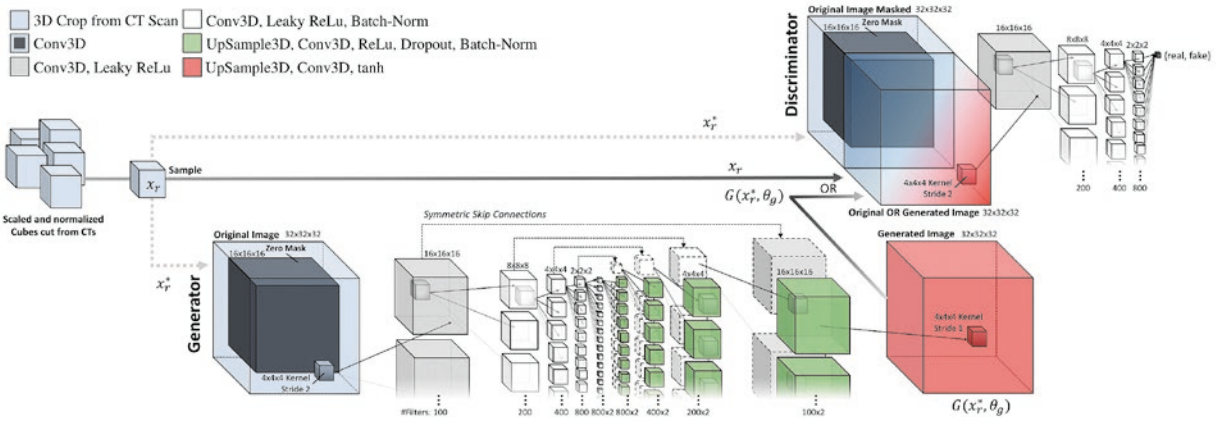


Figure 6. Rewriting CT Scans

Source: https://www.researchgate.net/publication/330357848_CT-GAN_Malicious_Tampering_of_3D_Medical_Imagery_using_Deep_Learning

Types of attack

Cyberattacks can target radiological systems at three levels. Primary infiltration that has a direct impact on hospital patients. Indirect influence is considered secondary. Tertiary infiltration refers to an attack on infrastructure such as power supplies or networks [12].

A potential attacker first tries to access the hospital network or equipment, then he evaluates what information and possibilities he has and compares them with intentions. The peak of an attack is when the attacker succeeds in his intention [13].

Actions in the last step can be divided into active (adjusting or stopping operation, and intercepting/changing data collected through radiological devices) and passive (accessing and collecting medical imaging records). [9].

Denial-of-service

An attack that aims to block all computers connected to a network and disable their communication by overflow is called a Distributed Denial-Of-Service (DDoS) attack. [14]. DDoS attack can send a large number of DICOM messages to overflow the server or send corrupted DICOM files to cause system crash [15].

Malware – an unauthorized program inserted into a computer

Malware (malicious software) can be any program that has a malicious purpose, such as causing a malfunction, disabling or limiting the control of the rightful owner and gaining control by the attacker [16].

According to the 2017 NTT Data ("2017 Global Threat Intelligence Report"), in the total number of *ransomware* attacks in all branches of the economy, healthcare organizations accounted for 15%, while in healthcare itself, *ransomware* accounted for 50% of incidents [17].

Cryptographic attack

A cryptographic attack is revealing data that has been hidden or decrypt information that is not intended for third parties [13]. Cryptography is the process of encrypting and decrypting information that only the sender and receiver can understand [18]. In radiology, there is a possibility of altering CT or MRI images. Adding or subtracting evidence of illness from medical images can stop a political candidate, sabotage research, commit insurance fraud, or even murder [20]. As insurance fraud, individuals can make personal gain based on falsified findings. Intention is getting undeserved benefits: life insurance, faking accident, incapacity to work or profit from insurance. In targeted attacks, a patient can be lured into a diagnostic examination by adding an appointment to the hospital system, faking a call for national screening or hacking routine laboratory tests. [20].

For the process to be successful and anatomically realistic, the following steps are followed (Figure 6). [19]:

1. Determining the location on the CT/MRI data where evidence should be added or removed
2. Cut out the "cube" from that position
3. Adding/removing the desired object (disease sign)
4. Fixing a modified "cube" with artificial intelligence
5. Checking the cube measurements
6. Inserting modified cube back to the CT/MRI data

Researchers from Israeli universities from the Department of Information Systems Engineering (Ben-Gurin University and Soroka University Hospital Center, Beer-Sheva) have published several papers on this topic. In this study, they hired three radiologists and used artificial intelligence to review CT scans and determine the diagnosis (Figure 7). [19].

As images, 70 computer-altered images were used in which signs of lung cancer were added or deleted, and 30 unchanged. Radiologists diagnosed lung cancer on 99% of subsequently altered images. On CT scans where signs of disease were removed by computer, 94% of them were declared healthy by radiologists. After the researchers introduced the radiologists to them, they repeated the examination. In this round, they incorrectly diagnosed 60% of the data with added signs of illness, and 87% with those removed. Also, after they used modern artificial intelligence for the automated *screening* method, they had a 100% error with the subsequently altered images, which

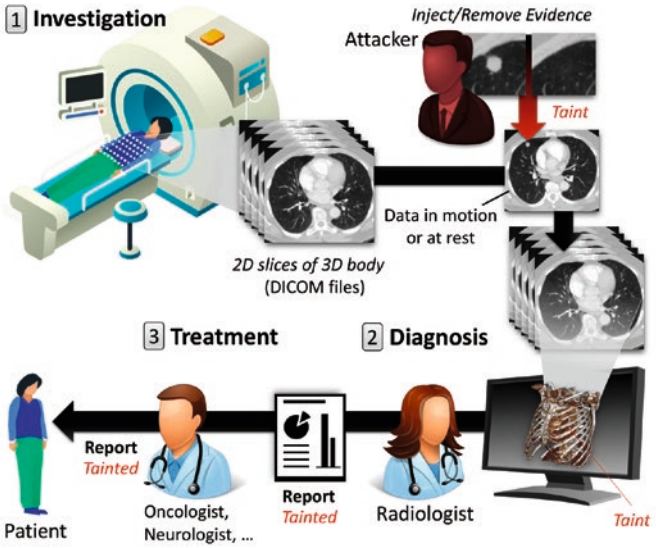


Figure 7. Modification procedure on CT scans
Source: https://www.researchgate.net/publication/330357848_CT-GAN_Malicious_Tampering_of_3D_Medical_Imagery_using_Deep_Learning

proves that it is very unreliable in these types of attacks (19).

Changes to device settings

Devices in radiology such as CT, MRI and radiotherapy accelerators, can be used to injure a patient by using their imaging methods. A documented incident from 1985 shows that similar scenarios are possible. Therac-25 was a radiotherapy device that had a defective safety switch which did not interrupt radiation on time. This was not a cyber attack, but it shows potential risk of changing settings. Today there are potential hazards with any radiological (and radiotherapy) device, especially now when all devices are networked [21]. Manipulation in contrast media injectors settings can change the amount of contrast given to the patient, reduce diagnostic value of examination or cause side effects with excessive doses and damage injector [20]. Radiological devices use multiple components with electric motors. By changing the settings on the control unit computer, an attacker can make unwanted movements in order to cause a collision and damage the device or injure the patient [20].

Specific parameters in diagnostic CT scans are mAs and kV. If these parameters are higher than supposed, it can cause radiation injuries. By changing CT settings, an attacker can influence the behavior of device and affect the imaging process or damage device. If calibration values are changed, device can be forced to use wrong parameters [20].

Changes in the configuration files of MRI device may produce a stronger magnetic field than intended which can damage the receiving coil. This may also include interference with the radio frequency signal that can cause damage to the device and burns in patients [21]. Another option is to falsely activate the magnet's rapid cooling ("*quenching*") security system, which is used if a fire or gas leak occurs. If there was no need for such a procedure, suffocation, hypothermia or rupture of the patient's eardrum may occur. Furthermore, it can damage the device [21].

DEFENSE OF RADIOLOGICAL SYSTEMS AGAINST CYBER ATTACKS

Securing communication by e-mail

In one study of invitations to radiology congresses and conferences, 73.3% of the 45 radiologist participants received invitations to participate in some way over a period of 2 weeks, but 96% of them were not related to their specialty at all [22].

Endpoints in radiological systems

The problem with larger devices such as CT or MRI that use their own workstations, so it is recommended to protect such systems through a firewall [4]. Some devices and workstations also use physical protection, to prevent connection (USB, network cable). This method of defense is useful if a potential attack is planned using the "man-in-the-middle" technique [24].

Organization of access

Radiology departments must identify all users and monitor their access to data, applications, systems and devices so it can restrict their access and activities if needed. [25]. Employees must work under their account and log out when done. This becomes an additional security of the PACS system [4].

Organization of the network

A successful method of maintaining network security is the use of firewall. In radiology, they play a fundamental role in security.

Another method of *cyber*-attacks security is segmentation into smaller ones. (Figure 8). These zones are di-

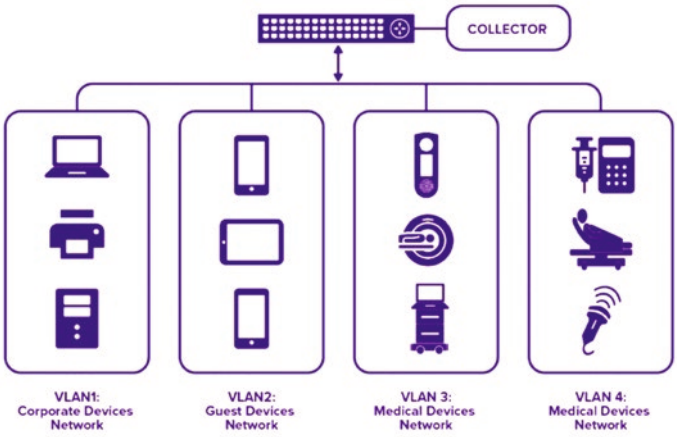


Figure 8. An example of the division of a network of radiological devices and other hospital networks
Source: https://www.armis.com/blog/healthcare-network-segmentation-bridging-the-nac-gap/

vided according to value of data [23]. Each segment is set up as an isolated part of the network. If all devices were connected, an attacker who gains access to one point can access all other devices on that network [26]. Web *proxy* systems provide important protection against *malware* attacks on radiological workstations. Most *malware* and *phishing* attacks are web-based, so they block access to known malicious sites (23). Some cyber-attacks require physical access to network devices so servers and routers should be located in safe places. Network cable paths between the server room and the radiology department can also be weak spot [23].

Data protection with DICOM encryption

DICOM can use advanced encryption algorithms AES or RSA to encrypt data. AES is a standard for DICOM encryption, it uses a symmetric algorithm with the same key for encryption and decryption. AES is used to encrypt current DICOM data due to its efficiency and speed, while RSA is more used for the secure data in transfer.

Cyber-attack response and recovery

The radiology department should detect attacks that bypassed security obstacles and responding against them and have guidelines for incident response (Figure 9). (23). According to research [27], Ransomware Cyber Attacks on radiological systems can be divided into four phases.

The earliest sign is that several IT systems within the radiology department are inaccessible. This causes the inability to access patient data in PACS or RIS. Networks must be disabled to prevent major damage and focus on patient safety and preventing further harm. The second phase begins with a sufficient amount of damage data in the radiology department. In phase three, attention is on network repair, and not on radiological procedures. Backing up to another network or unconnected server is the best option [28]. Antimalware programs probably can't identify all malware so entire system should be restored on software-clean devices.

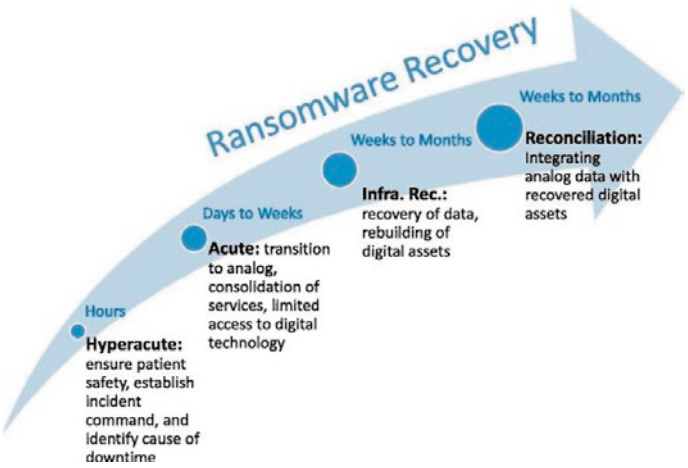


Figure 9. View cyber attack recovery timelines. The times required for the phases depend on the size, complexity and preparation of the radiology department
Source: https://pubmed.ncbi.nlm.nih.gov/34159418/

The first three phases focus on ensuring the continuation of work and providing safe care for the patient. The last phase is connecting data that has not been entered into the digital radiology. The success of this phase is highly dependent on the good organization of data collection from previous phases. *Cyberattacks* are unlikely to decrease over time so cybersecurity must be included in standard plans and budgets [27].

Attacks on radiological systems in the world

Orangeworm (Kwampiris)

In January 2015, the Orangeworm cyber group was discovered. Their malware, called Kwampirs, was found on the systems of large healthcare corporations in America, Asia and Europe. Kwampirs have been found on medical devices in radiology, such as X-rays and MRI. The problem was with devices that used older operating systems and were rarely upgraded. It could also be disguised in image records (Figure 10). For such outdated systems, all security vulnerabilities are well described, which makes them easy target (42, 43).

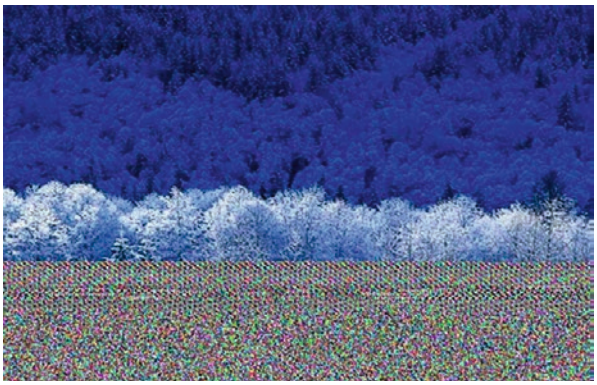


Figure 10. An example of an image that contains Kwampir, looks like an error in the image, but in fact it is a malware installation that thus avoids antivirus programs
Source: https://resources.cylera.com/hubfs/Cylera%20Labs/Cylera%20Labs%20Kwampirs%20Shamoon%20Technical%20Report.pdf

Kwampirs first analyzes the radiological device and sends the data to the authors only if it meets certain requirements. Interesting data are image records, details about the device and the computer network. It spreads further altering its record in the system to avoid security programs. It also allows remote control of radiological devices. It usually has no symptoms of infection [29].

Petya and NonPetya

Petya is a type of malware that appeared in 2016. It locks files and folders demand a ransom to retrieve them. Unlike previous types of malwares, Petya blocks the user's entire hard drive by blocking the file list and works only on Windows operating system. It spreads through e-mail messages as attachment or link. In 2017, NotPetya appeared. It encrypts the entire hard drive with all the data (Figure 11). It spreads rapidly because it does not require user activity.

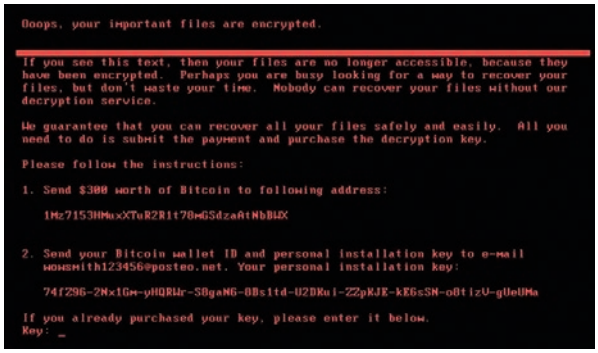


Figure 11. Screenshot after NotPetya malware attack
Source: https://www.forbes.com/sites/thomasbrewster/2017/06/27/petya-notpetya-ransomware-is-more-powerful-than-wannacry/?sh=6eb2317f532e

The original purpose was to attack various global corporations, but it also spread to hospital systems on all continents. The damage was only caused on computers using the Windows platform, while Linux systems were spared. For example, the Heritage Valley Health System (Pennsylvania, USA) states in a report that their radiology devices such as X-rays, CT scans or MRIs had no problems. The problem were workstations that saved MRI images and runs on Windows. Another hospital could not access preoperative radiological images of patients so surgical procedures had to be postponed [30].

Ryuk Ransomware

The Ryuk *ransomware* first appeared in 2018 when it crashed the computer systems of many institutions such as schools, businesses, government institutions and medical centers. It targets high-value data, encrypts them, and demands a ransom to regain access. It spreads through e-mails with fake Microsoft Office Word documents. Opening documents triggers *malware* that allows attackers to take control of computer by getting administrator accounts [31].

In 2020, it disabled more than 250 centers of the largest private health care provider, Universal Health Services, and the recovery cost about $65 million. In a statement, they stated that they do not have access to patient data, as well as CT or X-ray images [32].

In 2021, Ryuk attacked OrthoVirginia, the largest provider of orthopedic medicine and therapy services in the state of Virginia, USA. It encrypted PACS, which contained medical X-ray records crucial for orthopedic surgery. They saved some data by shutting down servers, and in the end, they claim that they did not even pay the ransom [33].

Wannacry

The global WannaCry ransomware attack began on May 12, 2017, on several continents and organizations. One of the biggest casualties was the English National Health Service. About 600 facilities were affected, of which 34 hospitals were completely left without medical devices. Indirectly, 46 hospitals were affected, but with difficulty [34]. The authors responsible for the attack took advantage of a security flaw in the Windows operating system called EternalBlue. Microsoft released the security patch almost two months before the WannaCry attack, but organizations did not update systems [35].

Major manufacturers of interventional and diagnostic radiological equipment, BD (Becton, Dickinson and Company) and Siemens have issued recommendations to users of their equipment and patches. Siemens provided guidance for 6 groups of its products which included CT and MRI machines [36]. One of the devices affected was Bayer contrast injector (Figure 12), which is used in radiology [37].

Despite its global spread, WannaCry has been slowed down by accident. Within its code, a link to a website was found. The malware only spreads if it could not connect to the specified URL. With the purchase of the domain, the "kill-switch" was activated. This did not stop the malware on devices where were already installed [38].

Conti Ransomware

The Conti Group is one of the largest and most active cybercriminal groups. Their first versions of *malware* appeared in early 2020. In 2021, the Irish health system had to temporarily shut down network due to the Conti attack. This caused problems for the entire healthcare infrastructure. Conti admitted that he had access to the network for

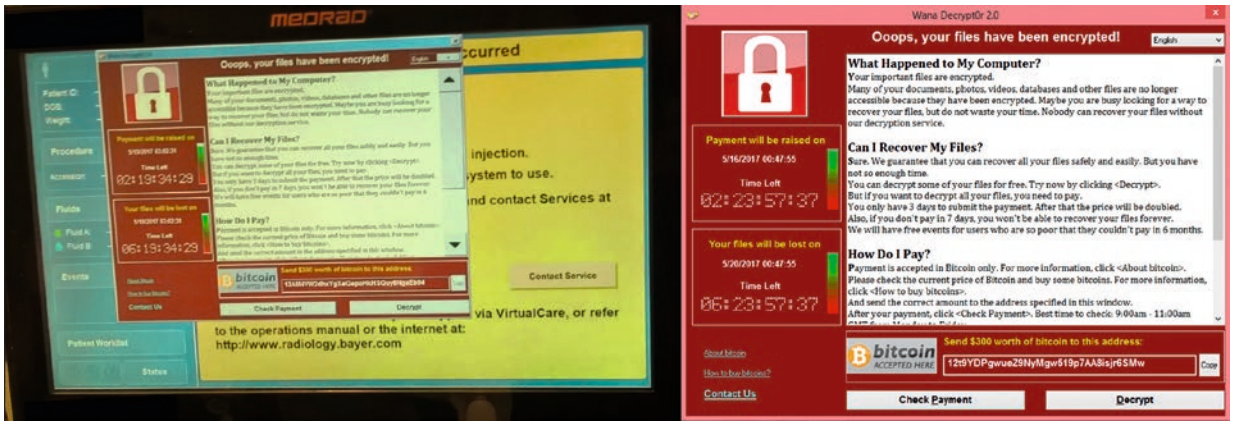


Figure 12. Screenshot from the affected Bayer injector (left), screenshot of the message itself on another device (right)
Source: https://www.forbes.com/sites/thomasbrewster/2017/08/03/wannacry-hackers-use-shapeshift-to-launder-bitcoin/?sh=220060323d0d
https://www.theverge.com/2019/4/4/18293817/cybersecurity-hospitals-health-care-scan-simulation

2 weeks, in which they downloaded 700 GB of data and demanded almost $20 million for ransom [39].

In a report published in the Irish Medical Journal entitled "The Impact of the Cyberattack on Radiology Systems in Ireland", they state that for security reasons they turned off the national medical imaging storage system after the attack, which affected the availability of radiology services nationwide. Radiological examinations were taken on the devices themselves and all communication was done via personal phones. Recovery from the damage cost about 100 million euros, while legal costs were not disclosed. About 113,000 private data of patients and employees were stolen (56.57).

BianLian Ransomware

BianLian is a *ransomware* criminal *cyber* group that has been targeting critical infrastructures of the U.S. organization since 2022. The group gained access to the victims network through remote computer management. They demanded financial compensation by extortion, threatening to publish the data if not paid [40].

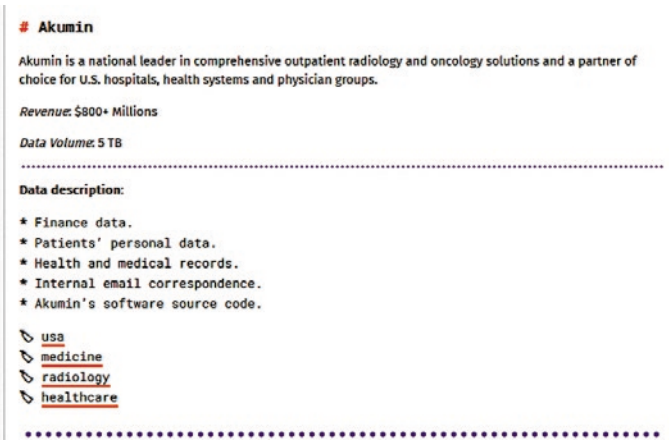


Figure 13. Publication of the BianLian Group on their website where they showed the quantity and what data they downloaded
Source: https://twitter.com/H4ckManac/status/1731992794137338295

In September 2023. BianLian attacked Akumin, Florida's second-largest health care company that provides radiology and oncology health services to about 1,000 hospitals in 48 U.S. states. The first signs of the attack appeared on 11.10.2023 and preventively shut down radiology centers in 50 places. According to the investigation, the attackers were able to gain access to servers with the personal data of patients [41].

They collected about 5 TB of medical records, imaging data of diagnostic procedures and copies of passports (Figure 13).

At the beginning of December, they were attacked again by the same *cyber* group [42]. This time, the data was not encrypted, but only downloaded, and the attack caused a 2-week interruption in the work of the Department of Nuclear Medicine and Diagnostic Radiology [43].



Figure 14. BrianLian's Statement on Her Attack on St. Rose Hospital
Source: https://thecyberexpress.com/bianlian-ransomware-st-rose-hospital-as-victim/

St. Rose Hospital in California was also the victim of the attack. According to their own claims, they had access to 1.7 TB of data to staff and patients. (Figure 14).

They downloaded 195 GB of data and claimed that they would publish it publicly [44].

Conclusion

Cyber-attacks on radiological systems are not receiving proper attention, which can be seen from the availability of literature and articles. A large number of papers were created after an attack, and the authors documented and analyzed cases after the damage had already been done. This leads to the conclusion that it is not interesting until it becomes a problem and it is too late. Worldwide there are more and more examples of financial allocations for the recovery of the system, payments of ransoms and compensation to patients who did not receive the required radiological diagnostic test on time or whose medical data became public. It is important that every employee of the radiology department is familiar with the basics of cyber security. That means recognizing the symptoms of malware and learning protocols for defense. It is the responsibility of IT service to update all computer systems on time, and the authorized healthcare manufactures their devices.

When the radiology department stops working, it has a devastating impact on the entire hospital system, from emergency admission to postponement of surgeries and other treatments. By paying more attention to attacks on radiological systems and cyber security in radiology, we can prevent or at least reduce their impact on the operation of health systems, show care and prevent harm to patients.

Cyber napadi na radiološke sustave

Sažetak:

Napretkom digitalnih tehnika snimanja (digitalni receptori slike, CT, MR) računala, računalni programi, računalne mreže i digitalne baze podataka su postali jedan od temelja suvremen radiologije. Radiološki odjel ima specifičan način rada te postoje standardi kao što su DICOM za medicinske slikovne zapise, PACS za arhiviranje i komunikaciju te HL7 za razmjenu informacija medicinskom sustavu. Kako radiologija postaje ekonomski zanimljiva grana, postaje meta za cyber napade. Ujedno, radiološki sustavi sadrže mnogo osobnih podataka koji mogu biti interesantni pojedincima. Razlozi za napade su često ostvarivanje financijske koristi, ali mogu biti i politički, ideološki ili osobni. Početak napada može biti fizički pristup radiološkim uređajima ili mrežni pristup, i same DICOM datoteke mogu biti početak napada. Napade dijelimo na one koji izravno utječu na pacijente i one koji imaju utjecaj na samu infrastrukturu. Najpoznatije vrste su denial-of-service, malware, kriptografički napadi i promjene na postavkama uređaja. Kod obrane od cyber napada bitno je osiguranje komunikacije elektroničkom poštom jer je česta kod malware napada a na računalima i uređajima održavati programe ažuriranima prema uputama proizvođača, osobito antivirusne i firewall programe. Informatička služba radiološkog odjela treba paziti na račune svih korisnika i provjeravati ovlasti sukladno radnim mjestima kako ne bi došlo do zlouporabe. Mreže moraju imati ograničenja pristupa te podijeljena prema radilištima i namjeni kako bi se otežali neželjeni pristupi. Web proxy zaštita ograničava pristup Internet lokacijama koje su potencijalno opasne. Osnove mreže odjela kao što su serveri potrebno je i fizički osigurati od pristupa, najbolje prostorijom koja se zaključava a nalazi se pod video nadzorom i alarmom. DICOM datoteke trebaju biti enkriptirane najsigurnijim dostupnim algoritmima. Kao odgovor na cyber napade potrebno je imati dogovorene postupke i takav sustav mora uvijek biti spreman. Poznati napadi na radiološke sustave su Kwampiris, Petja/NotPetya, Ryuk, Wannacry, Conti skupina i BianLian.

Ključne riječi: Cybernapadi, radiološki sustavi, sigurnost mreža

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REVIEW PAPER (PREGLEDNI RAD)

SWOT analysis of the application of artificial intelligence in radiologic technology and radiology

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Abstract

Artificial intelligence (AI) is bringing changes to radiology and radiologic technology, enabling the development of programs and algorithms that facilitate diagnosis and decisions. It is essential to understand how AI can improve patient outcomes, increase the efficiency of investigations and reduce costs. Machine and deep learning have proven to be extremely useful in the detection and characterization of lesions, improving routine imaging techniques and facilitating the work of radiologists by reducing workload and improving the quality of reporting. The practical application of artificial intelligence in radiology and radiologic technology has been slowed down by the lack of integrated solutions and well-structured data archives, as well as challenges such as non-transparency of decision-making systems and large amounts of quality data needed to train artificial intelligence models. There are concerns about the potential impact of AI on the work of radiologists and radiologic technologists, which may hinder the development and implementation of this technology. Textual data derived from image reports can provide valuable healthcare insights. Natural language processing (NLP), a subset of artificial intelligence, offers promising solutions for handling unstructured text in these reports, opening a new era in extracting information from medical images and related reports. Due to the challenges in training experts for the application of AI in healthcare, a multidisciplinary approach will have to be used and investments in collaboration and education will have to be made. There are outstanding issues of liability and regulation regarding data storage and privacy, particularly in the case of cloud storage. The concern of the workforce and their lack of education about artificial intelligence represents an obstacle to its adoption, but also offers an opportunity for the technological advancement of the profession.

Keywords: AI; radiologic technology; radiology; SWOT

Abbreviations and acronyms: AI (Artificial intelligence), CAD (Computer-Aided Diagnosis), CDS (Clinical Decision Support), CNN (Convolutional Neural Networks), CT (Computed Tomography), DL (Deep learning), GAN (Generative Adversarial Network), FDA (Food and Drug Administration), ML (Machine Learning), NLP (Natural Language Processing)

Introduction

History and evolution

The development of programmable digital computers in the 1940s sparked curiosity among mathematicians and philosophers about the capabilities of machines and their potential to mimic human functions. The concept of artificial intelligence (AI) was first introduced by John McCarthy of Dartmouth College in 1956 [1], defining it as any machine that exhibits intelligent behavior similar to humans. AI, in its broadest sense, involves advancements in computing hardware and software that leverage information to solve complex problems, generate solutions, and create new knowledge through algorithms inspired by human cognitive functions. The field of AI has experienced highs and lows but is currently undergoing a renaissance due to the increasing power and affordability of parallel computing systems, enabling the creation of more advanced AI systems with multiple layers of analysis, known as deep learning [2]. Radiology, born from the discovery of X-rays, has always been at the forefront of technologi-

cal innovations. Radiologists eagerly adopted nuclear PET and SPECT, MRI, digital radiography, CT, ultrasound, and optical imaging as these advancements revolutionized medical imaging, thanks to breakthroughs in physics, engineering, and technical developments [3]. The automatic exposure device, introduced in the 1980s, was an early example of AI in radiography. It allowed radiographers to select the kV value and determined the optimal exposure by measuring the quantum quantity reaching the film. This technology improved efficiency and reduced radiation exposure, but human oversight was still crucial due to potential errors and technical variations. Despite its benefits, it highlighted the ongoing need for human expertise and supervision in radiology [4].

Thomas Kuhn, a renowned philosopher of science from Harvard University, introduced the concept of a "paradigm shift" in his influential book, "The Structure of Scientific Revolutions" [5]. He explained how scientific progress occurs within a set of accepted rules and assumptions (the paradigm) until a radical new idea or technology disrupts this paradigm, leading to a fundamental change in direction. The field of medical imaging has undergone significant paradigm shifts in the past, driven by innovations such as CT scanning, MRI, and digital imaging. These advancements have transformed radiology, enabling remote image viewing, digital storage, and the use of numerical values with clinical significance. The introduction of MRI in the 1980s brought another paradigm shift, offering new imaging protocols and a wealth of new information. The development of pulse sequences and imaging biomarkers expanded radiology's role from diagnosis to patient management. Since then, all imaging modalities have continued to evolve, with improvements in resolution, speed, and safety. However, there are practical limits to these advancements, imposed by safety, cost, physics, and technology. As we look to the future, AI is poised to bring about the next paradigm shift in medical imaging. With its extensive collection of digital images and history of embracing technological advancements, radiology is an ideal field for AI integration. While AI's impact will be felt across medicine, its use in radiology is likely to be particularly profound [3]. The vast amount of imaging data collected during routine medical procedures has led to the emergence and rapid growth of radiomics as a significant field of medical research. Radiomics involves extracting predefined engineered features from images, capturing radiographic characteristics such as shape, intensity, and texture, and combining them with clinical outcome data. More recently, deep learning techniques have been incorporated, enabling automatic feature representation learning from example images and highlighting the clinical relevance of many radiographic features [6].

Applications of AI in radiology

Artificial intelligence and its subset, machine learning (ML), are rapidly evolving fields that have transformed computer science (Figure 2). AI in radiology is versatile, with applications in image-based analysis, computer-aided diagnosis (CAD) tools, and medical image classification. ML and its subset, deep learning (DL) are techniques that mimic the human brain, enabling systems to learn from data and adjust their actions. Radiomics, an ML subfield, extracts valuable quantitative properties from images. The integration of AI and ML algorithms in radiology aims to enhance existing algorithms and develop new ones to streamline diagnosis and reduce manual intervention in time-consuming conventional imaging tasks. This evolution is driven by two key factors: advancements in computer sciences and the growing availability of well-organized medical databases, which facilitate effective management and analysis of complex "big data" [7].

AI encompasses a diverse range of algorithmic learning techniques, including machine learning (ML), deep learning (DL) as a branch of ML, and natural language processing (NLP). ML empowers computers to learn from data through supervised, unsupervised, semi-supervised, or reinforcement learning approaches. Because of its exceptional performance, DL is the preferred learning technique in medical imaging for tasks like image segmentation, classification, and object detection. NLP, on the other hand, empowers computers to interpret un-

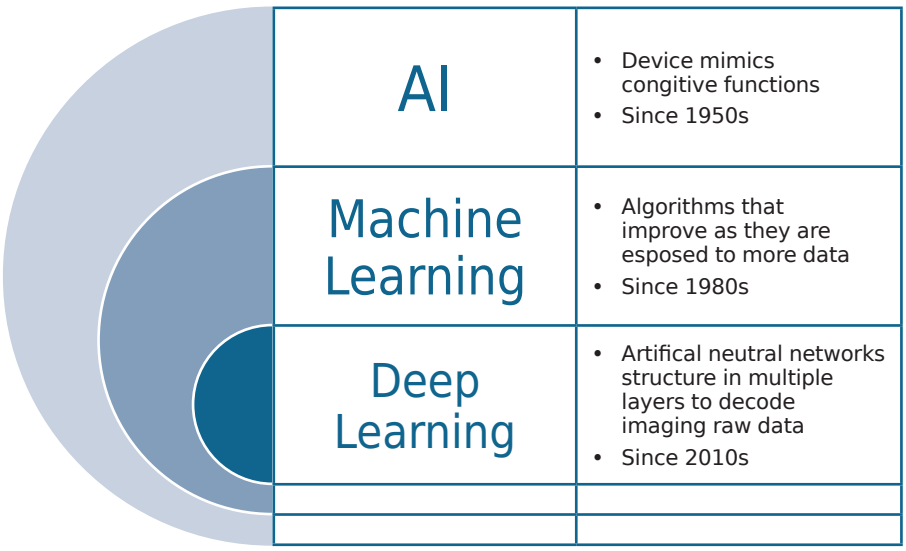


Figure 1. AI overview
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6199205/figure/Fig1/

structured text, including sensor data, by converting it into a structured format suitable for subsequent ML or DL processes [8]. The healthcare industry is shifting towards value-based care, emphasizing standards and guidelines for diagnostics and therapeutics. Clinical Decision Support (CDS) tools have become crucial for high-quality, cost-effective care in radiology and imaging-focused specialties. The American College of Radiology (ACR) and extensive literature endorse CDS. As a result, there is interest in leveraging AI to enhance CDS in clinical imaging, potentially leading to more structured reporting and a positive feedback loop where AI refines its performance over time using generated data [9]. CAD systems were initially developed to assist radiologists in detecting lesions, which is a fundamental aspect of radiology practice. They are an example of practical applications of image-based ML in radiology. These systems can automatically extract and classify specific image features. Tools like these also enable the classification and grading of lesions as malignant or benign by analyzing their morphological and physiological characteristics. Today, advanced segmentation techniques go beyond simple detection, providing valuable data extraction from medical images [7]. The field of AI has seen significant advancements with the emergence of deep learning algorithms, which have revolutionized the way we approach medical imaging. These algorithms eliminate the need for explicit feature definition, instead learning from data spaces. Convolutional Neural Networks (CNNs) have become the go-to choice in medical imaging due to their ability to extract complex features and map image inputs to desired endpoints. CNNs are composed of layers that process input images through convolution and pooling operations, followed by fully connected layers and an output layer for predictions. They are typically trained end-to-end using labeled data. Other architectures, such as autoencoders and GANs, excel in unsupervised learning tasks. The popularity of deep learning stems from its ability to automatically learn feature representations from data, enhancing informativeness and generalizability. Deep learning has the potential to revolutionize diagnosis and clinical care by providing more abstract and complex feature definitions. The advancements in deep learning algorithms hold great promise for improving healthcare outcomes, particularly in medical imaging [6]. As AI becomes integral to radiology practices it is essential for radiologists to develop a strong understanding of the concepts and workflows related to ML. To assess the potential impact of AI and ML in radiology, we can employ the SWOT (strengths, weaknesses, opportunities, and threats) model, a commonly used business strategy tool [7].

SWOT analysis is a strategic planning and strategic management technique used to identify Strengths, Weaknesses, Opportunities, and Threats related to business competition or project planning. It is intended to identify the internal and external factors that are favorable and unfavorable to achieving the objectives of the venture or project. By applying the SWOT model to the integration of AI in radiology and radiologic technology, we can gain valuable insights into the strengths, weaknesses, opportunities, and potential threats associated with this technological evolution [10].

Aim of the article

The aim of this article is to analyze the application of artificial intelligence in radiological technology and radiology using the SWOT model. Its development, current and future applications, as well as external and internal factors that can positively or negatively affect the application of this technology in the mentioned professions will be presented.

1.1. STRENGTH – Patient side

The main goal of early clinical AI research in imaging was to improve diagnostic accuracy, with recent studies demonstrating encouraging results and even human-level performance in AI-enabled computer-aided diagnosis. Beyond this core objective, AI can address practical issues in daily practice, such as optimizing worklists, pre-analyzing cases in high-volume settings to mitigate observer fatigue, extracting hidden information from images, and enhancing reconstructed image quality (Figure 2) [2].

AI excels in image-based diagnosis, detecting, segmenting, and classifying lesions. It can automatically identify anatomical landmarks and organs, improving scan times and reducing variability. Software for automatic organ segmentation and landmark detection is also showing promise, particularly in the spine, chest, and liver [7,11]. AI is being applied in various areas of oncology radiology and radiation treatment to improve accuracy, efficiency, and patient outcomes in cancer diagnosis and treatment. This includes early detection and characterization of cancers, assistance in radiation treatment planning, and continuous monitoring of treatment response, with appli-

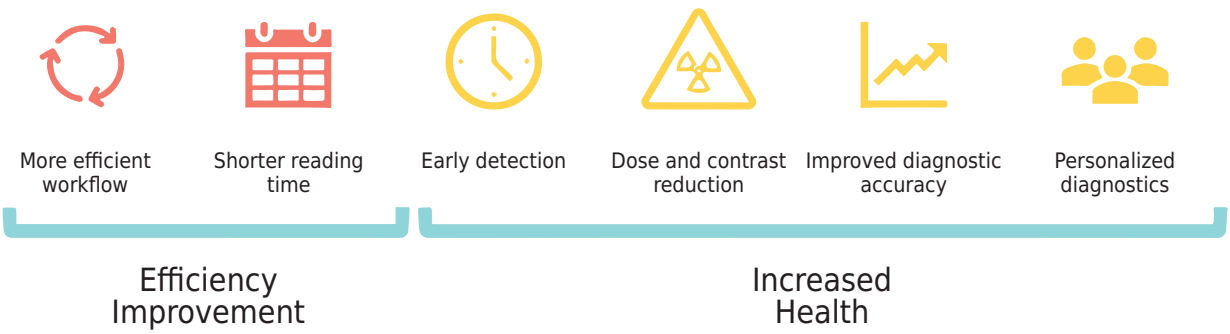


Figure 2. Possible improvements made possible by AI in healthcare
Source: https://link.springer.com/article/10.1007/s00247-021-05114-8/figures/1

cations in areas such as lung, colon, breast, and brain cancers, as well as incidental findings like liver lesions [6,12]. CNNs are well-suited for supervised diagnostic classification tasks, and studies have reported significant performance improvements in breast lesion and lung nodule classification using deep learning-based methods. Staging systems in oncology, such as the tumor-node-metastasis (TNM) system, rely on information from segmentation and diagnosis to classify patients into predefined categories, guiding treatment choices and predicting survival likelihood and prognosis. Deep learning is particularly suited for this multifaceted classification problem as it can learn joint data representations simultaneously [6]. In pediatrics, the automated bone age prediction is a well adopted AI solution aiding the quantification and reading efficiency of hand radiographs. The device could be used autonomously, potentially reducing the reading time to zero [13]. There is also a growing range of AI-driven methods for reducing radiation doses in mammography, CT scans, and PET/CT, as well as techniques for reducing MR scan times. These advancements offer the possibility of faster image acquisition and improved patient flow.

One of the most exciting aspects of AI-augmented image acquisition is its potential application in ultrasound examinations. Ultrasound image quality has traditionally been seen as highly dependent on the operator's skill and experience. However, with automated AI positioning and measurement tools, sonographers will be able to produce higher-quality ultrasound assessment reports with reduced error rates [14]. AI algorithms can enhance patient safety by suggesting appropriate imaging workups for each item on a problem list and identifying contraindications. This problem list-based approach could offer a "one-click" response with ranked, recommended examinations. AI tools will improve by extracting information from electronic health records (EHRs) more accurately, creating interconnected models of patient clinical problems, and assisting in decision-making by prioritizing acute issues. AI can also enable cohort-wide EHR monitoring, identifying high-value imaging opportunities and specific patient cohorts requiring further investigations, leading to earlier diagnoses and reduced low-value acquisitions, unnecessary procedures, and costly delays [9, 11].

Deep learning networks have also advanced radiomics, a field focused on extracting quantitative features from radiological images. Radiomics has the potential to provide valuable insights for predicting treatment responses, differentiating between benign and malignant tumors, and understanding cancer genetics across various cancer types by analyzing features such as intensity, shape, texture, and wavelength extracted from medical images [12, 15].

1.2. STRENGTH – Worker side

The application of ML techniques in radiology primarily focuses on image-based approaches. As the amount of detail and the number of images in radiological studies increase, radiologists may struggle to keep up with the workload. ML algorithms come into play by extracting information from images, aiding in lesion detection, and image segmentation, ultimately enhancing imaging reports with new data [7, 12]. The diagnostic process can be optimized with AI, improving the overall workflow. An example of this is already being used widely; AI software is now used to detect tuberculosis on chest radiographs. AI-supported tuberculosis detection has proven especially useful in developing countries, where staffing, expertise, and financial resources are often limited. This technology acts as an autonomous pre-screening tool, reducing the need for more time-consuming and costly microbiological tests [13]. AI can improve timeliness in urgent cases by automatically detecting life-threatening conditions and prioritizing them for immediate attention. It can also assist in addressing observer fatigue, especially in screening exams, by identifying cases with a high likelihood of true positives for early review [2]. The combination of AI and CDS improves the work of referrers and radiologists by increasing the appropriateness of ordered studies and enhancing the value of reports. AI technologies have the potential to revolutionize CDS by evolving today's scoring systems into advanced algorithms that consider the patient's comprehensive profile and the population receiving care. This combination has the potential to provide more structured guidance and automated data collection, improving workflow efficiency and patient care through data-driven decisions [9].

The field of radiology is shifting from a subjective skill to an objective science due to the increasing volume of imaging data. This change is necessary, as radiologists' work is currently limited by subjectivity, variability, and fatigue. AI can revolutionize radiology by automating routine tasks such as detection, characterization, and quantification, currently done manually by radiologists [15, 16].

AI applications may enhance the reproducibility of technical protocols, improving image quality and decreasing radiation dose, decreasing MRI scanner time and optimising staffing and CT/MRI scanner utilisation, thereby reducing costs [12]. With healthcare costs rising globally, it is crucial that we make efficient use of our limited resources. AI software could assist in scheduling imaging appointments and predicting no-shows even before the patient arrives at the radiology department. This predictive capability can be used for more efficient scheduling. Most of these solutions are not designed for patient detection or diagnosis, but rather for optimizing peripheral conditions like patient management. Consequently, they carry less risk and are subject to fewer regulations, making it easier to implement them in clinical practice [13]. AI can help streamline medical imaging guidelines by analyzing radiology referrals for CT and MRI scans, ensuring that the benefits outweigh the risks. AI can also aid in justification audits and real-time analysis, reducing radiation exposure and waitlist burdens. Additionally, DL techniques have been developed to synthesize contrast-enhanced CT images from non-contrast CT scans, potentially reducing the need for contrast media and minimizing risks associated with its use [17].

2.1. WEAKNESS – Standards and black boxes

The practical application of ML in radiology is hindered by several factors, including the lack of integrated solutions from industry vendors and well-structured archives of clinical data. Retrospective data usage is limited due to the predominance of free-text imaging reports, which

are not easily usable for AI algorithm training. External limitations include the need for advanced storage systems to handle the large volumes of data required by DL algorithms. Additionally, there is a lack of clear multidisciplinary road maps and standardization for ML implementation in imaging societies, requiring a clear definition of the radiologist's and radiologic technologist's role in this evolving landscape [7].

In a review from 2021, reseachers wanted to map the current landscape of commercially available artificial intelligence (AI) software for radiology and review the availability of their scientific evidence. The overview included 100 CE-marked AI products from 54 different vendors. For 64/100 products, there was no peer-reviewed evidence of its efficacy. There was a large heterogeneity in deployment methods, pricing models, and regulatory classes. The evidence of the remaining 36/100 products comprised 237 papers that predominantly (65%) focused on diagnostic accuracy. From the 100 products, only 18/100 AI products have demonstrated (potential) clinical impact [8]. Establishing standards and infrastructure, as well as creating a categorical model to understand the value of AI in clinical and research settings, are key to advancing AI in imaging. Developing image-sharing networks, reference datasets, standardized protocols, and a common language for AI applications would greatly benefit AI imaging research. Quality control, data integrity, curation standards, and informatics systems are important considerations [2, 18]. While ML techniques have the potential to revolutionize radiology, their wider implementation is hindered by several internal challenges. A major concern is the opacity of ML systems, often termed "black box" systems. This opacity makes it difficult for radiologists to trust and comprehend the decision-making process of the algorithms. It raises ethical and legal concerns and is a significant factor in radiologists' reluctance to adopt ML systems [7].

