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Impact of low dose CT radiation: Benefits and Potential Harms

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Abstract

With the technological advancements, we have witnessed a proliferation of innovative and beneficial methods in the utilization of CT devices. The contemporary application of low-dose CT (LDCT), both in adults and children, is considered the gold standard due to its wide range of indications. The aim of this study is to delineate the positive and negative impacts that LDCT imposes on the human body. The routine use of LDCT in practice raises numerous questions regarding its harmfulness and influence. Diverse opinions exist within the scientific community regarding the association between LDCT and cancer development; therefore, it is exceptionally important to consider the population involved in the study, the characteristics of the radiation itself, and the various body parts exposed to radiation prior to its application. Despite the considerable number of conducted studies advocating for the use of LDCT, its utilization and the development of potential consequences cannot be completely excluded. That is why one of the necessary prerequisites for the professional use of CT as the method of choice in diagnostics is knowledge and understanding of scientific studies and their results in accordance with the modern development of CT devices. What remains crucial in everyday practice is that the knowledge used is always scientifically based and ultimately — reasonable.

Keywords: CT; LDCT; radiation dose; radiation

Introduction

All living organisms on planet Earth are constantly exposed to numerous natural sources of ionizing radiation such as cosmic radiation or natural radioactive materials. Contrary to common misconception, a far smaller amount of radiation comes from artificial sources controlled by humans, such as the use of radiation in medicine. In order to minimize even that dose of radiation, the practice of using low-dose computed tomography (LDCT) is becoming increasingly common [1]. To comprehensively examine the use and impact of LDCT, it is necessary to understand the development of CT (Computed Tomography) devices throughout history, their generations and operating principles, mechanical components, and dosimetric methods. Due to the growing need for CT device usage, questions are increasingly raised and studies are conducted in scientific circles regarding its use, impact, development, and the radiation it produces. The most common questions raised regarding the use of CT devices are whether their use will inevitably lead to the development of cancer and whether this assumption can be completely dismissed with a low-dose protocol. Through a review of numerous studies and results, this paper will attempt to answer this question within the context of using LDCT as a reliable method of choice in diagnostics. For the conclusion to be credible and scientifically grounded, it is crucial to consider the research population itself, radiation characteristics (e.g., differences in the use of CT for diagnostic purposes versus for radiotherapy purposes), specific body parts, or the use of CT scans in pregnant women. By reviewing the biological impact of LDCT scans, efforts will be made to determine the presence of indications indicating changes in DNA before and after the diagnostic procedure itself, while the impact of LDCT on animals will attempt to demonstrate the connection between studies on animals and studies on humans and their usefulness for further research. Towards the end of the paper, the positive and negative aspects of LDCT will be addressed, and a conclusion will be drawn based on a series of earlier explained studies that rarely delve into the specific sphere of the harmful effects of LDCT on the human body.

Modern CT devices

The capabilities of the first CT devices were limited to examinations of the head and brain, but with the second generation of devices from 1975 onwards, examinations of both the head and body became possible [2]. The first recorded clinical use of CT on an actual patient, using a device called EMI-Mark I, was performed in 1972 at Atkinson Morley Hospital, London, under the guidance of neuroradiologist Dr. James Abraham Edward Ambrose. After the initial examinations, the effectiveness and importance of CT scans in detecting cystic tumours of the anterior frontal lobe were concluded. This significantly resonated within medical circles and rightfully earned the title of the greatest discovery in diagnostic radiology since the discovery of X-rays in 1895 [2-7]. Today's CT devices allow for continuous rotation of the detector and X-ray tube in a specific direction around the patient, who is automatically moved with the CT table through the primary beam of X-rays during exposure, enabling examination of a larger anatomical area in a very short period without interruption. This allows for imaging of organs in three-dimensional display with physiological movements (CT angiography, perfusion CT, etc.) [2, 8]. Improvements in the design of detectors in modern CT devices have led to the generation of a larger number of layers in a single rotation and a reduction in radiation dose [2, 9]. Furthermore, some modern CT devices, such as DSCT, use two X-ray tubes as sources of radiation that then circulate at a 90-degree angle opposite the detectors in two arrays, significantly improving image quality by reducing motion artifacts and proving to be extremely useful methods for examining cardiac patients [8, 10]. Measuring dose in modern CT devices, unlike conventional X-ray machines, brings a number of complications due to the rotation of the tube around the patient and the creation of fine slices of individual body parts. Due to the special imaging technique, modern CT devices also introduce special dosimetric parameters such as CTDI (CT dose index), DLP (Dose length product), and SSDE (Size-specific dose estimate) [11-13].