The transition from rule-based programs to data-driven learning paradigms has sparked discussions about interpretability and transparency. Despite the successes of deep learning, there remains a lack of comprehensive theoretical understanding, hence the term "hidden layers" for the layers between inputs and outputs. Identifying the specific image features that contribute to a prediction is largely speculative, making the decision-making process obscure. This lack of transparency makes it challenging to anticipate failures, address generalization issues, or explain the logic behind specific conclusions [6, 11, 17].

2.2. WEAKNESS – Quality of datasets

AI is only as good as the data used to train it and AI programs require vast amounts of data for effective training, but limited access due to institutional barriers and proprietary interests can result in insufficient training sets, leading to potential overfitting and reduced accuracy or generalizability. The ability of AI to handle diverse patient populations and variations in image acquisition protocols is also uncertain, which may introduce errors and affect the accuracy of results [2, 17]. ML algorithms depend on quality training data, but generating labeled data is costly and time-consuming. Unsupervised and semi-supervised ML algorithms are being developed to reduce this burden but are not as powerful yet.

Another challenge is the large volume of training data required by ML and DL algorithms, and the potential for overfitting if the model is not properly validated during training. This can lead to a model that performs poorly on new, unseen data. The development of advanced ML techniques and the need to process massive amounts of digital data have also led to increased hardware requirements, which can drive up costs [7].

Further research is required to validate the accuracy of deep learning-based reconstruction algorithms and their capacity to accurately replicate rare, unseen structures, as initial errors introduced during this stage can have detrimental consequences on patient outcomes [6]. A key limitation of current AI tools is their specialization in performing only one task. We have yet to create a comprehensive AI system capable of detecting multiple abnormalities across the entire human body. Data remains the most crucial element for training AI systems effectively. With a significant portion of population undergoing CT and MRI examinations annually, the volume of medical images generated is substantial. The implementation of advanced digital health systems, such as PACS, has facilitated the systematic organization and storage of these images. While large amounts of medical data are available, they are often uncurated, creating a significant challenge for AI model training. Curation, which involves selecting relevant patient cohorts and segmenting objects within images, ensures data quality and consistency. It is a time-consuming and expensive process that requires domain knowledge and expertise to ensure credibility. The volume of data needing curation, which deep learning methods are particularly susceptible to, further exacerbates this challenge [11, 12].

2.3. WEAKNESS – Job changes

Obermeyer and Emanuel [19], in an article for the New England Journal of Medicine, predict that machine learning will take over most of the work of radiologists and anatomic pathologists, and that machines will soon be more accurate than humans. Similarly, Chockley and Emanuel [20] argue in the JACR that machine learning will become a dominant force in the next decade and could potentially cause the decline of radiology as a specialty. Radiologic technologists and radiologists were at the forefront of the digital revolution in medicine. They were the first medical workers to embrace computer science and are now among the most digitally savvy healthcare professionals.

History has shown that radiologic technologists and radiologists have successfully incorporated seemingly disruptive technologies, such as non-X-ray-based modalities like ultrasound and MRI, into their practice. As a result, the definition of "radiology" has expanded to include radiation-free imaging modalities, encompassing almost all diagnostic medical imaging. Furthermore, electronic systems for reporting and archiving images were designed with radiologists in mind, reflecting their central role in healthcare [15]. While it is theoretically possible that the increased efficiency brought about by AI could reduce the number of radiologists needed, it is also possible that the opposite could occur, and the field may require more professionals. Historically, automation has not resulted in job loss but rather a reshaping of roles. The

efficiency gains provided by AI will enable radiologists to undertake more value-added tasks, such as integrating patient clinical and imaging information, having more professional interactions, becoming more visible to patients, and playing a vital role in integrated clinical teams. Thus, AI will not replace radiologists, but those who embrace AI will replace those who do not [12, 15, 16]. AI has the potential to revolutionize and greatly enhance the radiologic technologist's role in cross-sectional imaging. However, this level of automation also raises concerns about a potential reduction in radiologic technologists' responsibilities and roles. As healthcare organizations explore the benefits of AI technologies in improving radiology department efficiency, it is crucial to simultaneously address the associated risks and liabilities. Increased automation will lead to greater patient throughput and impact staffing requirements. With the continuous increase in demand for imaging, radiologic technologists will need to develop a range of competencies across different modalities and technologies. Given the expected importance of AI in future imaging approaches, radiologic technology graduates should possess the foundational skills to operate and oversee image acquisition across various imaging modalities [4,14].

3.1. OPPORTUNITY – New front

AI is expected to revolutionize image-based tasks in clinical radiology, including preprocessing, reporting, and diagnostics. One area where AI can make a significant impact is image reconstruction, as there is a growing gap between advancements in hardware and software. The first step in this process is reconstruction, which is an area where we see a growing disparity between advancements in image acquisition hardware and image reconstruction software. AI, particularly deep learning, can develop innovative methods to enhance image quality and reduce artifacts. For example, CT reconstruction algorithms have remained static for decades, and deep learning can provide alternative approaches [6]. Text-based data derived from imaging reports can be a valuable source of healthcare big data. Natural language processing (NLP), a subset of AI, has emerged as a promising solution to handle the unstructured text within these reports and extract valuable information. Advanced CT and MRI studies generate a lot of data, but the challenge is in generating labeled data. Transfer learning and data augmentation techniques are being used to reduce the need for extensive labeled data. GANs are also showing promise in generating large labeled datasets and enhancing image quality in low-dose CT scans. These NLP and ML approaches have the potential to revolutionize the handling and analysis of imaging data in radiology [7]. AI applications in healthcare open up new possibilities for extracting valuable information from images, advancing precision medicine. AI will play a pivotal role in discovering new imaging features to enhance the imaging phenotype, making it an indispensable tool in the pursuit of precision medicine [2, 12]. AI has a wide range of potential applications in radiology that could have an immediate positive impact. It can help prioritize reporting by automatically selecting urgent findings, compare current and previous examinations to save time, and quickly identify negative studies, especially in high-volume screening. AI can also aid in aggregating electronic medical records, automating recall and rescheduling of imaging follow-ups, and providing clinical decision support for ordering, interpreting, and managing patient care. Additionally, AI can assist in quality control, peer review, and resident training, as well as extract valuable insights from data, including radiation dose management [15].

Some potential application in radiologic technology that could have a positive impact include: AI-enabled devices are improving the quality of chest radiographs, such as GE's Critical Care Suite 2.0, which can detect issues like pneumothorax and prioritize critical studies. Philips' Radiology Smart Assistant provides real-time feedback to radiographers on image quality, improving departmental productivity and reducing radiation exposure [17]. Siemens Healthineers' YSIO X.pree system uses a 3D camera to speed up image acquisition and automatically detects the thorax, optimizing collimation and reducing radiation exposure. Modern CT scanners also use 3D cameras with deep learning to accurately position patients, reducing human error and improving image quality [17].

Deep learning algorithms can improve image quality and reduce radiation exposure in CT scans, and AI-based image reconstruction methods have reduced MRI scan times by up to 50% while maintaining image quality. Additionally, AI-enabled fluoroscopy systems can reduce radiation exposure by over 60% while maintaining high-quality images [17].

3.2. OPPORTUNITY- Multidisciplinary collaboration

Close collaboration between radiologists, AI developers, and industry partners is essential to drive innovation, create advanced AI tools that meet clinical needs, and ensure their safe and effective deployment [11, 16]. The upfront costs for AI, including investigator salaries, hardware, and software, are considerable. Nonetheless, forward-thinking departments and institutions will recognize the value of investing in these resources to support researchers and establish AI core laboratories accessible to all, similar to other core laboratory operations [2]. One challenge is the limited pool of investigators trained in radiology AI methods. However, this can be addressed by attracting AI specialists to the field of radiology and through educational initiatives already being pursued by radiology professional societies. Historically, important areas quickly attract capable individuals, so this is unlikely to remain a long-term problem. Practicing radiologists will need to familiarize themselves with AI but not necessarily become experts in AI research or program design to utilize AI-based outcomes effectively [2]. AI in radiology relies on human intelligence for tasks like creating training datasets and interpreting results. Radiologists' expertise is key to labeling data and identifying clinical applications where AI can make a meaningful impact. They can also interpret complex AI-generated data and link it to clinical utility [15].

Radiologists should recognize the value they bring to the table with these datasets and clinical knowledge and negotiate their role in guiding the clinical application of AI programs. This will involve increasing partnership with

bioengineers and computer scientists and embedding these professionals within radiological departments to foster everyday collaboration. Creating a "multidisciplinary AI team" will help ensure patient safety standards are met and judicial transparency is maintained, allowing legal liability to be assigned appropriately [12, 15].

4.1. THREAT – Legality, data, security concerns

Internationally, policy issues regarding the storage and custody of medical and imaging data, especially in cloud-based solutions, remain unresolved. Clear external regulatory policies are needed to define the responsibilities and duties of radiologists and ML systems, including data privacy and preservation. Inconsistent labeling of radiological data due to a lack of standardized agreements can also lead to reproducibility issues [7, 11].

Regulatory bodies like the FDA have overseen CAD systems using machine learning and pattern recognition for decades. However, the shift to deep learning presents new challenges and requires updated guidance in the approval process. Deep learning methods continue to evolve after market release as they process and learn from increasing data, making it crucial to address the implications of lifelong learning. One possible solution is to conduct periodic testing to ensure performance aligns with projections. There are ongoing discussions about whether regulatory entities have the right to question AI frameworks about their mathematical reasoning. This is challenging with deep learning, which has opaque inner workings. Despite this, the FDA has approved high-performance software solutions with unknown mechanisms of action, similar to some approved drugs [6]. Another issue that needs to be faced are the legal implications of AI systems in healthcare. As soon as AI systems start making autonomous decisions about diagnoses and prognosis, and stop being only a support tool, a problem arises as to whether, when something 'goes wrong' following a clinical decision made by an AI application, the reader (namely, the radiologist) or the device itself or its designer/builder is to be considered at fault. It is probable that a multidisciplinary AI team will take responsibility in difficult cases, considering relevant, but not always conclusive, what AI provided [12, 15]. The use of patient data to train AI systems raises important ethical concerns, and ensuring secure and privacy-preserving handling of this data is crucial. Typically, patient data is stored within networks of medical institutions, and when it comes to connecting this data to external, cutting-edge AI systems for analysis, security and privacy become a challenge [6]. The electronic databases storing identity photos must be secured within a robust, cyber-attack-proof system to safeguard individuals' identities and personal data from potential theft.

Concerns about data privacy and safety are not unfounded, as demonstrated by the Conti ransomware attack on Ireland's healthcare IT system on May 14, 2021, which compromised sensitive data of 520 patients [23]. This incident highlights the critical need for robust security measures to protect personal information in the context of automated personal identification systems in healthcare [17].

4.2. THREAT – Workforce opposition

Perceptions from both the general population and the medical community also play a role as an external obstacle, as there exists a belief that machines cannot provide more accurate diagnoses than radiologists, especially when it comes to interventional tasks [7]. This kind of opposition by the community may represent the biggest obstacle to potential implementation of AI in radiology and is explored in the context of an external factor. A study [21] published in 2021 which interviewed UK radiologists and radiographers found that radiographers expressed concerns about the potential impact of AI on their skills and job security, suggesting that their roles might be more vulnerable to capture by AI technology. Radiologists, on the other hand, felt less concerned that AI technology might constrain their professional role and autonomy and believed that AI could potentially enhance their skills [21]. In a survey from 2019: One hundred ninety-eight radiologists (198/270; 73.3%) estimated they had received insufficient previous information on AI, and 37/270 (13.7%) declared having received no previous specific information at all. Thirty-seven (37/270; 13.7%) attended a dedicated teaching on AI, and respectively 73/270 (27.0%) and 33/270 (12.2%) had taken part in one or more demonstrations of AI-based solutions. Two hundred thirty-one respondents (231/270, 85.6%) admitted they had read no (89/270; 33.0%) or less than five (142/270; 52.6%) scientific publications about AI over the last 12 months. Based on the aforementioned criteria, the authors estimated that 62/270 respondents (23.0%) had basic knowledge on AI in radiology [22]. The perspective of radiographers on AI adoption and automation has been largely absent from professional and industry literature, contrasting with the lively debates among radiologists about diagnostic AI. Since 2015, radiologists have published numerous papers discussing and evaluating AI, addressing concerns about role erosion and highlighting AI's potential as a supportive tool. This surge in interest may have been motivated by a desire to safeguard their profession, but it also emphasizes the value of human workers in the imaging process factor that is often overlooked in the pursuit of efficiency gains and cost reductions [4]. In a survey [25], conducted in 2020 on radiography professionals worldwide: A proportion of the respondents agree (n = 76, 26.2%) or somewhat agree (n = 70, 24.1%) that they feel well prepared to implement new AI technologies and innovations in daily practice. Of the respondents, 31.4% (n = 91) are somewhat confident in using AI technologies or innovations in their daily practice while 44.1% (n = 128) feel somewhat confident with AI terminologies. Some respondents disagree (82, 28.3%) or strongly disagree (55, 19.0%) that there is enough AI training opportunities currently available for radiographers. Thus, most respondents agree (n = 120, 41.4%) or strongly agree (n = 81, 27.9%) that the teaching of AI technologies should be included in the radiography teaching curriculum. Most respondents supported [strongly agree (n = 80, 27.6%) and agree (n = 116, 40.0%)] that AI will change daily clinical radiography practice. Only 2.8% (n = 8) of respondents disagreed to this view. Majority of respondents somewhat agree (n = 95, 32.8%) that AI will reduce the workload of the radiography workforce while only few (n = 6, 2.1%) strongly disagreed [25]. A survey [26] found most radiologists have

basic or advanced AI knowledge, and this is associated with a more positive attitude towards AI, increasing the likelihood of clinical adoption. It seems that AI receptivity can vary from acceptance of the perceived inevitability to a positive enthusiasm for such change. The more educated the workforce is regarding AI, the more levels of positive, active acceptance and engagement are seen [25]. Radiologists tend to view AI technology as affording an opportunity for professional development, whereas radiographers were more reticent, highlighting the possible threat which AI posed to their roles. It is likely that with wider availability of formal education in AI for radiographers, enhanced AI transparency and explainability radiographers' views towards AI will become more favourable. Of note, Yang and colleagues [27] concluded in a scoping review that the replacement of radiologists by AI is considered unlikely in the near future and the stakeholders identified the need for training and education since they anticipate a significant impact on radiology. The fear that the machines will "take over", reducing the professional value, job demand and roles is shared by a considerable part of the radiography workforce [25]. Respondents indicated that AI should be included in the radiography training curriculum at universities and reported that, currently, there aren't enough AI training opportunities available for the radiography workforce. There was consensus about this across all continents surveyed in this study. The need for more training and education is vital to successfully implement AI into clinical practice, with these views being shared globally by all key AI ecosystem stakeholders. Lack of understanding may lead to uncertainty in how to make sense of AI as it relates to radiography practice/careers, and thus education is needed in order to build the proficiency necessary to appreciate future directions [25].

CONCLUSION

The development and evolution of artificial intelligence has fueled a revolution in computer science, with far-reaching implications for a variety of industries, including radiologic technology and radiology. Its integration with these sciences, which have always accepted technological progress, has great potential. Artificial intelligence in radiology is characterized by its versatility, impact on diagnostics and treatment. On the patient side, AI improves diagnostic accuracy, early disease detection and treatment planning. In oncology, for example, artificial intelligence helps in the detection and characterization of lesions, early detection of neoplasms, and treatment planning for brain tumors. AI also improves efficiency by optimizing work lists, pre-analyzing cases and reducing radiologist fatigue. However, there are challenges and limitations. The lack of integrated solutions, well-structured clinical data and clear standardization hinders the implementation of artificial intelligence. External factors, such as the need for advanced and secure systems to store large amounts of data, the negative attitude of the profession towards this technology and regulatory restrictions, represent obstacles. In conclusion, AI has the opportunity to lead to a paradigm shift in radiologic technology and radiology, advancing these fields and improving patient care and outcomes. Although challenges exist, the benefits of integrating artificial intelligence are significant and far-reaching.

All data in this paper are part of the results of the undergraduate thesis "SWOT analysis of the application of artificial intelligence in radiologic technology and radiology – review paper" written at the University Department of Health Studies, University of Split [28].

SWOT analiza primjene umjetne inteligencije u radiološkoj tehnologiji i radiologiji

Sažetak

Umjetna inteligencija (AI) unosi promjene u radiologiju i radiološku tehnologiju, omogućavajući razvoj programa i algoritama koji olakšavaju dijagnozu i odluke. Bitno je razumjeti na koji način AI može poboljšati ishode pacijenata, povećati učinkovitost pretraga i smanjiti troškove. Strojno i duboko učenje pokazali su se kao iznimno korisni u otkrivanju i karakterizaciji lezija, poboljšavajući rutinske tehnike snimanja i olakšavajući rad radiologa smanjenjem opterećenja i poboljšanjem kvalitete izvještavanja. Praktična primjena umjetne inteligencije u radiologiji i radiološkoj tehnologiji usporena je nedostatkom integriranih rješenja i dobro strukturiranih arhiva podataka, a također i izazovima kao što su netransparentnost sustava kod donošenja odluka i velika količine kvalitetnih podataka potrebnih za obuku modela umjetne inteligencije. Postoji zabrinutost zbog potencijalnog utjecaja AI na posao radiologa i radioloških tehnologa što može kočiti razvoj i primjenu ove tehnologije. Tekstualni podaci izvedeni iz slikovnih izvješća mogu pružiti vrijedne uvide u zdravstvu. Obrada prirodnog jezika (NLP), podskup umjetne inteligencije, nudi obećavajuća rješenja za rukovanje nestrukturiranim tekstom u ovim izvješćima, što otvara novu eru u izdvajanju informacija iz medicinskih slika i pripadajućih izvješća. Zbog izazova u obuci stručnjaka za primjenu AI-a u zdravstvu morat će se koristiti multidisciplinarni pristup i ulagati u suradnju i obrazovanje. Postoje neriješena pitanja o odgovornosti i regulaciji u vezi s pohranjivanjem podataka i privatnosti, osobito u slučaju pohrane podataka na sistemu „oblaka". Zabrinutost i neinformiranost radne snage o umjetnoj inteligenciji predstavlja prepreku za njeno usvajanje, ali i nudi priliku za tehnološko napredovanje struke.

Ključne riječi: AI; radiologija; radiološka tehnologija; SWOT

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REVIEW PAPER (PREGLEDNI RAD)

The importance of MRI in determining the stage o f cervical cancer

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Summary

Cervical cancer is one of the most common malignant tumours in women. The treatment of early and locally advanced stages of this cancer typically involves surgery, chemotherapy, and radiotherapy. However, there is no standardised therapy for metastatic cervical cancer due to the diverse manifestations of the disease. Therefore, timely diagnosis and staging of the carcinoma are crucial for maintaining the quality of life of patients. Imaging during the initial diagnostic evaluation is essential for accurately assessing the extent of the tumour and metastases, and for selecting the optimal therapy, with the FIGO system further emphasising this role. Compared to other imaging techniques, MRI provides detailed information on the location and size of the tumour, invasion into surrounding tissues, and the presence of distant metastases. This allows MRI to facilitate a tailored approach in therapy selection, taking into account the specific characteristics of the tumour. The integration of MRI into the diagnostic and therapeutic process improves clinical outcomes for patients with cervical cancer, enabling effective care. MRI is used alongside other imaging modalities in the diagnosis and treatment planning, and without it, precise staging of the disease and establishing a final diagnosis would not be possible.

Keywords: FIGO staging; cervical cancer; magnetic resonance; PET/CT; US

Abbreviations and acronyms:

CT (Computed Tomography), DWI (Diffusion Weighted Imaging), HPV (Humani Papyloma Virus), MRI (Magnetic Resonance Imaging), PET/CT (Positron Emission Tomography/ Computer Tomography), TRUS (Transrectal Ultrasound), TVUS (Transvaginal Ultrasound), US (Ultrasound)

Introduction

Cervical cancer is the most common gynaecological malignant tumour in the world and one of the leading causes of cancer-related death in women. It develops due to the abnormal growth of cells that have the ability to spread to other parts of the body. One of the main causes of cervical cancer is long-term chronic inflammation of the vagina and cervix caused by the sexually transmitted human papillomavirus (HPV). Imaging methods used for early detection of the cancer itself include CT (Computed Tomography), PET/CT (Positron Emission Tomography and Computed Tomography), ultrasound (US), and MRI (Magnetic Resonance Imaging). MRI is a radiological imaging method used for staging cervical cancer and as a diagnostic imaging method during the initial evaluation of patients with cervical cancer. It is also used for better assessment of tumour spread, localization, and accurate determination of tumour size [1].

Cervical cancer

Cervical cancer is the fourth most common cancer in women, with approximately 660,000 new cases annually [2]. In Croatia, more than 300 women are diagnosed with invasive cervical cancer each year, and around 600 women are diagnosed with localised cancer (Latin: Ca in situ) [3]. Although cervical cancer rates are declining in more developed countries, the incidence and mortality remain high in underdeveloped nations due to inadequate treatment services and a lack of screening programs. Cervical cancer is the third leading cause of death and the second most commonly diagnosed cancer in women in less developed countries, with the main cause being long-term chronic cervical inflammation caused by HPV [4].

Incidence and risk factors

Cervical cancer ranks fourth in both incidence and mortality among women worldwide. According to the latest data,

274 new cases of cervical cancer were recorded in Croatia in 2018, accounting for 2% of all cancer cases in women. The average age of those affected was 55.6 years. In the majority of cases, infection with high-risk types of human papillomavirus (HPV) is considered the primary cause of cervical cancer. Over 99% of precancerous lesions are caused by HPV infection. Factors associated with HPV infection and the development of malignant disease include obesity, smoking, sexually transmitted infections, and coinfection with HIV or herpes simplex virus type 2 [5, 6].

Clinical presentation

Cervical cancer most commonly occurs in women between the ages of 40 and 55. HPV infection is asymptomatic in most cases, although the appearance of condylomas, or genital warts, is possible. Due to its asymptomatic nature, HPV infection can easily be transmitted sexually. The symptoms of cervical cancer depend on the stage of the disease. Early stages of cancer may also be asymptomatic. The first symptom is usually bleeding, accompanied by pain in the lower abdomen, pelvis, and hips, which often occurs as a result of the malignant process spreading to the uterine body, pelvic wall, or around the sciatic nerve [6, 7].

Diagnosis and treatment

A gynaecological examination is of crucial importance for diagnosing cervical cancer, as it helps determine the size and location of the tumour. The main goal is to detect cancer at the earliest possible stage. The most commonly used methods for detecting cervical cancer are the Papa test, HPV test, and colposcopy [7]. Tumour size can also be assessed via transvaginal ultrasound. Other diagnostic methods include CT, MRI, lymphadenectomy, lymphangiogram, diffusion-weighted MRI (DWI), and PET-CT. PET-CT is an excellent method for assessing distant metastases. Chest X-rays and bone scintigraphy can help identify the presence of metastases. Premalignant glandular changes and epithelial lesions can be removed using minimally invasive surgical procedures. In cases of malignant disease, surgical procedures such as hysterectomy, removal of tissues around the uterus along with pelvic lymph nodes, or removal of the uterus along with the ovaries and fallopian tubes are performed [8]. For patients who are not surgical candidates, chemotherapy may be one of the treatment options for primary metastatic cervical cancer. HPV testing and a Pap test should be conducted 12 and 24 months after the procedure [9].

FIGO classification

In 2018, a new FIGO classification for cervical cancer was published, which defines anatomically advanced disease and distinguishes survival outcomes (Table 1). Compared to the previous FIGO system from 2014, the main change is that stage IB now includes three subgroups instead of two [10]. The appropriate diagnostic methods and treatment options for each stage are also summarised. Pathological and imaging assessments of the pelvis, as well as the evaluation of para-aortic and pelvic lymph nodes, have been incorporated into the staging system. This staging system also allows for the comparison of patients and their outcomes. Technological advancements improve diagnosis and treatment, and cancer staging is a process that evolves in response to this progress [11].

Table 1. FIGO tumour classification [10]

FIGO stage	Definition
I (IA, IA1, IA2, IB, IB1, IB2, IB3)	Cervical cancer confined to the uterus
II (IIA, IIA1, IIA2, IIB)	Cervical cancer spread beyond the uterus but without infiltration of the pelvic wall or the lower third of the vagina.
III (IIIA, IIIB, IIIC)	Cancer involves the lower third of the vagina, with possible presence of: infiltration to the pelvic wall, hydronephrosis, or involvement of lymph nodes.
IV (IVA, IVB)	Tumour has spread beyond the pelvis or infiltrates the mucosa of the bladder or rectum.

Aim of the paper

The aim of this paper is to present the role of the latest technological advancements in the use of MRI for more accurate detection and localization of cervical tumours, evaluation of disease staging, and risk factors. It will also highlight the advantages and disadvantages of MRI compared to other imaging modalities, as well as how MRI can influence the identification of tumour characteristics that affect the choice of optimal therapeutic techniques. The literature was searched using key terms on PubMed for the period from 2000 to 2024. A total of 3,413 papers were found, 54 of which are relevant to the topic of this paper. In addition to the database, 5 websites and 1 book were also used.

Discussion

MR imaging of the healthy cervix

MRI as an imaging method provides insight into gynaecological anatomy that is not visible with other techniques. Due to its high contrast resolution for small structures and tissues, as well as multiplanar imaging capabilities, it is possible to differentiate even very small pathological changes [12]. To distinguish pathologically visible structures from anatomical ones, it is essential to understand the anatomically normal appearance of both the uterus and the cervix (Figure 5). Tissue layers within and outside the uterus, cervix, and vagina are displayed in all three planes [13]. The cervix is located at the lower part of the uterus and is cylindrical in shape, protruding partially into the vagina. The average length of an anatomically normal cervix is 3 to 4 cm, with a diameter of 2.5 cm. MRI allows visualisation of all three layers of the uterus: endometrium, myometrium, and perimetrium [14]. The most

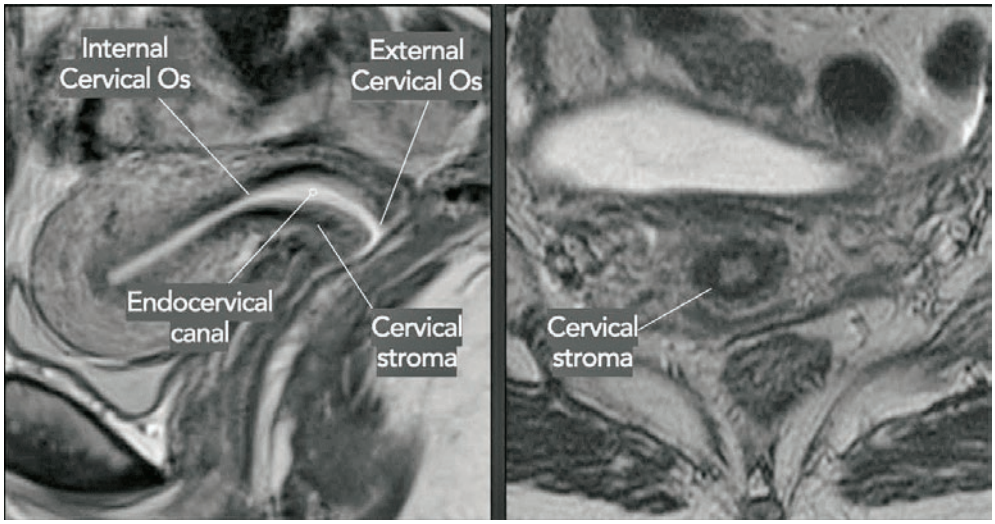


Figure 5. Anatomical MRI of a healthy cervix.
Source: https://radiologyassistant.nl/abdomen/unsorted/mr-in-cervical-cancer-1

common site for cervical tumours is the squamocolumnar junction, which is the boundary between the squamous and columnar epithelium lining the cervix. The cervix is separated from the bladder by the parametrium. The rectum is located posteriorly to the cervix, while the bladder is situated anteriorly. On T2-weighted images, the length and position of the cervix are clearly visible. A healthy cervix has two distinct zones: a central zone with high signal intensity, covered with mucus, and an outer zone with low signal intensity. On T1-weighted images, the surrounding parametrium is displayed with moderate signal intensity and is clearly distinguishable from connective tissue [13, 15].

The anatomy of the uterus and cervix varies with age. During the reproductive years, the different layers of the uterus and cervix are well-defined, and the muscular part of the uterine wall may be highly vascularized. The uterine cavity can be identified as a hypointense structure. In postmenopausal women, the anatomy becomes less visible, with cervical stroma and myometrium appearing hypointense on T2-weighted images. With age, the female reproductive organs gradually decrease in size, with a more pronounced loss of uterine volume compared to the cervix [16].

MR imaging of cervical carcinoma

MRI is the most precise and specific imaging technique used for the initial diagnosis and monitoring of cervical cancer. It provides a detailed assessment of disease and its spread within the cervix, as well as tumour extension into the pelvis, which significantly impacts treatment strategy and disease management [17]. The International Federation of Gynecology and Obstetrics (FIGO) staging system uses imaging and pathological evaluations for diagnosis and staging. The choice of imaging modality is based on the FIGO classification. MRI is considered the imaging modality of choice for assessing local tumour extension. It offers excellent soft tissue resolution, allowing accurate evaluation of tumour size, localization, and local infiltration, and provides insight into pelvic lymph node enlargement. The sequence most commonly used for diagnosing tumours is the Diffusion Weighted Imaging (DWI) sequence. This contrast-enhancing method is based on differences in diffusion. DWI shows the movement of water within tumour tissue. Pathological processes can affect water distribution within the tumour tissue. This characteristic allows insight into the tumour's microstructure, cellularity, and cellular membrane integrity. Cervical cancer tissue appears as restricted diffusion with high signal intensity in the primary tumour and metastatic lymph nodes. Cervical cancer is usually moderately hyperintense on T2-weighted images. The sagittal plane allows assessment of tumour extension to the uterine body or vagina. On T1-weighted non-contrast images, the tumour is typically displayed as isointense relative to the normal cervix. Smaller tumours usually grow homogeneously, while larger tumours may be necrotic and often show an enhanced margin. Large tumour size is a sign of aggressive disease. Isoechoic and hyperechoic tumours are more common in adenocarcinomas, whereas hypoechoic tumours frequently appear in squamous cell carcinomas of the cervix [18]. T2-weighted imaging is the mainstay for assessing cervical tumours on pelvic MRI. Images are acquired perpendicularly to the cervix, with thin slices of 3 to 4 mm recommended. Tumour size, whether greater or smaller than 4 cm, plays a crucial role in therapy selection, and accurate tumour size assessment is generally achieved. However, sometimes lesion size may be inaccurately assessed on T2 images due to the presence of inflammation or edema. Additionally, tumours may exhibit varied morphological characteristics, such as exophytic, infiltrative, or endocervical forms, and different growth patterns, which are essential for planning potential brachytherapy. Preservation of the hypointense fibrous ring on T2-weighted MRI often suggests a lack of parametrial invasion. However, disruption of the stromal ring without a clearly defined parametrial mass may result in microscopic invasion, leading to false-negative findings. Complete disruption of the ring, accompanied by nodular or irregular tumour signal intensity, are reliable indicators of tumour invasion [19] (Figure 6). Alongside diffusion imaging, MR spectroscopy is used as a specialised technique in cervical cancer imaging. It is a functional technique that

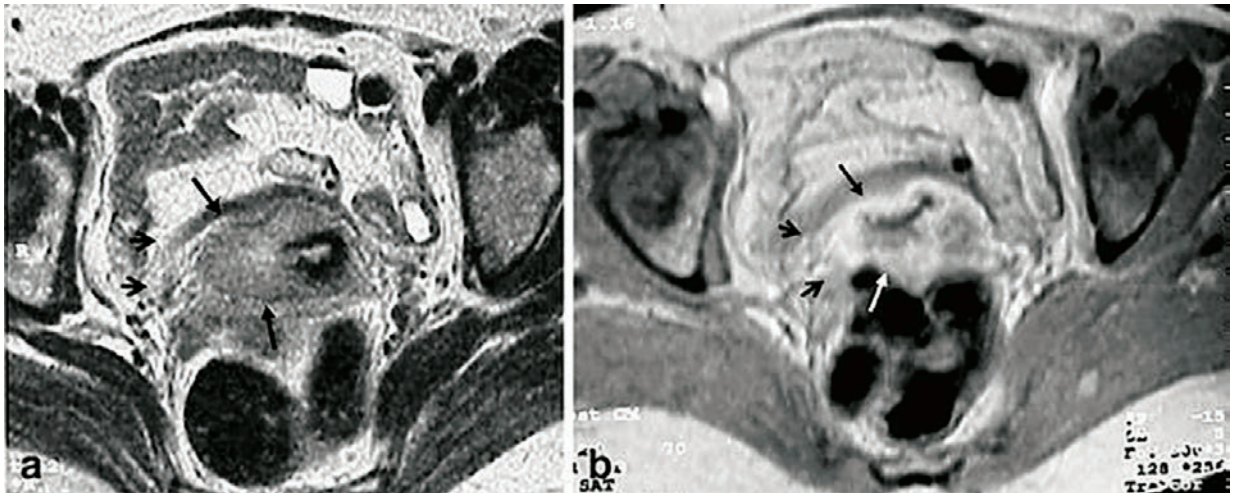


Figure 6. Axial T2 and T1-weighted contrast-enhanced images show a necrotic cervical mass (arrows) with right parametrial invasion (short arrows).
Source: https://link.springer.com/article/10.1007/s00330-005-2804-z/figures/2

detects the presence of small mobile molecules at commonly used MRI strengths of 1.5 T and 3 T [20].

Stage I cervical cancer on MRI

Early detection of cervical cancer with MRI can reduce the need for patients to undergo radical surgery. In the earliest stage of the disease, the tumour is not clinically visible, and diagnosis is made solely through biopsy and pathological analysis. Imaging modalities like conventional MRI cannot detect millimetre-sized changes at this stage and are not recommended for patients with stage IA of this disease. Additionally, the therapeutic options for these patients depend on whether they are in their reproductive years and the involvement of lymphatic and blood vessels. When assessing the stage of cancer in the early stages of the disease, caution is needed due to local inflammatory processes and edema resulting from the biopsy. Inflammation is often accompanied by edema, leading to high signal intensity on MRI and is a common reason for overestimating tumour size and staging the disease higher than it actually is [21].

For stage IB cervical cancer, prognosis depends on tumour volume, type, lymphovascular invasion, and lymph node status (Figure 7). T2-weighted MRI is precise for assessing tumour volume, especially with endovaginal techniques. Squamous cell carcinomas generally have a better response compared to adenocarcinomas, though adenocarcinomas typically have a worse prognosis, especially if poorly differentiated. The presence of tumour cells in vascular channels is a poor prognostic sign. MRI can be used as a prognostic biomarker to differentiate the histological characteristics of tumours in stage I disease [22].

Stage II cervical cancer on MRI

A tumor that has extended beyond the uterus but has not invaded the pelvic wall or the lower third of the uterus is classified as stage II. According to the classification,

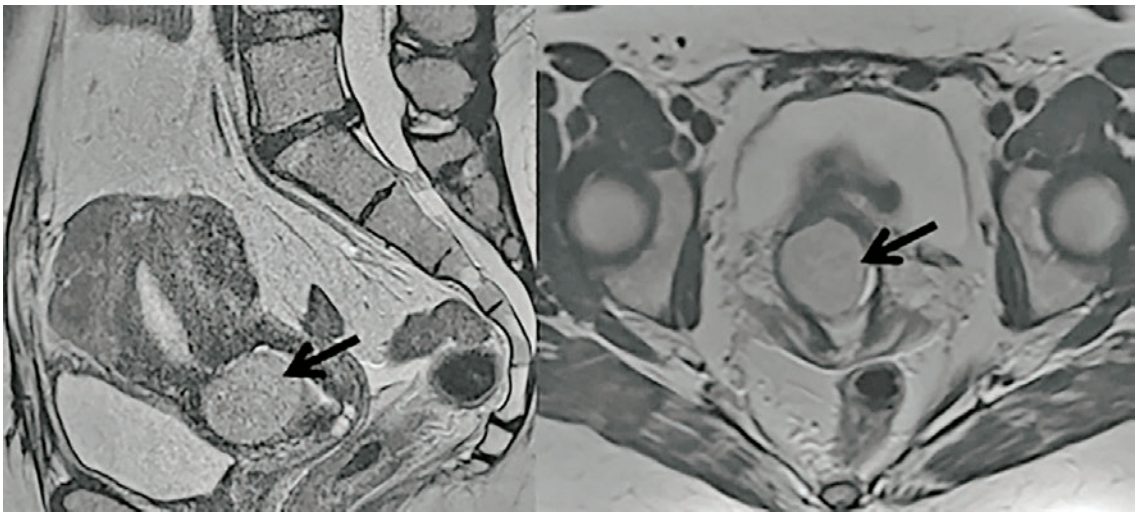


Figure 7. Stage IB cervical cancer on MRI
Source: https://repozitorij.mef.unizg.hr/islandora/object/mef%3A2823/datastream/PDF/view



Figure 8. FIGO stage IIA cervical cancer (<4cm) on TI in the sagittal plane
Source: https://zir.nsk.hr/islandora/object/mef:3661/datastream/PDF/view



Figure 9. FIGO stage IIA2 cervical cancer (>4 cm) in the sagittal plane on T2-weighted imaging
Source: https://zir.nsk.hr/islandora/object/mef:3661/datastream/PDF/view

tumours with a diameter of <4 cm fall under stage IIA1 tumours (Figure 8), while invasive cancers larger than 4 cm are classified as stage IIA2 (Figure 9). Stage IIB cancer involves parametrial invasion but not invasion of the pelvic wall. Tumours at this stage can be treated with surgery or radiation therapy [24]. On MRI, stage IIA appears as infiltration into the upper two-thirds of the vagina, with loss of the normally hypointense signal and thickening of the vaginal wall. In stage IIB, signs of parametrial invasion are visible, and there is a complete loss of the hypointense signal from the cervical stroma. T2-weighted imaging is justified when assessing parametrial invasion. On T1-weighted images, healthy tissue will give a brighter signal due to the presence of fat, while tumour tissue will appear darker [25].

Stage III cervical cancer on MRI

Stage III disease involves the spread of cancer to the lower third of the vagina or the pelvic wall, changes in the thickness or loss of the normal signal of the vaginal wall, and the presence of hydronephrosis (fluid accumulation in the kidney), as well as involvement of local and regional lymph nodes (Figure 10). Hydronephrosis is best assessed on T2-weighted images in a coronal plane that includes the kidneys [25, 26]. Healthy lymph nodes have an oval shape, with homogeneous intermediate signal intensity on T2-weighted images, hypointense on T1-weighted images, and high signal intensity on DWI images. The primary criterion for distinguishing malignant from benign tumours is size; nodes larger than 1 cm in their shortest

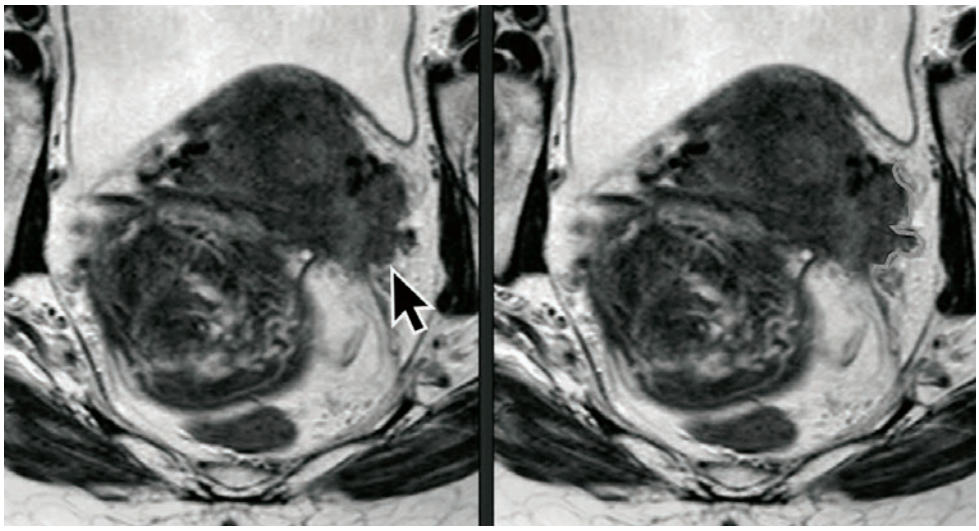


Figure 10. Pelvic lateral wall invasion of stage III cervical cancer
Source: https://radiologyassistant.nl/abdomen/unsorted/mr-in-cervical-cancer-1

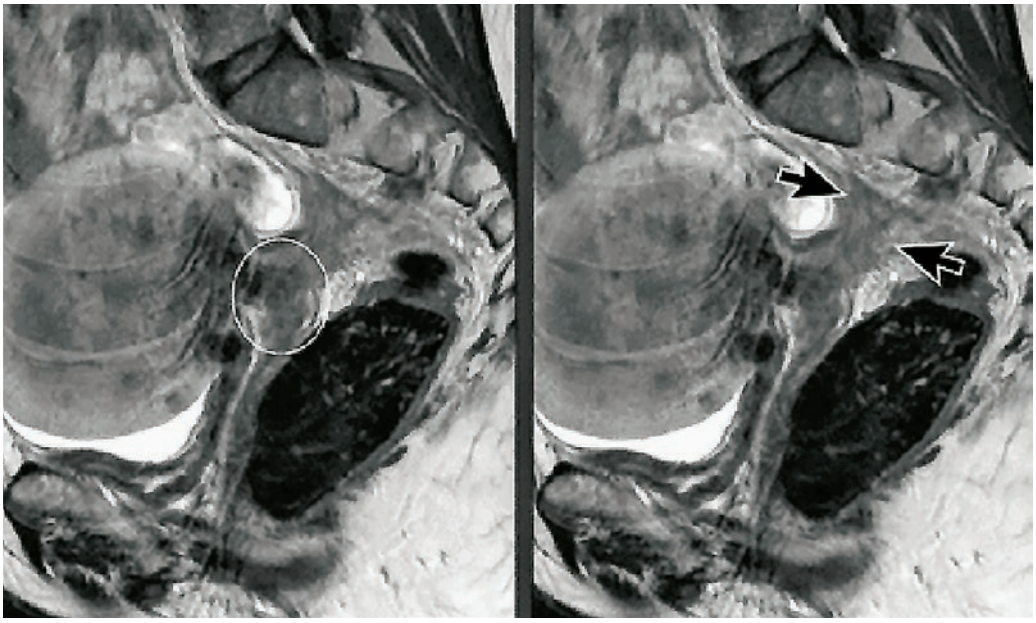


Figure 11. Locally advanced stage III cervical cancer (circle) with extensive invasion of the sacrouterine ligaments (arrows)
Source: https://radiologyassistant.nl/abdomen/unsorted/mr-in-cervical-cancer-1

axis may indicate a malignant process. Detection of positive lymph nodes is easiest on T2-weighted images due to their intermediate intensity compared to the hypointense blood vessels and muscles [27] (Figure 11). Metastases in lymph nodes associated with cervical cancer are linked to a lower survival rate, with a three-year survival rate of 64%, compared to 94% for patients without metastases [25, 27, 28]. The 2022 recommendations from national comprehensive cancer centres for treating stage III cancer suggest concurrent chemoradiotherapy and conventional external beam radiotherapy with doses ranging from 50 to 60 Gy. This dose is sufficient to control smaller metastatic lymph nodes but is inadequate for larger and more extensive lymph nodes. High doses of external brachytherapy and lymph node resections are the main treatment strategies for larger lymph nodes. However, increasing the dose carries the risk of serious and toxic side effects on adjacent organs such as the bladder, rectum, and intestines [26].

Stage IV cervical cancer on MRI

Stage IV is the terminal stage of cervical cancer. At this stage, there is extension of the cancer to adjacent organs, particularly the bladder and rectum, and there may also be metastasis to distant organs. Stage IV is divided into IVA and IVB. Stage IVA indicates metastasis to adjacent organs, while Stage IVB denotes metastasis to distant organs [29] (Figure 12). Concurrent surgical therapy and chemotherapy are approaches used for treating stage IV disease [30]. The overall five-year survival rate for patients with stage IV disease is 15%. MRI has a sensitivity for detecting involvement of soft tissue structures ranging from 71-100%, with specificity between 88-91% [31].