Radiation effects

The utilization of ionizing radiation in modern radiological diagnostics remains one of the indispensable methods despite continuous advancements in medicine and the information technology industry. Alongside some conventional radiological methods such as CT diagnostics, ionizing radiation is also employed in radiotherapy, for example, in irradiating malignant tumours of oncology patients. Despite various diagnostic and therapeutic benefits, ionizing radiation poses potentially harmful consequences to the human body. Bearing in mind the harmful effects alongside the benefits achieved through diagnostic methods, we must always strive for a multiple-fold benefit over risk [14]. Despite concerns and the risk of cancer development associated with exposure to ionizing radiation, in most cases, the indication for diagnostic examination will outweigh the relatively small risk of cancer development. Guided by these principles, we must always consider the harm that radiation exposure can inflict on the patient, especially professionals who work daily with sources of ionizing radiation. The frequent use of CT devices in recent years has raised concerns and numerous questions about their harmfulness despite numerous advantages. In 2021, it was estimated that the number of CT scans worldwide increases annually by 4%, totalling approximately 300 million scans per year, and with the development of technology, this trend is expected to continue to rise [15, 16]. It is precisely due to such data, guided by the ALARA principle, that the need for LDCT protocols arises.

CT device doses

In diagnostic examinations, particularly in CT scans, considering that the average dose for a CT abdomen, for instance, is around 10 mSv, there is no significant harm. However, if a patient undergoes this examination multiple times in a short period, the chances of harm are higher [1]. Lin, in his 2010 article, explains and compares the risks of radiation exposure and concludes that there is a potential risk of cancer induction for doses greater than 100 mSv [1]. The UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) report from 2012 also considers the value of 0.1 Gy = 100 mGy as the upper limit of low radiation dose values [17]. By using LDCT adapted protocols for dose reduction on CT devices through tube current modulation, image reconstruction methods, individualized approaches to patients based on their constitution (size), access to dose reports before and after the examination, and adherence to all radiation protection principles, we achieve sufficiently sharp and diagnostically correct images with extremely low radiation doses compared to standard CT scans [18] (Figure 1).

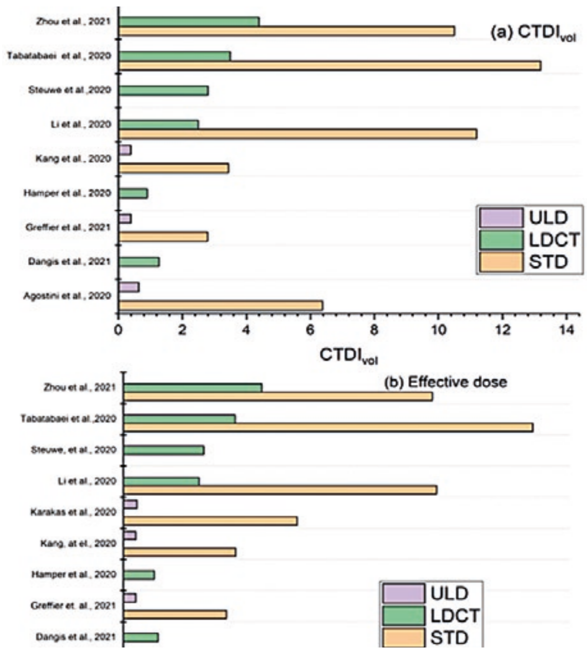

Figure 1. Comparison of dose parameters between standard CT protocol and LDCT and ULD protocols. Systematic literature review of various authors. *(Source:* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10146316/pdf/life-13-00992.pdf)

The aim of this article

The aim of this article is to define the positive and negative impacts that LDCT presents to the human body through an examination of a range of available scientific literature on the *Pubmed.gov*, *Science Direct* and *Ncbi* data base. Additionally, the purpose of the article is to present various scientific studies and their results that support the aforementioned facts and impacts of LDCT.

Discussion

Low Dose CT in Head and Neck Diagnosis

CT has become an indispensable diagnostic method for head and neck examinations, especially in diagnosing head traumas. With its reliability and high-quality images, it enables radiologists to make accurate diagnoses with minimal errors. Due to the area's exceptional sensitivity to ionizing radiation and associated risks, LDCT protocols are ideal for minimizing radiation dose while maintaining sufficient quality and accuracy. Wu et al. confirmed that the use of low-dose protocols resulted in a 45% dose reduction compared to standard CT protocols in patients with confirmed diagnoses of intracerebral haemorrhage (ICH) [19]. P. Morton et al. also found a significant dose reduction in children with head pathologies. The image quality at low dose was satisfactory and confirmed by all participating physicians, eliminating the need for re-imaging with standard CT protocols [20] (Figure 2).