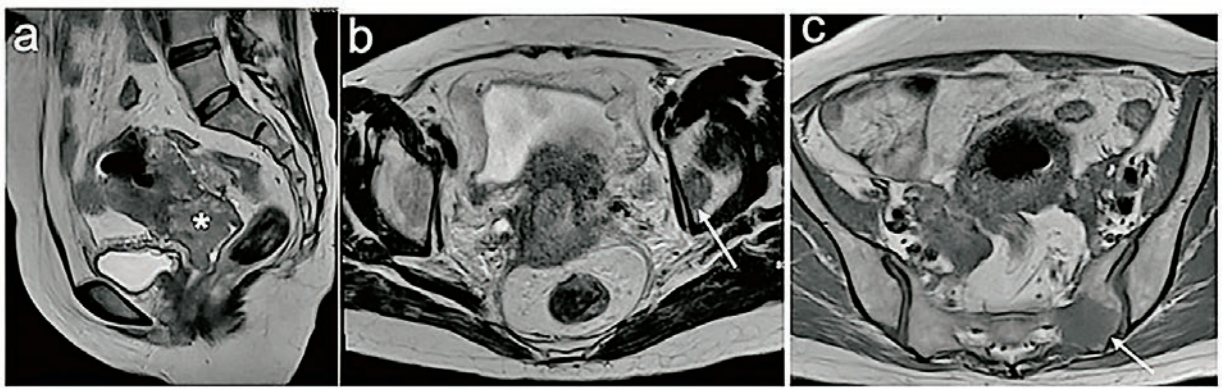


Figure 12. Sagittal T2 (a) shows a cervical tumor of intermediate signal intensity (*). Axial T2 at the mid-pelvic level (b) and sacrum (c) reveals focal regions of irregular low signal intensity within the left acetabulum (arrows) consistent with bone metastases. FIGO Stage IVB .
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10605640/#B29-cancers-15-05105

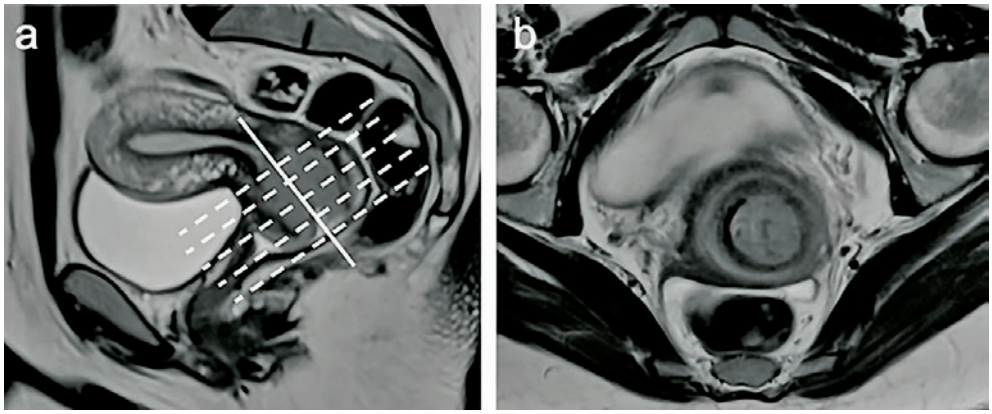


Figure 13. Sagittal T2 (a) highlights the long axis of the cervix (solid white line) and the perpendicular axis to the cervix (dashed white lines) from which (b) axial-oblique slices are obtained.
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10605640/

The presence of a hyperintense tumour within the bladder and rectum, with wall damage on T2-weighted images, clearly indicates tumour cell expansion. This radiological diagnosis is further confirmed by pathological analysis of tissue samples. Additionally, edema of the bladder mucosa may occur, potentially leading to an incorrect assessment of the posterior wall of the bladder, and can result in false-positive findings on T2-weighted images due to uniform thickening and high signal intensity throughout the wall [27, 32].

Role of MRI in the treatment of patients with cervical cancer

MRI plays a central role in patients with diagnosed cervical cancer and allows for accurate staging, which is crucial for determining the most appropriate treatment. MRI is the best imaging option for assessing tumour size, location, as well as parametrial and lateral wall invasion. A partially filled bladder ensures that the uterus is in an optimal position, so patients are advised to empty their bladder approximately half an hour before the examination to ensure it is partially filled during the scan. Prior to the procedure, an intramuscular medication is administered to calm peristalsis, thereby reducing movement artefacts caused by intestinal peristalsis [33]. In the standard MRI protocol for staging cervical cancer, a broad-field standard T2 image is obtained first. This image is used to plan subsequent imaging with higher resolution along the axis of the cervix, which is crucial for precisely locating the tumour and accurately determining parametrial involvement (Figure 13). The normal anatomy of the cervix is most clearly seen on T2, where the central endocervical glands and mucosa are hyperintense, surrounded by hypointense fibrous stroma and stroma of intermediate signal intensity extending to the parametria. Cervical tumours are best visualised on T2 as lesions of intermediate signal intensity, which clearly differentiate from the hypointense cervical stroma. DWI can assist in detecting tumours when the lesion has the same signal intensity as the cervix [34].

Certain guidelines recommend using a large FOV axial T1 and T2WI from the renal hilum to the pubic symphysis to assess additional associated diseases or pelvic metastases, such as enlarged lymph nodes, bone involvement, and hydronephrosis [35, 36]. Different tissues have

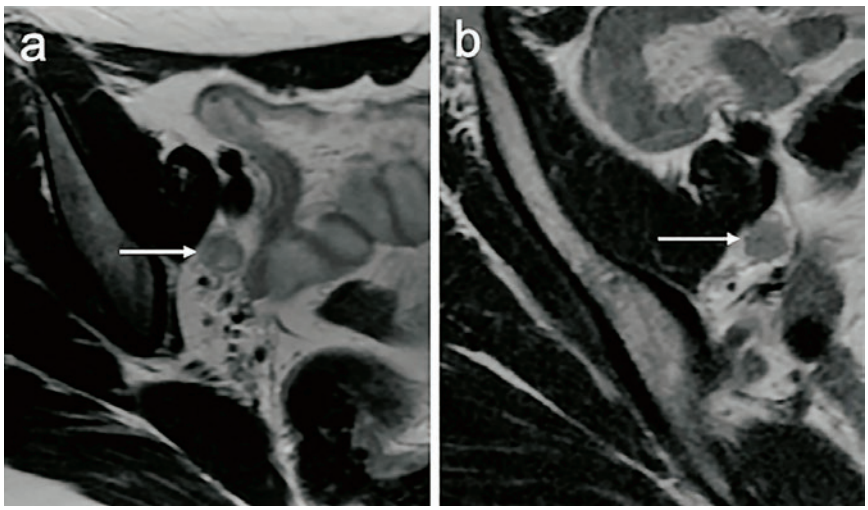


Figure 14. Appearance of metastatic lymph nodes with (a) rounded morphology and central necrosis and (b) irregular spiculated margins on axial T2WI.
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10605640/

characteristic diffusion properties, and in highly cellular tissues, water molecule diffusion is relatively restricted. This is manifested as high signal intensity on DWI images [37, 38, 39]. DWI facilitates the detection of lymph nodes; however, it is important to note that both physiological and pathological nodes show restricted diffusion. T1 and T2-weighted images can be used for further assessment of lymph node morphology. Suspicious features include rounded morphology, irregular borders, and loss of the fatty hilum (Figure 14). Size criteria for enlarged lymph nodes vary depending on the location [40].

Combined chemoradiotherapy is the treatment of choice for advanced cervical cancer. MRI is performed before and during treatment to enable tailored treatment planning and dose adjustment of radiotherapy, improving local tumour control and reducing treatment toxicity. If initial treatment fails, further therapeutic options are limited. Therefore, early and accurate prediction of treatment response significantly impacts patient prognosis. Many studies have investigated the potential role of contrast-enhanced MRI in staging as a predictor of treatment response. Studies have shown that tumours with poor enhancement (poorly perfused hypoxic tumours associated with increased aggressiveness, higher risk of metastasis, and treatment failure) had a poorer response to therapy and lower survival rates. However, studies have not identified a precise, reproducible value for these parameters, limiting their use in current clinical practice. Some studies have also shown that contrast-enhanced MRI can improve the sensitivity of detecting small isointense tumours, particularly for patients who may be candidates for fertility-sparing treatment. Cervical cancer is treated with curative intent, and FIGO staging aims to classify patients who are suitable for primary surgery and those who will have a better prognosis with chemoradiation. Surgical intervention is considered for patients with tumours smaller than 4 cm and confined to the cervix without parametrial or nodal invasion. For a selected group of patients who desire future fertility, fertility-sparing surgery may be an option. In such cases, tumour size is most accurately depicted by MRI, typically reserved for tumors confined to the cervix measuring < 2 cm (stages IA1, IA2, and IB1). For larger tumours confined to the cervix (> 2 cm) or for patients where fertility preservation is not a priority, surgical options include total abdominal hysterectomy with or without bilateral salpingo-oophorectomy and lymphadenectomy, performed either open or laparoscopically. Patients with FIGO stages IB and IIA may also be offered primary chemoradiotherapy if they are considered less favourable candidates for surgery. Standard treatment for locally advanced cervical cancer (stage IIB and higher) is chemoradiotherapy, which includes external radiation with concurrent chemotherapy, followed by intracavitary brachytherapy. MRI can be used to assess the precise placement of brachytherapy applicators and complications after brachytherapy. MRI during treatment (about 5 weeks after the start of chemotherapy with external radiation and before intracavitary brachytherapy) can help adjust the dose based on residual tumour volume, which can reduce toxicity. MRI is usually performed 3-6 months after chemoradiotherapy, and the regeneration of low-signal intensity cervical stroma on T2WI indicates a complete response. Changes after treatment can persist for up to 9 months after chemoradiotherapy; thus, differentiating residual tumours from post-treatment edema can be challenging, as both will appear as intermediate signal intensities on T2WI. The use of DWI can help distinguish between the two, as only tumours should show restricted diffusion.

Advantages and disadvantages of mri compared to other imaging modalities in cervical cancer

Before initiating treatment, local staging of cervical cancer often involves determining the stage using transvaginal or transrectal ultrasound and/or MRI. This helps assess the precise tumour size, depth of stromal invasion, and parametrial invasion. For evaluating metastases in pelvic and paraaortic lymph nodes and detecting distant metastases in locally advanced cervical cancer, both MRI and CT are widely used [46]. However, both MRI and CT have low sensitivity for detecting metastatic lymph nodes, whereas PET-CT shows better sensitivity. Nonetheless, PET/CT also has low sensitivity for diagnosing small/microscopic metastases [47]. Therefore, negative imaging findings for lymph node metastases based on any imaging modality do not rule out occult lymph node metastases in cervical cancer [48].

MRI and ultrasound in the imaging of cervical cancer

While MRI is considered the primary technique for assessing tumour size and parametrial extension, transvaginal ultrasound (TVUS) or transrectal ultrasound (TRUS) can provide comparable results. Ultrasound can be as accurate as MRI. However, MRI has the advantage of being easily reviewed during multidisciplinary tumor board meetings, whereas ultrasound depends on the operator's skill [49, 50]. Combining MRI with ultrasound can also successfully visualise disturbances in the stromal ring, a specific sign of parametrial involvement, which is typically characterised on MRI by a drastic reduction in T2 hypointensity of the fibrous stromal ring [51] (Figure 15). Recent technical advances in ultrasound have led to its increased use in cervical cancer management. Ultrasound diagnosis has been shown to enhance initial diagnosis and better assess the size of small tumours. Vascularization can be assessed using Doppler, and it is possible to differentiate between precancerous lesions and cervical cancer, improving diagnostic accuracy (Figure 16). The use of Doppler has led to reinterpretation of MRI data in patients with nodular cervical hyperplasia, and ultrasound has proven to be significantly better than MRI in assessing tumour size [52]. The limitation of ultrasound may be that certain factors can interfere with the ultrasound evaluation of some tumour characteristics, such as lesion borders, involvement of the fornices, and vascular patterns. Additionally, ultrasound may overestimate tumour dimensions, which could compromise the opportunity for fertility-sparing surgery in certain patients [53]. A comparison of 3D ultrasound with MRI for assessing parametrial infiltration showed a 79% concordance between the two techniques [54]. MRI and ultrasound have similar diagnostic effectiveness. The advantage of MRI over ultrasound is its greater ability to identify patients with metastatic lymph nodes. The

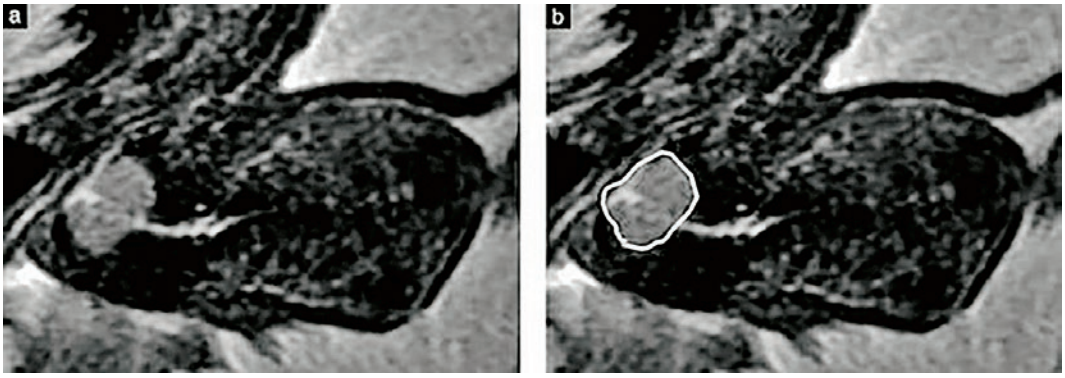


Figure 15. Sagittal T2-weighted MRI of cervical cancer infiltrating less than two-thirds of the stroma (FIGO stage IB). The tumor boundary is outlined, surrounded by free cervical stroma (b) [55].

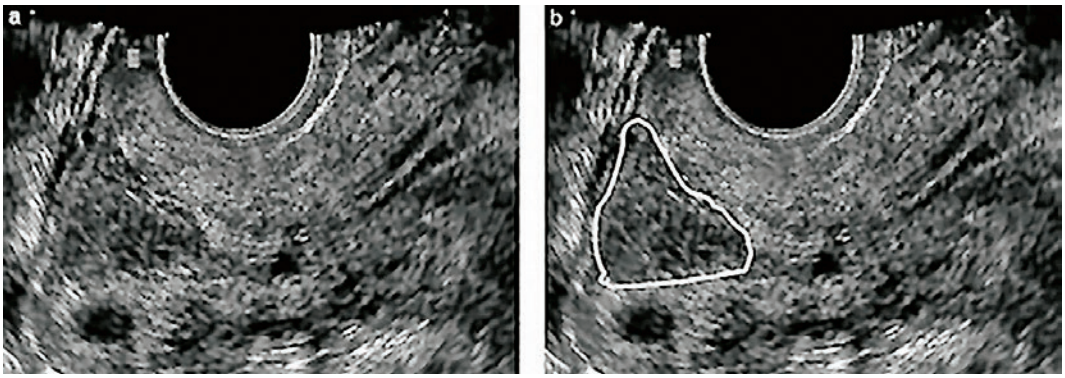


Figure 16. Transvaginal ultrasound image showing a longitudinal section of cervical cancer infiltrating less than two-thirds of the stroma (FIGO stage IB). The tumor boundary is outlined, surrounded by free cervical stroma (b) [55].

drawbacks of MRI include cost and the inability to perform dynamic examinations, as well as the length of the exam [55].

MRI and PET/CT in cervical cancer imaging

MRI and CT are used to assess paraaortic and pelvic lymph nodes in patients with cervical cancer. These methods have only moderate sensitivity and specificity for detecting metastases. A major limitation of these modalities is their inability to identify small lymph node metastases. Although PET has been shown to be superior to CT and MRI for detecting pelvic and paraaortic lymph node metastases due to cervical cancer, PET is limited in terms of anatomical and spatial resolution compared to CT or MRI [56]. However, PET has lower spatial resolution than CT or MRI. MRI and PET/CT are advanced imaging techniques routinely used today for staging and monitoring cervical cancer treatment. MRI provides the best visualisation of the primary tumour and the extent of disease in soft tissues. PET/CT is recommended for evaluating nodal involvement as well as distant metastases. Both MRI and PET/CT are used to monitor patients after treatment to assess recurrence. PET/CT is used before treatment when there is a possibility of tumour spread beyond the cervix or in patients considered for trachelectomy [57]. PET/CT plays a crucial role in depicting and assessing the local extent of the disease and can be helpful in delineating the edges of invasive tumours in cases of superior tumour spread. However, high intensity can excessively overestimate tumour spread into parametrium, as well as involvement of the bladder and rectum. Therefore, MRI should be used alongside PET/CT to avoid overestimation of local invasion into the parametrium, bladder, and rectum [58]. Similar to MRI imaging, PET/CT is evaluated as a functional imaging parameter for predicting disease

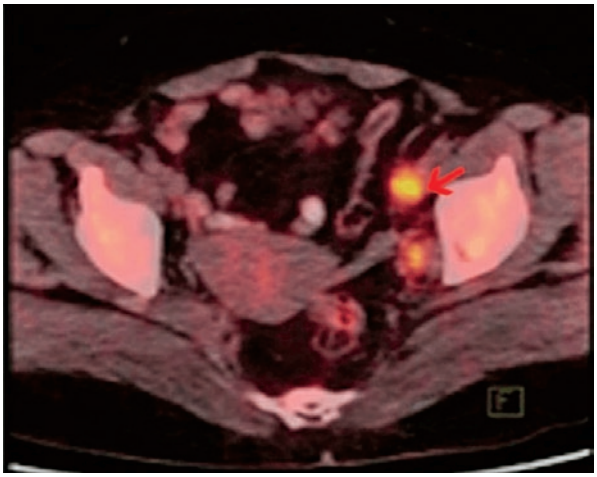


Figure 17. PET/CT image showing involvement of the left pelvic lymph node. The red arrow indicates FDG (Fluorodeoxyglucose) uptake in the left pelvic lymph node of a patient with early-stage cervical cancer.
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9803860/

response and prognosis, including disease-free survival and overall survival. PET/CT has advantages over MRI in assessing distant metastatic disease. PET is also used to avoid missing lesions at the edges of the MRI field of view. While MRI is useful for detecting enlarged pelvic and paraaortic metastatic lymph nodes, PET/CT is more sensitive than MRI for detecting metastatic lymph nodes from cervical cancer (Figure 17). Combining PET images with MRI images is an emerging technology used for assessing patients with cervical cancer. According to recent studies, the benefits of MRI in evaluating local tumour extension, paired with the strengths of PET in assessing lymph node metastases, result in a synergistic effect on staging accuracy for women with cervical cancer [59, 60].

Conclusion

MRI plays a crucial role in the diagnosis and treatment of cervical cancer, particularly in assessing tumour size, disease spread, and detecting metastases. It provides detailed visualisation of the primary tumour and accurately depicts soft tissues. Combining MRI with other imaging techniques can further enhance diagnostic and treatment accuracy. This includes the use of various imaging methods such as ultrasound, PET/CT, and MRI. Although MRI and CT are commonly used for evaluating metastases, PET/CT offers higher sensitivity but still has limitations in detecting smaller metastases. Additionally, combining MRI with ultrasound can successfully depict parametrial infiltration. While MRI and PET/CT are valuable for assessing disease spread and monitoring treatment, their combination can have a synergistic effect on staging accuracy. Furthermore, MRI plays an important role in surgical planning by allowing precise determination of tumour size and identification of affected adjacent structures. MRI is also used to monitor patients post-treatment to assess for potential disease recurrence. Despite its drawbacks, such as high costs and limitations in dynamic imaging, there is a need for further research and technological development. Nevertheless, its ability to provide detailed visualisation of anatomical structures and detect pathological changes makes it an indispensable diagnostic tool for rapid and accurate diagnosis and treatment monitoring in cervical cancer.

All data in this paper are part of the results of the undergraduate thesis „The role of MRI in the diagnosis and choice of treatment for cervical cancer“ written at the University Department of Health Studies, University of Split [61]. ■

Važnost MR-a u određivanju stadija raka vrata maternice

Sažetak

Rak vrata maternice jedan je od najčešćih malignih tumora koji pogađa žene. Kod bolesnica s ranim stadijem raka vrata maternice i lokalno uznapredovalim rakom vrata maternice princip liječenja je konvencionalan uključujući operaciju, kemoterapiju i radioterapiju, dok kod bolesnica s metastatskim rakom vrata maternice, ne postoji standardno liječenje zbog njegovih heterogenih manifestacija. Zbog svega toga ključno je na vrijeme dijagnosticirati i odrediti stadij karcinoma u svrhu kvalitete života. Snimanje tijekom primarne dijagnostičke obrade ključno je za točnu procjenu proširenosti tumora i metastatske bolesti kao i za odabir najbolje terapijske opcije, a pomoću FIGO sustava njegova je uloga dodatno naglašena. U odnosu na druge tehnike snimanja, MR nam pruža detaljne informacije o lokalizaciji i veličini tumora, invaziji u okolna tkiva, te prisutnost udaljenih metastaza. MR doprinosi individualiziranom pristupu u odabiru terapije, uzimajući u obzir specifične karakteristike tumora. Integracija MR-a u dijagnostički i terapijski proces poboljšava kliničke ishode pacijenata s karcinomom vrata maternice, omogućujući učinkovitu skrb. MR se nadopunjuje sa ostalim modalitetima snimanja kod dijagnostike i planiranja liječenja, te bez MR-a nije moguće utvrditi stadij bolesti i postaviti konačnu dijagnozu.

Ključne riječi: FIGO stadij; karcinom vrata maternice; magnetska rezonancija; PET/CT; UZV

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REVIEW PAPER (PREGLEDNI RAD)

The overview of imaging protocols for chest CT

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Abstract

Computed Tomography (CT) is a common method of choice in the diagnosis of thoracic diseases. Since CT operates on the principle of ionizing radiation and frequently involves the use of contrast agents, it is crucial to standardize CT protocols to reduce the need for repeat imaging and, consequently, minimize patient exposure to radiation. The selection of a CT protocol primarily depends on the patient's clinical indications and needs. The main classification of CT protocols distinguishes between the use of contrast agents (CECT) and non-contrast protocols (NCCT). The LDCT protocol is characterized by a low radiation dose and high sensitivity for detecting pulmonary nodules, making it suitable for lung cancer screening. Ultra-LDCT yields satisfactory results in diagnosing pneumonia and pneumothorax. Cine CT enables the assessment of cardiac function throughout the entire cardiac cycle, though it involves a high radiation dose and low temporal resolution. The use of contrast agents is particularly beneficial for differentiating adjacent non-vascular structures, more accurately identifying vascular anatomy, and improving the detection and characterization of pathological lesions. For diagnosing vascular pathologies, CTA is used, while CTPA is essential for diagnosing pulmonary embolism (PE) with high sensitivity and specificity. TRO CT is useful in cases of acute chest pain to rule out emergencies. Dynamic changes in tissue perfusion are monitored with DCE-CT, which is also valuable in tumor diagnostics. In pediatric applications of CT for the chest, it is essential to emphasize the use of the lowest possible radiation dose and contrast agent to minimize risks.

Keywords: contrast enhanced chest CT; CT; CT angiography; low dose CT; non-contrast chest CT

Abbreviations and acronyms:

ALARA (As Low As Reasonably Achievable), BMI (Body Mass Indeks), CECT (Contrast-Enhanced Computed Tomography), Cine CT (Cinematic Computed Tomography), CPR (Curved-Planar Reformation), COPD (Chronic Obstructive Pulmonary Disease), CT (Computed Tomography), CTA (Computed Tomography Angiography), CTPA (Computed Tomography Pulmonary Angiography), DCE-CT (Dynamic Contrast-Enhanced Computed Tomography), DSCT (Dual-Source Computed Tomography), ECG (Electrocardiogram), HU (Hounsfield Units), i.m. (intramuscular), i.v. (intravenous), ILD (Interstinal Lung Disease), kV (kilovolt), LDCT (Low Dose Computed Tomography), MinIP (Minimum Intensity Projection), MIP (Maximum Intensity Projection), MPR (Multiplanar Reconstruction), MS (Multi Segment), MSCT (Multi Slice Computed Tomography), mAs (milliampere-second), mSv (millisievert), PE (Pulmonary Embolism), PUO (Pyrexia of Unkown Origin), TRO (Triple Rule Out), VRT (Volume Rendering Technique)

Introduction

Computed Tomography (CT) is a fundamental imaging technique in the diagnosis of chest diseases. Due to the increasing range of clinical chest disorders, the frequency of CT examinations is rising. When ordering a CT scan, it is important to consider the risk of increased radiation exposure and the use of intravenous (i.v.) iodinated contrast agents, particularly in young patients and those requiring repeat imaging. Therefore, it is crucial to evaluate the benefits of obtaining diagnostic information against the risks to patient safety. CT protocols should, among other considerations, be standardised in case a patient needs to transfer to another institution for treatment. This would

prevent repeat imaging and avoid additional radiation exposure and contrast administration [1]

CT protocols and clinical indications

There are various CT protocols, and it is the clinician's responsibility to select the one that provides the most relevant information for a given clinical indication. CT protocols can be categorised into two main groups: non-contrast computed tomography (NCCT) and contrast-enhanced computed tomography (CECT), which are further divided into smaller, more specific protocol subgroups (Table 1).

Table 1. Types of imaging protocols [1]

CT protocols	
Non-contrast CT protocols	Routine NCCT
	LDCT
	Ultra-LDCT
	Cine CT
Contrast-enhanced CT protocols	Routine CECT
CT angiography protocols	CTA
	CTPA
	TRO
Functional imaging	DCE-CT

Contrast agents are chemical substances introduced into the body to enhance the contrast between adjacent structures that naturally exhibit low contrast due to similar attenuation values. They achieve their effect by altering the absorption of X-rays. Based on the method of administration, contrast agents can be applied parenterally (i.v., i.m.), enterally (orally, rectally, via catheters), or locally (injection into body cavities and organs). For CT applications, iodine-based and barium sulphate contrast agents are used. Due to the potential for side effects and allergic reactions, patients are required to sign informed consent prior to contrast-enhanced imaging [2-4].

Chest CT provides significant information about the condition of the lung parenchyma, hila, mediastinum, as well as the pleura, bones, and soft tissue organs of the chest. Consequently, there are numerous indications for CT (Table 2). CT may be chosen as the preferred method in further diagnostic evaluation when abnormalities are detected on other imaging modalities, such as conventional X-ray or ultrasound, or when further investigation is required for symptoms such as persistent cough, hemoptysis, chest pain, and similar conditions. It is commonly used for the assessment and screening of lung cancer, as well as for evaluating emphysema, infections, chronic pulmonary diseases, bronchiectasis, and traumatic injuries [5].

Table 2. Overview of clinical indications and corresponding CT protocols [1]

Klinical indications	CT protocol
Screening – pulmonary metastasis	NCCT
Screening – lung cancer	LDCT
Unexplained dyspnoea – suspected ILD	NCCT
Bronchiectasis	NCCT/LDCT
PUO	CECT (chest and abdomen)
Non-resolving pneumonia	CECT
Malignant pleural effusion, empyema	CECT
Staging and follow-up of lung cancer	CECT
Staging and follow-up of lymphoma	CECT (neck, chest and abdomen)
Unexplained vocal cord palsy	CECT
Evaluation of solitary pulmonary nodules	CECT, DCE-CT
Bunt or penetrating chest trauma	CECT, CTA
Recurrent/significant haemoptysis	CTA
Atypical chest pain (e.g. Pulmonary embolism, aortic dissection)	CTA
Suspected pulmonary thromboembolism	CTPA

Aim of the paper

The aim of this paper is to describe specific imaging protocols for chest CT and explain how to achieve the highest possible image quality with the lowest dose of ionising radiation for the patient. CT protocols with and without the use of contrast agents are compared. A literature search was conducted using key terms on PubMed for the period 2000–2024, yielding 306 studies, of which 33 were relevant to the topic of this paper. In addition to the PubMed database, 13 relevant websites and 2 undergraduate and graduate theses were utilised.

Discussion

NCCT protocols

The purpose of NCCT protocols is to avoid administering contrast agents to patients when it is not necessary. This reduces the risk of adverse side effects, such as hypersensitivity reactions and contrast-induced nephropathy [6].

Routine NCCT

During a routine NCCT of the chest, the patient lies with their arms raised above the head, and the scan direction is craniocaudal. The scan field covers an area from 1 cm

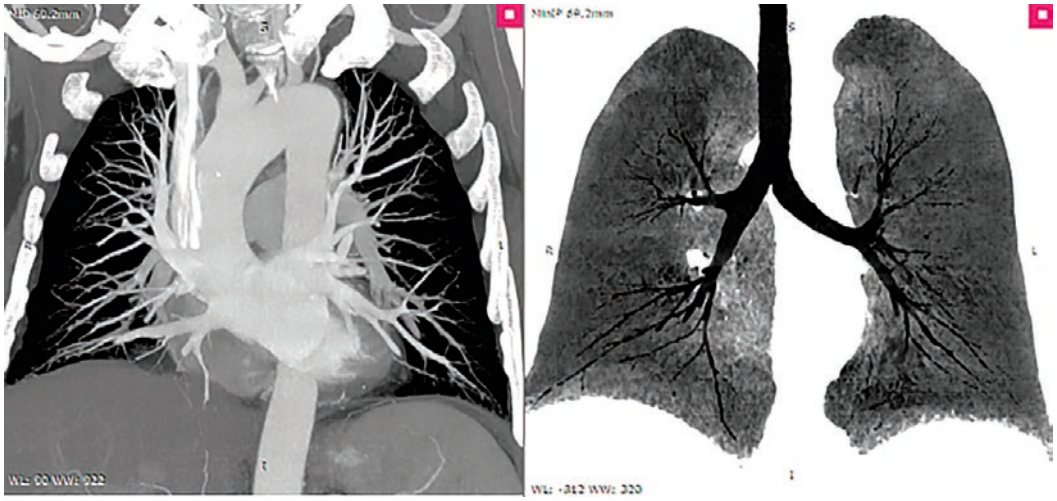


Figure 1. Comparison of images from conventional CT dose (6.7 mSv; left image) and ultra-low CT dose (0.2 mSv; right image)
Source: https://www.radiantviewer.com/dicom-viewer-manual/3dmpr-thickness.html

above the lung apex to below the lung base. Imaging is performed during inspiration. The tube voltage is 120 kV (~ 80-113 kg), and the tube current is 130-200 mAs. Slice thickness ranges from 1.2 to 15 mm, and the image matrix consists of 512x512 pixels. The obtained CT images are reconstructed using a soft tissue window (soft algorithm: 20-30 kernels) and a lung window (sharp algorithm: 60-80 kernels). Volumetric data can be further processed using various techniques, such as multiplanar reconstruction (MPR), maximum intensity projection (MIP), minimum intensity projection (MinIP), and virtual bronchoscopy. MIP is recommended for assessing lung nodules, while MinIP is recommended for airway evaluation (Figure 1). The expected radiation dose for NCCT protocols is 3-8 mSv [1, 6, 7].

Low dose CT (LDCT)

Low dose computed tomography (LDCT) significantly contributes to reducing mortality from lung cancer, which is currently one of the leading causes of death [8]. It is particularly beneficial for patients requiring repeated imaging, as it significantly reduces the cumulative radiation dose, aligning with the ALARA (As Low As Reasonably Achievable) principle [1]. LDCT has become the standard for lung cancer screening by increasing the rate of early detection while maintaining a low radiation dose (Figure 2) [9]. During the procedure, the patient lies supine on the table in a craniocaudal orientation. The scanning field covers an area from 1 cm above the lung apex to below the lung base. The scan is performed during inspiration, and the patient must hold their breath briefly during the imaging. The tube voltage ranges from 80-120 kV, and the tube current is 20-40 mAs [1, 10, 11]. However, some studies suggest that a tube current of 10 mAs does not significantly affect the sensitivity for detecting lung nodules, indicating that this value should be considered the diagnostic threshold [12]. For LDCT, the slice thickness is between 1.2-1.5 mm, and the image matrix is a standard size of 512x512 pixels [1]. Thanks to advanced techniques like iterative reconstructions, LDCT provides satisfactory image quality, with sensitivity and specificity in detecting lung nodules comparable to standard CT [13]. The advantage of iterative algorithms is the reduction of noise while preserving spatial resolution, CT number accuracy, and linearity. In addition to lung information, LDCT can also provide diagnostic data for cardiovascular diseases and

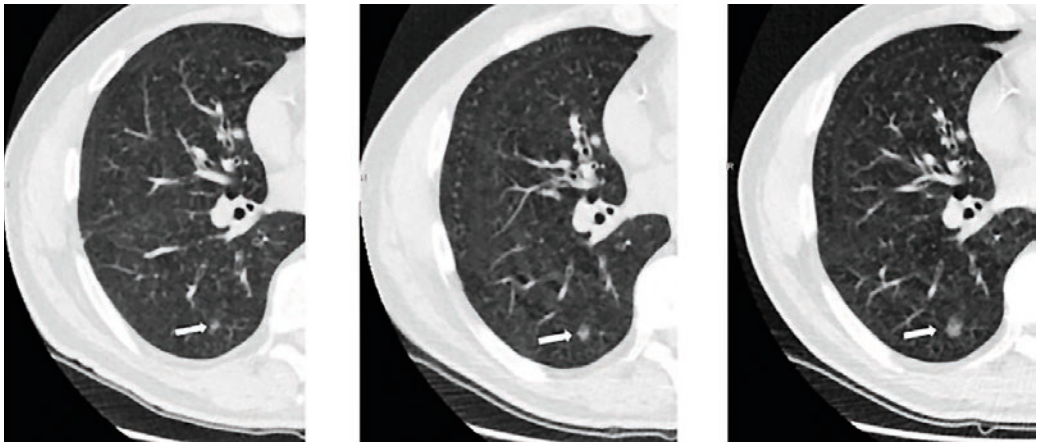


Figure 2. Monitoring of a pulmonary nodule using the LDCT protocol First image (2007) shows a nodule measuring 5.5 mm; second image (2009) shows a nodule measuring 8.5 mm; third image (2012) shows a nodule measuring 11 mm
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3569671/

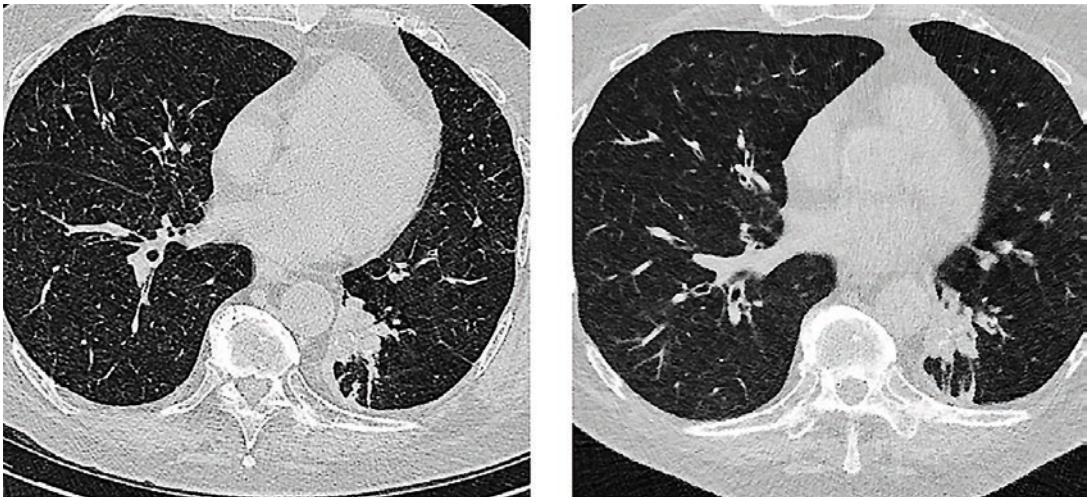


Figure 3. Depiction of chest CT in MIP (left image) and MinIP projection (right image)
Source: https://radiologysa.com.au/subspecialty-services/ultra-low-dose-ct-chest

COPD (Chronic Obstructive Pulmonary Disease) [14]. The expected radiation dose for LDCT protocols is 1-3 mSv [1].

Ultra-LDCT

Low-dose diagnostic methods, including ultra-LDCT, have garnered increasing interest in recent years. It is an excellent choice for lung cancer screening, detecting pneumonia and pneumothorax, as well as for patients requiring repeated imaging or when further clarification of conventional X-ray findings is needed [15, 16]. The tube voltage used in this CT protocol is 120 kV, with a current of 10-20 mAs and a slice thickness of 1 mm. A key feature of ultra-LDCT is the dose of < 1.5 mSv [1, 17]. Although lower doses increase image noise, this can be significantly reduced using iterative reconstruction techniques, thereby improving image quality [18]. There is an ongoing debate about the potential use of ultra-LDCT instead of conventional X-rays for selected indications, even in emergency cases. In images obtained by ultra-LDCT, mucosal airway filling and partial collapse of the left lower lung lobe remain clearly visible (Figure 3). However, the availability and cost of this diagnostic method pose challenges, so it is anticipated that it will not enter routine use in the near future [17, 19].

Cine CT

The assessment of the heart throughout the entire cardiac cycle became possible with the introduction of the multiphase acquisition technique, cine CT (*Cinematic Computed Tomography*). Cine CT, or 4D CT, provides dynamic imaging for functional analysis during systole and diastole. The reconstructed cine images allow the visualisation of contraction and relaxation during the cardiac cycle, offering insights into heart wall motion [20]. The primary drawback of this CT protocol is the high radiation dose, which can range from 6 to 15 mSv, along with low temporal resolution. The use of Multi-Segment (MS) reconstructions can help reduce the dose [20, 21]. In addition to heart imaging, cine CT enables continuous recording of other body movements, such as breathing. It can therefore be used to reliably assess dynamic airway collapse. Once the region of collapse is localised, cine CT with a slice thickness of 2 mm, an X-ray tube voltage of 120 kV, and a current of 53-145 mAs continuously collects data while the patient breathes deeply and slowly. Cine CT has been shown to have comparable diagnostic efficacy to flexible bronchoscopy [1, 22].

CECT PROTOCOLS

The use of contrast agents in CT protocols enables reliable identification of blood vessel anatomy, facilitates the differentiation of adjacent non-vascular structures, and improves the detection and characterization of pathological lesions. Contrast agents are employed in the assessment of mediastinal structures, vascular structures, chronic pleural diseases, and other conditions [23].

Routine CECT

The routine CECT protocol generally retains the same parameters as NCCT, with the addition of contrast administration. CECT of the chest is often extended to include the upper abdomen (liver and adrenal glands) for the initial staging and follow-up of lung cancer, and to the neck and abdomen for assessing Pyrexia of Unknown Origin (PUO) or other malignancies, such as lymphoma (Figure 4) [1]. The patient is positioned supine on the table in a craniocaudal direction, with scanning starting, as before, from 1 cm above the lung apex to the lung base, while breath is held during inspiration. Tube voltage settings of 120 kV and tube current of 150 mAs are typically selected [24]. The scan delay, or the time interval between contrast administration and the start of scanning, depends on the body region being imaged, diagnostic needs, and the patient's physiological factors. To minimise patient dose, factors such as age, sex, height, weight, and underlying pathology should be considered. The use of iterative reconstruction improves image quality by reducing noise [25]. Current CT devices allow the use of 1-1.5 ml/kg of contrast agent for a routine CECT protocol [1]. The expected radiation dose for CECT protocols is approximately 6.1 mSv [26].

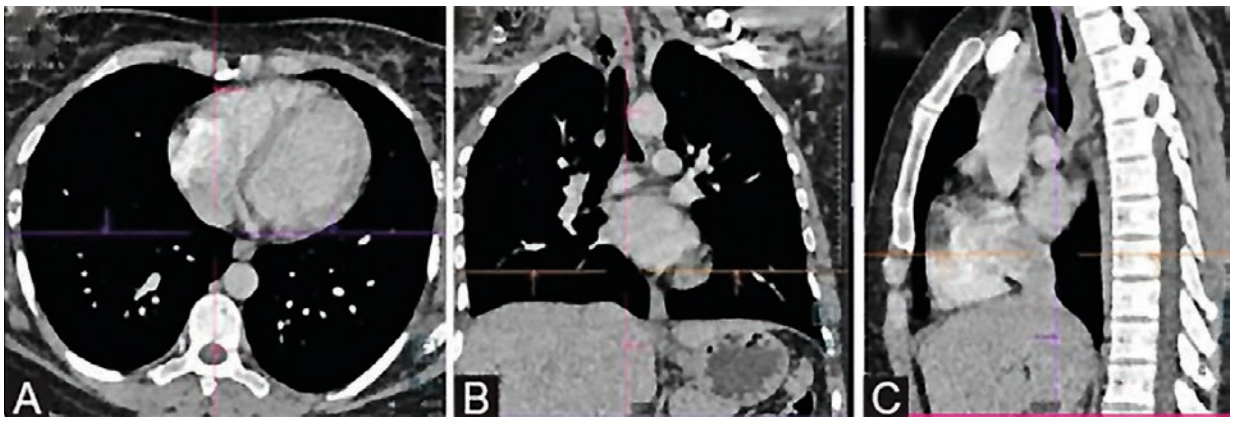


Figure 4. Illustration of routine CECT protocol in axial, coronal, and sagittal planes
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6857267/#ref18

CT an giography (CTA)

The computed tomography angiography (CTA) protocol is used for diagnosing and evaluating various vascular pathologies, such as aneurysms, blood clots, vascular malformations, and vessel dissections (Figure 5) [27]. It is particularly important for diagnosing acute aortic syndrome, which is associated with high morbidity and mortality [28]. The patient is positioned supine on the table in a craniocaudal direction, with scanning conducted from 1 cm above the lung apex to the lower boundary of the L2 vertebra. Imaging is performed during inspiration, with an X-ray tube voltage of 100-120 kV, a tube current of 150 mAs, and a contrast injection rate of 3-5 ml/s. In CTA, bolus tracking is employed to determine the optimal timing for imaging as the contrast passes through the vessels. A region of interest (ROI) is placed on a selected vessel, and a threshold of Hounsfield units (e.g., 130 HU) is used to trigger the scan. The aorta is opacified with contrast for 15-20 seconds, depending on cardiac output. The reconstruction slice thickness is < 2 mm. Reconstruction settings are adjusted with a mediastinal window width of 400 HU and a centre of 40 HU (soft tissue algorithm: 30 kernel). Sagittal plane image reconstruction at a 45° angle displays the aorta from proximal to distal, aiding in aortic pathology assessment [1, 28, 29]. Image quality can be affected by pulsation artefacts, but these can be minimised by synchronising with ECG [28].

CT pulmonary angiography (CTPA)

The primary role of Computed Tomography Pulmonary Angiography (CTPA) is the diagnosis and assessment of pulmonary embolism (PE), the third most common cause of cardiovascular death, following stroke and myocardial infarction. CTPA offers high sensitivity (96-100%) and specificity (89-98%) in detecting PE (Figure 6) [30]. The patient is positioned supine, but in a caudocranial direction to avoid streak artefacts from contrast media in the superior vena cava or subclavian vein. Scanning extends from the lung apex to just below the lung base, except in pregnant women and young patients with minimal suspicion of PE, where it is limited to just above the aortic arch to just below the heart. The scan should be performed during shallow inspiratory breath-hold. The tube voltage is 80-120 kV, depending on the patient's body mass index (BMI), and the tube current is 150-200 mAs. The contrast injection rate is 3-4 ml/s if the patient has a normal resting heart rate [1, 31]. Images are displayed in the pulmonary

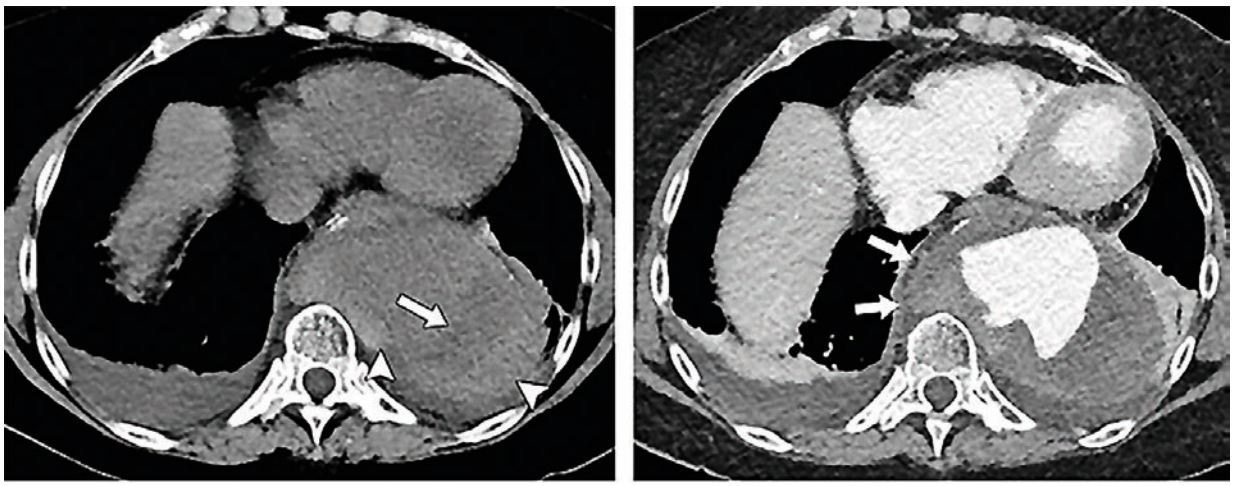


Figure 5. Aneurysm rupture; axial non-contrast image (left) and axial post-contrast image (right)
Source: file:///C:/Users/miaml/Downloads/ko-et-al-2021-chest-ct-angiography-for-acute-aortic-pathologic-conditions-pearls-and-pitfalls.pdf

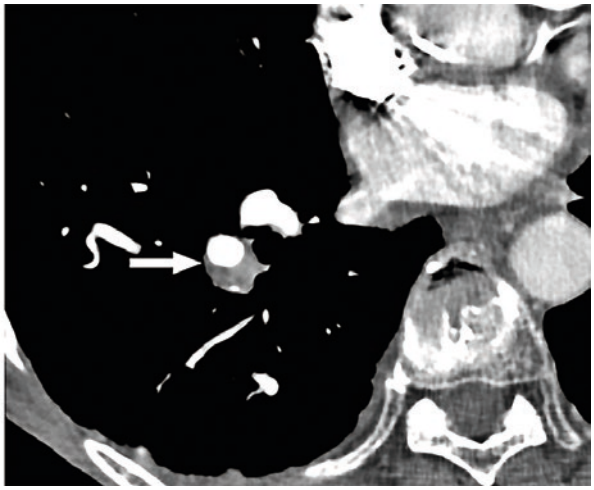


Figure 6. FIGO stage IIA2 cervical cancer (>4 cm) in the sagittal plane on T2-weighted imaging
Source: https://zir.nsk.hr/islandora/object/mef:3661/datastream/PDF/view

window (window width, 1500 HU; window centre, -600 HU), the mediastinal window (window width, 350 HU; window centre, 40 HU), and the PE-specific window (window width, 700 HU; window centre, 100 HU), which is critical as PE may be missed if only viewed in the mediastinal window due to strong contrast [32]. In addition to iterative reconstructions that reduce image noise, MIP reconstruction is also applied [1].

CTA for hemoptysis

Hemoptysis is the expectoration of blood from the tracheobronchial tree, most commonly caused by bronchiectasis, chronic bronchitis, and lung cancer, and represents a life-threatening condition. The expectorated blood typically originates from the bronchial arteries. Computed Tomography Angiography (CTA) is a non-invasive method that can identify the presence, origin, number, and course of systemic thoracic and pulmonary arterial sources of bleeding. After confirming the suspicion of hemoptysis, it is essential to determine its severity, locate the site of bleeding, and identify the underlying cause. The image shows a coronal maximum intensity projection (MIP) of a CT scan with consolidation in the upper lobe and bronchiectasis. Enlarged right-sided orthotopic bronchial arteries (arrow) are visible in the mediastinum (Figure 7). CTA successfully identifies the bleeding site in 70-88% of cases [33]. In a CT protocol for hemoptysis, the patient is positioned supine in a craniocaudal orientation, and the scanning area extends from the base of the neck to the level of the renal arteries, corresponding to the L2 vertebra. The scan is performed during maximal inspiratory breath-hold. The tube voltage is set at 120 kV, with a tube current of 180 mAs, and the slice thickness is 1.25 mm [1, 34]. High-resolution reconstructions of the pulmonary parenchyma are suitable for assessing the cause of bleeding and its impact on the parenchyma, while multiplanar and volumetric reconstructions are used for airway evaluation [33].

TRO CT

Triple Rule Out Computed Tomography (TRO CT) is an angiographic protocol designed to evaluate the aorta, coronary artery, pulmonary artery, and lower half of the thorax in a single scan. It is a valuable tool for assessing patients with acute chest pain in emergency situations, aiding in the exclusion of acute coronary syndrome, pulmonary embolism (PE), or acute aortic syndrome (Figure 8) [1, 35, 36]. The scanning area extends from the upper arch of the aorta to below the heart. The tube voltage is set at 120 kV, and the tube current at 600 mAs. In the absence of tube modulation, the radiation dose for the patient is 18 mSv, while with tube modulation, the dose is reduced to 8.75 mSv. To complete the scan in a single breath-hold, the device must be capable of scanning the required volume using ECG monitoring within a maximum of 15 seconds, necessitating a CT scanner with at least 64 detector rows. ECG synchronisation eliminates motion artefacts related to heartbeats [1, 35]. For image reconstruction, techniques such as multiplanar reconstruction (MPR), maximum intensity projection (MIP), volume rendering technique (VRT), and curved-planar reformation (CPR) can be utilised [37].



Figure 7. Hemoptysis in a 28-year-old male with cystic fibrosis
Source: https://pubs.rsna.org/doi/10.1148/rg.2021200150

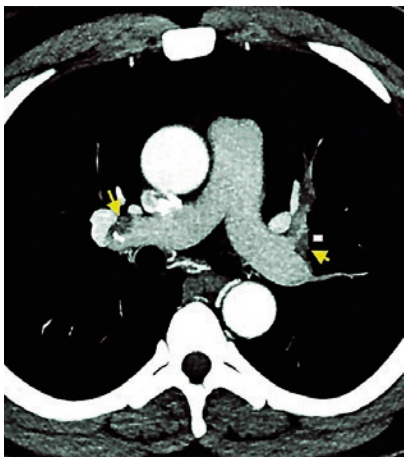


Figure 8. TRO CT image of a 38-year-old male with chest pain: extensive bilateral PE detected
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10028717/

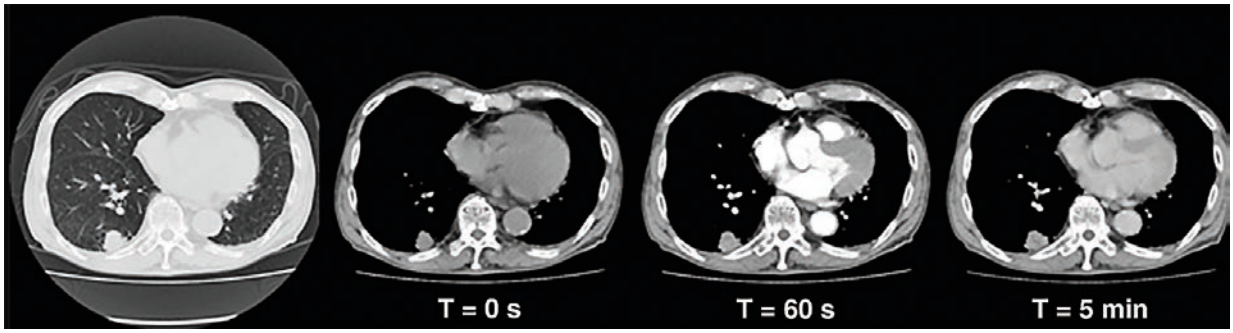


Figure 9. 79-year-old male with lung adenocarcinoma
Source: https://www.ajronline.org/doi/10.2214/AJR.13.11888

DCE-CT

Dynamic Contrast Enhanced Computed Tomography (DCE-CT) is a functional imaging technique that involves capturing a dynamic series of images over time following the administration of contrast agents. It allows for the monitoring of changes in tissue vascularization and perfusion, making it useful in diagnosing various pathological conditions, including tumours. However, DCE-CT has certain limitations, such as when nodules are smaller than 8 mm or in patients with panic attacks or difficulty holding their breath [38]. There are two approaches for conducting DCE-CT protocols. The first is the „first pass" method, which tracks dynamic changes in the distribution of the contrast agent during its initial passage through the target area, usually a tumour or lesion. This approach involves rapid and continuous image acquisition after the contrast injection, followed by the assessment of various perfusion-related parameters. The first image on the left shows a non-contrast scan, while the images on the right display DCE-CT images. „T" denotes the time after the bolus administration of the contrast agent, and the images show a 25 mm nodule in the right lower lobe (Figure 9). This technique is primarily used in research settings [39]. The second method, currently used in clinical practice, involves the analysis of dynamic image series of the nodule before and after contrast administration. This technique allows for the measurement of the nodule's maximum average enhancement in Hounsfield units (HU), with malignant nodules typically demonstrating higher contrast enhancement (an increase of >20 HU at 100 kV) [40, 41]. The recommended tube voltage is 100 kV, while the tube current is determined by the patient's weight: 200 mAs for patients weighing <60 kg, 350 mAs for those between 60-90 kg, and 500 mAs for patients weighing >90 kg. The slice thickness is 3 mm, with reconstructions performed at 2 mm thickness. The nodule should be analysed in the mediastinal window (window width 400 HU, window centre 40 HU) in the axial plane [38].

Paediatric application of CT chest protocols

The use of ionising radiation in paediatrics is always a concern, which is why it is crucial to carefully analyse the benefits and risks and strictly adhere to the ALARA principle [42]. Radiation doses in children are significantly more carcinogenic than equivalent doses in adults for several reasons, including their longer life expectancy, which increases the risk of radiation-induced tumour development [43]. Due to the higher heart rate in children, it is preferable to use faster CT scanners. LDCT protocols are recommended, requiring 34-50 mAs for quality imaging, instead of the standard 100-200 mAs [44, 45]. The optimization of CT protocols aims to achieve diagnostic image quality with minimal radiation exposure [46]. During chest CT imaging in paediatrics, patients lie in the supine position in a craniocaudal direction, with the scan area covering from the lung apex to the lung base. For all patients, including paediatric ones, it is desirable to raise their arms above their heads for chest imaging. Tube voltage is adjusted based on the child's weight; for children weighing less than 9 kg, 80 kV is required, while for those weighing 10-25 kg, 100 kV is used. The X-ray tube current should be reduced to the extent that the resulting image noise does not interfere with the radiologist's interpretation of the CT image. In some cases, the use of contrast agents is necessary, with a dosage of 1.5-2 ml/kg [42, 46, 47]. Improved temporal resolution reduces the need for sedation in the paediatric population. In addition to sedation, ECG synchronisation is also commonly used [44]. The expected dose for children is 2.5 mSv (ages 1-5) and 3 mSv (ages 6-10), compared to the adult dose of 5.9 mSv for chest CT examinations [48].

Conclusion

CT significantly enhances the quality and accuracy of diagnosing various thoracic diseases. Detailed imaging protocols for chest CT and their execution procedures have been thoroughly described. The selection of an appropriate CT protocol is critical for accurate diagnosis and monitoring of various pathological conditions, with protocol choice based on clinical indications and the patient's condition. The primary classification of protocols distinguishes between those using contrast agents and those without. Contraindications for contrast agent use may include poor renal function or the presence of allergies. When determining technical settings, individual patient characteristics, such as body weight and height, must be taken into consideration. Reconstruction methods greatly improve the quality of diagnostic images while reducing the radiation dose. It is important to carefully assess the benefits and risks of using ionising radiation, adhering to the ALARA principle during procedures. Special emphasis

is placed on paediatric patients regarding the use of ionising radiation. Through protocol optimization and the application of advanced techniques, such as LDCT and ECG synchronisation, diagnostic image quality is ensured while minimising radiation exposure. In conclusion, continuous protocol optimization and technological advancements contribute to increasing reliability and safety in diagnosing various thoracic pathologies, paving the way for early detection and precise disease monitoring.

All data in this paper are part of the results of the undergraduate thesis „Imaging protocols for chest CT“ written at the University Department of Health Studies, University of Split [49].

Pregled slikovnih protokola za CT prsnog koša

Sažetak

Kompjutorizirana tomografija (CT) je česta metoda izbora kada je u pitanju dijagnostika bolesti prsnog koša. Budući da CT radi na principu ionizirajućeg zračenja, a uz to je i česta primjena kontrastnog sredstva, nužno je standardizirati CT protokole ne bi li se smanjila potreba za ponovnim snimanjem, a samim time i izloženost pacijenta zračenju. Odabir CT protokola prvenstveno ovisi o kliničkim indikacijama i potrebama pacijenta. Glavna podjela CT protokola je ona na primjenu kontrastnog sredstva (CECT) i bez primjene (NCCT) istog. LDCT protokol odlikuje se niskom dozom zračenja te visokom osjetljivošću otkrivanja plućnih čvorova, zbog čega se primjenjuje za probir raka pluća. Ultra-LDCT daje zadovoljavajuće rezultate prilikom dijagnosticiranja upale pluća i pneumotoraksa. Procjenu srčane funkcije tijekom cijelog srčanog ciklusa, omogućuje pak cine CT, ali uz visoku dozu zračenja i nisku vremensku rezoluciju. Primjena kontrastnih sredstava prednjači prilikom razlikovanja susjednih nevaskularnih struktura, preciznijeg identificiranja anatomije krvnih žila te bolje detekcije i karakterizacije patoloških lezija. Za dijagnosticiranje vaskularnih patologija, primjenjuje se CTA, dok je CTPA ključna u dijagnosticiranju PE s visokom osjetljivošću i specifičnošću. TRO CT je koristan kod akutne boli u prsima, ne bi li se isključila hitna stanja. Dinamičke promjene u perfuziji tkiva prati DCE-CT, a koristan je i u dijagnostici tumora. Pedijatrijska primjena CT protokola za prsni koš naglašava važnost primjene najniže moguće doze zračenja i kontrastnog sredstva kako bi se rizici sveli na minimum.

Ključne riječi: bezkontrastni CT prsnog koša; CT; CT angiografija; kontrastni CT prsnog koša; niskodozni CT

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PROFESSIONAL PAPER (STRUČNI RAD)

Treba li nam sustav za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji?

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Sažetak:

Cilj: Ovim radom nastoji se ukazati na važnost uspostave sustava za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji.

Metode: Studija je provedena retrospektivno, usporedbom kvalitete radiološke slike i načina dobivanja radiološke slike. Ocijenjeno je 20 radioloških slika zdjelice, a ocjena je provedena prema europskim kriterijima za kvalitetu radiološke slike zdjelice. Kvalitetu slike su ocjenjivali radiolog, radiološki tehnolog i student radiološke tehnologije. Usporedbom s istim kriterijem analiziran je i način rada pri oslikavanju zdjelice u 3654 pacijenta te srca i pluća u 57758 pacijenata. Analizirana je i praksa sužavanja rendgenskog snopa na područje od interesa za 50 radioloških slika srca i pluća.

Rezultati: Samo jedna slika zdjelice ocijenjena je najvećom mogućom ocjenom od strane sva tri ocjenitelja. Subjektivne procjene ocjenitelja vezano uz odabir parametara ekspozicije razlikovale su se u većini ocjenjivanih slika zdjelice. Naponi na rendgenskoj cijevi korišteni pri oslikavanju zdjelice većinom su bili u preporučenom rasponu, dok su za srce i pluća u većini slučajeva bili manji od preporučene vrijednosti. Zdjelice su većinom oslikavane korištenjem udaljenosti žarišta rendgenske cijevi od prijemnika slike koje su bile u prihvatljivom rasponu osim u slučaju onih pacijenata koji su za vrijeme oslikavanja stajali. U slučaju oslikavanja srca i pluća ove su udaljenosti uglavnom bile u prihvatljivom rasponu osim u slučaju ležećih pacijenata kada je veći broj pacijenata oslikan korištenjem manjih udaljenosti. Svih 50 analiziranih radioloških slika srca i pluća bilo je uređeno na način da su po provedenom oslikavanju uklonjeni rubni dijelovi slike.

Zaključci: Rezultati provedene analize ukazuju na potrebu uspostave i provedbe sustava za ocjenu kvalitete radiološke slike koji bi uključivao i analizu načina rada.

Ključne riječi: kvaliteta radiološke slike, ekspozicijski indeks, napon na rendgenskoj cijevi, udaljenost žarišta od rendgenske cijevi, kolimacija

Uvod

Hrvatski propisi nalažu korisniku izvora ionizirajućeg zračenja koji se u medicini koristi za provedbu dijagnostičkog, intervencijskog ili radioterapijskog postupka uspostavu i provedbu programa osiguranja kvalitete [1]. Program osiguranja kvalitete, među ostalim, mora obuhvaćati i opis načina bilježenja i analize odbačenih ili nekvalitetnih radioloških slika [1]. Propisi, međutim, ne nalažu i analizu radioloških slika koje su prihvaćene kao radiološke slike zadovoljavajuće kvalitete. Analizu ovih slika preporučuju međunarodne preporuke poput primjerice europskih koje

su dane za konvencionalnu radiografiju [2,3], konvencionalnu radiografiju dječjih pacijenata [4] i kompjutoriziranu tomografiju [5]. U navedenim preporukama dani su kriteriji vezano uz vidljivost pojedinih anatomskih struktura na radiološkoj slici, a dane su i preporučene vrijednosti pojedinih parametara oslikavanja, udaljenosti žarišta rendgenske cijevi od prijemnika slike, veličine žarišta rendgenske cijevi, položaj pacijenta tijekom oslikavanja, projekcija i drugo.

U zadnje vrijeme puno se pažnje posvećuje optimizaciji provedbe dijagnostičkog postupka, a time i kvaliteti radiološke slike pri oslikavanju kompjutoriziranom tomografijom [6–8] obzirom da je to modalitet koji rezultira većim ili značajno većim ozračenjem pacijenta od drugih modaliteta, ovisno o provedenom postupku [9]. No ipak, prema zadnjem izvješću Znanstvenog odbora Ujedinjenih naroda za učinak ionizirajućeg zračenja (UNSCEAR, od engl. *United Nations Scientific Committee on the Effects of Atomic Radiation*) iz 2021. godine, učestalost oslikavanja konvencionalnom radiografijom je veća nego kompjutoriziranom tomografijom pri čemu doprinos ozračenju stanovništva nije zanemariv. Prema UNSCEAR izvješću koje prikazuje rezultate analize podataka koje je za razdoblje 2009. – 2018. godine dostavilo četrdesetak država svijeta, udio dijagnostičkih postupaka provedenih konvencionalnom radiografijom iznosi oko 63 % pri čemu ozračenju stanovništva kao posljedici medicinskog ozračenja doprinose s 23 % [10]. Iz tog bi razloga neopravdano bilo zanemariti važnost optimizacije ovih dijagnostičkih postupaka. Jedan od doprinosa optimizaciji svakako je i provedba redovite ocjene kvalitete radioloških slika učinjenih konvencionalnom radiografijom [11].

Cilj ovoga rada je temeljem analize radioloških slika zdjelice te srca i pluća učinjenih konvencionalnom radiografijom ukazati na važnost uspostave sustava za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji.

Materijali i metode

Studija je provedena retrospektivno. Prikupljeni su podaci o radiološkim slikama zdjelice te srca i pluća odraslih pacijenata učinjenih tijekom godine dana (u vremenskom periodu 1.8.2023. – 31.7.2024.) konvencionalnom radiografijom korištenjem tri rendgenska uređaja. Svaki rendgenski uređaj ima mogućnost generiranja strukturiranog doznog izvješća (RDSR, od engl. *radiation dose structured report*). Rendgenski uređaji su označeni slovom R te brojevima 1, 2 i 3 kako bi se osigurala anonimnost. Sva tri rendgenska uređaja su stacionarna, odnosno u ovom radu nisu analizirane radiološke slike nastale korištenjem pokretnih rendgenskih uređaja. Jedan rendgenski uređaj koristi se za potrebe hitne službe (rendgenski uređaj R3). Podaci su prikupljeni korištenjem sustava za praćenje ozračenja pacijenata (DMS, od engl. *dose management system*). Analiziran je način rada, odnosno način provedbe oslikavanja na temelju podataka sadržanih u RDSR-u za ukupno 61409 radioloških slika. Broj radioloških slika za pojedinu anatomsku regiju, rendgenski uređaj te način oslikavanja i projekciju dan je u tablici 1. Pacijenti koji su oslikani ležeći u krevetu su za potrebe oslikavanja dovezeni u snimaonicu.

Ocjena kvalitete provedena je za 20 nasumično odabranih radioloških slika zdjelice prema kriterijima koji su dani u europskim preporukama [2,3]. Kriteriji prema kojima se ocjenjivala kvaliteta odabranih radioloških slika dani su u tablici 2. Na slici 1. su na radiološkoj slici zdjelice označena područja koja su se ocjenjivala. Ukoliko je na radiološkoj slici pojedina struktura bila vidljiva na način kako kriterij zahtijeva, radiološkoj slici je pridijeljen 1 bod. Pojedinoj radiološkoj slici moglo je biti pridijeljeno najviše 7 bodova. Ocjenu kvalitete radiološke slike proveli su student završne godine studija radiološke tehnologije, radiološki tehnolog s 40 godina radnog iskustva u struci te

Tablica 1. Ukupan broj analiziranih radioloških slika po rendgenskom uređaju

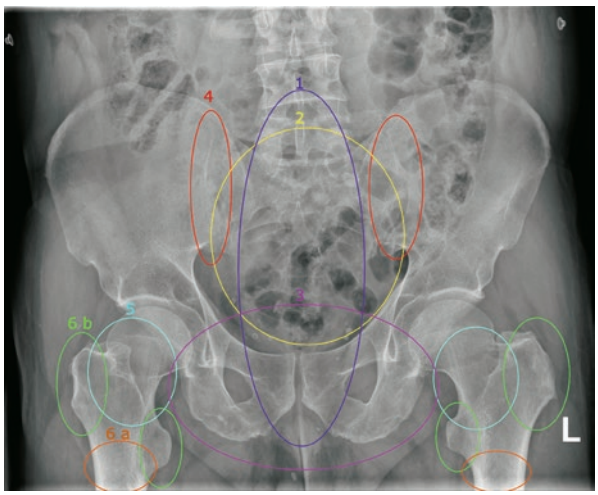
Anatomska regija	Oznaka rendgenskog uređaja	Položaj pacijenta i projekcija	Broj analiziranih radioloških slika	
			Za položaj pacijenta i projekciju	Ukupno za anatomsku regiju po uređaju
Zdjelica	R1	Ležeći AP	599	619
		Stojeći AP	20	
	R2	Ležeći AP	442	954
		Stojeći AP	493	
		U krevetu AP	19	
	R3	Ležeći AP	1516	2078
Srce i pluća	R1	Stojeći LAT	5130	10904
		Stojeći PA	5774	
	R2	Stojeći LAT	3889	8913
		Stojeći PA	4691	
		Ležeći AP	16	
		U krevetu AP	317	
	R3	Stojeći LAT	14007	37941
		Stojeći PA	16202	
		Ležeći AP	148	
		U krevetu AP	7584	
		Stojeći AP	562	

doktor medicine specijalist kliničke radiologije s 20 godina radnog iskustva u struci. Ocjenitelji su bili zamoljeni i da za svaku radiološku sliku procijene je li podeksponirana ili preeksponirana ili su, prema njihovom mišljenju, tijekom oslikavanja odabrani odgovarajući parametri ekspozicije.

Tablica 2. Kriteriji za ocjenjivanje kvalitete radiološke slike zdjelice (AP projekcija) konvencionalnom radiografijom [2,3]

R.b.	Kriterij za ocjenjivanje radiološke slike zdjelice (AP projekcija)
1	Simetrični prikaz zdjelice prema pomaku pubične simfize/preponskog sraštenja (lat. *symphysis pubica*) preko medijalne ravnine križne kosti (lat. *os sacrum*)
2	Vizualno oštar prikaz križne kosti i njenih prednjih i stražnjih sakralnih otvora (lat. *foramina sacralis anterior et posterior*)
3	Vizualno oštar prikaz grana stidne (lat. *ramus superior et inferior ossis pubis*) i sjedne (lat. *ramus ossis ischii*) kosti
4	Vizualno oštar prikaz sakroilijakalnih/križno-bočnih sveza (lat. *ligg. sacroiliaca*)
5	Vizualno oštar prikaz vrata bedrene kosti (lat. *collum femoris*) koji ne smije biti iskrivljen skraćivanjem ili rotacijom
6	Vizualno oštar prikaz a) spongioznog (lat. *substantia spongiosa*) i kompaktnog (lat. substantia comapacta) b) koštanog tkiva velikog i malog obrtača (lat. *trochanter major et minor*)

Način rada analiziran je za sve radiološke slike zdjelice te srca i pluća učinjenih tijekom prethodno navedenog perioda. U tablici 3. su dane vrijednosti pojedinih parametara provedbe oslikavanja zdjelice te srca i pluća konvencionalnom radiografijom korištenjem stacionarnih rendgenskih uređaja koji se smatraju primjerom dobre prakse, a preuzete su iz europskih preporuka [2,3]. Za svaku radiološku sliku su vrijednosti pojedinih parametara koje su dane u RDSR-u uspoređene s vrijednostima danim u tablici 3. Spomenute preporuke ne predviđaju oslikavanje zdjelice bez korištenja rešetke u onih pacijenata koji leže u krevetu pa su vrijednosti uspoređene s vrijednostima danim za slučaj korištenja rešetke. Spomenute preporuke ne predviđaju niti oslikavanje srca i pluća u pacijenata koji leže (na ležaju ili u krevetu) korištenjem stacionarnih rendgenskih uređaja, a prema saznanjima kojima raspolažu autori ovoga rada, preporuke za ovakav položaj pacijenta pri oslikavanju srca i pluća postoje samo za slučaj korištenja pokretnih rendgenskih uređaja sukladno kojima se oslikavanje srca i pluća pacijenata koji leže u krevetu korištenjem pokretnih rendgenskih uređaja provodi s udaljenosti žarišta rendgenske cijevi od prijemnika slike od 100 cm te naponima na rendgenskoj cijevi većima od 100 kV ukoliko se koristi rešetka i u rasponu 80 – 90 kV ako se rešetka ne koristi [2]. Iz tog su razloga vrijednosti pojedinih parametara korištenih pri oslikavanju ležećih pacijenata stacionarnim rendgenskim uređajima uspoređene i s preporukama za oslikavanje pacijenata koji stoje korištenjem stacionarnih rendgenskih uređaja (tablica 3.) i s preporukama za oslikavanje pokretnim rendgenskim uređajima [2].



Slika 1. Prikaz zdjelice uz označena područja ocjenjivanja kvalitete prema kriterijima koji su dani u tablici 2. (Izvor: autor)

Tablica 3. Primjer dobre radiografske tehnike oslikavanja zdjelice te srca i pluća konvencionalnom radiografijom korištenjem stacionarnih rendgenskih uređaja [2,3]

		Zdjelica	Srce i pluća
Položaj pacijenta		Ležeći ili stojeći	Stojeći
Projekcija		AP	PA, LAT
Udaljenost žarišta rendgenske cijevi od detektora (cm)	**Preporučena**	115	180
	Prihvatljivi raspon	100 – 150	140 – 200
Napon na rendgenskoj cijevi (kV)		75 – 90	125

Jedan od rendgenskih uređaja uključenih u ovu studiju generira RDSR koji sadrži i podatke o korištenoj veličini (površini) rendgenskog snopa (visina i širina). Ova vrijednost uspoređena je s veličinom slike poslane u PACS za 50 nasumično odabranih radioloških slika srca i pluća.

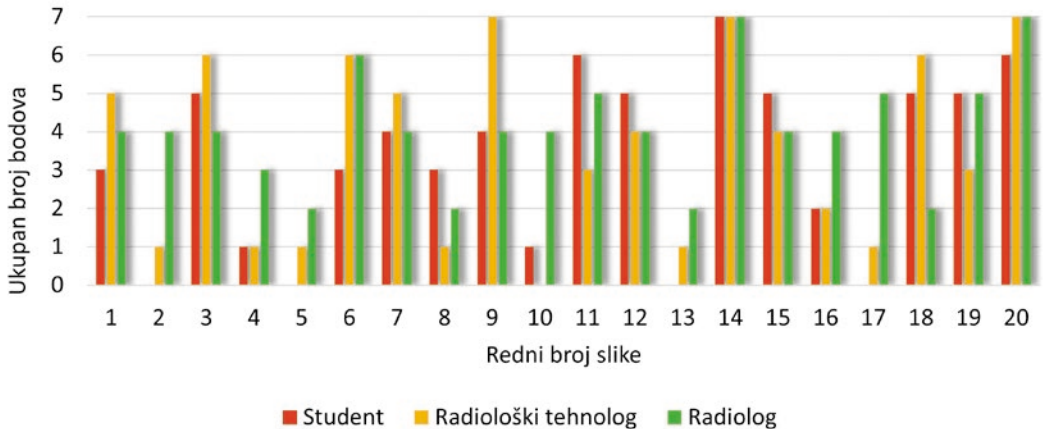
Rezultati

Ocjena kvalitete radiološke slike zdjelice

Pridijeljeni bodovi za svaki kriterij za svaku radiološku sliku zdjelice prikazani su na slici 2. Najmanji broj bodova pojedinom kriteriju pridijelio je student (46 %), zatim radiološki tehnolog (51 %) te radiolog (59 %). Ukupan broj bodova pridijeljen pojedinoj radiološkoj slici prikazan je na slici 3. Radiolog je 45 % slika ocijenio kvalitetnijima nego student i radiološki tehnolog, a radiološki tehnolog 50 % više slika nego student. Samo jednoj slici (5 %) i student i radiološki tehnolog i radiolog pridijelili su najveći mogući broj bodova.

R.b. slike	1. Simetrični prikaz zdjelice prema pomaku pubične simfize/preponskog sraštenja reko medijalne ravnine križne kosti			2. Vizualno oštar prikaz križne kosti i njenih prednjih i stražnjih sakralnih otvora			3. Vizualno oštar prikaz grana stidne i sjedne kosti			4. Vizualno oštar prikaz sakrolilijakalnih/križ no-bočnih sveza			5. Vizualno oštar prikaz vrata bedrene kosti koji ne smije biti iskrivljen skraćivanjem ili rotacijom			6a. Vizualno oštar prikaz spongioznog i kompaktnog koštanog tkiva			6b. Vizualno oštar prikaz velikog i malog obrtača		
	Student	Radiološki tehnolog	Radiolog	Student	Radiološki tehnolog	Radiolog	Student	Radiološki tehnolog	Radiolog	Student	Radiološki tehnolog	Radiolog	Student	Radiološki tehnolog	Radiolog	Student	Radiološki tehnolog	Radiolog	Student	Radiološki tehnolog	Radiolog
1					■			■	■				■	■	■	■	■	■	■	■	■
2			■					■	■									■			■
3		■		■	■		■	■	■				■	■	■	■	■		■	■	■
4									■							■	■	■		■	■
5									■		■							■			
6	■	■	■	■				■	■	■	■	■		■	■		■	■		■	■
7	■	■	■		■		■	■	■	■	■				■	■		■		■	
8									■				■			■			■	■	■
9	■	■	■		■		■	■	■		■		■	■	■	■	■	■		■	
10			■						■							■		■			■
11	■	■	■	■			■	■	■	■			■	■	■	■		■			■
12				■			■	■	■				■	■	■	■	■	■	■	■	■
13		■																■			■
14	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
15	■	■	■	■			■	■	■				■	■	■	■				■	■
16	■		■				■	■	■									■		■	■
17			■					■	■						■			■			■
18	■	■	■	■	■		■	■	■				■	■		■	■			■	
19	■	■					■	■	■	■		■	■	■	■	■	■	■			■
20	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■

Slika 2. Bodovi za pojedini kriterij za svaku sliku. Zelena polja označavaju udovoljavanje kriteriju (1 bod), a bijela polja neudovoljavanje kriteriju (0 bodova) (Izvor: autor)

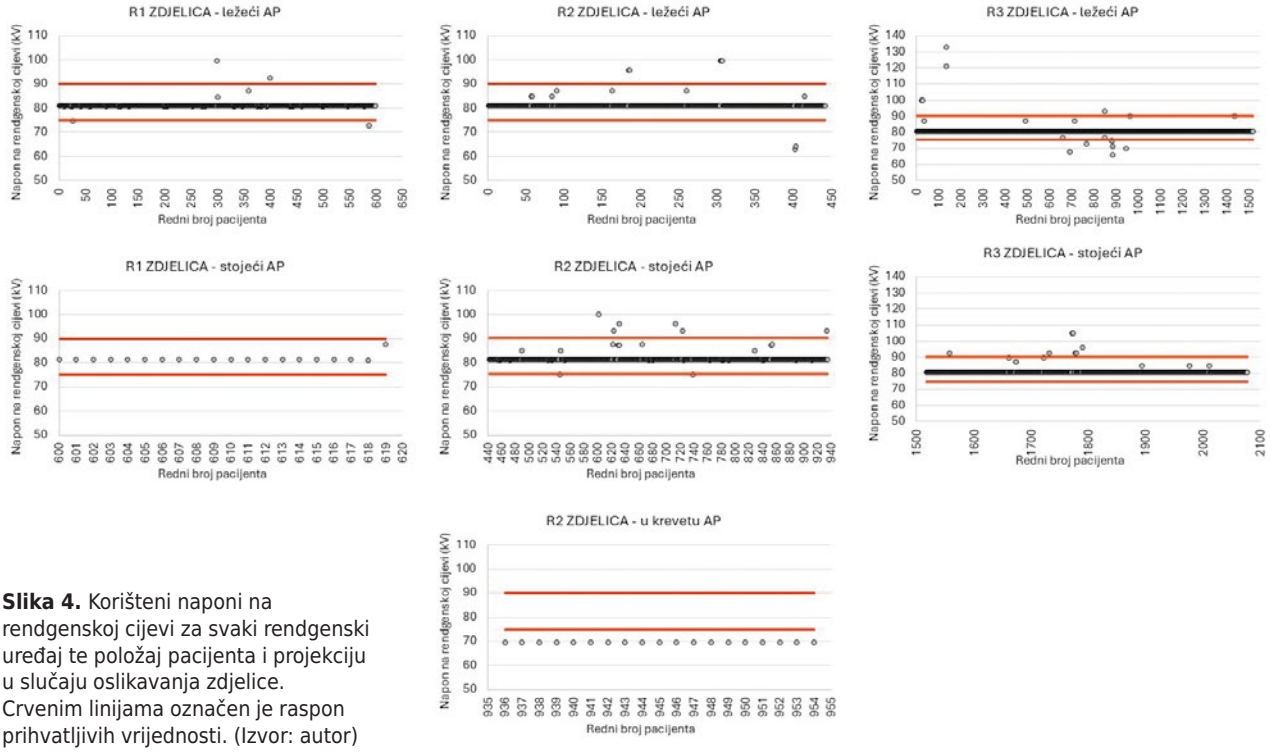


Slika 3. Ukupan broj bodova za svaku sliku (Izvor: autor)

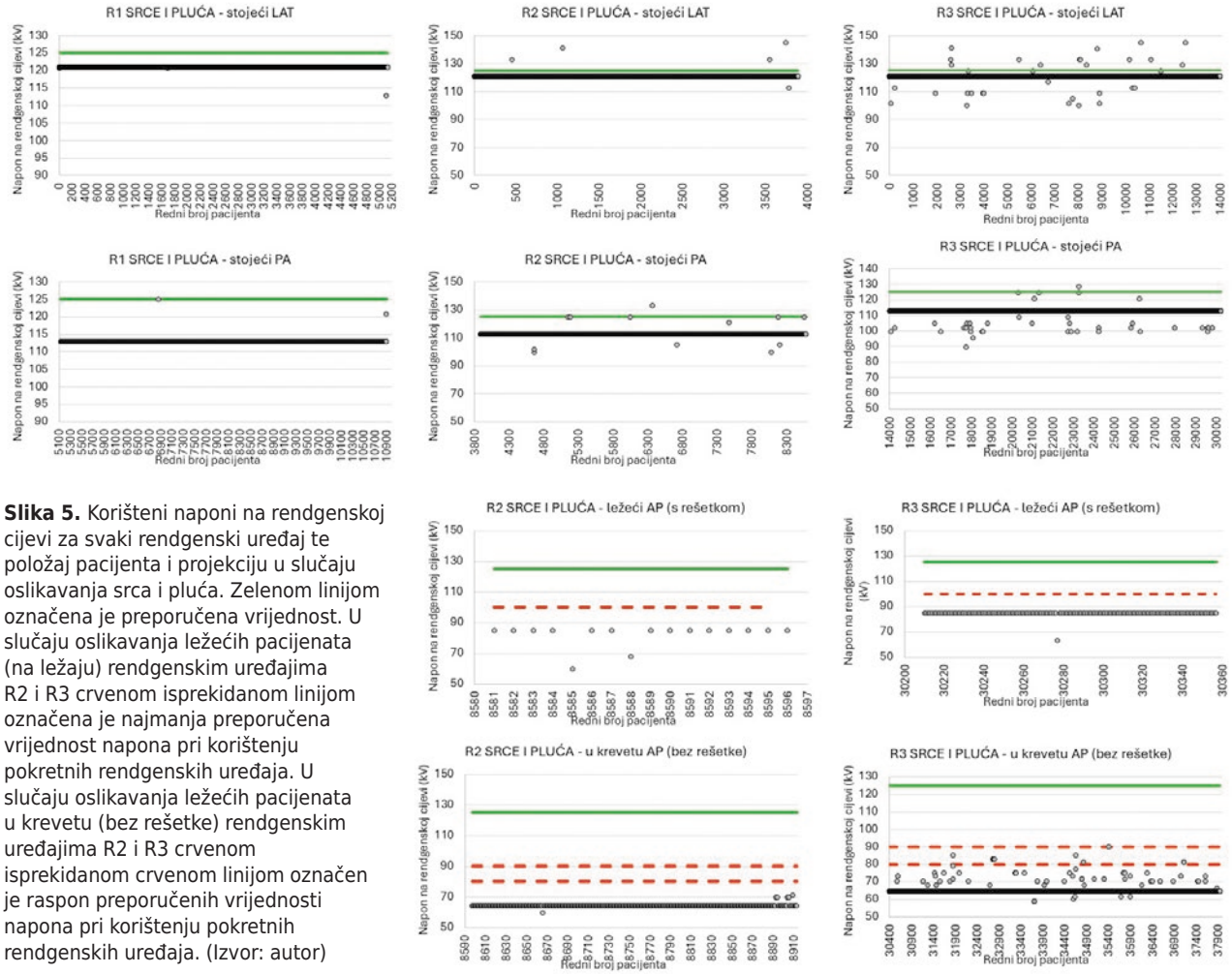
Način rada – odabir napona na rendgenskoj cijevi

Korišteni naponi na rendgenskoj cijevi za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja zdjelice prikazani su na slici 4., a u slučaju oslikavanja srca i pluća na slici 5.

Za oslikavanje zdjelice svim rendgenskim uređajima se u slučaju većine pacijenata koristio napon na rendgenskoj cijevi koji je bio u prihvatljivom rasponu osim u slučaju oslikavanja pacijenata u krevetu rendgenskim uređajem R2 kada se koristio napon vrijednosti manje od donje granice prihvatljivog raspona (tablica 4.). Korišteni naponi na rendgenskoj cijevi tijekom oslikavanja srca i pluća bili su u rasponu 113 – 125 kV za rendgenski uređaj R1, 60 – 145 kV za rendgenski uređaj R2 te 59 – 145 kV za rendgenski uređaj R3. Preporučena vrijednost napona na rendgenskoj cijevi koristila se u slučaju 0,02 % oslikavanja pluća i srca stojećih pacijenata u PA projekciji rendgenskim uređajima R1 i R3 (tablica 5). U većini slučajeva korišteni su naponi na rendgenskoj cijevi koji su manji od 125 kV (tablica 5).



Slika 4. Korišteni naponi na rendgenskoj cijevi za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja zdjelice. Crvenim linijama označen je raspon prihvatljivih vrijednosti. (Izvor: autor)



Slika 5. Korišteni naponi na rendgenskoj cijevi za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja srca i pluća. Zelenom linijom označena je preporučena vrijednost. U slučaju oslikavanja ležećih pacijenata (na ležaju) rendgenskim uređajima R2 i R3 crvenom isprekidanom linijom označena je najmanja preporučena vrijednost napona pri korištenju pokretnih rendgenskih uređaja. U slučaju oslikavanja ležećih pacijenata u krevetu (bez rešetke) rendgenskim uređajima R2 i R3 crvenom isprekidanom crvenom linijom označen je raspon preporučenih vrijednosti napona pri korištenju pokretnih rendgenskih uređaja. (Izvor: autor)

Tablica 4. Udio radioloških slika ovisno o korištenom naponu na rendgenskoj cijevi za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja zdjelice

	R1		R2			R3	
	Ležeći AP	Stojeći AP	Ležeći AP	Stojeći AP	U krevetu AP	Ležeći AP	Stojeći AP
U prihvatljivom rasponu (75 – 90 kV)	99,3 %	100 %	98,4 %	98,4 %	0 %	99,1 %	98,8 %
Manje od 75 kV	0,3 %	0 %	0,5 %	0,4 %	100 %	0,5 %	0,0 %
Veće od 90 kV	0,3 %	0 %	1,1 %	1,2 %	0 %	0,3 %	1,2 %

Tablica 5. Udio radioloških slika ovisno o korištenom naponu na rendgenskoj cijevi za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja srca i pluća

	R1		R2				R3			
	Stojeći LAT	Stojeći PA	Stojeći LAT	Stojeći PA	Ležeći AP	U krevetu AP	Stojeći LAT	Stojeći PA	Ležeći AP	U krevetu AP
Preporučenih 125 kV (za stacionarne rendgenske uređaje)	0 %	0,02 %	0 %	0,11 %	0 %	0 %	0 %	0,02 %	0 %	0 %
Manje od 125 kV	100 %	99,98 %	99,9 %	99,85 %	100 %	100 %	99,9 %	99,98 %	100 %	100 %
Veće od 125 kV	0 %	0 %	0,1 %	0,0 %	0 %	0 %	0,1 %	0,01 %	0 %	0 %
Veće od 100 kV	/*	/*	/*	/*	0 %	/*	/*	/*	0 %	/*
Manje od 100 kV	/*	/*	/*	/*	100 %	/*	/*	/*	100 %	/*
Preporučeni raspon (80 – 90 kV) (za pokretne rendgenske uređaje)	/**	/**	/**	/**	/**	0 %	/**	/**	/**	0,2 %
Manje od 80 kV	/**	/**	/**	/**	/**	100 %	/**	/**	/**	99,8 %
Veće od 90 kV	/**	/**	/**	/**	/**	0 %	/**	/**	/**	0 %

* S kriterijem koji je dan uspoređene su samo korištene vrijednosti napona pri oslikavanju ležećih pacijenata uz korištenje rešetke.
** S kriterijem koji je dan uspoređene su samo korištene vrijednosti napona pri oslikavanju ležećih pacijenata bez korištenja rešetke.

Način rada – udaljenost žarišta rendgenske cijevi od prijemnika slike

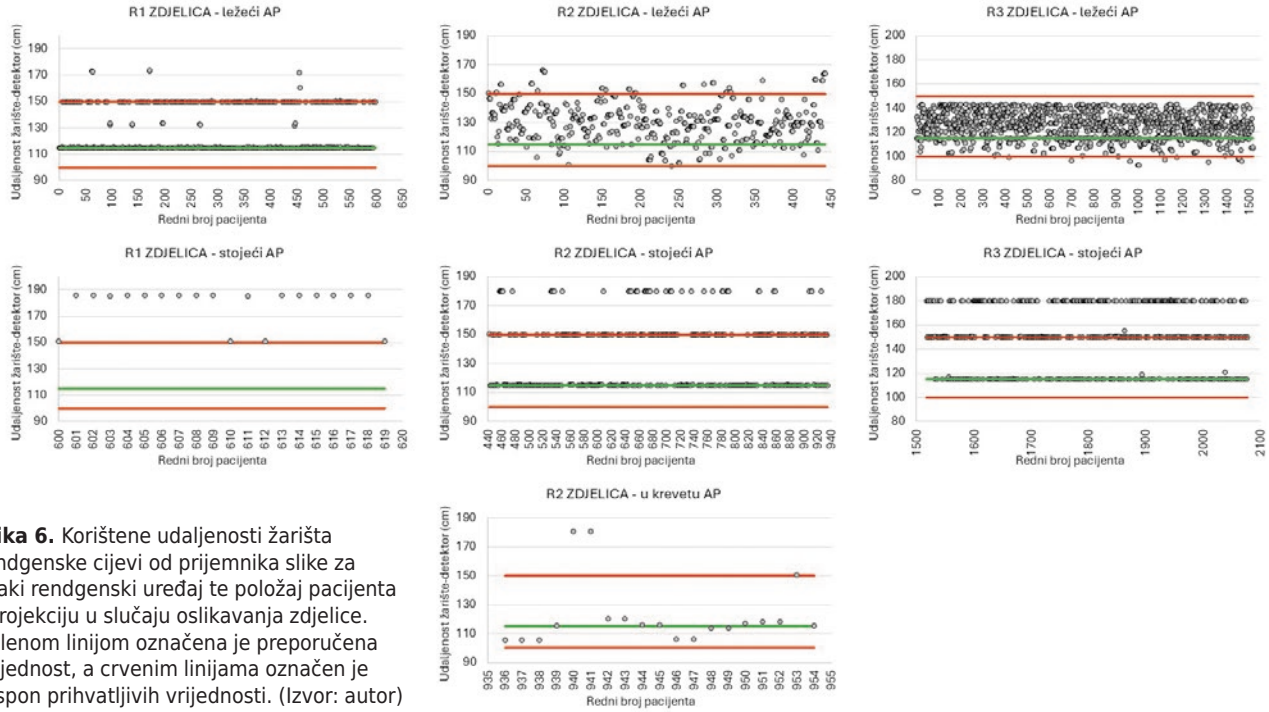
Korištene udaljenosti žarišta rendgenske cijevi od prijemnika slike za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja zdjelice prikazani su na slici 6., a u slučaju oslikavanja srca i pluća na slici 7.

Pri oslikavanju zdjelice je u najvećem broju slučajeva korištena udaljenost žarišta rendgenske cijevi od prijemnika slike koja je u prihvatljivom rasponu udaljenosti, osim u slučaju rendgenskih uređaja R1 i R3 tijekom oslikavanja zdjelice pacijenta koji stoji kada je većina korištenih udaljenosti bila veće od gornje prihvatljive granice (tablica 6.). Preporučena udaljenost korištena je najčešće u slučaju oslikavanja rendgenskim uređajem R1 pacijenta koji leži na ležaju (51 %).