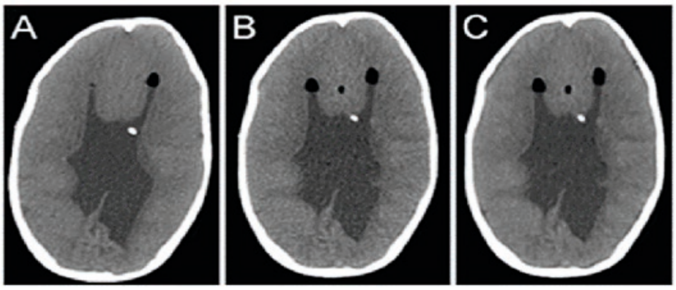

Figure 2. Comparison of the quality of axial head image of a three-year-old child. A – standard CT, B – LDCT, C – LDCT with filter.
(Source: https://pubmed.ncbi.nlm.nih.gov/23971634/)

Low Dose CT in Chest Diagnosis

Recognizing that CT scans can provide various benefits in diagnosing lung parenchyma, the use of LDCT protocols is becoming standard in combating the leading cause of cancer-related deaths worldwide, lung cancer [21]. Studies such as the largest European study NELSON (Dutch acronym) (Figure 3) show a significant reduction in mortality among high-risk patients in lung cancer screening using LDCT protocols, with a remarkable reduction in effective dose of up to 1.5 mSv [22, 23]. Prompted by the recent global COVID-19 pandemic, Suliman et al. compared different diagnostic methods for COVID-19-infected patients using various CT protocols. They primarily compared dose

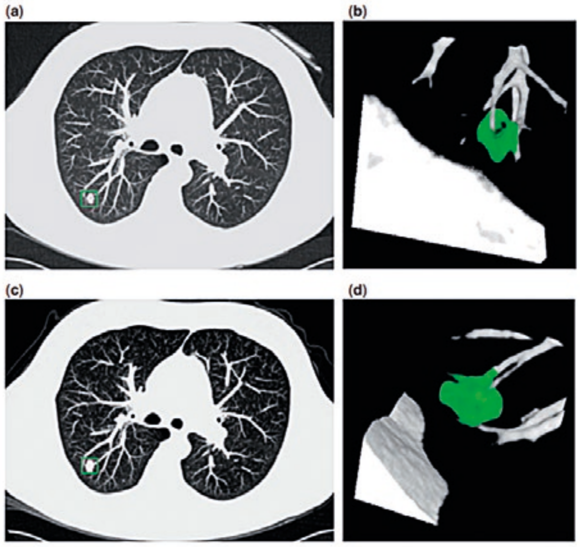

Figure 3. NELSON study LDCT of the thorax of a 68-year-old patient with a 3-month interval. a), b) nodule volume 303 mm3 during the first examination, c) d) – nodule volume 576 mm3. Control after 3 months indicates a 90% increase in volume growth percentage. Histopathology of the resected nodule indicates squamous cell carcinoma.
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3266562/)

reduction using LDCT protocols versus standard CT and concluded a significant reduction in radiation dose, justifying the potential replacement of standard CT protocols with LDCT and ULDCT protocols as the method of choice [18].

Low Dose CT in Abdominal and Pelvic Diagnosis

The constant rise in the use of CT as a method of choice also finds its place in abdominal and pelvic diagnostics. A significant increase in CT utilization is evident in the diagnosis of one of the most common acute clinical conditions, acute abdomen (multiple symptoms or signs of severe and intense pain in the abdominal cavity that potentially require emergency surgical intervention) [24]. Due to such symptoms of undefined location and broad pain projection, CT as a diagnostic tool is of utmost importance. Moloney et al. in a prospective study compare LDCT and standard CT protocols in the diagnosis of acute abdomen using image reconstruction methods and report a 87% dose reduction without significant deviation in image quality [24]. Various other studies also confirm significant dose reductions in various pathologies such as acute appendicitis, kidney stones, etc., and consider LDCT as an ideal diagnostic method, although potential downsides such as high image noise due to large patient body mass, intestinal content, etc., need to be taken into account [25, 26].