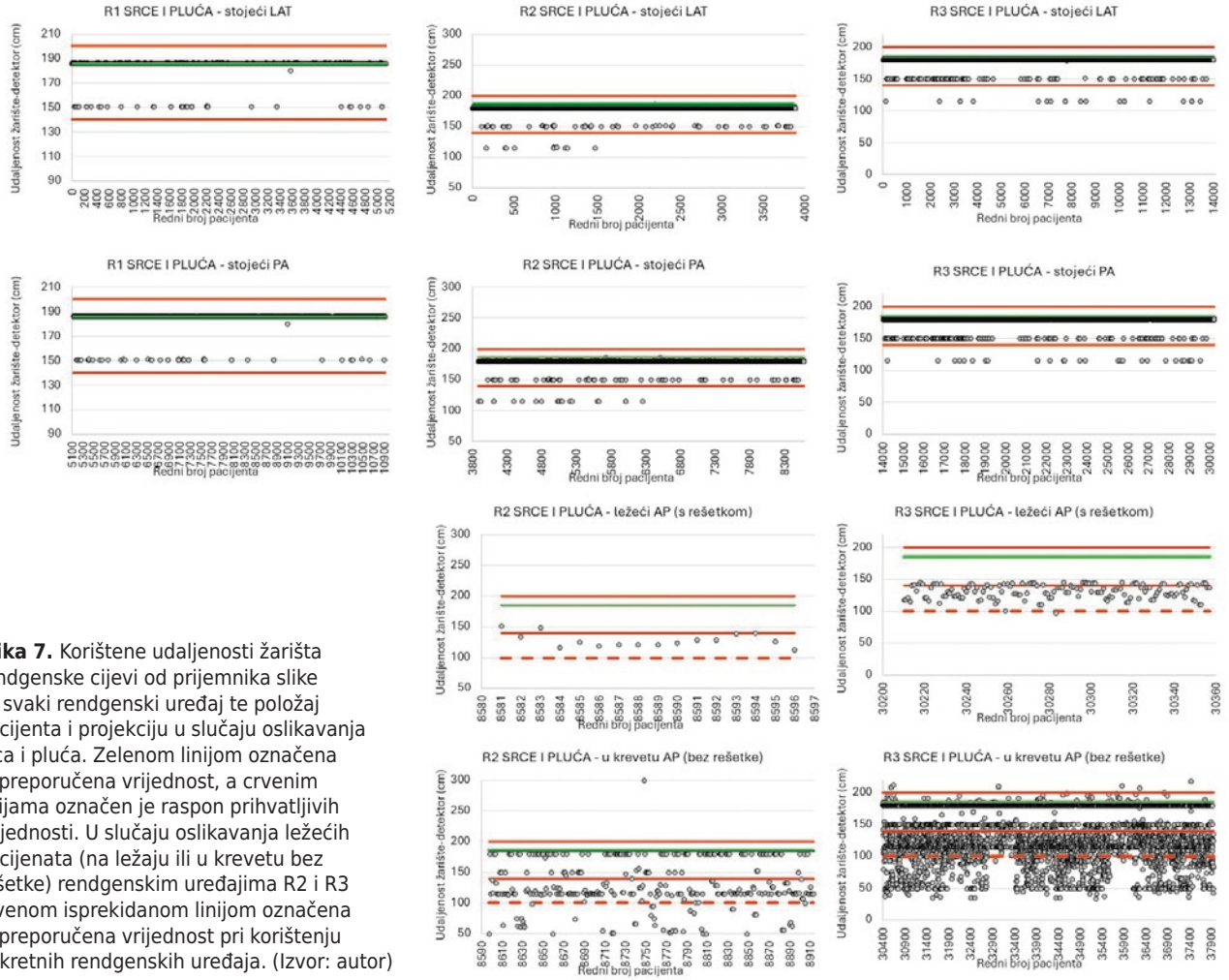
U najvećem broju slučajeva pri oslikavanju srca i pluća korištena udaljenost žarišta rendgenske cijevi od prijemnika slike bila je u prihvatljivom rasponu udaljenosti, osim u slučaju oslikavanja zdjelice pacijenta koji leži kada je većina korištenih udaljenosti bila manja od donje prihvatljive granice (rendgenski uređaj R2 – pacijent leži na ležaju ili u krevetu te rendgenski uređaj R3 – pacijent leži na ležaju) (tablica 7.). Niti jedan pacijent nije oslikan korištenjem preporučene udaljenosti žarišta rendgenske cijevi od prijemnika slike.

Tablica 6. Udio radioloških slika ovisno o korištenoj udaljenosti žarišta rendgenske cijevi od prijemnika slike za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja zdjelice

	R1		R2			R3	
	Ležeći AP	Stojeći AP	Ležeći AP	Stojeći AP	U krevetu AP	Ležeći AP	Stojeći AP
Preporučena udaljenost (115 cm)	51 %	0 %	0 %	34 %	11 %	1 %	10 %
U prihvatljivom rasponu (100-150 cm)	98 %	0 %	91 %	82 %	89 %	99 %	42 %
Manje od 100 cm	0 %	0 %	0 %	0 %	0 %	1 %	0 %
Veće od 150 cm	2 %	100 %	9 %	18 %	11 %	0 %	58 %



Slika 6. Korištene udaljenosti žarišta rendgenske cijevi od prijemnika slike za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja zdjelice. Zelenom linijom označena je preporučena vrijednost, a crvenim linijama označen je raspon prihvatljivih vrijednosti. (Izvor: autor)



Slika 7. Korištene udaljenosti žarišta rendgenske cijevi od prijemnika slike za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja srca i pluća. Zelenom linijom označena je preporučena vrijednost, a crvenim linijama označen je raspon prihvatljivih vrijednosti. U slučaju oslikavanja ležećih pacijenata (na ležaju ili u krevetu bez rešetke) rendgenskim uređajima R2 i R3 crvenom isprekidanom linijom označena je preporučena vrijednost pri korištenju pokretnih rendgenskih uređaja. (Izvor: autor)

Tablica 7. Udio radioloških slika ovisno o korištenoj udaljenosti žarišta rendgenske cijevi od prijemnika slike za svaki rendgenski uređaj te položaj pacijenta i projekciju u slučaju oslikavanja srca i pluća

	R1		R2				R3			
	Stojeći LAT	Stojeći PA	Stojeći LAT	Stojeći PA	Ležeći AP	U krevetu AP	Stojeći LAT	Stojeći PA	Ležeći AP	U krevetu AP
Preporučena udaljenost od 185 cm (za stacionarne rendgenske uređaje)	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
U prihvatljivom rasponu (140-200 cm)	100 %	100 %	99,7 %	99,6 %	13 %	36,9 %	99,9 %	99,8 %	28 %	51,1 %
Manje od 140 cm	0 %	0 %	0,3 %	0,4 %	88 %	62,8 %	0,1 %	0,2 %	72 %	48,7 %
Veće od 200 cm	0 %	0 %	0 %	0 %	0 %	0,3 %	0 %	0 %	0 %	0,2 %
Prepručena udaljenost od 100 cm (za pokretne rendgenske uređaje)	/*	/*	/*	/*	0 %	0,3 %	/*	/*	0 %	0,1 %
Manje od 100 cm	/*	/*	/*	/*	0 %	13,6 %	/*	/*	2 %	16,9 %
Veće od 100 cm	/*	/*	/*	/*	100 %	86,1 %	/*	/*	99 %	83 %

* S kriterijem koji je dan uspoređene su samo korištene vrijednosti udaljenosti žarišta rendgenske cijevi od prijemnika slike pri oslikavanju ležećih pacijenata.

Način rada – sužavanje rendgenskog snopa na područje od interesa

Sve analizirane radiološke slike srca i pluća manje su površine nego je bila površina rendgenskog snopa (slika 8.). Smanjenje površine bilo je u rasponu 0,5 – 48 %. U slučaju gotovo trećine analiziranih slika (28 %) površina radiološke slike manja je od površine rendgenskog snopa za više od 25 %.

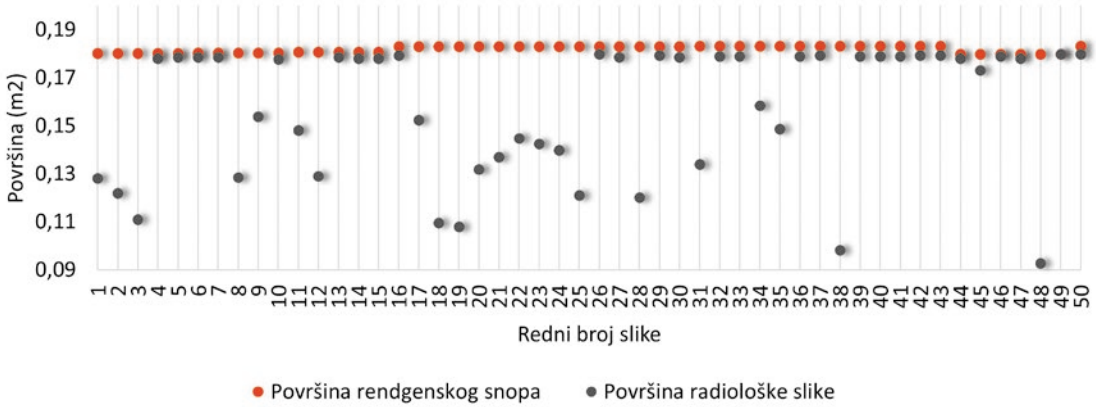
Subjektivna procjena ocjenitelja

Subjektivne procjene ocjenitelja vezano uz odabir parametara ekspozicije prikazane su na slici 9. na kojoj su istovremeno prikazane i vrijednosti ekspozicijskog indeksa za pojedinu radiološku sliku te vrijednost ciljanog ekspozicijskog indeksa. U slučaju 20 % slika sva tri ocjenitelja procijenila su da su tijekom oslikavanja odabrani dobri parametri ekspozicije – za pacijente broj 6, 8, 14 i 20. Za radiološke slike navedenih pacijenata devijacijski indeksi iznosili su -0,5, 1, -1,5 te 1,5.

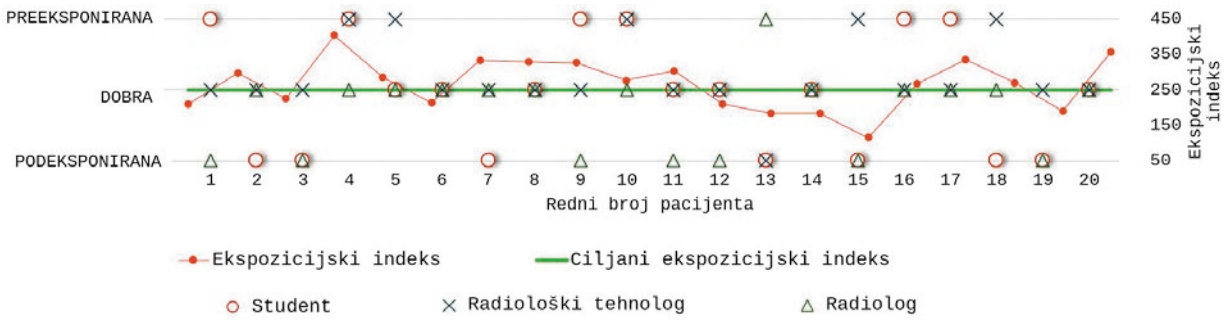
Rasprava

Ocjenu kvalitete radiološke slike zdjelice provela su tri ocjenitelja – student završne godine studija radiološke tehnologije, radiološki tehnolog s 40 godina radnog iskustva u struci i radiolog s 20 godina radnog iskustva u struci. Ocjene udovoljavanja pojedinom kriteriju su se u većini slučajeva razlikovale (slika 2.). Radiološki tehnolog i radiolog jednako su ocijenili 69 % kriterija, radiolog i student 66 %, a radiološki tehnolog i student 74 % (slika 2.). Ukupan broj bodova iznosa 5, 6 ili 7 radiolog je pridijelio 30 % analiziranih radioloških slika, a radiološki tehnolog i student svaki po 40 % (slika 3). Samo jednoj radiološkoj slici (5 %) pridijeljen je najveći mogući broj bodova od strane sva tri ocjenitelja (slika 3). Ovakvi rezultati su očekivani obzirom na školovanje i iskustvo radiologa, ali ukazuju na potrebu ovakvih zajedničkih analiza.

Subjektivne procjene ocjenitelja vezano uz odabir parametara ekspozicije razlikovali su se u većini ocjenjivanih slika zdjelice (80 %) (slika 9.). Bolji u procjeni odabira parametara ekspozicije bio je student koji je u slučaju 50 % radioloških slika odabir parametara ekspozicije ocijenio u skladu s vrijednosti ekspozicijskog indeksa, dok su procjene radiološkog tehnologa i radiologa bile u skladu s vrijednosti ekspozicijskog indeksa u slučaju 25 % radioloških slika (slika 9). Odabir parametara ekspozicije ocijenjen je kao dobar za veći broj onih radiološki slika kod kojih je vrijednost ekspozicijskog indeksa veća od ciljanog (34 % procjena), nego je to u slučaju radiološki slika kod kojih je vrijednost ekspozicijskog indeksa manja od ciljanog indek-



Slika 8. Usporedba površine rendgenskog snopa i radiološke slike srca i pluća (Izvor: autor)



Slika 9. Subjektivne procjene ocjenitelja vezano uz odabir parametara ekspozicije. Na slici su prikazane i vrijednosti ekspozicijskog indeksa (crvena boja) te ciljanog ekspozicijskog indeksa (zelena boja). (Izvor: autor)

sa ekspozicije (18 % procjena) što je vjerojatno posljedica činjenice da je po provedenom oslikavanju preeksponiranu radiološku sliku moguće dodatno „ručno" urediti (za razliku od podeksponirane).

Rezultati analize 50 odabranih radioloških slika srca i pluća ukazuju na to da je uobičajena klinička praksa ne prilagođavati veličinu (površinu) rendgenskog snopa području od interesa obzirom da su sve analizirane slike uređene na način da su po oslikavanju uklonjeni rubni dijelovi (slika 8.). Ovakvim načinom oslikavanja nepotrebno se povećava ozračenje pacijenta i narušava kvaliteta slike obzirom da širi rendgenski snopovi rezultiraju većom količinom raspršenog zračenja. Važno je napomenuti i da se ovakvim načinom rada dio dobivene dijagnostičke informacije neopravdano uklanja i stoga ne stiže do radiologa.

Oslikavanje zdjelice pacijenata koji leže na ležaju ili stoje provedeno je u većini slučajeva korištenjem napona u prihvatljivom rasponu (tablica 4. i slika 4.). Oslikavanje svih pacijenata koji leže u krevetu provedeno je korištenjem napona na rendgenskoj cijevi manjim od 75 kV. Dodatnom analizom utvrđeno je da su pacijenti koji se u snimaonici oslikavaju u krevetu postoperativni pacijenti koji se rendgenskim uređajima uključenim u ovu studiju oslikavaju u svrhu kontrole po obavljenoj operaciji zdjelice, bez korištenja rešetke, a parametri ekspozicije odabiru se ručno (ne koristi se automatska kontrola ekspozicije).

Rendgenskim uređajem R1 i rendgenskim uređajem R3 oslikano je svega 0,02 % srca i pluća stojećih pacijenata korištenjem preporučene vrijednosti napona na rendgenskoj cijevi (tablica 5. i slika 5.). Svi ostali pacijenti koji su za vrijeme oslikavanja stajali oslikani su naponom manjim od preporučene vrijednosti pri čemu je najniži korišteni napon bio 113 kV u slučaju rendgenskog uređaja R1, 100 kV u slučaju rendgenskog uređaja R2 te 90 kV u slučaju rendgenskog uređaja R3 (slika 5.). Svi pacijenti koji su ležali na ležaju prilikom oslikavanja srca i pluća (uz korištenje rešetke) su u slučaju rendgenskih uređaja R2 i R3 oslikani korištenjem napona koji su manji i od preporučene donje granice od 100 kV dane za pokretne rendgenske uređaje (tablica 5.); najmanji korišteni napon u slučaju rendgenskog uređaja R2 bio je 60 kV, a najveći 85 kV, a u slučaju rendgenskog uređaja R3 najmanji korišteni napon bio je 63 kV, a najveći 85 kV (slika 5.). Dodatnom analizom utvrđeno je da su pacijenti kojima se srce i pluća u snimaonici oslikavaju u krevetu postoperativni pacijenti ili pacijenti s dijagnozama takvima da bi im se zdravstveno stanje prebacivanjem na ležaj narušilo. I u slučaju ovih pacijenata oslikavanje se provodi bez korištenja rešetke, a parametri ekspozicije odabiru se ručno. Rendgenskim uređajem R2 svi su pacijenti koji su ležali u krevetu oslikani naponom koji je manji od vrijednosti iz preporučenog raspona (80 – 90 kV) danog za pokretne rendgenske uređaje; najmanji korišteni napon bio je 60 kV, a najveći 70 kV (slika 5.). Rendgenskim uređajem R3 oslikano je 0,2 % pacijenata koji leže u krevetu korištenjem napona na rendgenskoj cijevi čija vrijednost je u prihvatljivom rasponu danom za pokretne rendgenske uređaje, dok su ostali pacijenti oslikani naponima koji su manji od donje granice prihvatljivog raspona (tablica 5.); najmanji korišteni napon bio je 59 kV, a najveći 90 kV (slika 5.).

Korištene udaljenosti žarišta rendgenske cijevi od prijemnika slike su pri oslikavanju zdjelice pacijenta koji leži na ležaju ili u krevetu u većini slučajeva bile u prihvatljivom rasponu pri čemu se pri oslikavanju rendgenskim uređajem R1 preporučena udaljenost koristila u 51 % pacijenata, dok je za rendgenske uređaje R2 i R3 taj postotak znatno manji (tablica 6. i slika 6.). Zdjelice su oslikavane i u stojećem položaju pacijenta kod onih pacijenata kod kojih je traženo oslikavanje zdjelice (i) pod opterećenjem. Pri oslikavanju stojećih pacijenata rendgenskim uređajima R1 i R3 u većini slučajeva udaljenosti žarišta rendgenske cijevi od prijemnika slike bile su veće od gornje granice prihvatljivog raspona (tablica 6. i slika 6.) Naknadnom analizom utvrđeno je da radiološki tehnolog nije pomaknuo cijev na potrebnu udaljenost jer je prethodno oslikavanju zdjelice oslikavao druge anatomske regije istog pacijenta pri čemu su se koristile veće udaljenosti (primjerice pluća).

Niti jedna radiološka slika srca i pluća nije nastala korištenjem preporučene udaljenosti žarišta rendgenske cijevi od prijemnika slike, ali su u slučaju oslikavanja pacijenta koji stoji (obje projekcije) u većini slučajeva bile u prihvatljivom rasponu (tablica 7. i slika 7.). Oslikavanje srca i pluća pacijenta koji leži na ležaju ili u krevetu uglavnom se provodilo korištenjem udaljenosti koje su manje od donje granice prihvatljivog raspona koja je dana za stacionarne rendgenske uređaje (tablica 7. i slika 7.). Međutim, korištene udaljenosti pri oslikavanju srca i pluća rendgenskim uređajima R2 i R3 u većine pacijenata koji su ležali na ležaju ili u krevetu bila je veća od preporučene udaljenosti od 100 cm koja je dana za slučaj oslikavanja srca i pluća pokretnim rendgenskim uređajem pri čemu je praksa izraženije neujednačena nego u slučaju oslikavanja pacijenata koji stoje (tablica 7. i slika 7.).

Zaključak

Rezultati ovoga rada ukazuju na važnost uspostave i provedbe sustava za ocjenu kvalitete radioloških slika koje su prihvaćene kao radiološke slike zadovoljavajuće kvalitete. U postupak ocjene kvalitete radioloških slika trebaju biti uključene sve struke – radiološki tehnolog i radiolog te medicinski fizičar. Osim kriterija kojima se opisuje kvaliteta radiološke slike pojedinog anatomskog područja, tijekom ocjene kvalitete radiološke slike trebalo bi analizirati najmanje i korištene napone na rendgenskoj cijevi, udaljenosti žarišta rendgenske cijevi od prijemnika slike te ekspozicijske indekse obzirom da mogu ukazati na potrebu poduzimanja korektivnih radnji kojima bi se postupak oslikavanja optimizirao. Ovo se pokazalo posebno važno pri oslikavanju srca i pluća stacionarnim rendgenskim uređajem u pacijenata koji leže na ležaju, uz korištenje rešetke ili u krevetu, bez korištenja rešetke obzirom da jasne preporuke za ovakve slučajeve nisu dane. U postupku analize načina rada važnu ulogu može imati korištenje DMS-a ukoliko je dostupan obzirom da bitno olakšava uvid u vrijednosti pojedinih parametara i omogućuje uključivanje velikog broja radioloških slika u analizu. ■

Do we need an image quality evaluation system in conventional radiography?

Abstract:

Aim: This work aims to point out the importance of establishing a system for image quality evaluation in conventional radiography.

Methods: The study was conducted retrospectively and it included image quality evaluation as well as analysis of imaging procedure. 20 radiographic images of pelvis were evaluated and the evaluation was carried out according to the European criteria for the quality of the radiographic images of pelvis. The imaging procedure was analysed using 3,651 radiographic images of the pelvis and 57,758 radiographic images of the chest. The analysis of the imaging procedure was carried out by comparing the used values with the recommended ones. The practice related to narrowing the X-ray beam to the area of interest using 50 radiological images of the chest was additionally analysed.

Results: Only one radiographic images of the pelvis were given the highest possible grade. Subjective evaluations of evaluators related to the selection of exposure parameters differed in the majority of evaluated pelvic images (80%). The X-ray tube voltages used during pelvic imaging were mostly in the recommended range but in case of imaging of chest X-ray tube voltage were lower than the recommended value in most cases. Pelvis were mostly imaged using X-ray tube source-to-detector distances that were within an acceptable range except for those patients who were standing during imaging. In the case of heart and lung imaging, these distances were generally in the acceptable range except in the case of supine patients when a larger number of patients were imaged using smaller distances. All 50 analysed radiological images of the chest were cropped.

Conclusions: The results of the analysis indicate the need to establish and implement a system for evaluating the quality of radiographic images, which would also include an analysis of the imaging procedure.

Key words: image quality, exposure index, tube voltage, source-to-detector distance, collimation

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PROFESSIONAL PAPER (STRUČNI RAD)

Tumor Hypoxia and Radioresistance

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Abstract

Tumor hypoxia is a prevalent feature of solid tumors, significantly contributing to increased tumor aggressiveness, metastatic potential, and resistance to conventional therapies such as radiotherapy. This review explores the complex relationship between tumor hypoxia and radioresistance, highlighting the molecular mechanisms involved and potential therapeutic strategies to enhance radiotherapy efficacy in hypoxic tumors. Key mechanisms include the role of hypoxia-inducible factors (HIFs), particularly HIF-1α, which regulates numerous genes involved in tumor survival, proliferation, and resistance under hypoxic conditions. The review also discusses the oxygen enhancement ratio (OER) and its impact on radiotherapy outcomes, emphasizing how hypoxia leads to reduced radiosensitivity by limiting the formation of radiation-induced DNA damage. Despite the development of various strategies to counteract hypoxia-induced radioresistance, such as HIF inhibitors, hypoxia-targeted gene therapy, and hypoxia-activated prodrugs (HAPs), clinical results have been mixed, necessitating further research. Additionally, advances in imaging techniques for detecting tumor hypoxia are explored, which may allow for more personalized radiotherapy approaches, such as dose painting. The future of overcoming tumor hypoxia in radiotherapy lies in the integration of innovative therapeutic strategies, personalized medicine, and improved imaging technologies, offering hope for enhanced treatment outcomes in cancer patients.

Keywords: Tumor hypoxia, radioresistance, hypoxia-inducible factors (HIFs), radiotherapy, oxygen enhancement ratio (OER)

Abbreviations and Acronyms:

ATP – Adenosine Triphosphate, BOLD MRI – Blood Oxygen Level-Dependent Magnetic Resonance Imaging, CAFs – Cancer-Associated Fibroblasts, CBP – CREB-Binding Protein, DCE-MRI – Dynamic Contrast-Enhanced Magnetic Resonance Imaging, DNA – Deoxyribonucleic Acid, ECM – Extracellular Matrix, ECs – Endothelial Cells, EMT – Epithelial-Mesenchymal Transition, GLUT – Glucose Transporters, HAPs – Hypoxia-Activated Prodrugs, HBOT – Hyperbaric Oxygen Treatment, HBO – Hyperbaric Oxygen, HIF – Hypoxia-Inducible Factor, HIF-1α – Hypoxia-Inducible Factor 1 alpha, HRE – Hypoxia Response Element, MAPK – Mitogen-Activated Protein Kinase, NFκB – Nuclear Factor kappa-light-chain-enhancer of activated B cells, NIRS – Near-Infrared Spectroscopy, OER – Oxygen Enhancement Ratio (ako je ipak odlučiš zadržati), PET – Positron Emission Tomography, PHD – Prolyl Hydroxylase, PI3K/AKT/mTOR – Phosphoinositide 3-kinase/Protein kinase B/Mammalian target of rapamycin pathway, RNA – Ribonucleic Acid, ROS – Reactive Oxygen Species, SBRT – Stereotactic Body Radiotherapy, VEGF – Vascular Endothelial Growth Factor

Introduction

Hypoxia is a frequent and significant characteristic of solid tumors. In tumors, hypoxia occurs when there is an imbalance between oxygen supply and demand. It is strongly linked to tumor progression, greater aggressiveness, increased metastatic potential, resistance to radiation or chemotherapy, and reduced overall survival across different tumor types. Additionally, hypoxia can promote the selection of cell clones that resist apoptosis and contribute to tumor metastasis [1]. Radiotherapy is suitable for treating roughly half of all cancers, yet local recurrence and disease relapse often happen because of clinical radioresistance. Hypoxia contributes to radioresistance via various molecular pathways, and many strategies have been devised to counteract this. However, these strategies have generally yielded disappointing outcomes, with adverse effects and limited effectiveness. Further clinical studies are necessary to gain a deeper understanding of the intricate hypoxia pathways [2]. The primary aim of this review is to explore the complex relationship between tumor hypoxia and radioresistance, with a focus on

identifying potential therapeutic targets and strategies to enhance the efficacy of radiotherapy in hypoxic tumors.

Mechanisms of tumor hypoxia

Rapid growth of tumor cells, insufficient blood supply, and hypoxia are common characteristics of the microenvironment in most solid tumors [3]. Solid tumors are composed of transformed cells encased in a framework of connective tissue or mesenchyme, creating the tumor microenvironment. This environment comprises vascular endothelial cells (ECs), cancer-associated fibroblasts (CAFs), immune cells, and the extracellular matrix (ECM). As tumor cells expand, they enlist surrounding non-tumor cells to participate in collaborative processes that create a tumor microenvironment favorable for local expansion and metastasis to distant sites. This assembly of tumor cells interacting with host cells creates an organ-like structure that is abnormal [1].

Hypoxia in the tumor microenvironment is defined by oxygen pressure levels being below 5–10 mm Hg. This condition results from heightened oxygen consumption linked to significantly increased tumor cell proliferation, and a deficient oxygen supply to cells and tissues caused by the formation of a disorganized tumor microvasculature network featuring leaky vessels that are unable to compensate for the lack of oxygen [4].

Hypoxia triggers various intricate intracellular signaling pathways, including the prominent hypoxia-inducible factor (HIF) pathway. Additional pathways influenced by hypoxia encompass PI3K/AKT/mTOR, MAPK (also recognized as ERK pathways), and NFκB. These pathways play roles in cellular functions such as proliferation, survival, apoptosis, metabolism, migration, and inflammation [5]. The Hypoxia-inducible factor (HIF) is crucial in the adaptive cellular response to hypoxia within the tumor microenvironment. HIF-1 is a type of isoform made up of one of three alpha subunits (HIF-1α, HIF-2α, or HIF-3α) and a beta subunit (HIF-1β, also referred to as aryl hydrocarbon nuclear transporter, or ARNT). HIF-1α is regarded as a key transcriptional regulator of the tumor cell response to hypoxia [3]. Under hypoxic conditions, the breakdown of HIF-1α is decreased, and it moves to the nucleus due to the inhibited function of prolyl hydroxylase (PHD). In the nucleus, HIF-1α combines with HIF-1β to form heterodimers. These HIF-1α/1β heterodimers activate the HIF target gene and enhance HIF expression by interacting with p300/CBP and the hypoxia response element (HRE) [6].

Experimental data specifically show that HIF-1α, a crucial transcription factor for adapting to hypoxia, controls the expression of more than 100 downstream genes.

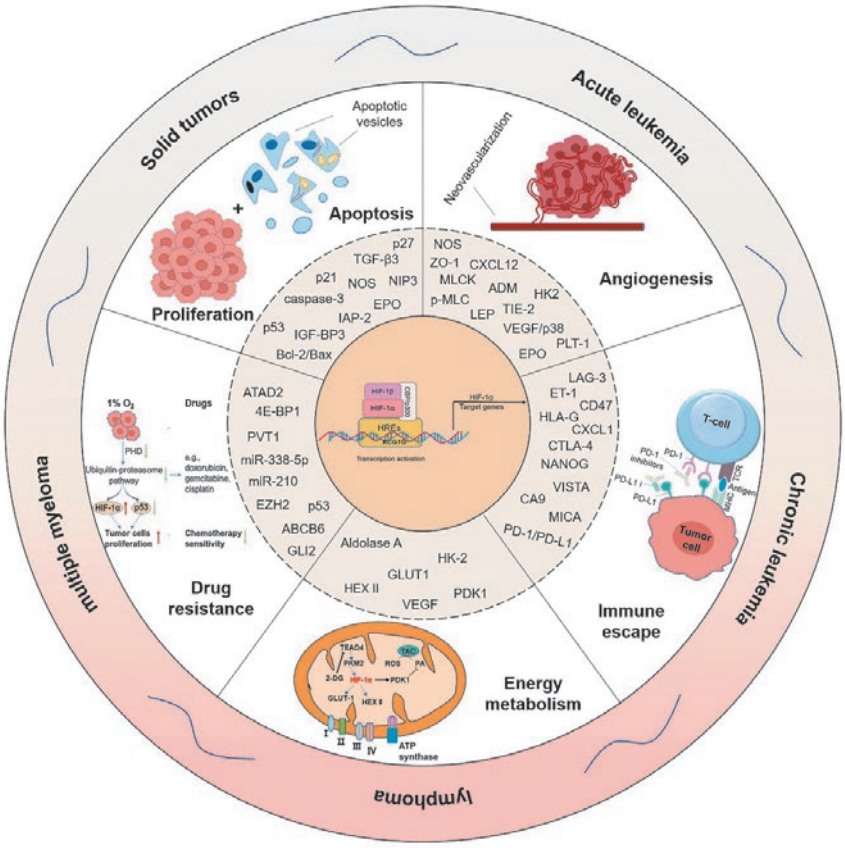


Figure 1. Malignant biological behaviors of HIF-1α in tumorigenesis under hypoxia. In the tumor microenvironment (TME), hypoxia plays a critical role in tumorigenesis due to reduced oxygen delivery and increased oxygen consumption by rapidly proliferating tumor cells. This creates a hypoxic microenvironment (HME) that fosters tumor growth. Under these conditions, HIF-1α accumulates and activates various genes that enhance tumor cell capabilities like proliferation, angiogenesis, energy metabolism, epithelial–mesenchymal transition (EMT), and immune escape, enhancing the tumor's adaptability and aggressiveness in HME.

Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10425810/

These genes fall into four main categories essential for protein production and tumor processes: vascular endothelial growth factor (VEGF), glucose transport and glycolytic enzymes (GLUT), factors crucial for tumor invasion and metastasis, and proteins associated with tumor proliferation and apoptosis. During disease progression, these genes can alter the relative homeostasis of the internal environment in tissues and cells under hypoxic conditions. For instance, they regulate not only classical biological behaviors such as stem cell maintenance, cell survival, apoptosis, erythropoiesis, and angiogenesis but also affect the microenvironment and metabolic state of tumors, the energy metabolism of nucleotides, amino acids, and glucose, and participate in immune evasion. Furthermore, HIF-1α significantly adjusts genes related to drug resistance and other response alterations, positioning it as a pivotal factor in tumorigenesis [7].

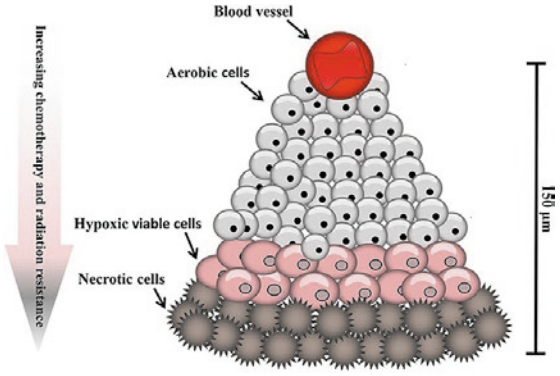


Figure 2. Hypoxic regions of solid tumors. Tumors contain regions of oxygenated cells situated near to blood vessels, becoming increasingly hypoxic with increased distance from a functional blood supply.
Source:https://www.frontiersin.org/journals/cell-and-developmental-biology/articles/10.3389/fcell.2019.00004/full

Impact of hypoxia on radioresistance

While hypoxia can be fatal for many cells, a subset of tumor cells not only survives under these conditions but also develops resistance to chemotherapy and radiotherapy. The influence of hypoxia on therapy resistance has been recognized for over 60 years [5]. In 1909, in the Münchener Medizinische Wochenschrift, Gottwald Schwarz demonstrated a reduced skin response to radiation when blood flow to the irradiated area was restricted. Later, Mottram, Crabtree, Cramer, and others more thoroughly investigated the impact of oxygen on radiation effects. They found that cells were significantly more sensitive to X-rays when oxygen was present. The oxygen enhancement ratio (OER) quantifies the relationship between cellular response to ionizing radiation (IR) and available oxygen. It is defined as the ratio of radiation doses needed under hypoxic versus normoxic conditions to achieve the same biological effect. In hypoxic regions, tumor cells' survival rate against ionizing radiation is 2-3 times higher compared to normoxic areas. The concentration and timing of oxygen exposure are critical factors. For inducing apoptosis, molecular oxygen needs to be present either during radiotherapy or within the lifespan of the radiation-induced free radicals. Only a minimal amount of oxygen, about 0.5% or a pO2 of approximately 3 mmHg, is necessary for radiosensitivity [8, 9].

In oxygen-rich conditions, normoxic cells are vulnerable to radiation due to „oxygen fixation," where oxygen molecules react with DNA's free radicals caused by ionizing radiation, leading to irreversible DNA damage. Conversely, cells in hypoxic conditions resist radiation-induced death because of the reduced production of DNA radicals and decreased DNA damage, as there is a lower generation of reactive oxygen species and potential for chemical restoration of DNA [5].

Tumor radiosensitivity varies with the cell cycle. Cells are more resistant to radiotherapy during the late S (chromosome replication) and G0 phases, while being more sensitive during the G2/M phase (separation of replicated chromosomes). Radiation sensitivity shifts throughout the cell cycle, with older cells showing higher oxygen enhancement ratios (OER). In the G1 phase, cells are more radiosensitive with a lower OER compared to the S phase. Under low oxygen conditions, HIF-1α can inhibit the transition to the S phase by upregulating genes that code proteins for cell cycle regulation, such as Waf1 (p21) and Kip1 (p27), leading to cell growth arrest under hypoxic conditions [2]. Additional signaling pathways such as mTOR, NF-κB, and the unfolded protein response are influenced by hypoxia, which in turn modulates further changes in transcription and translation processes [10].

Cells require a specific oxygen concentration for aerobic respiration to produce ATP, the energy source for many biological processes. Both pathological conditions like cancer, inflammation, and diabetes, as well as non-pathological situations such as high altitude, can lead to a state of hypoxia. Cancer cells respond to hypoxia by adjusting their metabolism through changes in gene expression and proteomics, influencing various functions like energy production, vascularization, invasion, metastasis, genetic stability, cell longevity, stem cell maintenance, and resistance to chemotherapy. Hypoxia significantly affects mitochondrial functions and metabolism, including changes in ROS production and signaling. Over the past twenty years, numerous studies have explored how HIF-1 drives metabolic shifts in various pathways such as glycolysis, lipid metabolism, and mitochondrial functions like the ETC and TCA cycles. This interaction between HIF-1 and mitochondria is vital for managing the hypoxic conditions in tumor cells by maintaining oxygen balance through the suppression of mitochondrial oxidative metabolism, thus reducing oxygen use [11].

Strategies to overcome hypoxia-induced radioresistance

Radiotherapy operates on the „5 Rs" of radiobiology: repair of sublethal damage, reassortment within the cell cycle, repopulation, intrinsic radioresistance, and reoxygenation. Developing effective strategies requires consideration of these principles [8]. Ever since the discovery of the hypoxic tumor environment, research has primarily concentrated on sensitizing hypoxic tumor cells and enhancing the hypoxic conditions within tumors. The main approaches to treating hypoxic tumors involve administering drugs that specifically target hypoxic conditions and

enhancing the oxygenation of the tumor environment. Various strategies have been suggested to target hypoxic tumor cells, including specific inhibition of HIFs, gene therapy, and focusing on pathways critical to hypoxic cells like the mTOR pathway. Additionally, the lower pH of tumor tissue compared to healthy tissue provides a unique target for directing acids to induce tumor cell death [3].

Due to the critical role of the HIF system and related hypoxia in cancer cells, they are considered potential therapeutic targets. In recent years, various strategies and drugs aimed at inhibiting HIF activity and its pathways have been developed, though only a few have progressed to clinical trials because of issues like tolerance, selectivity, and specificity concerning HIF isoforms. The primary method involves blocking different stages of HIF activation, including transcription, translation, stability, nuclear transport, heterodimerization, DNA binding, transcriptional activity, and affecting HIF target genes. HIF-1α inhibitors have been studied more extensively than those for HIF-2α, with several chemical agents being tested for these purposes [11].

Hypoxia-targeted gene therapy is a promising approach for selectively treating tumors, enhancing the effectiveness of radiation therapy. This strategy involves the selective delivery of treatments to hypoxic areas of tumors, controlled by hypoxia-dependent transcription and oxygen-sensitive prodrug metabolism, allowing for targeted action against hypoxic, radioresistant tumor cells both in vitro and in vivo. It is now considered important to explore the potential of gene therapy as a supplement to radiotherapy [12]. An effective method to reduce HIF activity involves disrupting the HIF-1α/P300 complex, crucial for hypoxia-induced transcription. Inhibiting the interaction between HIF-1 and P300 curtails HIF-1 expression. The ODD domain of HIF, rich in proline residues, undergoes hydroxylation by prolyl hydroxylase (PHD 1–3), which facilitates HIF-α's binding to the VHL complex, leading to the degradation of HIF proteins. Additionally, IDH1's role in converting isocitrate to α-ketoglutaric acid (α-KG) influences HIF-1α's stability, with increased α-KG lowering HIF-1α expression [3].

Hypoxia-activated prodrugs (HAPs) are bioreductive drugs designed to be selectively activated in the low-oxygen conditions of solid tumors, effectively targeting their hypoxic regions. Currently under investigation, notable examples include tirapazamine and evofosfamide. These drugs have shown promising anti-tumor effects in a variety of pre-clinical and clinical trials, both as standalone treatments and in combination with other therapies [1].

Hyperbaric Oxygen Treatment (HBOT) is a medical procedure that involves administering 100% oxygen at pressures higher than the normal atmospheric levels [13]. Radiotherapy combined with Hyperbaric Oxygen (HBO) therapy is employed in two clinical settings: (1) as a treatment for managing late radiation injuries, and (2) as a radiosensitizer to enhance the efficacy of radiotherapy [14]. Currently, respiratory hyperoxia is frequently used as a supplementary treatment for various conditions, particularly those involving hypoxia or ischemia. In the context of triple-negative breast cancer, HBO (Hyperbaric Oxygen) therapy has been shown to reduce tumor hypoxia, which in turn can curb tumor growth and metastasis. HBO therapy is known to inhibit the hypoxia-activated STAT3, slowing tumor progression and reducing drug resistance. Historical and clinical evidence suggests that HBO improves tumor oxygenation and enhances the effectiveness of both radiotherapy and cytotoxic drugs in treating solid tumors [3].

Radiotherapy modifications: dose escalation and hypofractionation

Conventional fractionation has been a cornerstone of radiation oncology for many years, utilizing a split of the total radiation dose into daily fractions of 1.8 to 2 Gy, administered five days a week, reaching a total of 40–70 Gy. This approach leverages the biological differences between tumor and normal tissues, typically causing less damage to normal tissues while effectively controlling tumor growth. The process of reoxygenation occurs when radiosensitive normoxic cells are depleted after a low dose of ionizing radiation (IR). This leads to the gradual reoxygenation of the surviving, more hypoxic tumor cells over hours or days. With conventional fractionation, this reoxygenation repeats throughout the treatment, improving tumor control by continuously targeting these reoxygenated cells without affecting normoxic normal tissue [15].

Hypofractionation is a type of radiation therapy where fewer but larger doses of radiation, typically greater than 2 Gy per fraction, are administered, leading to a shorter overall duration of treatment compared to conventional low dose fractionated regimens. The effectiveness of hypofractionation is primarily due to the increased biologically effective dose delivered to tumor cells. Additionally, damage to tumor vasculature and the stimulation of antitumor immunity from higher doses per fraction may also contribute significantly. The impact of hypoxia on hypofractionation's effectiveness remains an open question [15]. Research has demonstrated that vascular injury-induced secondary or indirect cell death significantly contributes to the effectiveness of high-dose radiation treatments in tumors. Specifically, exposing an experimental rodent tumor to 10 Gy or more has been shown to cause severe vascular damage, which subsequently leads to indirect tumor cell death [16].

Recent studies, primarily from the Vozenin lab, have revealed that FLASH irradiation, which is administered at ultra-high dose rates exceeding 30-40 Gy/s, significantly reduces normal tissue toxicity compared to traditional clinical irradiation rates of a few Gy/min. The exact biological mechanisms behind the unique sparing effect of FLASH irradiation on normal tissues compared to tumor tissues remain unclear. However, several theories have been suggested, including the rapid depletion of oxygen leading to temporary hypoxia, interactions between radicals, and differences in immune responses when compared to traditional dose rate irradiation [17]. The once popular but now discredited oxygen depletion hypothesis suggested that normal tissues could temporarily resist radiation after exposure to ultra-high dose rates, possibly due to the preservation of stem cell niches in hypoxic regions. Another theory proposed that healthy tissues could better eliminate reactive organic hydroperoxides, preventing harmful Fenton reactions. Additionally, the differential mitochondrial metabolism between normal and malignant tissues has been considered a potential explanation for the observed FLASH effect in radiation

therapy. Before proton FLASH therapy can be routinely applied in clinical settings, several challenges remain, such as defining treatment plans and dose rates for pencil beam scanning. Currently, FLASH conditions cannot be achieved with the photon linear accelerators available on the market. Despite these hurdles, it is anticipated that these technical obstacles will eventually be resolved [25].

Clinical implications – detecting hypoxia and personalized radiotherapy approaches

Accurate detection of hypoxic regions in tumors is thought to help guide treatment choices and enhance tumor response. Although initial clinical attempts to target tumor hypoxia have been mixed, largely due to inadequate patient selection, advances in understanding hypoxia's molecular pathways and the development of new hypoxia markers are making the targeting of hypoxia increasingly feasible [18]. Methods for assessing tumor hypoxia are categorized into three main types: those directly measuring oxygen levels, those analyzing physiological processes involving oxygen, and those assessing the expression of endogenous markers in response to hypoxic conditions [19].

Direct methods for assessing oxygen levels can be implemented either through tissue-based techniques such as needle electrodes and fiberoptic probes, or through blood-based methods which involve measuring or imaging oxyhemoglobin saturation and oxygen diffusion.

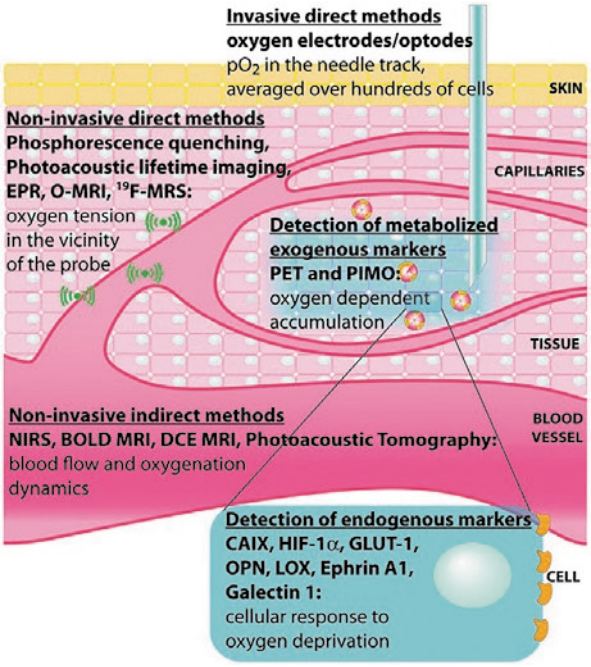


Figure 3. Hypoxia imaging methods and the type of information provided by each modality. BOLD MRI, blood oxygen level-dependent magnetic resonance imaging; DCE-MRI, dynamic contrast-enhanced magnetic resonance imaging; EPR, electron paramagnetic resonance; HIF-1α, hypoxia-inducible factor 1α; NIRS, near-infrared spectroscopy; OMRI, Overhauser-enhanced MRI; PALI, photoacoustic lifetime imaging; PAT, photoacoustic tomography; PET, positron emission tomography; PIMO, pimonidazole.
Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4159937/

Other methods for identifying hypoxic cells in tumors include the immunohistochemical detection of exogenously administered drugs like pimonidazole and EF5, which specifically label hypoxic cells. Additionally, non-invasive imaging techniques such as positron emission tomography (PET) with hypoxia-specific tracers (e.g., 2-nitroimidazole, ^18F-labeled tracers like MISO and FMISO), and MRI methods like blood oxygenation level dependent (BOLD) or tissue oxygenation level dependent (TOLD) MRI, are also used for this purpose. Endogenous molecular markers for tumor hypoxia include proteins and genes that are activated by exposure to low oxygen conditions. The hypoxia-inducible factor-1 (HIF-1) pathway is extensively studied in this context, as it regulates genes associated with critical cellular functions such as metabolism, angiogenesis, invasion, metastasis, and apoptosis [20].

In typical clinical settings, radiotherapy treatments generally involve a uniform dose and fractionation across all patients. Specifically, the same radiation dose is administered to every part of the tumor, without considering the unique biological characteristics and radiosensitivity of different tumor subregions. The technique known as dose painting in radiotherapy involves customizing treatment based on imaging that identifies hypoxic areas within a tumor. Essentially, this method involves selectively increasing the radiation dose to regions of the tumor that are more resistant to standard doses, thereby targeting those areas more effectively [21]. Encouraged by promising preclinical findings of bystander and systemic effects, and positive initial clinical outcomes, this approach is currently being advanced to a phase I clinical trial [15].

Future directions

Various strategies have been developed to target tumor hypoxia, including methods to directly deliver oxygen to tumors, such as the catalytic breakdown of endogenous hydrogen peroxide and light-triggered water splitting. Additionally, numerous clinical trials are exploring hypoxia-targeted therapies using different drugs. A significant focus is on HIF inhibitors, such as PX-478 and LW6, which have shown promising anti-tumor effects both as standalone treatments and in combination with other therapies [1].

Numerous past and ongoing clinical trials are examining anticancer therapies that target the HIF pathways. It's crucial to recognize that while HIF targeting is promising for future cancer treatments, it poses significant challenges, such as the need for specificity to prevent affecting normal tissue functions. Current trials are assessing the toxicities and effectiveness of various HIF-targeted strategies, and more research is needed to fully understand HIFs' complex roles in cancer [23]. Hypoxia-activated prodrugs (HAPs) are bioreductive drugs that become active specifically in the low-oxygen conditions of solid tumors, targeting these hypoxic areas effectively. Research on HAPs, including drugs like tirapazamine and evofosfamide, is ongoing. Both pre-clinical and clinical studies have shown promising anti-tumor results with these drugs, whether used alone or in combination with other treatments. One significant area of focus in targeting tumor hypoxia is the mTOR pathway, crucial for tumor metabolism, where mTOR-targeted drugs help regulate the

tumor microenvironment in hypoxic conditions. Extensive research has aimed to enhance the effectiveness of anti-vascular treatments (like anti-VEGF/VEGFR drugs such as bevacizumab and sunitinib). These strategies suggest that alleviating tumor hypoxia and improving perfusion could boost the effectiveness of radiotherapy, chemotherapy, and immunotherapy. Moreover, blocking PD-L1, which is upregulated by HIF-1α under hypoxic conditions, might offer a new approach to cancer immunotherapy [1]. Hypoxia-activated prodrugs specifically target hypoxic tumor cells and demonstrate selective toxicity and extensive antitumor effects. Drugs that target HIF and downstream genes have effectively suppressed tumors, significantly enhanced patient survival, and shown better tolerability. However, these drugs do come with some toxic side effects. Many clinical trials lack adequate data to fully assess the safety and effectiveness of the drugs being tested [24].

Our current understanding of how tumor cell destruction and normal tissue damage occur in hyperfractionated radiotherapy and stereotactic body radiotherapy (SBRT) and their clinical impact is quite limited. Developing sensitive tools to monitor tumor hypoxia before and during radiotherapy is crucial for overcoming resistance and treatment failures. Hypoxia-targeted dose painting is a promising personalized radiotherapy strategy based on detecting spatial variations in tumor hypoxia, though its impact in routine clinical practice remains minimal [25].

As we look to the future of overcoming tumor hypoxia in radiotherapy, it is clear that interdisciplinary approaches will be pivotal. Innovations in molecular biology and technology promise new therapeutic strategies that could significantly improve oxygenation within tumors, thereby enhancing the efficacy of radiotherapy. Personalized medicine, based on genetic profiling of tumors, may allow us to tailor treatments that specifically target the hypoxic zones, potentially overcoming one of the major hurdles in effective cancer treatment. Furthermore, advancements in imaging techniques could provide more precise mapping of hypoxic areas, enabling targeted radiotherapy that spares healthy tissue while intensifying treatment in resistant tumor sections. Finally, ongoing research into novel agents and modalities, including the use of nanoparticles and hyperbaric oxygen therapy, opens up additional avenues for addressing the challenge of tumor hypoxia. The integration of these new tools and approaches holds great promise for improving outcomes in patients undergoing radiotherapy for cancer.

Conclusion

In conclusion, the relationship between tumor hypoxia and radioresistance presents a significant challenge in the treatment of cancer, yet it also offers a fertile ground for innovative therapeutic strategies. As we have explored, understanding the mechanisms by which hypoxia contributes to radioresistance can lead to more effective treatments, including the use of hypoxia-targeted therapies and advanced radiotherapy techniques. The future holds promise for integrating new technologies and personalized approaches to specifically counteract the protective shield that hypoxia provides to tumors. By continuing to refine our understanding and improving our technological toolset, we can enhance the precision and efficacy of radiotherapy, ultimately leading to better patient outcomes. The journey to conquer tumor hypoxia is complex and requires a concerted effort from researchers, clinicians, and technologists alike, but the potential to significantly improve cancer treatment is clear and compelling. ■

Hipoksija tumora i radiorezistentnost

Sažetak

Tumorska hipoksija predstavlja čestu karakteristiku solidnih tumora, značajno pridonoseći povećanoj agresivnosti tumora, njegovom metastatskom potencijalu i otpornosti na konvencionalne terapije poput radioterapije. Ovaj pregled analizira složenu povezanost između tumorske hipoksije i radiorezistentnosti, ističući molekularne mehanizme koji sudjeluju u tom procesu te potencijalne terapijske strategije usmjerene na povećanje učinkovitosti radioterapije kod hipoksičnih tumora. Ključni mehanizmi uključuju ulogu faktora induciranih hipoksijom (HIF), s posebnim naglaskom na HIF-1α, koji regulira brojne gene uključene u preživljavanje, proliferaciju i otpornost tumora u uvjetima hipoksije. U pregledu se također raspravlja o omjeru povećanja kisika (OER) i njegovom utjecaju na ishode radioterapije, naglašavajući kako hipoksija smanjuje radiosenzitivnost ograničavanjem nastanka oštećenja DNA izazvanih zračenjem. Unatoč razvoju različitih strategija za suzbijanje radiootpornosti uzrokovane hipoksijom, poput inhibitora HIF-a, genske terapije ciljane na hipoksične stanice i pro-lijekova aktiviranih hipoksijom (HAPs), klinički rezultati su često neujednačeni, što ukazuje na potrebu za dodatnim istraživanjima. Osim toga, pregledava se napredak u tehnikama snimanja za detekciju tumorske hipoksije, što bi moglo omogućiti preciznije i personaliziranije pristupe radioterapiji, poput „dose painting“ metode. Budući napori u prevladavanju tumorske hipoksije u kontekstu radioterapije usmjerit će se prema integraciji inovativnih terapijskih strategija, personalizirane medicine i naprednih tehnologija snimanja, nudeći nadu za poboljšane ishode liječenja kod oboljelih od raka.

Ključne riječi: Tumorska hipoksija, radiorezistentnost, faktori inducirani hipoksijom (HIF), radioterapija, omjer povećanja kisika (OER)

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Radiološki tehnolozi u eri teleradiologije – „remote“ teleasistencija

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Ubrzan razvoj tehnologije i pristupačnija suvremena tehnološka rješenja u medicini kao i pandemija virusa COVID 19, rezultirali su većim zahtjevom za očitavanje radioloških pregleda na udaljenim lokacijama od mjesta snimanja. Teleradiologija kao grana telemedicine koja podrazumijeva očitavanje radioloških pregleda na udaljenim lokacijama od mjesta snimanja, oblikovala je potpuno novu sliku radiologije te se počela višestruko primjenjivati u svakodnevnoj kliničkoj praksi, bilo da se radi o uslugama vanjskih teleradioloških servisa ili novom načinu rada radiologa u matičnim zdravstvenim ustanovama. Okolnosti koje su tome prethodile su kronični nedostatak radioloških kadrova, izraženije u manjim zdravstvenim ustanovama, veća potražnja za slikovnim dijagnostičkim pregledima s posljedičnim produljenjem lista čekanja što je posredno utjecalo na potrebe za maksimalnim iskorištavanjem slikovnih dijagnostičkih uređaja, a sve u cilju pružanja najkvalitetnije zdravstvene usluge pacijentima, između ostalih i u zdravstvenim ustanovama u kojima nisu ostvareni preduvjeti poput dostupnosti liječnika specijalista radiologije užih specijalnosti ili zaposlenih radioloških tehnologa osposobljenih za rad na dijagnostičkim uređajima posljednje generacije, a iste ili posjeduju ili su u postupku nabave. Zdravstvena zaštita najviše kvalitete nedvojben je cilj kojem stremimo, a za dostignućem tog cilja nužno je premostiti razdoblje prilagodbe s postojećeg u napredniji sustav rada, višestruko ga mijenjajući u brojnim aspektima čime bi se omogućio brži i jednostavniji procese digitalne transformacije i sveobuhvatnije iskoristila napredna informatička rješenja primjenjiva i u radiologiji.

Usklađivanje i standardizacija protokola snimanja i tehničke izvedbe složenih slikovnih radioloških pregleda samo su neki od prepoznatljivijih čimbenika koji se prioritetno nameću kao sastavnica cjelovitog i dugoročnog rješenja. Telekonzultanskom ulogom osposobljenih radioloških tehnologa modelom teledirigiranih ili teleasistiranih aktivnosti tzv. „remote“ usluga, ostvario bi se višestruki učinak u znatno kraćem razdoblju i ujedno premostio kronični nedostatak stručno osposobljenih tehnologa zaposlenih u matičnim zdravstvenim ustanovama. Takav način rada zasigurno bi omogućio bržu i učinkovitiju edukaciju koja bi rezultirala osposobljavanjem većeg broja radioloških tehnologa, a ujedno je financijski i organizacijski najisplativija za poslodavca. Slijedom pozitivnih čimbenika, takav model funkcioniranja rezultirao bi učinkovitijom distribucijom i raspodjelom radioloških pregleda, a radiološku slikovnu dijagnostiku najsloženijih pretraga učinilo dostupnijom, liste čekanja kraćim i rasteretilo najopterećenije opće i kliničke bolničke centre mobilizacijom dostupnih uređaja za slikovnu dijagnostiku koji su u državnom vlasništvu.

Izuzev potonjeg, nužne su izmjene u zakonskim regulativama i pravilnicima o uvjetima, organizaciji i obavljanju telemedicine koji datiraju iz 2011. i 2012. godine i svakako su predmet daljnjih rasprava u svrhu otklona zakonskih nejasnoća i administrativnih ograničenja. Nužno ih je uskladiti i osuvremeniti sa trenutnim okolnostima, odnosno izjednačiti sa praksom preslikanom iz drugih zemalja članica Europske unije. Koordinacija stručnog radiološkog društva i društva radioloških tehnologa, liječničke komore i komore zdravstvenih radnika, Ministarstva zdravstva usuglašenim stavom i zajedničkom inicijativom osovina su kojom su takve promjene izgledne i ujedno jamac napretka i održive kvalitete. Predstojeći izazovi za struku radioloških tehnologa su prilagodba postojećih ovlasti i ograničenja čime bi se otklonile zapreke i dvojbe u obavljanju telekonzultantske usluge radioloških tehnologa. Brojne nedoumice koje se moraju detaljno razjasniti primjerice jesu li radni zadaci radiološkog tehnologa kao stručno osposobljene osobe koja uvodi pacijenta u prostoriju snimaonice, postavljanje i pozicioniranje pacijenta u uređaj za dijagnostičko snimanje isključivo u nadležnosti radiološkog tehnologa ili su moguća i drugačija rješenja u kojima bi se osposobili medicinski tehničari i medicinske sestre odnosno nemedicinsko administrativno osoblje s položenim ispitima o sigurnosti i pozicioniranju pacijenata, pružanju prve pomoći u neočekivanim okolnostima tijekom dijagnostičkog snimanja te krucijalno pitanje u čijoj su nadležnosti otvaranje venskog puta neophodno za ubrizgavanje kontrastnog sredstva automatskom štrcaljkom. Iznalaženje konsenzusa i usklađivanje pravnih i stručnih regulativa, koncept tehnologa na daljinu otvara dodatne mogućnosti radiološkim tehnolozima u izboru i kreativnosti radnog mjesta, visoku fleksibilnost u dodatnom opterećenju ili rasterećenju na dnevnoj i tjednoj osnovi uz pretpostavku da su osigurani preduvjeti za takvim radom poput sigurnosti na radu, IT sigurnost i zaštita podataka.

U novoj eri radiologije telekonzultantska i teleasistentska uloga uslijed demografskih oscilacija, globalnih izazova i promjena predstavlja optimalno rješenje u svim granama medicine i zasigurno jamči kvalitetu zdravstvene zaštite. U preopterećenom sustavu deficitarnih radioloških tehnologa, perspektiva koju nudi „remote“ usluga između prethodno nabrojanog predstavlja i pokretačku polugu u motivaciji i regrutaciji novih radioloških tehnologa, profesionalno i poslovno zadovoljstvo kao nezaobilazna potreba u kontinuiranom procesu rada i održivosti razvoja i napretka radiološke tehnologije. ■

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1. SIMPOZIJ STUDENATA RADIOLOŠKE TEHNOLOGIJE

Petak, 25. listopad 2024.

08:00 – 09:00	**Registracija studenata**
09:00 – 10:00	**Simpozij studenata radiološke tehnologije I, voditelji: Tatjana Matijaš, Frane Mihanović, Damir Ciprić**
09:00 – 09:15	Uvodna riječ
09:15 – 09:30	Poznavanje profesije radiološke tehnologije prije i poslije upisa studija, *M. Buljan, A. Mrčela*
09:30 – 09:45	Pristup nastavnika i mentora nastavi – studentski osvrt, *T. Ljubić, M. Zulić*
09:45 – 10:00	SWOT analiza kvalitete nastave Kliničkih vještina iz perspektive studenata, *M. Mihanović, M. Špar, T. Matijaš*
10:00 – 10:30	**Pauza za kavu**
10:30 – 11:30	**Simpozij studenata radiološke tehnologije II, voditelji: Melita Kukuljan, Maja Karić, Dražen Horvatinec**
10:30 – 10:45	Metoda izbora aplikacije kontrastnog sredstva kod pretrage vratnih i torakalnih organa, *A. Vukelić, M. Karić*
10:45 – 11:00	Sigurnost pacijenta u zdravstvenom radiološkom sustavu, *B. Pleše, M. Karić*
11:00 – 11:15	Uloga radiološkog tehnologa u CT-om vođenoj transtorakalnoj biopsiji, *N. Franki, M. Kukuljan*
11:15 – 11:30	Uloga radiološkog tehnologa u osiguravanju kvalitete CT-a toraksa, *K. Bužonja, M. Kukuljan*
11:30 – 11:45	**Pauza**
11:45 – 13:00	**Simpozij studenata radiološke tehnologije III, voditelji: Klaudija Višković, Andrija Čop, Velimir Karadža**
11:45 – 12:00	Umjetna inteligencija kod kompjutorizirane tomografije toraksa u bolesnika s COVID – 19 pneumonijom, *N. Mrvoš, K. Višković*
12:00 – 12:15	Should I stay or should I go? Vodič za mlade radiološke tehnologe, *I. Bilić, V. Bahun*
12:15 – 12:30	Melanom, *A. Bistrović, L. Periša, D. Ciprić*
12:30 – 12:45	Što sve može ionizirajuće zračenje? *M. Svjantko, J. Stanivuković, L. Periša, L. Rukelj, D. Ciprić*
12:45 – 13:00	Odobrenje za samostalan rad zdravstvenih radnika, *M. Karić*
13:00 – 13:45	Okrugli stol – studiji radiološke tehnologije
13:00 – 15:30	**Registracija sudionika kongresa**
DANI RADIOLOŠKE TEHNOLOGIJE – plenarna predavanja, moderatori: Andrija Čop, Velimir Karadža	
16:00 – 16:30	Otvaranje Kongresa
16:30 – 17:00	dGEMRIC – prvih 10 godina, naša iskustva, *D. Primorac, K. Štefančić*
17:00 – 17:30	Teleradiologija i radiološka tehnologija – danas i sutra, *T. Salha*
17:30 – 18:00	Donositelji slike ili donositelji odluka – gdje su radiološki tehnolozi? *V. Bahun, V. Karadža*
18:30	**Koktel dobrodošlice**

Subota, 26. listopad 2024.

08:00	**Registracija sudionika kongresa**
PREDAVANJA I, moderatori: Ivanka Herman, Nenad Vodopija	
10:00 – 10:15	Treba li nam sustav za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji? *D. Mesarić, I. Kralik*
10:15 – 10:30	Znanje stanovnika Požeško-slavonske županije o zračenju te radiološkim dijagnostičkim postupcima, *B. Škrabal, T. Šitum, D. Dobiš, S. Klišanić*
10:30 – 10:45	Uloga radiologije u COVID-19 pandemiji, *N. Grepo, M. Marinović Guić*
10:45 – 11:00	Upotreba MR 7T u kliničke svrhe, *B. Barnjak, N. Tomić*
11:00 – 11:30	**Pauza za kavu**
PREDAVANJA II, moderatori: Josip Mamić, Branka Horvatinec	
11:30 – 11:45	Uloga radiološkog tehnologa u Programu osiguranja kvalitete za Lexell Gamma Knife Icon u KBC-u Zagreb, *J. Sabljak, B. Ladešić, J. Čumpek, M. Ležaić, R. Rogić, Đ. Harmicar, E. Al-Khazae, S. Mihailovič Marasanov, H. Hršak, L. Luketin*
11:45 – 12:00	Što nedostaje komunikaciji u zdravstvu? *B. Malnar Cazin*
12:00 – 12:15	Optimizacija cjelokupnog radiološkog procesa u manjim medicinskim centrima: Iskustva iz Medicinskog centra Gorica, *B. Kukić*
12:15 – 12:30	Validacija sive skale na C-luku u korelaciji s HU na CT-u, *B. Kovalisko, F. Mihanović*
12:30 – 14:00	**Ručak**
PREDAVANJA III, moderatori: Branko Kovalisko, Tomislav Jovanić	
14:00 – 14:15	Izazovi u implementaciji photon-counting CT-a u kliničkoj praksi, *L. Bratinčević, T. Matijaš*
14:15 – 14:30	NAEOTOM Alpha Photon Counting CT u kliničkoj praksi: pregled mogućnosti, *I. Alerić, D. Kosmina, D. Schwarz*
14:30 – 14:45	Izolacija plućnih vena postupkom krioablacije kod pacijenata s paroksizmalnom atrijskom fibrilacijom, *R. Barišić, B. Barac, D. Šegota Ritoša, Z. Katić, M. Karić*
14:45 – 15:00	Svijest žena o važnosti screening mamografije, *A. Vukojević, K. Dolić*
15:00 – 15:15	**Pauza**
PREDAVANJA IV, moderatori: Vedran Manestar, Krunoslav Marinčević	
15:15 – 15.30	Inject less. Strive for more – Elucirem, *K. Marinčević, sponzorirano predavanje Pharmacol*
15:30 – 15:45	Magnetska rezonancija u suvremenoj radioterapiji, *E. Al-Khazae, F. Mihanović*
15:45 – 16:00	SWOT analiza primjene umjetne inteligencije u radiološkoj tehnologiji i radiologiji, *M. Delija, F. Mihanović*
16:00 – 16:15	MARLIN (Medical Applications of Radiation – Learning from Incidents and Near Misses) the European Consensus Guidelines, *V. Manestar*
16:15 – 16:45	**Pauza za kavu**
PREDAVANJA V, moderatori: Tatjana Matijaš, Ivan Skejić	
16:45 – 17:00	Inovativne radiokirurške metode, *J. Oroz*
17:00 – 17:15	Cyber napadi na radiološke sustave, *D. Viculin, F. Mihanović*
17:15 – 17:30	Jesmo li samostalni u nuklearnoj medicini? *H. Medvedec*
17:45 – 18:00	Radiološki pristup imunokompromitiranom pacijentu, *D. Babić, S. Lovrić Kojundžić*
18:00	**Završna riječ drugog dana Kongresa**

Nedjelja, 27. listopada 2024.

10:00 – 10:30	SWOT analiza profesije radioloških tehnologa u RH, *F. Mihanović, D. Ciprić, V. Bahun, V. Karadža*
10:30 – 11:30	Okrugli stol – Jesmo li samostalni? / EXPLORING AUTONOMY, moderatori: *F. Mihanović, M. Karić, V. Bahun;* Panelisti: *G. Roić, V. Vidjak, K. Dolić, M. Kukuljan*
11:30 – 12:00	**Pauza za kavu**
12:00	**Zatvaranje Kongresa**

KNJIGA SAŽETAKA

Poznavanje profesije radiološke tehnologije prije i poslije upisa studija

Mirela Buljan[1], Antonija Mrčela[1]

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Sažetak: Profesija radiološke tehnologije i znanje o njoj nisu široko rasprostranjeni u društvu pa dolazi do predrasuda i neinformiranosti o istoj. Prijediplomski sveučilišni studij radiološke tehnologije traje 3 godine uz mogućnost upisa i diplomskog sveučilišnog studija. Cilj rada je usporediti predznanje o radiološkoj tehnologiji i znanje stečeno nakon završetka studija. Prije upisa samoga studija većina studenata nije upoznata sa širokim spektrom radnih mjesta na kojima mogu obavljati poslove iz područja radiološke tehnologije. Nedostatak znanja o zračenju i njegovim biološkim učincima stvara negativno mišljenje o profesiji. Studenti promijene mišljenje tijekom studiranja temeljem usvajanja novih znanja i vještina kroz predavanja, seminare i kliničke vježbe. S obzirom na napredovanje tehnologije, obrazovanje ne završava samim završetkom studija već se nastavlja kroz cijeli radni vijek. Cjeloživotno učenje i napredovanje potiče zainteresiranost radioloških tehnologa za usvajanje novih tehnologija. Poslije završenog studija postoji problem brzog pronalaska pripravničkog staža, a kasnije i radnog mjesta. Negativno razmišljanje i predrasude o radiološkoj tehnologiji ne bi trebale sprečavati studente da upišu studij i otkriju zanimljivosti i prednosti radiološke tehnologije kao profesije.

Ključne riječi: profesija; radiološka tehnologija; studenti; znanje

Knowledge of the profession of radiological technology before and after enrolling in the program

Summary: The profession of radiological technology and the knowledge about it are not widely spread in society which leads to prejudice, misinformation and lack of information in general. The undergraduate university program in radiological technology lasts for three years, with the option to enroll in a graduate program. The aim of this paper is to compare the students' prior knowledge of radiological technology with the knowledge after completing the program. Before enrolling in the program, most students are not familiar with the wide range of job opportunities available in the field of radiological technology. The lack of knowledge about radiation and its biological effects causes a negative perception of the profession. Students change their opinions during their studies by acquiring new knowledge and skills through lectures, seminars, and clinical practice. Given the advancements in technology, education does not end with the completion of the program but continues throughout their working life. Lifelong learning and professional development stimulate radiological technologists' interest in accepting and using new technologies. After completing the program, students face the challenge of finding an internship position and, later on, a permanent workplace. Negative perceptions and prejudices about radiological technology should not prevent students from enrolling in the program and discovering the interesting aspects and benefits of radiological technology as a profession.

Keywords: knowledge; profession; radiological technology; students

Pristup nastavnika i mentora nastavi – studentski osvrt

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Sažetak: Cilj rada je analiza načina rada i pristupa nastavi nastavnika i mentora na Sveučilišnom odjelu zdravstvenih studija Sveučilišta u Splitu na studiju radiološke tehnologije kroz osvrt studenata. Svaki nastavnik i mentor ima individualan pristup i način prenošenja teorijskih i praktičnih znanja studentima tijekom nastave. Zadatak nastavnika u obrazovnom procesu je prenijeti teorijska znanja različitim oblicima nastave kao npr. predavanja, seminari, razne radionice, rad u skupinama, istraživanja itd. Rad mentora obuhvaća ne samo prenošenje znanja, već i komunikacijske vještine s aktivnostima koje će pomoći studentima kako bi stekli adekvatne kompetencije i vještine iz područja radiološke tehnologije. Zbog razlika u načinu rada i pristupa mentora prema studentima ali i pristupa studenata nastavi, većeg ili manjeg zalaganja moguće su razlike između mentora koje mogu primjetiti studenti a što može utjecati na njihovu percepciju o profesiji. Stoga će u ovom radu foku s biti na prednostima i nedostatcima koje studenti uočavaju u nastavi s nastavnicima i svojim mentorima.

Ključne riječi: nastava; mentori; nastavnici; studenti; kliničke vještine

Teacher's and mentor's approach to teaching – student review

Summary: The aim of the paper is to analyze the way of work and approach to teaching of teachers and mentors at the University Department of Health Studies of the University of Split on the study of radiological technology through the students' review. Each teacher and mentor has an individual approach and way of imparting theoretical and practical knowledge to students during classes. The teacher's task in the educational process is to transfer theoretical knowledge to different forms of teaching, such as lectures, seminars, various workshops, group work, research, etc. The work of a mentor includes not only the transfer of knowledge, but also communication skills with activities that will help students to acquire adequate competencies and skills in the field of radiological technology. Due to the differences in the way of work and the mentor's approach to students, but also the students' approach to teaching, greater or lesser commitment, there are possible differences between mentors that can be noticed by students and which can affect their perception of the profession. Therefore, in this paper, the focus will be on the advantages and disadvantages that students perceive in classes with teachers and their mentors.

Keywords: clinical skills; mentors; teachers; teaching; students

SWOT analiza kvalitete nastave Kliničkih vještina iz perspektive studenata

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Sažetak: Kliničke vještine sastavni su dio nastave prijediplomskog sveučilišnog studija radiološke tehnologije koje se odvijaju krajem svake akademske godine. Ovi kolegiji imaju svoje prednosti i nedostatke koji su analizirani koristeći metodu SWOT analize. Analiza je pokazala kako je najveća snaga ovih kolegija izravan doticaj studenata s profesijom uz nazočnost mentora. S druge strane, uočena je neproporcionalnost trajanja kolegija s obzirom na godinu prijediplomskog studija i razine stečenog teoretskog znanja. Iz toga proizlaze moguća različita rješenja kao što je reorganizacija nastave samih kolegija te raspodjela vremena i načina na koji će studenti pristupiti kolegiju. Najveću prijetnju predstavlja gubitak zainteresiranosti studenata za stjecanje novih znanja te mogući razvoj negativnog mišljenja o profesiji ako tijekom studiranja prevladaju navedene slabosti i prijetnje vezane za izvođenje navedenih kolegija.

Ključne riječi: kolegij; mentori; profesija; studenti; SWOT

SWOT analysis of the quality of Clinical skills education from the students' perspective

Summary: Clinical skills are an integral part of the undergraduate university programme in radiologic technology, taking place at the end of each academic year. They have been evaluated using the SWOT analysis

method, revealing advantages and disadvantages. The analysis showed that the greatest strength of clinical skills is the hands-on experience that students gain under the guidance of mentors. However, a disproportion was observed between the course duration and students' level of theoretical knowledge. This has led to potential solutions such as restructuring the course and reallocating the time and adjusting the students' approach to it. The greatest threat is the potential loss of student interest in acquiring new knowledge and the development of a negative perception of the profession if the weaknesses mentioned above and threats persist.

Keywords: course; mentors; profession; students; SWOT

Metoda izbora aplikacije kontrastnog sredstva kod pretrage vratnih i torakalnih organa

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Sažetak: Primarni cilj ovog istraživanja je procjena učinkovitosti bifazične primjene kontrastnog sredstva u dijagnostici kod kompjutorske tomografije (CT) za vratne i torakalne organe. Bifazična primjena kontrastnog sredstva u dijagnostici vratnih i torakalnih organa kod CT-a vrlo je važna metoda za adekvatni slikovni prikaz procjene anatomskih detalja te otkrivanje većine patoloških stanja u pacijenata. Moderna tehnologija suvremenih CT uređaja znatno smanjuje vrijeme skeniranja i omogućuje detaljnu rekonstrukciju snimaka bez dodatne izloženosti zračenju. Radiološki tehnolozi imaju ključnu ulogu u radu na pretragama koje se izvode na CT uređajima. Njihove odgovornosti obuhvaćaju niz tehničkih, kliničkih i administrativnih zadataka koji osiguravaju preciznu snimku, sigurnost pacijenata i učinkovitost tijeka rada. Metoda rada kod bifazične aplikacije kontrastnog sredstva, podijeljena na arterijsku i vensku fazu što omogućuje bolju vizualizaciju vaskularnih struktura i patoloških tvorbi. Ovaj pristup smanjuje potrebu za ponovljenim skeniranjima i time dodatno smanjuje izloženost zračenju. Standardni protokol uključuje administrativnu i fizičku pripremu pacijenta te preciznu aplikaciju kontrastnog sredstva u dvije faze s pauzom za optimalni prikaz cirkulacije. Ovaj pristup osigurava sve potrebne dijagnostičke informacije uz minimalnu dozu zračenja. Posebno je naglašena važnost pravovremenog davanja kontrasta za točan prikaz venske i arterijske cirkulacije. U pretragama torakalnih organa, kontrast razlikuje vaskularne strukture medijastinuma od patoloških tvorbi, dok u vratu pomaže pri detekciji tumora i drugih patoloških procesa. Zaključno, bifazična aplikacija kontrastnog sredstva pri CT pretragama preporučuje se za točnu i učinkovitu dijagnostiku patoloških stanja torakalnih i vratnih organa. Radiološki tehnolozi imaju ključnu ulogu u osiguravanju točnosti dijagnostičkih rezultata pri CT pretragama te u održavanju sigurnosti i dobrobiti pacijenata. Zahvaljujući njihovim tehnološkim vještinama, kliničkom znanju i profesionalnoj etici, oni su najvažnija karika u uspješnoj izvedbi pretraga.

Ključne riječi: bifazična primjena kontrastnog sredstva, kompjutorska tomografija

Method for Selecting Contrast Agent Application in the Examination of Cervical and Thoracic Organs

Abstract: The primary aim of this study is to evaluate the effectiveness of the biphasic application of a contrast agent in the diagnosis of computed tomography (CT) for neck and thoracic organs. Biphasic application of a contrast agent in the diagnosis of neck and thoracic organs in CT is a very important method for adequate imaging of the assessment of anatomical details and the detection of most pathological conditions in patients. The modern technology of modern CT devices significantly reduces the scanning time and enables detailed reconstruction of images without additional exposure to radiation. Radiologic technologists play a key role in the work on examinations performed on CT devices. Their responsibilities include a range of technical, clinical and administrative tasks that ensure accurate imaging, patient safety and workflow efficiency. The working method for biphasic contrast agent application, divided into arterial and venous phase, which enables better visualization of vascular structures and pathological formations. This approach reduces the need for repeated scans and thus further reduces radiation exposure. The standard protocol includes administrative and physical preparation of the patient and precise application of contrast in two phases with a pause for optimal circulation. This approach provides all necessary diagnostic information with minimized radiation dose. The importance of timely administration of contrast for accurate visualization of venous and arterial circulation is particularly emphasized. In examinations of the thoracic organs, the contrast distinguishes the vascular structures of the mediastinum from pathological formations, while in the neck it helps in the detection of tumors and other pathological processes. In conclusion, the biphasic application of a contrast medium during CT examinations is recommended for accurate and efficient diagnosis of pathological conditions of the thoracic and neck organs. Radiologic technologists play a key role in ensuring the accuracy of diagnostic results from CT scans and in maintaining the safety and well-being of patients. Thanks to their technological skills, clinical knowledge and professional ethics, they are the most important link in the successful performance of investigations.

Keywords: biphasic application of contrast medium, computer tomography

Sigurnost pacijenta u zdravstvenom radiološkom sustavu

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Sažetak: Cilj ovog rada je analiza i evaluacija sigurnosti pacijenata u zdravstvenom sustavu, s posebnim naglaskom na prevenciju štetnih utjecaja i smanjenje rizika od pogrešaka u zdravstvenoj skrbi. Riječ je o problemu od javnozdravstvenog značaja koji zahtijeva razvoj kulture sigurnosti unutar zdravstvenih organizacija. Istraživanje je obuhvatilo pregled zakonskih okvira, pravilnika i standarda koji reguliraju kvalitetu zdravstvene zaštite u Hrvatskoj. Istraženi su različiti tipovi neželjenih događaja u raznim medicinskim okruženjima kao što su bolničke jedinice intenzivne njege, hitne službe, laboratoriji i radiologija. Također su detaljno proučeni glavni uzroci medicinskih pogrešaka, uključujući dijagnostičke pogreške, bolničke infekcije i greške u primjeni lijekova. Rezultati pokazuju da je sigurnost pacijenata ključno javnozdravstveno pitanje te da medicinske pogreške predstavljaju jedan od vodećih uzroka smrti u tranzicijskim zemljama. Postizanje visoke kvalitete zdravstvene skrbi zahtijeva kontinuirano mjerenje i unapređivanje kvalitete, kao i promjenu kulture rada koja se ne bazira na optuživanju već na ispravljanju pogrešaka. Otvoreni sustavi za prijavljivanje neželjenih događaja i kontinuirana edukacija o sigurnosti pacijenata ključni su za poboljšanje rada u zdravstvenim institucijama. Zaključno, sigurnost pacijenata predstavlja ključno javnozdravstveno pitanje koje zahtijeva integrirani pristup zdravstvenih radnika, organizacija i pacijenata. Edukacija, akreditacijski standardi i usporedba nacionalnih i međunarodnih pokazatelja, zajedno s međunarodnom suradnjom, temeljni su za razvoj i održavanje sustava sigurnosti pacijenata. Bolnice moraju kontinuirano planirati, djelovati, analizirati i unapređivati kvalitetu skrbi kako bi postigle visoke standarde sigurnosti pacijenata.

Ključne riječi: akreditacijski standardi, neželjeni događaji, medicinske pogreške, unapređivanje kvalitete

Patient safety in the health radiology system

Abstract: The aim of this study is the analysis and evaluation of patient safety in the healthcare system, with a special emphasis on the prevention of harmful effects and the reduction of the risk of errors in health care. It is a problem of public health importance that requires the development of a safety culture within healthcare organizations. The research included an overview of the legal framework, regulations and standards that regulate the quality of healthcare in Croatia. Different types of adverse events have been investigated in various medical settings such as hospital intensive care units, emergency departments, laboratories and radiology. The main causes of medical errors, including diagnostic errors, hospital-acquired infections and medication errors, are also studied in detail. The results show that patient safety is a key public health issue and that medical errors are one of the leading causes of death in transition countries. Achieving high quality healthcare requires continuous measurement and improvement of quality, as well as a change in the work culture that is not based on accusations but on correcting mistakes.

Open systems for reporting adverse events and continuous education about patient safety are key to improving work in healthcare institutions. In conclusion, patient safety is a key public health issue that requires an integrated approach of healthcare professionals, organizations and patients. Education, accreditation standards and comparison of national and international indicators, together with international cooperation, are fundamental for the development and maintenance of patient safety systems. Hospitals must continuously plan, act, analyze and improve the quality of care in order to achieve high standards of patient safety.

Keywords: accreditation standards, adverse events, medical errors, quality improvement

Uloga radiološkog tehnologa u CT-om vođenoj transtorakalnoj biopsiji

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Sažetak: CT-om vođena transtorakalna biopsija (TTB) je invazivna radiološka metoda koja se koristi u dijagnostici patoloških stanja u toraksu (pluća, medijastinuma, pleure i torakalne stijenke). To je metoda kojom se pod vodstvom slikovnih metoda pomoću biopsijskih igala pribavlja stanični ili tkivni uzorak za citopatološku i /ili histopatološku analizu na osnovu koje se dolazi do definitivne dijagnoze, koja je neophodna za određivanje strategije liječenja. Karakterizira ju mala invazivnost, relativna sigurnost, precizno uzimanje uzorka te visoka dijagnostička točnost, koja se kreće u rasponu od 64% do 97%. Uvođenjem ove dijagnostičke metode u svakodnevnu praksu mogu se izbjeći invazivnije alternativne dijagnostičke procedure (torakoskopija, medijastinoskopija ili eksplorativna torakotomija), čime se skraćuje boravak u bolnici, umanjuje broj komplikacija i smanjuju ukupni troškovi liječenja. U timu za CT-om vođenu transtorakalnu biopsiju su intervencijski radiolog, radiološki tehnolog i instrumentar. Svaki član tima ima specifične zadatke. Prvi zadatak radiološkog tehnologa je namještaj bolesnika. Naime, nakon što interventni radiolog isplanira put pristupa ciljnoj leziji u toraksu radiološki tehnolog namješta bolesnika u odgovarajući položaj (pronacija, supinacija, lateralni, kosi), koji ovisi o lokalizaciji lezije, ali ponajviše o toleranciji bolesnika za određeni položaj. Adekvatan namještaj bolesnika ključan je za uspjeh intervencije, tijekom koje bolesnik mora bti potpuno miran, a to je moguće samo ako je u udobnom položaju. Slijedi, određivanje polja skeniranja, odnosno na topogramu se odredi volumen skeniranja i to samo onaj dio plućnog krila unutar kojeg je lezija predviđena za biopsiju. Potom radiološki tehnolog odabire CT presjek u visini predviđenog mjesta ulaska igle u toraks, izmjeri udaljenost planiranog mjesta ulaska igle u toraks od jedne od fiksnih anatomskih točaka (proc. spinosus torakalnih kralježaka, sternum, rubovi skapule), dovede stol u željenu poziciju pomoću „alata" na sučelju ekrana (Same Table Position-SAME TP) i postavlja radiopaktni marker na mjesto predviđeno za ulaz igle u toraks na koži bolesnika. Nakon toga se skenira prethodno određen dio toraksa u cilju provjere položaja markera i određivanja distance između markera i ciljne lezije na osnovu koje se bira duljina punkcijske igle. Ovo su zadnje predbiopsijske radnje nakon kojih interventni radiolog može započeti s biopsijom. Uvođenje punkcijske igle do cijne lezije ide postupno, „korak po korak". Radiološki tehnolog izvodi kontrolna skeniranja nakon svakog koraka, odnosno kontinuirano prati tijek intervencije, odnosno položaj biopsijske igle tijekom intervencije i pojavu eventualnih komplikacija. Po završetku biopsije, isključivo poradi utvrđivanja eventualnih komplikacija kod svih bolesnika radiološki tehnolog učini kontrolni CT toraksa, pri čemu skenira čitav toraks debljinom sloja od 5 mm i rekonstruira u medijastinalnom i plućnom prozoru.

Ključne riječi: transtorakalna biopsija, stanični – tkivni uzorak, patohistološka analiza

The role of the radiologic technologist in CT-guided transthoracic biopsy

Abstract: CT-guided transthoracic biopsy (TTB) is an invasive radiologic technique for diagnosing thorax pathological conditions (lungs, mediastinum, pleura, and thoracic wall). This method, performed under image guidance with biopsy needles, allows for collecting cellular or tissue samples for cytopathological and/or histopathological analysis, which leads to a definitive diagnosis necessary for determining the treatment strategy. The procedure is characterized by minimal invasiveness, relative safety, precise sample acquisition, and high diagnostic accuracy, which ranges from 64% to 97%. The introduction of this diagnostic method into routine practice can help avoid more invasive alternative diagnostic procedures (such as thoracoscopy, mediastinoscopy, or exploratory thoracotomy), thereby reducing hospital stays, minimizing complications, and lowering overall treatment costs. The CT-guided transthoracic biopsy team consists of an interventional radiologist, a radiologic technologist, and a scrub nurse, with each member having specific responsibilities. The radiologic technologist's primary task is patient positioning. After the interventional radiologist plans the access path to the target lesion in the thorax, the technologist positions the patient appropriately (prone, supine, lateral, or oblique) based on the lesion's location and, most importantly, on the patient's ability to tolerate the chosen position. Proper patient positioning is crucial for the success of the intervention, as the patient must remain completely still during the procedure, which is only possible if they are comfortably positioned. Next, the technologist defines the scanning field. On the topogram, the scan volume is set to include only the portion of the lung containing the lesion intended for biopsy. The technologist then selects the CT slice at the level of the planned needle entry point into the thorax, and measures the distance from the planned needle entry point to a fixed anatomical landmark (such as the thoracic vertebral spinous process, sternum, or scapular borders), adjusts the table position using the interface tools („Same Table Position" – SAME TP), and places a radiopaque marker on the patient's skin at the planned needle entry site. A follow-up scan of the pre-defined thoracic area is performed to verify the marker's position and to measure the distance between the marker and the target lesion, which determines the appropriate needle length. These are the final pre-biopsy steps before the interventional radiologist begins the procedure. The insertion of the biopsy needle towards the target lesion is performed step by step, with the radiologic technologist conducting control scans after each step to ensure the accurate positioning of the biopsy needle and to promptly detect any potential complications. After the biopsy, the technologist performs a control CT scan of the entire thorax to check for complications, scanning with a 5 mm slice thickness and reconstructing images in both mediastinal and lung windows.

Keywords: cell-tissue sample, pathohistological analysis, transthoracic biopsy

Uloga radiološkog tehnologa u osiguravanju kvalitete CT-a toraksa

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Sažetak: CT pregled toraksa započinje odabirom protokola i planiranjem polja skeniranja, što ovisi o kliničko-radiološkoj indikaciji. Na Kliničkom zavodu za dijagnostičku i intervencijsku radiologiju u Rijeci, za CT pregled toraksa koristimo četiri protokola, a to su: standardni protokol nativni i s kontrastom te visoko rezolucijski protokol (HR-high resolution protocol), također s ili bez uporabe kontrasta. Koji će se protokol koristiti određuje radiolog na temelju priložene medicinske dokumentacije. Ako je indikacija za CT pregled sumnja na maligni tumor, pregledom trebaju biti obuhvaćene nadbubrežne žlijezde. Kod ostalih indikacija, skenira se od visine gornje aperture toraksa do dna kostofreničnih recesusa. Pacijent se početno skenira u položaju supinacije, s rukama iznad glave. Važan zadatak radiološkog tehnologa je uputiti pacijenta na ponašanje tijekom skeniranja, odnosno objasniti mu da tijekom skeniranja mora biti potpuno miran i upozoriti ga na zadržavanje daha za vrijeme skeniranja, odnosno da se pregled vrši u apneji nakon maksimalno dubokog udaha. Po završetku skeniranja, radiološki tehnolog je dužan provjeriti kvalitetu pregleda. Najprije treba otkriti eventualne artefakte uzrokovane pomicanjem ili disanjem pacijenta tijekom skeniranja. Potom mora provjeriti je li pregled učinjen u adekvatnom inspiriju, jer ako nije, rezultat je hipoventilacija pluća koja se manifestira ground-glass opacifikacijama (eng. ground-glass opacities, GGO), što može imitirati patološka stanja u plućima. Nedovoljan inspirij tijekom skeniranja najbolje se prepoznaje po obliku traheje, koja je u maksimalnom inspiriju na aksijalnom CT presjeku

okrugla, dok je u ekspiriju stražnja stijenka traheje zaravnata ili ventralno konkavna. U oba slučaja potrebno je konzultirati radiologa u vezi eventualnog ponavljanja pregleda. Nadalje, radiološki tehnolog je dužan provjeriti transparenciju parenhima pluća uz dorzalni torakalni zid. Ako je transparencija smanjena zbog retikularnih ili GGO zasjenjenja, radiološki tehnolog je dužan, bez konzultacije s radiologom, ponoviti skeniranje u položaju pronacije, također u maksimalnom inspiriju. Ovo je posebno važno za pacijente kod kojih se zbog sumnje na intersticijsku bolest pluća koristi HR protokol. Drugi radiomorfološki znak koji radiološki tehnolog na CT presjecima treba prepoznati je mozaična perfuzija. U tom slučaju, također bez konzultacije s radiologom, mora učiniti pregled u ekspiriju kako bi se razjasnila etiologija mozaične perfuzije. Naime, ukoliko se na ekspiratornim presjecima na mjestu mozaične perfuzije vidi fenomen zarobljavanja zraka (air treping) to je siguran pokazatelj obstrukcije na nivou malih zračnih puteva. Nadalje radiološki tehnolog mora provjeriti stanje na početnim i završnim presjecima. Ukoliko je na početnim presjecima pregledom djelomično obuhvaćen patološki proces koji se širi iz vrata treba u dogovoru s radiologom nadopuniti pregled s CT-om vratnih organa. Isto tako ukoliko je na završnim presjecima pregledom djelomično obuhvaćen patološki proces nekog od abdominalnih organa, treba u dogovoru s radiologom nadopuniti pregled s CT-om abdomena. U slučaju da klinička indikacija zahtjeva CT toraksa s kontrastom na našem Kliničkom zavodu koristimo bifazičnu tehniku aplikacije kontrasta, koja nam omogućava podjednaku postkontrastnu opacifikaciju medijastinalnih i hilarnih arterija i vena, što je preduvjet za dobro razlikovanje i razgraničavanje ev. patoloških promjena u medijastinumu i hilusima, poglavito uvećanih limfnih čvorova. Zadatak radiološkog tehnologa je procijeniti postkontrastnu opacifikaciju navedenih vaskularnih struktura i ukoliko nije dostatna za detaljnu analizu, treba u dogovoru s radiologom razmotriti eventualno ponavljanje pregleda.

Ključne riječi: CT toraksa, HRCT toraksa, protokol snimanja

The role of the radiologic technologist in ensuring the quality of chest CT

Abstract: A CT scan of the thorax begins with the selection of the protocol and planning of the scanning field, which depends on the clinical-radiological indication. At the Clinical Department of Diagnostic and Interventional Radiology in Rijeka, we use four protocols for thoracic CT: the standard native and contrast-enhanced protocols, and the high-resolution protocol (HR) with or without contrast. The choice of protocol is determined by the radiologist based on the provided medical documentation. If the clinical indication for the CT scan is suspected malignant tumor, the adrenal glands must be included in the scan. For other indications, scanning is performed from the level of the thoracic inlet to the bottom of the costophrenic recesses. The patient is initially scanned in the supine position, with arms above the head. A key responsibility of the radiologic technologist is to instruct the patient on how to behave during the scan, emphasizing the need to remain completely still and to hold their breath during the scan, as the examination is performed in apnea following a maximal deep breath. After the scan, the radiologic technologist is required to check the quality of the images. The first step is to detect any artifacts caused by patient movement or breathing during the scan. Then, the technologist must verify that the scan was performed in adequate inspiration, as insufficient inspiration results in hypoventilation of the lungs, manifesting as ground-glass opacities (GGO), which can mimic pathological conditions in the lungs. Inadequate inspiration is best identified by the shape of the trachea; in maximal inspiration on axial CT slices, the trachea appears round, while in expiration, the posterior tracheal wall becomes flattened or ventrally concave. In either case, it is necessary to consult with the radiologist regarding the potential need for a repeat scan. Furthermore, the radiologic technologist must check the transparency of the lung parenchyma against the dorsal thoracic wall. If transparency is reduced due to reticular or GGO opacities, the technologist should, without consulting the radiologist, repeat the scan in the prone position, again in maximal inspiration. This is particularly important for patients undergoing the HR protocol due to suspected interstitial lung disease. Another radiomorphological sign the radiologic technologist must recognize on CT slices is mosaic perfusion. In this case, again without consulting the radiologist, an expiratory scan should be performed to clarify the etiology of the mosaic perfusion. Specifically, if air trapping is observed on expiratory slices at the site of mosaic perfusion, it is a reliable indicator of small airway obstruction. Additionally, the radiologic technologist must inspect the initial and final slices. If a pathological process extending from the neck is partially captured on the initial slices, the technologist should consult with the radiologist to supplement the scan with a CT of the neck. Similarly, if a pathological process in an abdominal organ is partially captured on the final slices, a CT of the abdomen should be considered in consultation with the radiologist. If the clinical indication requires a contrast-enhanced thoracic CT scan, our department uses a biphasic contrast injection technique, which ensures balanced post-contrast opacification of mediastinal and hilar arteries and veins. This balance is crucial for distinguishing and delineating potential pathological changes in the mediastinum and hila, particularly enlarged lymph nodes. The radiologic technologist is responsible for assessing the post-contrast opacification of these vascular structures and, if the opacification is insufficient for detailed analysis, should consult with the radiologist to consider repeating the scan.

Keywords: CT chest, HRCT chest, imaging protocol

Umjetna inteligencija kod kompjutorizirane tomografije toraksa u bolesnika s COVID – 19 pneumonijom

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Sažetak: Bolest COVID – 19 izazvana virusom SARS – CoV – 2 prezentira se kašljem, povišenom tjelesnom temperaturom te respiratornim simptomima. Promjene na plućima kod pneumonije najpreciznije se prikazuju kompjutoriziranom tomografijom (CT). Stoga je CT bila glavna radiološka metoda za probir pacijenata s težim oblicima COVID – 19 pneumonije. Kako bi se ubrzao dijagnostički proces, u radiologiju se implementirao sustav umjetne inteligencije (UI). Ciljevi ovog rada bili su utvrditi prednosti u primjeni alata umjetne inteligencije (strojnog učenja i dubokog učenja) u analizi snimaka bolesnika s COVID – 19 pneumonijom pomoću CT – a u usporedbi s analizom snimaka koje su očitali isključivo radiolozi te analizirati etičke probleme kod primjene alata umjetne inteligencije (strojnog učenja i dubokog učenja) u dijagnostici bolesti COVID – 19. Ovim preglednim radom analizirano je devetnaest članaka s tematikom primjene UI u CT dijagnostici bolesti COVID – 19, te jedanaest članaka vezanih za etičnost primjene UI u radiologiji. Analiza radova pokazala je da je UI značajno pomogla u kvalitetnoj i brzoj dijagnostici COVID – 19 pneumonije, ali da je te sustave potrebno dalje razvijati kako bi što preciznije postavili brzu dijagnozu. U člancima s temom etičke primjene UI u radiologiji ističu se problemi odgovornosti za točnost završne dijagnoze te zaštićenosti podataka pacijenata. Predloženo je sastavljanje univerzalnog etičkog kodeksa kojim bi se definirali i razriješili navedeni problemi.

Ključne riječi: COVID – 19; duboko učenje; kompjutorizirana tomografija prsnog koša; strojno učenje; umjetna inteligencija

Artificial intelligence in computed tomography of the thorax in patients with COVID-19 pneumonia

Summary: The COVID-19 disease caused by the SARS-CoV-2 virus is presented by cough, fever and respiratory symptoms. Changes in the lungs in pneumonia are most accurately shown by computed tomography (CT). Therefore, CT was the main radiological method for screening patients with severe forms of COVID-19 pneumonia. To speed up the diagnostic process, an artificial intelligence (AI) system has been implemented in radiology. The objectives of this study were to determine the advantages in the application of artificial intelligence tools (machine and deep learning) in the analysis of CT images of patients with COVID-19 pneumonia compared to the analysis of images read exclusively by radiologists, and to analyze ethical problems in the application of artificial intelligence tools (machine and deep learning) in the diagnosis of COVID-19 disease. This review analyzed nineteen articles on the application of AI in CT diagnostics of COVID-19, and eleven articles related to the ethics of AI application in radiology. The analysis of the papers showed that AI has significantly helped in the quality and rapid diagnosis of COVID-19

pneumonia, but that these systems need to be further developed to make a rapid diagnosis as accurately as possible. Articles on the ethical application of AI in radiology highlighted the problems of responsibility for the accuracy of the final diagnosis and the protection of patient data. It is proposed to create universal code of ethics that would define and resolve these problems.

Keywords: artificial intelligence; computed tomography of the chest; COVID-19; deep learning; machine learning

Should I stay or should I go? Vodič za mlade radiološke tehnologe

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Sažetak: U današnjem globaliziranom zdravstvu mladi radiološki tehnolozi suočavaju se s dilemom: ostati u Hrvatskoj ili nastaviti karijeru u inozemstvu? Ova će prezentacija pružiti vodič radiološkim tehnolozima na ovoj prekretnici, nudeći uvid u profesionalne, ali i osobne čimbenike koji se mogu uzeti u obzir. Financijski, rad u inozemstvu često donosi bolje benefite. Ipak, valja razmišljati o odnosu troškova života, poreznom opterećenju te o potencijalnoj nestabilnosti radnih mjesta. S druge strane, Hrvatska često nudi niža primanja, ali siguran posao te stabilnije prihode, a ponekad i bolju ravnotežu između poslovnog i privatnog života koja dugoročno može prevagnuti u pozitivnijem smjeru. Međunarodni angažmani često ubrzavaju profesionalni rast, pristupom naprednim tehnologijama i snažnim programima kontinuiranog obrazovanja. Hrvatska, iako skromnijeg opsega, konstantno napreduje u tim područjima, posebice uvođenjem novih tehnologija i povećanim mogućnostima za akademsku suradnju. Zadovoljstvo poslom još je jedan ključan čimbenik. Dobro strukturirani sustavi i institucije u inozemstvu mogu ponuditi više resursa i naprednije tehnologije. Ipak, hrvatski zdravstveni sustav, unatoč izazovima, pruža poznatije radno okruženje, koje nekima može biti jednako ispunjavajuće. Na kraju, mladi radiološki tehnolozi bi trebali uzeti u obzir i humani aspekt – obitelj, kulturu, religiju i osobno zadovoljstvo. Ostajanje blizu voljenih, te rad unutar poznatog sustava može s vremenom iznijeti dobre osobne benefite.

Ključne riječi: radiološki tehnolozi, zaposlenje, zdravstveni sustav

Should I stay or should I go? A human guide for young radiology technologists

Abstract: In today's globalized healthcare, young radiology technologists face a dilemma: whether to stay in Croatia or pursue a career abroad. This presentation aims to provide an extensive, human-centered guide for radiology technologists navigating this crossroads, offering insights into the professional and personal factors they could consider.

Financially, working abroad often brings better benefits packages. Still, these must be weighed against the cost of living, taxation, and potential job instability. On the other hand, Croatia may offer lower salaries, but with job security, a steady income, and sometimes a better work-life balance that can enhance overall well-being in the long run. International placements often accelerate professional growth, with access to advanced technologies and strong continuing education programs. Yet Croatia, while more modest in scale, is steadily improving in these areas, especially with the introduction of new technologies and increased opportunities for academic collaboration. Job satisfaction is another crucial factor. Well-structured systems and institutions abroad may offer more resources and technology. Still, the Croatian healthcare system, despite its challenges, provides a more familiar work environment, which, for some, can be equally fulfilling. Lastly, students should consider the human aspect—family, culture, religion and personal well-being. Staying close to loved ones and operating within a familiar system may prove beneficial over time.

Keywords: radiological technologists, employment, health system

Melanom

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Sažetak: Melanom je zloćudni tumor kože koji nastaje malignom preobrazbom melanocita. Obolijevaju žene i muškarci, no sam melanom pojavljuje se na različitim dijelovima tijela, ovisno o spolu. Kod muškaraca najčešća je pojava na trupu, dok kod žena na donjim ekstremitetima. Incidencija pojavnosti ovisi o blizini ekvatora, godišnjem dobu, dobi dana, dobi i spolu. Razlikujemo tri skupine rizičnih čimbenika za nastanak melanoma: genetski, okolišni i fenotipske manifestacije interakcije gena i okoliša. Od genetskih čimbenika izdvajaju se svijetla put, svijetle oči, crvena kosa, a od okolišnih UV zračenje. Prevencija ima veliku ulogu kod melanoma, a uključuje ABCDEFG pregled, izbjegavanje dugotrajnom izlaganju UV zračenju, nošenje zaštitne odjeće i nanošenje zaštitnih sredstava za sunce te redoviti dermatološki pregledi, dok je najvažniji cilj prevencije rano otkrivanje što uvelike pospješuje liječenje. Cilj prezentacije je osvijestiti ljude o prevenciji i prije svega učestalosti postojanja ove zloćudne bolesti. Od toga je važno spomenuti melanom među radiološkim tehnolozima budući da se u tom području smatra profesionalnom bolešću. Uz pomoć mentora i istraživanjem znanstvene literature, u radu su iznesene činjenice od definicije, manifestacija i prevencija karcinoma kože. Zaključno možemo reći kako obzirom na napredak tehnologije i unapređenja znanja postoji mnogo načina za prevenciju zloćudne bolesti, a od toga je najvažniji sam čovjek i njegov pravovremeni odaziv na preventivne preglede .

Ključne riječi: melanom, prevencija, profesionalna bolest, rizični čimbenici

Melanoma

Abstract: Melanoma is a malignant tumor of the skin that results from the malignant transformation of melanocytes. Women and men are affected, but melanoma itself appears on different parts of the body, depending on gender. In men, the most common occurrence is on the trunk, while in women, it occurs on the lower extremities. The incidence of occurrence depends on proximity to the equator, season, time of day, age and sex. We distinguish three groups of risk factors for the development of melanoma: genetic, environmental and phenotypic manifestations of the interaction of genes and the environment. Of the genetic factors, bright skin, bright eyes, red hair stand out, and of the environmental factors, UV radiation. Prevention plays a major role in melanoma, and includes an ABCDEFG examination, avoiding long-term exposure to UV radiation, wearing protective clothing and applying sunscreen, and regular dermatological examinations, while the most important goal of prevention is early detection, which greatly improves treatment. The goal of the presentation is to make people aware of prevention and, above all, the frequency of this malignant disease. Of these, it is important to mention melanoma among radiologic technologists, since it is considered an occupational disease in that field. With the help of a mentor and the research of scientific literature, the paper presents facts from the definition, manifestations and prevention of skin cancer. In conclusion, we can say that in view of the progress of technology and advancement of knowledge, there are many ways to prevent a malignant disease, and the most important of these is the person himself and his timely response to preventive examinations.

Keywords: melanoma, prevention, occupational disease, risk factors

Što sve može ionizirajuće zračenje?

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Sažetak: Ionizirajuće zračenje je zračenje koje ima dovoljno energije da uzrokuje ionizaciju atoma, odnosno gubitak energije što ovisi o atomskoj gustoći materije kroz koju prolazi.. Iako razlikujemo dva osnovna oblika ionizirajućeg zračenja, prvenstveno ćemo u prezentaciji prikazati upo-

trebu fotonskog ionizirajućeg zračenja čiji atenuirani snop korištenjem detektora pretvaramo u vidljivi slikovni zapis. Taj zapis prikazuje razlike unutar objekta koje smo snimili rendgenskim zračenjem i prikaz različitih intenziteta sive skale omogućava da tumačimo što ne vidimo kroz površinu objekta kao i u rtg dijagnostici. Hipoteza s kojom smo krenuli bila je: „Ima li ionizirajuće zračenje upotrebu i izvan medicine?“ Nakon istraživanja, za koje smo koristili dostupne izvore i literaturu, te uz pomoć mentora došli smo do spoznaje kako, osim velike važnosti u medicini, ionizirajuće zračenje ima značajnu i široku ulogu u drugim djelatnostima. Djelatnosti u kojima smo vidjeli upotrebu ionizirajućeg zračenja su antropologija, industrija, forenzika, patologija kao i umjetnost.

Ključne riječi: antropologija, industrija, ionizirajuće zračenje, forenzika, patologija, umjetnost

What can ionizing radiation do?

Abstract: Ionizing radiation is radiation that has enough energy to cause ionization of atoms and loss of energy, which depends on the atomic density of the matter through which it passes. Although we distinguish between two basic forms of ionizing radiation, primarily in the presentation we will show the use of photon ionizing radiation, the attenuated beam of which is converted into a visible image using a detector.

The hypothesis we started with was: „Does ionizing radiation have a use outside of medicine?“ significant and broad role in other activities. Activities in which we have seen the use of ionizing radiation are anthropology, industry, forensics, pathology as well as art.

Keywords: anthropology, industry, ionizing radiation, forensics, pathology, art

Teleradiologija i radiološka tehnologija – danas i sutra

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Sažetak: Teleradiologija je grana telemedicine koja podrazumijeva očitavanje radioloških pregleda na udaljenim lokacijama od mjesta snimanja. Ubrzan razvoj tehnologije, napredna tehnološka dostignuća kao i pandemija virusa COVID 19, rezultirala su većom potrebom teleradioloških usluga, bilo da se radi o uslugama vanjskih teleradioloških servisa ili novom načinu rada matičnih radiologa pojedine ustanove. Razlog tome je nedostatak radioloških kadrova, posebno u manjim ustanovama, potreba za skraćenjem lista čekanja ili bolja iskoristivost naprednijih dijagnostičkih uređaja te pružanja vrhunske zdravstvene usluge pacijentima u ustanovama gdje nedostaju kadrovi uže specijalnosti ili osposobljenih radioloških tehnologa. Teleradiologija premošćuje geografska, socijalna i vremenska ograničenja u skrbi za pacijente. Pravna ograničenja i nedostatak jasnijih i prilagođenijih pravnih regulativa ograničava efikasnu implementaciju i bolju iskoristivost odnosno primjenu teleradioloških usluga. Kvalitetno očitanje nalaza zahtjeva dostupnost ključnih kliničkih informacija i prethodnih pregleda. Dostupnost takvih informacija može biti izazovan zadatak budući da zdravstvene ustanove često imaju različite PACS preglednike i načine pohranjivanja podataka. Tehnološko i učinkovito informatičko rješenje prevladavanja ove prepreke uvođenjem jedinstvenog PACS sustava i načina pohranjivanja podataka bez ugrožavanja zaštite podataka pacijenata značajno bi unaprijedilo kvalitetu teleradiološkog očitanja pretraga. Sličan problem predstavlja neujednačenost u protokolima snimanja i kvaliteti tehničke izvedbe slikovnih pretraga kao i alarmantan nedostatak obučenih radioloških tehnologa za rad na sofisticiranim radiološkim dijagnostičkim uređajima. Neprimjenjivanje standardizacije protokola na nacionalnoj razini nameće pravno i stručno pitanje odabira protokola pregleda koji se snimaju za vanjski teleradiološki servis, odnosno mogu li teleradiološki servisi uvjetovati vlastite protokole ili im se nameće prilagođavanje standardu svake zdravstvene ustanove, kao i mogućnost angažiranja telekonzultanta radiološkog tehnologa tzv. „remote“ tehnologa obučenog za izvedbu najsloženijih radioloških pretraga. Osim standardizacije protokola, ključna je i kvalitetna komunikacija telekonzultanta radiologa s radiološkim tehnologom zaduženim za izvedbu pretrage te dostupnost za konzultacije i izvan redovnog radnog vremena. Rješavanje ovih pitanja i izjednačavanje sustava s praksom preslikano iz drugih zemalja članica Europske unije i svijeta mogu unaprijediti obavljanje ove djelatnosti i na taj način omogućiti pacijentima pružanje najkvalitetnije zdravstvene skrbi u najkraćem vremenu.

Ključne riječi: standardizacija, telekonzultant, teleradiologija

Teleradiology and radiological technology – today and tomorrow

Abstract: Teleradiology is a branch of telemedicine that involves reading radiological examinations at remote locations from the imaging site. The rapid development of technology, advanced technological achievements, as well as the pandemic of the COVID 19 virus, have resulted in a greater need for teleradiology services, whether it is employment of external teleradiology services or a new way of work organization for the main radiologists in a health institution. The reason for this is the lack of radiological staff, especially in smaller institutions, the need to shorten waiting lists or better use of more advanced diagnostic devices, and to provide top-quality health care services to patients in institutions where there is a lack of sub-specialised staff or trained radiological technologists. Teleradiology bridges geographical, social and time limitations in patient care. Legal restrictions and the lack of clearer and more adapted legal regulations limit the efficient implementation and better utilization of teleradiology services. A quality reading of the findings requires the availability of key clinical information and previous examinations. Availability of such information can be a challenging task as healthcare facilities often have different PACS and data storage methods. A technological and efficient IT solution to overcome this obstacle by introducing a unique PACS system and way of storing data without jeopardizing the protection of patient data would significantly improve the quality of teleradiological examination readings. A similar problem is the unevenness in recording protocols and the quality of the technical performance of imaging examinations, as well as the alarming lack of trained radiological technologists to work on sophisticated radiological diagnostic devices. The non-application of protocol standardization at the national level imposes the legal and professional question of selecting examination protocols when recording for an external teleradiology service, i.e. whether teleradiology services can condition their own protocols or are they forced to adapt to the standard of each health institution, as well as the possibility of engaging a radiological technologist teleconsultant, the so-called „remote“ technologist trained to perform the most complex radiological examinations. In addition to the standardization of the protocol, quality communication between the teleconsultant radiologist and the radiological technologist responsible for the examination and availability for consultations outside regular working hours is also crucial.

Solving these issues and equating the system with practice copied from other member states of the European Union and the world can improve the performance of this activity and thus enable patients to be provided with the highest quality healthcare in the shortest possible time.

Keywords: standardization, teleconsultant, teleradiology

Donositelji slike ili donositelji odluka – gdje su radiološki tehnolozi?

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Sažetak: Radiološki tehnolozi imaju važnu ulogu u zdravstvu, čineći okosnicu slikovne dijagnostike na globalnoj razini. U Hrvatskoj je profesija djelomično priznata i suočava se s jedinstvenim izazovima u usporedbi s međunarodnim standardima. Hrvatski tehnolozi prolaze standardiziranu edukaciju i licenciranje, no pravni okvir još uvijek ograničava njihovu autonomiju. U međuvremenu, u zemljama poput Ujedinjenog Kraljevstva, SAD-a i Kanade, tehnolozi često samostalno izvode složenije postupke. Globalno, inicijative za miješanje vještina proširile su sve odgovornosti

zdravstvenih radnika kako bi se smanjilo opterećenje zdravstvenih sustava. Nažalost, Hrvatska sporo usvaja te strategije, ostavljajući svojim radiološkim tehnolozima tradicionalnije, ograničenije uloge. To je u suprotnosti sa zemljama u kojima tehnolozi imaju veću autonomiju, aktivnije pridonoseći skrbi za pacijente. Ova će prezentacija istražiti sličnosti i razlike u licenciranju, obrazovnim zahtjevima i svakodnevnim obavezama radioloških tehnologa u Hrvatskoj u usporedbi sa svjetskom pozornicom. Promatrajući hrvatski model kroz međunarodnu prizmu, možemo otkriti mogućnosti za rast i razvoj u ovom području, osiguravajući da tehnolozi budu pripremljeni za suočavanje s budućim zdravstvenim izazovima, kako u zemlji tako i u inozemstvu. Prezentacija ima za cilj pružiti uvid u to kako hrvatski radiološki tehnolozi mogu proširiti svoju stručnost i pozicionirati se kao ključni igrači u međunarodnoj sceni medicinskog oslikavanja.

Ključne riječi: radiologija, slikovna dijagnostika, profesionalna autonomija

Image Makers or Decision Makers – Where Do Radiology Technologists Stand?

Abstract: Radiology technologists play a crucial role in healthcare, forming the backbone of diagnostic imaging globally. In Croatia, the profession is partly recognised and faces unique challenges compared to international standards. Croatian technologists undergo standardised education and licensing, but the legal framework still limits their autonomy. Meanwhile, in countries like the U.K., U.S. and Canada, technologists often perform more complex procedures independently. Globally, *skill mix* initiatives have expanded all healthcare workers' responsibilities to reduce the load on healthcare systems. Unfortunately, Croatia has slowly adopted these strategies, leaving its radiology technologists with more traditional, restricted roles. This contrasts with countries where technologists have greater autonomy, contributing more actively to patient care. This presentation will explore the similarities and differences in licensing, educational requirements, and daily responsibilities of radiologic technologists in Croatia compared to the global stage. By looking at the Croatian model through an international lens, we can uncover opportunities for growth and development in this field, ensuring that technologists are equipped to meet future healthcare challenges, both at home and abroad. The presentation aims to provide insight into how Croatian radiologic technologists can expand their expertise and position themselves as key players in the international medical imaging landscape.

Keywords: radiology, diagnostic imaging, professional autonomy

Treba li nam sustav za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji?

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Sažetak: ***Cilj***: Cilj ovoga rada je ukazati na potrebu uspostave sustava za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji, kao i na potrebu provedbe tog sustava. MATERIJALI I METODE: Studija je provedena retrospektivno. Odabrano je 20 radioloških slika zdjelice učinjenih konvencionalnom radiografijom. Ocjena kvalitete odabranih radioloških slika provedena je sukladno europskim preporukama. Uz ocjenu kvalitete radioloških slika, analizirani su i parametri ekspozicije te indeks ekspozicije i devijacijski indeks. ***Glavni rezultati***: Prosječna ocjena kvalitete odabranih radioloških snimki iznosi 3,25, a ocjene su se kretale od 0 do 7 uz 7 kao najveću moguću ocjenu. Najveća ocjena pridijeljena je 5 % radioloških slika, a najmanja 20 %. Najčešće uočene pogreške pri provedbi oslikavanja bile su pozicioniranje pacijenta te podeksponiranost ili preeksponiranost; indeks ekspozicije bio je u rasponu 115 – 404 (uz ciljanu vrijednost od 250), a devijacijski indeks je bio u rasponu -3,5 – 2. Vrijednosti korištenog napona na rendgenskoj cijevi te vremena trajanja ekspozicije bile su u skladu s preporučenim vrijednostima. Korištene udaljenosti žarišta rendgenske cijevi od detektora su u većini slučajeva bile unutar prihvatljivog raspona (80 %), dok su u slučaju 20 % slika bile u skladu s preporučenom vrijednošću. ***Zaključak***: Sustav za ocjenu kvalitete radiološke slike u konvencionalnoj radiografiji je potrebno uspostaviti i provoditi u skladu s međunarodnim preporukama.

Ključne riječi: ocjena kvalitete; parametri ekspozicije; pozicioniranje pacijenta; radiološka slika

Do we need an image quality evaluation system in conventional radiography?

Abstract: ***Aim***: The aim of this paper is to point out the need to establish a system for evaluating the quality of images in conventional radiography, as well as the need for its implementation. ***Materials and methods***: The study was conducted retrospectively. 20 plain radiography pelvis images were selected. The quality assessment of the selected images was carried out in accordance with European recommendations. In addition to the evaluation of image quality, the exposure parameters as well as the exposure index and deviation index were also analysed. ***Main results***: The average quality rating of the selected images is 3.25, and the ratings ranged from 0 to 7 with 7 being the highest possible rating. The highest rating was assigned to 5% of images, and the lowest to 20%. The most frequently observed errors during imaging were patient positioning and underexposure or overexposure; the exposure index was in the range 115 – 404 (with a target value of 250), and the deviation index was in the range -3.5 – 2. The values of the x-ray tube voltage used and the exposure time were in accordance with the recommended values. The used distances of the focus of the X-ray tube from the detector were in most cases within the acceptable range (80%), while in the case of 20% of the images they were in accordance with the recommended value. ***Conclusion***: A system for evaluating the quality of images in conventional radiography needs to be established and implemented in accordance with international recommendations.

Keywords: quality evaluation; exposure parameters; radiological image; patient positioning

Znanje stanovnika Požeško-slavonske županije o zračenju te radiološkim dijagnostičkim postupcima

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Sažetak: ***Cilj rada:*** Ovaj rad ispituje razinu znanja i stav te percepciju stanovnika Požeško-slavonske županije o ionizirajućem zračenju i radiološkim dijagnostičkim postupcima. ***Materijali i metode:*** Dizajniran je anketni upitnik koji se sastojao od dvadeset i četiri pitanja. U anketi je sudjelovalo ukupno 454 ispitanika; od toga su analizirane 432 ankete, dok su 22 ankete odbačene jer ispitanici nisu stanovnici Požeško-slavonske županije. ***Rezultati:*** Analizirane su 432 ankete. Većina ispitanika bile su žene (73,4%) i osobe između 18 i 39 godina (53,1%). Više od polovice ispitanika (68,3%) je srednje zabrinuto zbog zračenja emitiranog prilikom radioloških dijagnostičkih pregleda. Samo je 22,4% ispitanika točno odgovorilo da CT ima najveću dozu zračenja dok ih 26.3% smatra da magnetna rezonanca najviše zrači. Većina ispitanika (94,7%) smatra da bi liječnik, koji im preporučuje radiološku dijagnostičku pretragu, trebao ukratko objasniti zašto je ta pretraga potrebna. Također 62,7% ispitanika žele u budućnosti biti više informirani o zračenju i radiološkim dijagnostičkim pregledima. ***Zaključak:*** Rezultati rada pokazali su da ispitanici imaju općenito ograničeno te donekle i „iskrivljeno" znanje o zračenju te radiološkim dijagnostičkim postupcima što odražava potrebu za većom edukacijom javnosti.

Ključne riječi: stav, znanje, zračenje

Požega-Slavonia County inhabitants' knowledge about radiation and radiological diagnostic procedures

Abstract: ***Aim:*** This paper examines the level of knowledge, outlook, but also the perception of the inhabitants of Požega-Slavonia County about ionizing radiation and radiological diagnostic procedures. ***Materials and methods:*** A survey questionnaire consisting of twenty-four questions was designed. A total of 454 respondents participated in the survey;

of these, 432 surveys were analyzed, while 22 surveys were rejected because the respondents are not residents of Požega-Slavonia County. ***Results:*** 432 surveys were analyzed. The majority of respondents were women (73.4%) and people between 18 and 39 years of age (53.1%). More than half of the respondents (68.3%) are moderately concerned about the radiation emitted during radiological diagnostic examinations. Only 22.4% of respondents correctly answered that CT has the highest dose of radiation. While 26.3% of them believe that MRI radiates the most. The majority of respondents (94.7%) believe that the doctor who recommends a radiological diagnostic test should briefly explain why this test is necessary. Also, 62.7% of respondents want to be more informed about radiation and radiological diagnostic examinations in the future. ***Conclusion:*** The results of the study showed that the subjects have a generally limited and somewhat misinterpreted knowledge about radiation and radiological diagnostic procedures, which reflects the need for greater public education.

Keywords: outlook, knowledge, radiation

Uloga radiologije u COVID-19 pandemiji

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Sažetak: Koliko infektivne bolesti zbog složenog modaliteta mogu biti opasne, te koliko borba protiv njih može biti iscrpljujuća i zahtjevna, čak i u suvremenoj medicini, pokazalo se za vrijeme COVID pandemije. Ciljevi rada su istaknuti ulogu radiologije, opisati specifičnosti rada radioloških tehnologa sa pacijentima oboljelim od, do 2019. godine, nepoznatog virusa, radiološki prikazati najčešće manifestacije i komplikacije COVID-19 bolesti, te opisati bazične algoritme umjetne inteligencije kao pomoćnog alata u radiološkoj obradi. Prethodno navedeni ciljevi rada sistematizirani su i obrađeni uz pomoć dostupnih znanstvenih radova objavljenih u „PubMed“ bazi podataka. Zlatni standard kod postavljana dijagnoze je RT-PCR test, te radiološke metode koje svojim specifičnim prikazima ukazuju na oboljenja. Radiološki prikaz manifestacija uključuje radiograme torakalnih organa koji se koriste za evaluaciju plućnih promjena, CT koji pruža detaljan prikaz abnormalnosti, PET/CT i UZV pluća koji dodatno pomažu u dijagnostici i praćenju, te MR koja se koristi za detaljnu procjenu komplikacija i post covid sindroma. Komplikacije COVID infekcije s najvećom incidencijom su plućne, neurološke, hematološke, bubrežne i srčane. Tijekom pandemije pokazala se njihova ozbiljnost i nepredvidljivost s obzirom da su ishod bolesti dodatno činile neizvjesnim i otežavale oporavak. Posebnu inspiraciju i motivaciju za nova znanstvena istraživanja daju sindrom post covida-a i multisistemski inflamatorni sindrom u djece s obzirom da imaju karakteristične značajke kliničke slike.

Ključne riječi: COVID-19; komplikacije; manifestacije; radiologija

The role of radiology in the COVID-19 pandemic

Summary: How infectious diseases can be dangerous due to their complex modalities, and how the fight against them can be exhausting and demanding, even in modern medicine, was demonstrated during the COVID pandemic. The objectives of this work are to highlight the role of radiology, describe the specifics of the work of radiological technologists with patients suffering from a previously unknown virus until 2019, radiologically present the most common manifestations and complications of COVID-19, and describe basic algorithms of artificial intelligence as an auxiliary tool in radiological processing. The aforementioned objectives have been systematized and processed with the help of available scientific papers published in the 'PubMed' databases. The gold standard for diagnosis is the RT-PCR test, along with radiological methods that indicate diseases with their specific images. Radiological representation of manifestations includes radiographs of thoracic organs used to evaluate pulmonary changes, CT scans that provide detailed portrayals of abnormalities, PET/CT, and lung ultrasound, which further assist in diagnosis and monitoring, as well as MRI, which is used for detailed assessment of complications and post-COVID syndrome. The complications of COVID infection with the highest incidence are pulmonary, neurological, hematological, renal, and cardiac. During the pandemic, their severity and unpredictability became apparent, as the outcomes significantly contributed to the uncertainty of the disease and complicated recovery. A particular inspiration and motivation for new scientific research come from post-COVID syndrome and multisystem inflammatory syndrome in children, given that they have characteristic features in their clinical presentation.

Keywords: COVID-19; complications; manifestations; radiology

Upotreba MR 7T u kliničke svrhe

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Sažetak: Magnetska rezonanca, MR, omogućuje ranu, brzu i točnu dijagnostiku bez štetnog ionizirajućeg zračenja. S obzirom da igra veliku ulogu u dijagnosticiranju, provode se različita istraživanja sa svrhom unaprjeđenja. Jedno od glavnih otkrića je povećanje jačine magnetskog polja jer se time poboljšava prostorna rezolucija i kontrastnost slike. Ovo otkriće je osobito važno kod MR uređaja snage 7T. Iako se MR 7T trenutačno koristi uglavnom u istraživačke svrhe, FDA je 12. listopada 2017. godine odobrila njegovu kliničku upotrebu u SAD-u za pregled glave i ekstremiteta. U Europi je još uvijek ograničen na istraživanja, no očekuje se uvođenje u kliničku praksu. Istraživanja prikazuju prednosti i nedostatke MR 7T te razmatraju njegovu stvarnu svrhu i mogućnosti primjene u kliničke svrhe zbog veličine magnetnog polja. MR 7t pruža izrazito visoku prostornu rezoluciju, poboljšava kontrastnost između različitih tkiva i struktura te omogućuju bolju detekciju i karakterizaciju patologija. Također, omogućava primjenu naprednih tehnika snimanja kao što su funkcionalna MR (fMRI) i spektroskopiju koja omogućava veću točnost prilikom analize. Visoka jačina magnetskog polja može uzrokovati zagrijavanje ugrađenih implantata i biološke smetnje. Također, metali u tijelu izloženi su privlačnim silama u MR okruženju, a intenzitet tih sila ovisi o sastavu, obliku i orijentaciji metala. Naglašava se potreba daljnjeg istraživanja MR 7T te postavljanja jasnih smjernica za njegovu sigurnu kliničku primjenu.

Ključne riječi: magnetno polje, MR 7T, prostorna rezolucija

Use of 7T MRI for clinical purposes

Summary: Magnetic Resonance Imaging (MRI) allows for early, rapid, and accurate diagnosis without harmful ionizing radiation. Given its significant role in diagnostics, various studies are conducted with the aim of improving the technology. One of the major advancements is the increase in magnetic field strength, which enhances spatial resolution and image contrast. This advancement is particularly important for 7T MRI devices. Although 7T MRI is currently primarily used for research purposes, the FDA approved its clinical use in the U.S. on October 12, 2017, for head and extremity imaging. In Europe, it is still restricted to research, but its clinical introduction is anticipated. Research shows both the advantages and disadvantages of 7T MRI and explores its practical applications and potential in clinical settings due to the high magnetic field strength. 7T MRI offers exceptionally high spatial resolution, improves contrast between different tissues and structures, and allows for better detection and characterization of pathologies. It also enables the application of advanced imaging techniques such as functional MRI (fMRI) and spectroscopy, which provides greater accuracy in analysis. The high magnetic field strength can cause heating of implanted devices and biological artifacts. Additionally, metals in the body are exposed to attractive forces in the MRI environment, with the intensity of these forces depending on the composition, shape, and orientation of the metal. There is a highlighted need for further research into 7T MRI and the establishment of clear guidelines for its safe clinical application.

Keywords: magnetic field, MR 7 T, spatial resolution

Uloga radiološkog tehnologa u Programu osiguranja kvalitete za Lexell Gamma Knife Icon u KBC-u Zagreb

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Sažetak: ***Cilj***: Predstaviti ulogu radioloških tehnologa u Programu osiguranja kvalitete (POK) za Leksell Gamma Knife (LGK) Icon u Kliničkom bolničkom centru Zagreb (KBC Zagreb). ***Materijali i metode***: LGK tim u Klinici za neurokirurgiju KBC-a Zagreb uključuje: neurokirurge, medicinske fizičare, medicinske sestre i radiološke tehnologe, s ciljem pružanja sigurne i učinkovite neuroradiokirurgije. Jedna od odgovornosti radioloških tehnologa je sudjelovanje u provođenju POK-a. To uključuje provođenje dnevnih i tjednih procedura provjera kvalitete. ***Rezultati***: Od kliničkog starta LGK Icon uređaja u KBC-u Zagreb 2019. godine, radiološki tehnolozi uspješno provode dnevne i tjedne geometrijske i sigurnosne testove iz POK-a: provjera položaja sektora s izvorima Co-60, provjera točnosti radiološkog fokusa i točnosti CBCT sustava, provjera alarma u slučaju nužde, tipkala za pauzu i prekid postupka, provjera bočne zaštite ležaja, upozoravajućeg svjetla i audio/video sustava. ***Zaključak***: Radiološki tehnolozi imaju važnu ulogu u provođenju Programa osiguranja kvalitete za Leksell Gamma Knife Icon, sudjelujući u stvaranju okruženja za sigurnu i učinkovitu neuroradiokirurgiju.

Ključne riječi: Gamma knife, Kontrola kvalitete, Gamma knife, Neuroradiokirurgija

The role of RTTs in the Quality Assurance Program for the Leksell Gamma Knife Icon at the UHC Zagreb

Abstract: ***Aim*:** To present the role of radiotherapy technologists (RTTs) in the Quality Assurance (QA) Program for the Leksell Gamma Knife (LGK) Icon at the University Hospital Centre Zagreb (UHC Zagreb). ***Materials and Methods:*** The LGK team at the Department of Neurosurgery, UHC Zagreb, involves neurosurgeons, medical physicists, nurses and RTTs, aiming to ensure safe and efficient neuroradiosurgery. One of the responsibilities of the RTTs is to participate in the execution of the LGK QA Program. This includes performing daily and weekly QC procedures. ***Results:*** From the clinical start of the LGK Icon at the UHC Zagreb in 2019, RTTs successfully have performed daily and weekly geometrical and safety QA tests for LGK: Co-60 sectors position, radiation focus and CBCT precision, emergency alarm, pause and emergency stop button, treatment couch side protection, radiation warning lamp, and video/audio system tests. ***Conclusion:*** RTTs have an important role in the Leksell Gamma Knife Icon Quality Assurance Program, participating in the creation of an environment for safe and efficient neuroradiosurgery.

Keywords: Gamma knife, Quality Assurance, Neuroradiosurgery

Što nedostaje komunikaciji u zdravstvu?

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Sažetak: Komunikacija u zdravstvu često pati od nedostataka koji mogu negativno utjecati na kvalitetu i sigurnost pružanja zdravstvene skrbi.Jedan od glavnih nedostataka je nedostatak jasnoće u prijenosu informacija.Pregledi, dijagnoze i terapije često su kompleksni i zahtijevaju objašnjenje pacijentima.Međutim, zdravstveni radnici često koriste stručne termine što može stvoriti nerazumijevanje.Također, nedostatak vremena za komunikaciju često je prisutan u zdravstvu.Zdravstveni radnici imaju prevelik broj pacijenata i nedovoljno vremena da se posvete svakom pojedincu onoliko koliko bi trebali.Ovo može rezultirati neadekvatnim informiranjem pacijenata o njihovom zdravstvenom stanju.Pacijenti se često osjećaju kao da se ne vodi računa o njihovim potrebama.Često se događa da pacijenti moraju prenositi iste informacije različitim zdravstvenim radnicima, što može dovesti do nepotrebnog gubitka vremena. Da bi se poboljšala komunikacija u zdravstvu, potrebne su promjene. Potrebno je poticati bolje obrazovanje zdravstvenih radnika kako bi se usvojile vještine komunikacije s pacijentima.Također je važno osigurati dovoljno vremena za komunikaciju i osnažiti pacijente kako bi aktivno sudjelovali u svojoj zdravstvenoj skrbi.U konačnici, dobra komunikacija je ključna za pružanje kvalitetne zdravstvene skrbi i pacijentovo zadovoljstvo.Osiguravanje jasnoće, vremena i komunikacije u zdravstvu ključno je za unaprjeđenje sustava zdravstvene skrbi i osiguravanje optimalnih rezultata za pacijente.

Ključne riječi: Komunikacija; zdravstvo; vrijeme; pacijenti; edukacija

What is lacking in communication in healthcare?

Abstract: Communication in healthcare often suffers from shortcomings that can negatively affect the quality and safety of healthcare provision. One of the main shortcomings is the lack of clarity in the transmission of information. Examinations, diagnoses and therapies are often complex and require explanation to patients. However, healthcare professionals often use expert terms, which can create misunderstandings. Also, lack of time for communication is often present in health care. they often feel as if their needs are not taken into account. It often happens that patients have to convey the same information to different health professionals, which can lead to unnecessary loss of time. In order to improve communication in health care, changes are needed. Better education needs to be encouraged healthcare workers to acquire communication skills with patients. It is also important to ensure sufficient time for communication and empower patients to actively participate in their healthcare. Ultimately, good communication is key to providing quality healthcare and patient satisfaction. Ensuring clarity, time and communication in health care is essential for improving the health care system and ensuring optimal results for patients.

Keywords: Communication; health care; time; patients; education

Optimizacija cjelokupnog radiološkog procesa u manjim medicinskim centrima: Iskustva iz Medicinskog centra Gorica

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Sažetak: Primjenom ovih mjera, Medicinski centar Gorica značajno je unaprijedio svaki korak u radiološkom procesu. Optimizacijom vremena potrebnog za pripremu i obradu nalaza, centar je postigao veću učinkovitost u svakodnevnom radu. Uspostavljen je bolji sustav upravljanja vremenom i resursima, čime su smanjena administrativna opterećenja, a medicinsko osoblje je oslobodilo više vremena za fokusiranje na klinički rad i pacijente. Integracija telemedicine i digitalnih alata omogućila je bržu i precizniju razmjenu informacija između timova unutar centra, ali i s vanjskim suradnicima, što je doprinijelo povećanju kvalitete dijagnostike. Povećanjem dostupnosti dijagnostičkih postupaka ubrzan je proces donošenja medicinskih odluka. Osim tehnoloških unaprjeđenja, ključno je bilo poboljšanje komunikacije unutar radiološkog tima, što je dovelo do boljeg protoka informacija, učinkovitijeg planiranja i bržeg odgovaranja na potrebe pacijenata. Ovaj rad ne samo da prikazuje praktične aspekte optimizacije, već služi i kao primjer kako manje medicinske ustanove mogu usvojiti nove strategije kako bi pružile visokokvalitetne radiološke usluge u složenim uvjetima ograničenih resursa. Kroz sustavan pristup poboljšanjima, Medicinski centar Gorica je uspio osigurati održivu razinu učinkovitosti i kvalitetu usluga koje su prilagođene specifičnim potrebama lokalne zajednice. Ove smjernice mogu biti korisne za druge zdravstvene ustanove koje traže slične načine za optimizaciju svojih radioloških procesa, pokazavši da i uz ograničene resurse mogući su značajni rezultati u poboljšanju svakodnevnog rada i zadovoljstva pacijenata.

Ključne riječi: digitalizacija; optimizacija; radiološki proces; telemedicina; zdravstveni centri

Optimization of the entire radiological process in smaller medical centers: Experiences from the Gorica Medical Center

Abstract: By applying these measures, the Gorica Medical Center has significantly improved every step of the radiology process. By optimizing the time required for preparation and report processing, the center has achieved greater efficiency in its daily operations. A better system for managing time and resources has been established, reducing administrative burdens and freeing up more time for medical staff to focus on clinical work and patient care. The integration of telemedicine and digital tools has enabled faster and more accurate information exchange between teams within the center and with external collaborators, contributing to improved diagnostic quality. Increased availability of diagnostic procedures has accelerated the decision-making process. In addition to technological advancements, improving communication within the radiology team has led to better information flow, more efficient planning, and faster responses to patient needs. This work not only highlights the practical aspects of optimization but also serves as an example of how smaller medical institutions can adopt new strategies to provide high-quality radiology services in complex conditions with limited resources. Through a systematic approach to improvements, Gorica Medical Center has managed to ensure a sustainable level of efficiency and service quality adjusted to the specific needs of the local community. These guidelines can be useful for other healthcare institutions looking for similar ways to optimize their radiological processes, showing that significant results in improving daily operations and patient satisfaction can be achieved even with limited resources.

Keywords: digitization; optimization; radiological process; telemedicine; medical centers

Validacija sive skale na C-luku u korelaciji s HU na CT-u

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Sažetak: Upotreba radioloških uređaja koji stvaraju sliku u prikazu sive skale manje su tehnički zahtjevni te lakši za korištenje. Kod radiografskog uređaja (3D C-luk), stupanj atenuacije rtg zraka prikazan je nijansama sive skale (GSV). Kod CT snimanja, Hounsfieldova jedinica (HU) proporcionalna je stupnju slabljenja rtg zraka u tkivu. Dokazivanje korelacije između HU i GSV omogućilo bi širu i lakšu primjenu radiografskog prikaza u područjima izvan područja biomedicine i zdravstva te primjenu kvantitativnih metoda istraživanja. Za dobivanje potrebnih mjernih vrijednosti skenirao se CT fantom na dva radiološka uređaja. Mjerenje je izvršeno na C-luku i CT-u. Iz dobivenih Meta podataka sa DICOM slika istražio se odnos između GSV i HU pomoću MedCalc Statistical. Rezultati dobiveni obradom podataka ukazuju da izmjerena i prikazana vrijednost koeficijenta korelacije r=0,185 između C-luka s naponom rtg cijevi od 115 kV i CT- a od 110 kV opisuje kao r=neznatna i pozitivna. S naponom rtg cijevi od 80 kV na CT- u i C-luku izmjerena je i prikazana slaba i pozitivna korelacija r=0,450. Rezultati koji su se dobili mjerenjem između CT-a 110 kV i C-luka od 80 kV prikazuju slabu i pozitivnu korelaciju r=0,434. Nakon dobivenih rezultata iz ovog istraživanja i pregledom dostupne literature GSV-a na CBCT- u i HU na CT- u može se reći da postoji veza između GSV-a i HU. Zbog nedostatka literature koja istražuje GSV na C-luku i HU na CT- u nisu se mogli usporediti dobiveni rezultati ovog istraživanja te je potrebno osvrnuti se na preporuke i savjete autora radova koje imaju poveznice u validaciji GSV-a i HU.

Ključne riječi: C luk; CT fantom; Hounsfieldove jedinice; koeficijent korelacije; siva skala

Validation of grey scale on C-arm in correlation with HU on CT

Summary: The use of radiological devices that generate images in grayscale is less technically demanding and easier to operate. In radiographic devices (3D C-arm), the degree of X-ray attenuation is represented by shades of grayscale (GSV). In CT imaging, the Hounsfield Unit (HU) is proportional to the degree of X-ray attenuation in tissue. Proving a correlation between HU and GSV would allow broader and easier application of radiographic imaging in fields beyond biomedicine and healthcare, as well as the application of quantitative research methods. To obtain the necessary measurement values, a CT phantom was scanned using two radiological devices. Measurements were conducted on both the C-arm and CT. The relationship between GSV and HU was investigated using MedCalc Statistical software based on metadata from DICOM images. The results of the data analysis indicate that the measured and displayed correlation coefficient of r=0.185 between the C-arm with an X-ray tube voltage of 115 kV and the CT at 110 kV is described as insignificant and positive. With an X-ray tube voltage of 80 kV on both the CT and C-arm, a weak and positive correlation of r=0.450 was measured and displayed. The results from the measurements between the CT at 110 kV and the C-arm at 80 kV show a weak and positive correlation of r=0.434. Based on the results of this study and a review of the available literature on GSV in CBCT and HU in CT, it can be concluded that there is a connection between GSV and HU. However, due to the lack of literature investigating GSV on C-arm and HU on CT, the obtained results of this study could not be compared, making it necessary to refer to the recommendations and advice of authors with related work on the validation of GSV and HU.

Keywords: C-arm; CT phantom; Hounsfield units; correlation coefficient; grayscale

Izazovi u implementaciji photon-counting CT-a u kliničkoj praksi

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Sažetak: CT detektor s brojačem fotona, PCCT, donosi tehnološki iskorak u usporedbi s konvencionalnim CT uređajima. Tradicionalni detektori mjere ukupnu energiju, dok PCD broji pojedinačne fotone što omogućuje bolju kvalitetu slike uz manju dozu zračenja što je važno za pedijatrijsku populaciju. Istraživanja pokazuju da PCCT ima brojne prednosti, poput poboljšanje prostorne rezolucije zbog manje veličine piksela i užeg snopa, što omogućuje precizniju vizualizaciju i bolju detekciju malih lezija. Također, kontrastna rezolucija je bolja jer razlikuje različite materijale i tkiva na temelju njihovih energetskih spektralnih karakteristika, što pridonosi boljoj kontrastnosti između mekih tkiva. PCCT smanjuje šum i artefakte zbog sposobnosti detektora da odbace niskoenergetske fotone koji najviše doprinose artefaktima. Unatoč svemu navedenom, PCCT ima brojne nedostatke i ograničenja. Održavanje i nadogradnja uređaja su vrlo skupi zbog složenosti detektora i softvera. PCCT smanjuje određene vrste artefakata, ali može povećavati nivoe šuma pri nižim dozama zračenja. Umjetna inteligencija poboljšava PCCT smanjenjem šuma, poboljšanjem kvalitete slike i optimizacijom kontrasta. Radiomika dodatno poboljšava analizu medicinskih slika, kroz algoritme za obradu podataka te se koristi za izdvajanje značajki, izradu prediktivnih modela, detaljnu kvantifikaciju teksture slike i analizu odnosa piksela. Ovi procesi pomažu u preciznijem donošenju kliničkih odluka, čime se povećava vrijednost PCCT-a u medicini.

Ključne riječi: PCCT, PCD, prostorna rezolucija, radiomika, umjetna inteligencija.

Challenges in the implementation of photon-counting CT-a in clinical practice

Summary: The Photon-Counting CT, PCCT detector represents a significant technological advancement over conventional CT systems. While traditional detectors measure total energy, Photon-Counting Detectors (PCD) count individual photons, resulting in better image quality with reduced radiation dose, which is particularly important for pediatric patients. Researches demonstrate that PCCT offers key advantages, including enhanced spatial resolution due to smaller pixel sizes and narrower beam widths, leading to more precise visualization and improved detection of

small lesions. Additionally, PCCT provides better contrast resolution by differentiating materials and tissues based on their energy spectral characteristics, enhancing contrast between soft tissues. It also reduces noise and artifacts by filtering out low-energy photons that predominantly contribute to artifacts. Despite these benefits, PCCT has several drawbacks and limitations. The maintenance and upgrading of devices are very costly due to the complexity of the detectors and software. While PCCT minimizes certain artifacts, it may increase noise levels at lower radiation doses. Artificial Intelligence (AI) enhances PCCT by reducing noise, improving image quality, and optimizing contrast. Radiomics further advances image analysis by using data processing algorithms to extract features, develop predictive models, perform detailed texture quantification, and analyze pixel relationships. These processes aid in making more precise clinical decisions, thereby increasing the value of PCCT in medicine.

Keywords: artificial intelligence.PCCT, PCD, radiomics, spatial resolution.

NAEOTOM Alpha Photon Counting CT u kliničkoj praksi: pregled mogućnosti

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Sažetak: NAETOM Alpha predstavlja prvi CT sustav sa brojanjem fotona (PCCT) instaliran u Hrvatskoj. Opremljen je dvostrukim izvorom te sadrži dvije Vectron™ Xray cijevi. QuantumMax detektori za brojanje fotona sa kadmij teluridom omogućuju veliku prostornu rezoluciju, uz minimalnu debljinu sloja od 0.2mm. Brzina rotacije do 0.25 sekundi dopušta brže skeniranje pacijenata u usporedbi s konvencionalnim CT-om. QuantumPlus mod pruža mogućnost naknadne obrade snimki; skeniranjem sa naponom cijevi od 120 kV ili 140 kV mogu se generirati monoenergetske slike u rasponu od 40 keV do 190 keV. Osim toga, naknadna spektralna obrada omogućuje generiranje virtualnih bezkontrastnih slika i mapiranje joda. Visokokvalitetne slike dobivene uz smanjenu izloženost zračenju od ključne su važnosti za pacijente koji zahtijevaju redovitu dijagnostičku obradu i praćenje. Osim za dijagnostičke svrhe, uloga NAETOM Alpha uređaja je simulacija za potrebe provođenja stereotaksijske ablativne radioterapije (SABR). Visoka rezolucija PCCT-a omogućuje preciznu delineaciju tumora i okolnih organa. Jedna od prednosti uređaja, bitna za provođenje radioterapije, je smanjenje artefakata koje stvaraju metalni implantati u tijelu. Navedene karakteristike pružaju točniji izračun doze i isporuku zračenja u tumor, te poštedu zdravog tkiva. Uvođenje NAETOM Alpha uređaja u medicinsku dijagnostiku i radioterapiju važan je korak za napredak u onkologiji i radiologiji. Ova tehnologija otvara napredne mogućnosti skeniranja koji vode prema optimizaciji liječenja.

Ključne riječi: PCCT, spektralna obrada, stereotaksijska ablativna radioterapija

NAEOTOM Alpha Photon Counting CT in clinical practice: a review of possibilities

Abstract: NAETOM Alpha represents the first photon-counting CT system (PCCT) installed in Croatia. It is equipped with a dual source and contains two Vectron™ Xray tubes. QuantumMax photon counting detectors with cadmium telluride enable high spatial resolution, with a minimum layer thickness of 0.2 mm. A rotation speed of up to 0.25 seconds allows faster scanning of patients compared to conventional CT. QuantumPlus mode provides the possibility of post-processing recordings; scanning with a tube voltage of 120 kV or 140 kV can generate monoenergetic images in the range from 40 keV to 190 keV. In addition, post-spectral processing enables the generation of virtual contrast-free images and iodine mapping. High-quality images obtained with reduced radiation exposure are critical for patients who require regular diagnostic work-up and follow-up.

In addition to diagnostic purposes, the role of the NAETOM Alpha device is simulation for the purposes of performing stereotaxic ablative radiotherapy (SABR). The high resolution of PCCT enables precise delineation of the tumor and surrounding organs. One of the advantages of the device, essential for the implementation of radiotherapy, is the reduction of artifacts created by metal implants in the body. The mentioned characteristics provide more accurate calculation of the dose and delivery of radiation to the tumor, as well as sparing healthy tissue.

The introduction of the NAETOM Alpha device into medical diagnostics and radiotherapy is an important step for progress in oncology and radiology. This technology opens advanced scanning capabilities that lead to treatment optimization.

Keywords: PCCT, spectral processing, stereotaxic ablative radiotherapy

Izolacija plućnih vena postupkom krioablacije kod pacijenata s paroksizmalnom atrijskom fibrilacijom

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Sažetak: ***Ciljevi:*** atrijska je fibrilacija jedna od aritmija koja utječe na srčani ritam i srce kao pumpu što posljedično povećava mogućnost embolijskog inzulta. Zbog električnih stimulansa koji potječu iz ušća plućnih vena i njihova lumena indicira se njihova izolacija, uglavnom krioablacijom. Glavni ciljevi ovoga istraživanja su istražiti odnos između izmjerenih nadir temperatura tijekom krioablacije svake pojedinačne vene te usporediti uspješnost izolacije prvom krioablacijom. Ispitanici i metode: istraživanje je uključivalo 40 ispitanika koji su podvrgnuti izolaciji plućnih vena krioablacijom zbog atrijske fibrilacije, bez obzira na spol i dob. Zahvati su provedeni tijekom 2022. godine u Kliničkom bolničkom centru Zagreb gdje su i preuzeti podaci. Svi podaci trajno su zapisani u odvojenoj kriokonzoli kojom se diktira tijek cijeloga zahvata. Rezultati: S obzirom na to da je sudjelovalo 40 pacijenata, analizirano je 160 plućnih vena. T-test pokazuje da je gornja lijeva plućna vena najpogodnija za izolaciju, a da je donja desna plućna vena najnezgodnija. Analiza dobivenih p-vrijednosti pokazuje značajne razlike između plućnih vena lijeve i desne strane, s time da je ta razlika puno manja između plućnih vena lijeve strane. Uz to, hi-kvadrat test potvrdio je značajnu razliku između uspješnih prvih krioablacija lijevih i desnih plućnih vena, čime se pokazalo da su ljevostrane plućne vene lakše za izolirati prvom krioablacijom. Zaključak: izolacija plućnih vena krioablacijom je izvrstan dokaz implementiranja temeljnih fizikalnih principa u medicinske svrhe. Ovo istraživanje ostavlja otvoren prolaz za druga istraživanja u metodama liječenja atrijske fibrilacije. Prema tome, uspoređivanjem našeg istraživanja s nedavnom literaturom upućuje na veću uspješnost u izolaciji lijevih plućnih vena od izolacije desnih plućnih vena.

Ključne riječi: fibrilacija atrija; izolacija plućne vene; krioablacija

Isolation of pulmonary veins by cryoablation in patients with paroxysmal atrial fibrillation

Abstract: Objectives: atrial fibrillation is one of the arrhythmias that affects the heart rhythm and the heart as a pump, which consequently increases the possibility of an embolic insult. Because of the electrical stimuli originating from the mouth of the pulmonary veins and their lumen, their isolation is indicated, mainly by cryoablation. The main goals of this research are to investigate the relationship between the measured nadir temperatures during the cryoablation of each individual vein and to compare the success of isolation by the first cryoablation. Subjects and methods: the study included 40 subjects who underwent pulmonary vein isolation by cryoablation due to atrial fibrillation, regardless of gender and age. The procedures were carried out during 2022 at the Zagreb Clinical Hospital Center, where the data were taken. All data is permanently recorded in a separate cryoconsole that dictates the course of the entire procedure. Results: Given that 40 patients participated, 160 pulmonary veins were analyzed. The T-test shows that the upper left pulmonary vein is the most suitable for isolation, and that the lower right pulmonary vein is the most inconvenient. The analysis of the obtained p-values shows significant differences between the pulmonary veins of the left and right side, with the fact that this difference is much smaller

between the pulmonary veins of the left side. In addition, the chi-square test confirmed a significant difference between successful first cryoablations of the left and right pulmonary veins, showing that the left pulmonary veins are easier to isolate with the first cryoablation. Conclusion: the isolation of pulmonary veins by cryoablation is an excellent proof of the implementation of basic physical principles for medical purposes. This research leaves the passage open for other research into methods of treating atrial fibrillation. Therefore, by comparing our research with recent literature, it indicates a greater success rate in the isolation of the left pulmonary veins than the isolation of the right pulmonary veins.

Keywords: atrial fibrillation; cryoablation; pulmonary vein isolation

Svijest žena o važnosti screening mamografije

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Sažetak: Svijest žena o važnosti probira karcinoma dojke, ključna je u prevenciji i ranom otkrivanju istog. Istraživanja pokazuju da postoje brojne prepreke za redoviti probir. Edukativne kampanje i pristup kvalitetnoj zdravstvenoj skrbi ključni su koraci prema optimalnoj osviještenosti žena u programima probira u smanjenju incidencije karcinoma dojke. Cilj je istražiti koliko su žene svjesne važnosti i.o. screening mamografije za rano otkrivanje karcinoma dojke te procjeniti njihovu informiranost o prednostima i važnosti istog. Istraživanje će analizirati koliko su žene upoznate sa svim aspektima istog. Nadalje, istražit će se postoji li korelacija između razine obrazovanja, socioekonomskog statusa i svijesti žena o važnosti mamografskog screeninga. Obradom podataka, cilj je identificirati moguće nedostatke i unaprijediti postojeći nivo informiranosti. U analizi su uključeni pregledni članci, kliničke studije i metaanalize. Analizom prikupljenih podataka može se zaključiti kako svijest žena o mamografskom pregledu za otkrivanje karcinoma dojke je suboptimalan. Dio pacijentica navodi nedovoljnu informiranost o mogućnostima probira. Sociodemografske karakteristike, zanimanje, obrazovni i bračni status pokazuju povezanost s osviještenosti o karcinomu dojke. Strah od dijagnoze i brojni sociodemografski čimbenici su također razlozi slabijeg odaziva mamografskog probira. Inovativan pristup korištenja multimedija znatno će doprinijeti poboljšanju podizanja svijesti o mogućnostima probira i odazivu na isti.

Ključne riječi: bolesti dojke, dojke, karcinom dojke, mamografija, mamografski probir, probir

Women's awareness of the importance of screening mammography

Summary: Awareness among women about the importance of breast cancer screening is crucial in its prevention and early detection. Research shows that there are numerous barriers to regular screening. Educational campaigns and access to quality healthcare are key steps toward achieving optimal awareness among women in screening programs to reduce the incidence of breast cancer. The aim is to investigate how aware women are of the importance of screening mammography for the early detection of breast cancer and to assess their knowledge about its benefits and significance. The study will analyze how familiar women are with all aspects of screening. Furthermore, the research will explore whether there is a correlation between education level, socioeconomic status, and women's awareness of the importance of mammographic screening. By processing the data, the aim is to identify potential gaps and improve the current level of awareness. The analysis includes review articles, clinical studies, and meta-analyses. Based on the analysis of the collected data, it can be concluded that women's awareness of mammographic screening for breast cancer detection is suboptimal. A few patients report insufficient knowledge about the screening options. Sociodemographic characteristics, occupation, educational level, and marital status are shown to be linked to awareness about breast cancer. Fear of diagnosis and various sociodemographic factors are also reasons for lower participation in mammographic screening. An innovative approach using multimedia will significantly contribute to improving awareness of screening opportunities and increasing participation.

Keywords: breast, breast cancer, breast diseases, mammogram, mammography, screening mammography

„Inject Less. Strive for More." Elucirem – gadopiclenol

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Sažetak: Kontrastna sredstva na bazi gadolinija su u upotrebi u MR dijagnostici od 1988. godine te se koriste kao kontrastno sredstvo izbora u neurološkim, spinalnim, torakalnim, abdominalnim, zdjeličnim i vaskularnim MR snimanjima te MR snimanjima dojke i srca. Diljem svijeta, kontrastna sredstva na bazi Gd se primjenjuju na više od 30 milijuna pacijenata godišnje, te se svake godine bilježi daljnji rast broja provedenih MR dijagnostičkih snimanja uz primjenu navedenih kontrastnih sredstava. Regulatorna tijela Europe i Amerike izdale su preporuku za korištenje što manje doze kontrastnih sredstava na bazi Gd bez kompromitiranja dijagnostičke učinkovitosti, s obzirom da upotreba Gd predstavlja medicinski, javnozdravstveni i ekološki problem. Također, u periodu od proteklih 30 godina zabilježen je značajni razvoj i napredak tehnologije korištene u uređajima za dijagnostička snimanja te je nužno da karakteristike kontrastnih sredstava prate i razvoj tehnologije. Ove činjenice nametnule potrebu za razvojem kontrastnog sredstva na bazi Gd sa smanjenom količinom samog gadolinija kao aktivne tvari ali s visokim relaksivitetom radi postizanja visokokvalitetnog i preciznog dijagnostičkog oslikavanja s ciljem postavljanja ispravne i pravovremene dijagnoze. Također, molekula takvog kontrastnog sredstva mora biti visoke stabilnosti, kod koje ne dolazi do otpuštanja Gd niti deponiranja u tkivu. Iz laboratorija Guerbet, nakon više desetljeća istraživanja, predstavljaju potpuno novi koncept primjene kontrastnog sredstva za MRI.

Ključne riječi: kontrastna sredstva, gadolinij, MRI.

Inject Less. Strive for More. Elucirem – gadopiclenol

Summary: Gadolinium-based contrast agents have been in use in MR diagnostics since 1988 and are used as the contrast agent of choice in neurological, spinal, thoracic, abdominal, pelvic and vascular MR imaging as well as breast and cardiac MR imaging. All over the world, Gd-based contrast agents are applied to more than 30 million patients annually, and every year a further increase in the number of MR diagnostic imaging performed with the use of said contrast agents is recorded. The regulatory bodies of Europe and America issued a recommendation for the use of the lowest possible dose of Gd-based contrast agents without compromising diagnostic efficiency, given that the use of Gd represents a medical, public health and environmental problem. Also, in the period of the past 30 years, there has been significant development and progress in the technology used in devices for diagnostic imaging, and it is necessary that the characteristics of contrast agents follow the development of technology. These facts imposed the need to develop a Gd-based contrast agent with a reduced amount of gadolinium itself as an active substance but with high relaxivity in order to achieve high-quality and precise diagnostic imaging with the aim of establishing a correct and timely diagnosis. Also, the molecule of such a contrast agent must be of high stability, in which Gd is not released or deposited in the tissue. From the Guerbet laboratory, after several decades of research, they present a completely new concept of applying a contrast agent for MRI.

Keywords: contrast agents, gadolinium, MRI.

Magnetska rezonancija u suvremenoj radioterapiji

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Sažetak: Ovaj rad bavi se integracijom tehnologije magnetske rezonancije u modernu kliničku praksu radioterapije, ispitujući njen potencijal za poboljšanje preciznosti, učinkovitosti i ishoda za pacijente. Opisuje kako se MR primjenjuje u radioterapiji, od simulacije do provedbe liječenja u stvarnom vremenu. Rad detaljno opisuje registraciju MR i CT slika, nakon čega slijedi fokus na osiguranje kvalitete, posebno u pogledu geometrijskih distorzija. U uvodu se raspravlja o korištenju MR-a u planiranju radioterapije j ulozi MR-a tijekom liječenja, uključujući funkcionalne tehnike snimanja i kontrolu pokreta. Također istražuje dozimetrijske zahtjeve i metode koje omogućuju MR-u da zamijeni CT, kao i slikovnu provjeru polja zračenja u stvarnom vremenu. Predstavljeni su početni rezultati MR-linearnih akceleratora, istaknuti su tehnički izazovi i trenutni status ovih uređaja. Zaključno, rad razmatra buduću ulogu MR-a u radioterapiji, iz analiza različitih stručnih članaka koji se bave istom tematikom.

Ključne riječi: adaptivna radioterapija; MRIgRT; MR- linearni akcelerator; suvremena radioterapija

Magnetic resonance in modern radiotherapy

Summary: This presentation addresses the integration of magnetic resonance imaging technology into modern radiotherapy clinical practice, examining its potential to improve precision, efficiency, and patient outcomes. It outlines how MRI is applied throughout the radiotherapy process, from initial simulation to real-time treatment implementation. The thesis details the registration of MRI and CT scans, followed by a focus on quality assurance, particularly regarding geometric distortion. The introduction discusses the use of MRI in radiotherapy planning and its role during treatment, including functional imaging techniques and MRI's use in motion control. It also explores dosimetric requirements and methods that allow MRI to replace CT, as well as real-time imaging verification of the radiation field. Initial results from MRI-linear accelerators are presented, highlighting technical challenges and the current status of these devices. In conclusion, the thesis considers the future role of MRI in radiotherapy, drawing insights from the analysis of various professional studies on the topic.

Keywords: adaptive radiotherapy; modern radiotherapy; MRIgRT; MR-linear accelerator

SWOT analiza primjene umjetne inteligencije u radiološkoj tehnologiji i radiologiji

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Sažetak: Umjetna inteligencija (AI) unosi promjene u radiologiju i radiološku tehnologiju, omogućavajući razvoj algoritama koji olakšavaju dijagnozu i odluke. AI može poboljšati ishode pacijenata, povećati učinkovitost pretraga i smanjiti troškove. Strojno i duboko učenje pokazali su se kao iznimno korisni u otkrivanju i karakterizaciji lezija, poboljšavajući rutinske tehnike snimanja i kvalitetu izvještavanja. Praktična primjena umjetne inteligencije u radiologiji i radiološkoj tehnologiji usporena je nedostatkom integriranih rješenja i dobro strukturiranih arhiva podataka, a i izazovima kao što su netransparentnost sustava kod donošenja odluka i velika količine kvalitetnih podataka potrebnih za obuku modela umjetne inteligencije. Postoji zabrinutost zbog potencijalnog utjecaja AI na posao radiologa i radioloških tehnologa što može kočiti razvoj i primjenu. Tekstualni podaci izvedeni iz slikovnih izvješća mogu pružiti vrijedne uvide u zdravstvu, otvarajući novu eru u izdvajanju informacija iz medicinskih slika i izvješća. Zbog izazova u obuci stručnjaka za primjenu AI-a u zdravstvu morat će se koristiti multidisciplinarni pristup i ulagati u suradnju i obrazovanje. Postoje neriješena pitanja o odgovornosti i regulaciji u vezi s pohranjivanjem podataka i privatnosti, osobito u slučaju pohrane podataka na sistemu „oblaka". Zabrinutost i neinformiranost radne snage o umjetnoj inteligenciji predstavlja prepreku za njeno usvajanje, ali i nudi priliku za tehnološko napredovanje struke.

Ključne riječi: AI; radiologija; radiološka tehnologija; SWOT

SWOT analysis of the application of artificial intelligence in radiologic technology and radiology

Summary: Artificial intelligence (AI) is bringing changes to radiology and radiologic technology, enabling the development of algorithms that facilitate diagnosis and decisions. AI can improve patient outcomes, increase the efficiency of scans and reduce costs. Machine and deep learning have proven to be extremely useful in the detection and characterization of lesions, improving routine imaging techniques the quality of reporting. The practical application of artificial intelligence in radiology and radiologic technology has been slowed down by the lack of integrated solutions and well-structured data archives, as well as challenges such as non-transparency of decision-making systems and large amounts of quality data needed to train artificial intelligence models. There are concerns about the potential impact of AI on the work of radiologists and radiologic technologists, which may hinder its development and implementation. Textual data derived from image reports can provide valuable insights, opening a new era in extracting information from medical images and reports. Due to the challenges in training experts for AI in healthcare, a multidisciplinary approach will have to be. There are issues of liability and regulation regarding data storage and privacy, especially with cloud storage. Concern of the workforce and their lack of education about AI represents an obstacle to its adoption, but also offers an opportunity for the technological advancement of the profession.

Keywords: AI; radiologic technology; radiology; SWOT

MARLIN (Medical Applications of Radiation – Learning from Incidents and Near Misses) the European Consensus Guidelines

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Sažetak: ***Ciljevi rada***: Direktiva EU 2013/59/EUROATOM od 5. 12. 2013. postavila je temelje temeljnih sigurnosnih standarda (Basic Safety Standards Directive BSSD) u zaštiti od opasnosti proizašlih iz izlaganja ionizirajućem zračenju. To obuhvaća slučajno i neželjeno prekomjerno ozračivanje, kao i nedovoljno ozračivanje prilikom radioterapije, brahiterapije i terapijske nuklearne medicine. Obveza je svaki takav događaj prijaviti nadležnom tjelu, kao i poduzeti korektivne mjere, kako se isto nebi ponovilo. Jednako tako, obveza je osigurati da se podatci učine široko dostupnima, kako bi svi zainteresirani bili svjesni potencijalnih rizika. U tom cilju uspostavljeno je nekoliko međunarodnih baza podataka koje sadrže opise neželjene događaje (ROSEIS – Radiation Oncology Safety Education and Information System, SAFRAD – Safety in Radiological Procedures, SAFRON Safety in Radiation Oncology). Te baze podataka dio su šireg pristupa sustavu učenja na greškama (ILS – Incident learning system). ***Materijale i metode***: Za izradu smjernica korištena je anketa u kojoj su skupljeni podatci iz zemalja članica, pregledana je stručna literatura te mišljenje stručnjaka. Navedene podatke razmotrio je tim stručnjaka sastavljen od predstavnika: European Institute for Biomedical Imaging Research (EIBIR), European Federationa of Organisations for Medical Phyisics (EFOMP) i European Society for Radiotherapy and Oncology (ESTRO). Na temelju prikupljenih podataka, tim je izradio nacrt dogovornih smjernica koje je dao na razmatranje i korekciju širem krugu stručne javnosti sa ciljem pstizanja šireg dogovora i kvalitetnih rješenja. ***Rezultati***: Studija je pokazala nehomogenost u pristupu i primjeni BSSDa u zemljama članicama EU. To se prvenstveno odnosi na razliku u nazivlju i kategorizaciji neželjenih događaja, kao i na procedure i postupanja u slučaju neželjenih događaja. Predložene su smjernice koje opisuju uloge i odgovornosti kliničkih ustanova, regulatornih tijela i profesionalnih društava u njegovanju sigurnosne kulture i trajnog unaprijeđenja sigurne upotrebe ionizirajućeg zračenja u medicini. Također, opisani su pojmovi i definicije kako bi se postigla nedvosmislena komunikacija među velikim brojem učesnika. ***Zaključak***: Standardizirani pristup učenju iz grešaka ima za cilj pojednostavniti i olakšati prijenos informacija u međunarodnom i višejezičnom okružju kako bi se neželjeni događaji što kvalitetnije dokumentirali i iskoristili za unaprjeđenje sigurnosti. Zajednički pristup posebno je značajan za manje države koje nemaju kapaciteta samostalno razvijati ovakove sustave.

Ključne riječi: Guidelines, ILS, MARLIN, SAMIRA

MARLIN (Medical Applications of Radiation – Learning from Incidents and Near Misses) the European Consensus Guidelines

Abstract: ***Purpose***: Directive EU 2013/59/EUROATOM from 5. 12. 2013. has set up the Basic Safety Standards Directive (BSSD) to report and learn from patient-related incidents and near misses in the medical application of ionising radiation, such as radiotherapy, interventional cardiology, nuclear medicine, and interventional and diagnostic radiology. There is an obligation to report these events to the Competent authority (CA) and to undertake corrective measures to prevent further incidents. These lessons learned should be disseminated to the professional community to mitigate future risks. Incident Learning System (ILS) such as Radiation Oncology Safety Education and Information System (ROSEIS), Safety in Radiological Procedures (SAFRAD) and Safety in Radiation Oncology (SAFRON) are used. ***Methods***: The guidelines were drafted based on a literature review, survey results and expert interviews. The data were analyzed by an expert consortium, comprising members of the European Institute for Biomedical Imaging Research (EIBIR), European Federation of Organisations for Medical Physics (EFOMP) and European Society for Radiotherapy and Oncology (ESTRO) Based on the data collected, the consortium outlined the consensus guidelines and presented the document to the broader counterparts community. ***Results***: The study showed the inhomogeneity in the approach and application of BSSDa among member states. This includes the differences in taxonomy and categorisation of incidents as well as procedures and actions taken. The proposed guidelines address the roles and responsibilities of clinical facilities, competent authorities and professional organisations in fostering a culture of safety and continuous improvement in. Također, opisani su pojmovi i definicije kako bi se postigla nedvosmislena komunikacija među velikim brojem učesnika. ***Conclusion***: The standardised approach to incident learning aims to simplify and ease information transfer in international and multilingual environments. The incidents must be well documented and exploited for quality improvement. A joint effort is especially important for the smaller state members lacking the resources to independently develop ILS.

Keywords: Guidelines, ILS, MARLIN, SAMIRA

Inovativne radiokirurške metode

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Sažetak: Stereotaksijska ablativna radioterapija (engl. Stereotactic ablative radiotherapy – SABR; stereotactic body radiotherapy – SBRT) odnosno radiokirurgija, radioterapijski je postupak u kojem se isporučuju visoke, ablativne doze ionizirajućeg zračenja u ciljni tumorski volumen unutar tijela uz hipofrakcioniranje (1-5 frakcija) i maksimalnu poštedu okolnih zdravih tkiva. Radi uspješnosti u tretiranju tumorskih promjena u cijelom tijelu, zadnjih godina postaje jedna od prvih metoda izbora u liječenju onkoloških pacijenata. Radiokirurški uređaj Varian Edge moderni je sustav za isporuku ablativne doze zračenja. Koristi tehnologiju VMAT (volumetric modulated arc therapy) za brzu isporuku doze (2400 MU/min), a snopovi se modeliraju HD multyleaf collimatorima (2.5, 5 mm). Submilimetarsko namještanje pacijenta omogućava terapijski stol sa šest stupnjeva slobode kretanja. Na Varian Edge sustavu obavljamo sve vrste radiokirurških procedura u CNS-u, toraksu, abdomenu i zdjelici, metodama slobodnog disanja ili zadržavanja dubokog udaha uz nadzor sustavom OSMS-AlignRT (optical surface monitoring system) te namještanjem bolesnika uz pomoć Cone beam CT (CBCT). Radiokirurško liječenje u općoj endotrahealnoj anesteziji predstavlja inovativnu radiokiruršku metodu koja zahtjeva suradnju anesteziološkog i radiokirurškog tima. Stereotaksijska radioablacija srčanih aritmija (stereotactic aritmia radioablation – STAR) označava primjenu SABR u liječenju srčanih aritmija (ventrikularnih tahikardija). STAR, kao učinkovit, neinvazivan i dobro podnošljiv tretman pokazuje se kao metoda za pacijente koji su rezistentni na kardiološko liječenje srčanih aritmija. Accuray CyberKnife S7 jedini je sustav za isporuku ablativnih doza zračenja koji ima linearni akcelerator na robotskoj ruci koja se kreće oko pacijenta koji leži na terapijskom stolu sa šest stupnjeva slobode kretanja. Zbog neizocentričnog kretanja robotske ruke u više stotina različitih kutova isporuka doze je mnogo preciznija i brža. Radiokirurška talamotomija metoda je funkcijske radiokirurgije s korištenjem submilimetarske preciznosti i robotskog navođenja linearnog akceleratora uz isporuku visoke doze usmjerenog zračenja bez upotrebe invazivnih metoda imobilizacije. Cilj ovog postupka je ablacija VIM jezgre talamusa. Neophodna je dobra suradnja cjelokupnog tima. Linearni akcelerator Varian Ethos sustav je koji pomoću visoke preciznosti isporuke doze i umjetne inteligencije omogućava adaptivnu radiokirurgiju i radioterapiju za vrijeme tretmana pacijenta. Adaptivna radiokirurgija prostate predstavlja novitet u zračenju bolesnika s tumorima prostate jer omogućava adaptaciju isporuke doze u ciljni tumorski volumen tijekom provođenja tretmana. Cilj ovog predavanja je predstaviti navedene moderne inovativne radiokirurške metode te uređaje i procedure koji se na njima obavljaju.

Ključne riječi: Radiokirurgija, ablativna, submilimetarska preciznost, adaptivna

Innovative radiosurgical methods

Abstract: Stereotactic ablative radiotherapy (Stereotactic ablative radiotherapy – SABR; stereotactic body radiotherapy – SBRT), i.e. radiosurgery, is a radiotherapy procedure in which high, ablative doses of ionizing radiation are delivered to the target tumor volume inside the body with hypofractionation (1-5 fractions) and maximum sparing the surrounding healthy tissues. Due to its effectiveness in treating tumor changes in the whole body, in recent years it has become one of the first methods of choice in the treatment of oncology patients. The Varian Edge radiosurgery device is a modern system for delivering an ablative dose of radiation. It uses VMAT (volumetric modulated arc therapy) technology for fast dose delivery (2400 MU/min), and the beams are modeled with HD multileaf collimators (2.5, 5 mm). Submillimeter adjustment of the patient enables the therapy table with six degrees of freedom of movement. On the Varian Edge system, we perform all types of radiosurgical procedures in the CNS, thorax, abdomen and pelvis, using methods of free breathing or holding deep breaths with monitoring by the OSMS-AlignRT system (optical surface monitoring system) and patient positioning with the help of Cone beam CT (CBCT). Radiosurgical treatment under general endotracheal anesthesia is an innovative radiosurgical method that requires the cooperation of the anesthesiology and radiosurgery team. Stereotactic radioablation of cardiac arrhythmias (stereotactic arrhythmia radioablation – STAR) refers to the use of SABR in the treatment of cardiac arrhythmias (ventricular tachycardia). STAR, as an effective, non-invasive and well-tolerated treatment, proves to be a method for patients who are resistant to cardiological treatment of cardiac arrhythmias. The Accuray CyberKnife S7 is the only ablative radiation dose delivery system that features a linear accelerator on a robotic arm that moves around the patient lying on the treatment table with six degrees of freedom of movement. Due to the non-isocentric movement of the robotic arm in hundreds of different angles, the delivery of the dose is much more precise and faster. Radiosurgical thalamotomy is a method of functional radiosurgery using submillimeter precision and robotic guidance of a linear accelerator with the delivery of a high dose of directed radiation without the use of invasive immobilization methods. The aim of this procedure is to ablate the VIM nucleus of the thalamus. Good cooperation of the entire team is necessary. The Varian Ethos linear accelerator is a system that uses high precision dose delivery and artificial intelligence to enable adaptive radiosurgery and radiotherapy during patient treatment. Adaptive radiosurgery of the prostate represents a novelty in the radiation of patients with prostate tumors, as it enables the adaptation of dose delivery to the target tumor volume during treatment. The aim of this lecture is to present the mentioned modern innovative radiosurgical methods and the devices and procedures performed on them.

Keywords: Radiosurgery, ablative, submillimeter precision, adaptive

Cyber napadi na radiološke sustave

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Sažetak: Osnova današnjih radioloških uređaja su računala i mreže. Odjel radiologije ima specifičan način rada i postoje standardi kao što su DICOM za medicinske snimke, PACS za arhiviranje i komunikaciju te HL7 za razmjenu informacija u medicinskom sustavu. Kako radiologija postaje ekonomski zanimljiva grana, postaje meta kibernetičkih napada. Istodobno, radiološki sustavi sadrže mnogo osobnih podataka koji su vrijedni. Razlozi za napade često su financijska korist, politička, ideološka ili osobna. Početak napada može biti fizički pristup radiološkim uređajima ili pristup mreži. DICOM datoteke mogu biti okidač napada. Napade dijelimo na one koji izravno utječu na pacijente, one koji imaju neizravan učinak i one koji utječu na infrastrukturu. Dobro poznate vrste su Denial-Of-Service, malware, kriptografski napadi i mijenjanje postavki uređaja. U obrani od kibernetičkih napada važno je osigurati komunikaciju e-poštom i ažurirati softver. Informatički odjel odjela radiologije treba nadzirati račune svih korisnika i provjeravati autorizacije. Mreže moraju imati ograničenja pristupa prema radnim mjestima i namjenama kako bi se spriječio neželjeni pristup. Web proxy zaštita ograničava pristup internetskim stranicama koje su potencijalno opasne. Osnove mreže odjela, poput poslužitelja, moraju biti fizički zaštićene od pristupa. DICOM datoteke trebaju biti šifrirane najsigurnijim dostupnim algoritmima. Kao odgovor na kibernetičke napade potrebno je imati standardne procedure i takav sustav uvijek mora biti u stanju pripravnosti. Poznati napadi na radiološke sustave su Kwampiris, Petja/NotPetya, Ryuk, Wannacry, Conti group i BianLian.

Ključne riječi: kibernetički napadi, radiološki sustavi, mrežna sigurnost

Cyber attacks on radiological systems

Abstract: The Basis of today's radiological devices are computers and networks. The radiology department has a specific way of working and there are standards such as DICOM for medical image records, PACS for archiving and communication, and HL7 for information exchange in the medical system. As radiology becomes an economically interesting branch, it becomes a target for cyber-attacks. At the same time, radiological systems contain a lot of personal data that are valuable. The reasons for the attacks are often financial gain, political, ideological or personal. The start of an attack can be physical access to radiological devices or network access. DICOM files can be the trigger of an attack. We divide attacks into those that directly affect patients, those that have an indirect impact, and those that affect the infrastructure. Well known types are Denial-Of-Service, malware, cryptographic attacks and making changes of device settings. When defending against cyber-attacks, it is important to secure communication by e-mail and to keep software updated. The IT department of the radiology department should observe accounts of all users and check the authorizations. Networks must have access restrictions according to workplaces and purposes in order to prevent unwanted access. Web proxy protection restricts access to Internet sites that are potentially dangerous. The basics of the department's network, such as servers, must be physically secured from access. DICOM files should be encrypted with the most secure algorithms available. In response to cyber-attacks, it is necessary to have standard procedures and such systems must always be on standby. Known attacks on radiological systems are Kwampiris, Petja/NotPetya, Ryuk, Wannacry, Conti group and BianLian.

Keywords: cyberattacks, radiological systems, network security

Jesmo li samostalni u nuklearnoj medicini?

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Sažetak: Nuklearna medicina je područje radiološke tehnologije koje tijekom studija, a i kasnije tijekom pripravničkog staža, ostavlja radiološkim tehnolozima dosta teorijskih i praktičnih nepoznanica u području rada i djelovanja. U RH još uvijek, unatoč brojnim aktivnostima komore i društva (HKZR, SR ZRTD i HDRT), praksa u nuklearnoj medicini nije uključena u pripravnički staž koji je zakonski obavezan nakon završetka studija, osim u slučaju primitka na staž u području radioterapije, kada pripravnici provedu 3 mjeseca na klinici / zavodu za nuklearnu medicinu. Cilj ovog rada je opisati ključne kompetencije i svakodnevne uloge radioloških tehnologa u različitim područjima nuklearno medicinske dijagnostike te objasniti u kojim segmentima rada, radiološki tehnolozi samostalno obavljaju dijagnostičke i terapijske postupke. U razmatranje su uzeti u obzir praktični elementi usvojeni tijekom školovanja te tijekom provedbe staža, a sve je, u okviru mogućnosti usporedbe, objašnjeno sa gledišta europskih smjernica, kompetencija i protokola koji su trenutno dostupni. Prikazane su metode svakodnevne kliničke prakse, od pripreme za rad do završetka pojedinog dijagnostičkog postupka. Opisane su dostupne edukacije i pomoćni alati na web stranicama krovne europske udruge, dokumenti do sada objavljeni po pitanju osnovnih i naprednih kompetencija, a uz to su navedene i dosadašnje aktivnosti lokalnih udruga po pitanju suradnje i usvajanja novih vještina. U zaključku, iako u svjetlu dostupnih činjenica pomak ka napretku i samostalnosti teče sporo i naizgled stoji, promicanje svijesti, razmjena iskustava i prvenstveno edukacija na lokalnom, europskom i svjetskom nivou, daje vedriju i pozitivnu perspektivu u godinama koje slijede.

Ključne riječi: dijagnostički postupci, edukacija, kompetencije, nuklearna medicina, radiološka tehnologija, samostalnost

Exploring autonomy in Nuclear Medicine

Summary: Nuclear medicine is a field of radiological technology that, during studies and later during internship, leaves radiological technologists with a lot of theoretical and practical unknowns in the field of work and activity. In the Republic of Croatia, despite the many activities of the chamber and society (HKZR, SR ZRTD and HDRT), practice in nuclear medicine is not included in the internship which is legally mandatory after the end of the studies, except in the case of receiving an internship in the field of radiotherapy, when trainees spend 3 months at the clinic / institute for nuclear medicine. The aim of this paper is to describe the key competencies and daily roles of radiological technologists in different areas of nuclear medical diagnostics and to explain in which work segments radiological technologists independently perform diagnostic and therapeutic procedures. The practical elements adopted during education and during the implementation of the internship were taken into consideration, and everything, within the scope of comparison, was explained from the point of view of European guidelines, competences and protocols that are currently available. Methods of daily clinical practice are presented, from preparation for work to completion of a particular diagnostic procedure. The available education and auxiliary tools on the websites of the umbrella European association are described, the documents published so far regarding basic and advanced competences, and the previous activities of local associations regarding cooperation and the adoption of new skills are also listed. In conclusion, although considering the available facts, the move towards progress and independence is slow and seemingly at a standstill, the promotion of awareness, the exchange of experiences and, above all, education at the local, European and world level, gives a brighter and more positive perspective in the years to come.

Keywords: autonomy, diagnostic procedures, education, competencies, nuclear medicine, radiologic technology

Radiološki pristup imunokompromitiranom pacijentu

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Sažetak: Cilj ovog prikaza je pobliže objasniti pojam imunokompromitiranosti, te vrste imunokompromitiranih stanja i njihove etiološke čimbenike. Među nabrojanim uzročnicima, istaknuto je značenje HIV-a kao nezaobilaznog problema modernog svijeta, te kao jednog od glavnih i najvećih uzročnika imunodeficijencije u bolesnika. Naglašeno je kako su imunokompromitirani pacijenti izravno izloženi širokoj lepezi raznih

infektivnih bolesti, koje u pojedinca s narušenim i disfunkcionalnim imunološkim sustavom mogu imate letalne posljedice. Detaljno je opisana radiološka obrada ovakvih pacijenata i njihovih složenih patoloških stanja. Kao literatura korišteni su dostupni materijali, u vidu članaka i znanstvenih radova, koji su objavljeni na *PubMed* platformi. Svi pronađeni izvori literature bili su predstavljeni u narativnom i deskriptivnom obliku na engleskom jeziku. Osim internetskih izvora, također su korištene i stručne knjige na hrvatskom i engleskom jeziku. U prikazu je definirana uloga radiologije u postavljanju dijagnoze, liječenju i praćenju imunokompromitiranih pacijenata. Svaka od relevantnih radioloških metoda je objašnjena i dodatno potkrijepljena slikovnim primjerom. Kao zaključak može se reći da su radiološke metode oslikavanja vrlo važan alat za postavljanje precizne dijagnoze koja vodi k promptnom početku liječenja pacijenata. To je poglavito važno kod imunokompromitiranih pacijenata, kod kojih je vrijeme odlučujući čimbenik za uvođenje odgovarajućeg terapijskog tretmana.

Ključne riječi: HIV; imunokompromitiranost; infekcije; radiologija

Radiological approach to the immunocompromised patient

Summary: The aim of this presentation is to elaborate the concept of immunocompromised diseases, the types of immunocompromised conditions and their etiological factors. Among the listed causes, it is highlighted the importance of HIV as an unavoidable problem of the modern world, and one of the main and biggest causes of immunodeficiency in patients. It was emphasized that immunocompromised patients are directly exposed to a wide range of various infectious diseases, which can have lethal consequences in an individual with a deficient and dysfunctional immune system. Radiological procedures used for assessment of such patients and their complex pathological conditions are described in details. As a literature source articles and scientific papers, which were published on the PubMed platform, were used. Literature sources were presented in narrative and descriptive form in English language. In addition to Internet sources, professional books in Croatian and English were also used. In the presentation, the role of radiology in the diagnosis, treatment and monitoring of immunocompromised patients was defined. Each of the relevant radiological methods is explained and additionally supported by a pictorial example. As a conclusion we can confirm the idea that radiological imaging methods are a powerful tool for establishing a precise diagnosis which is followed by a prompt initiation of patient's treatment. This is especially important in immunocompromised patients, for whom time is an determined factor for introduction of adequate therapeutic treatment.

Keywords: HIV; immunocompromisedness; infections; radiology

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