Low Dose CT in Musculoskeletal Diagnosis

The musculoskeletal system, consisting of bones, muscles, and ligaments, is crucial for movement. In diagnosing bone pathology, CT emerges as the gold standard diagnostic method. Knowing that CT is typically associated with a significantly higher dose than standard devices using ionizing radiation, most CT devices already have adapted standard CT protocols to reduce radiation in diagnosing bone fractures. By using LDCT and ULDCT protocols, the dose itself could be considerably lower while maintaining diagnostic accuracy, thus potentially eliminating potential harm associated with exposure to ionizing radiation. Xiao et al. confirm this in a prospective study where they encompass nondisplaced fractures of the shoulder, knee, wrist, and ankle joints and compare the diagnostic accuracy of standard CT and ULDCT in fracture evaluation [27]. Evaluation of the results yielded similar image quality between the two protocols, while ULDCT showed a significantly lower effective dose (Figure 4) [27].

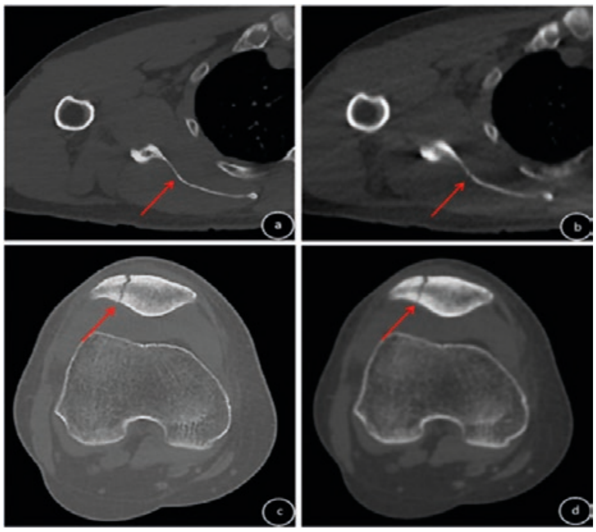

Figure 4. Comparison of quality (a, c) standard CT and ULDCT (b, d) protocols in the diagnosis of non-displaced fractures (a, b) of the shoulder, (c, d) knee. *(Source:* https://pubmed.ncbi.nlm.nih.gov/36882617/)

Low Dose CT in the Diagnosis of Pregnant Women and Children

Unlike other sources of ionizing radiation in pregnant women, CT exposes the fetus to the highest dose. The amount of radiation exposure to the mother and fetus largely depends on the tissue area exposed to radiation. For example, CT of the pelvis delivers the highest dose to the fetus, approximately 50 mGy. Although this dose may seem significant, it is still within the range where there are no significant adverse effects on the fetus [28]. Due to the high dose produced by CT, we should certainly consider other diagnostic options for pregnant women, such as ultrasound (UZV), magnetic resonance imaging (MRI), or conventional X-ray, before finally opting for CT as the method of choice. According to Kutanzi et al., children are more susceptible to the risks of ionizing radiation than adults [29]. The reason is their developing bodies and the expected long lifespan after exposure to sources of ionizing radiation [29]. In a retrospective study by Polleti et al. conducted on pregnant women over 18 years old with their consent, suspected of acute appendicitis, the application of LDCT protocol and ultrasound was compared when MRI availability was not possible. Subsequently, the results were compared with the standard CT protocol, revealing a significant dose reduction (average effective dose of 1.9 mSv) with exceptional diagnostic accuracy of the LDCT protocol. LDCT is recommended as the method of choice with supplementation of ultrasound over standard CT [30].

Low Dose CT in Radiotherapy

It is important to distinguish between the different characteristics of radiation used for diagnostic purposes and for planning in radiotherapy. The doses used for diagnostic purposes in CT scans are significantly lower than the doses patients receive during radiotherapy planning [31]. Due to the higher dose received by patients during radiotherapy planning, there are increased risks for this already vulnerable group. Protocols aimed at reducing the dose during planning are necessary to minimize potential risks. For this reason, Kim et al. conducted a study on a Computerized Imaging Reference Systems (CIRS) phantom [32]. They used a standard protocol of 120 kV and 350 mAs and compared it with obtained HU values using five different protocols (50, 100, 200, 350, and 400 mAs). In the final step, they used the iDose 5 reconstruction algorithm, which is tasked with dose reduction [32, 33]. The results showed that reducing the tube current increased image noise, but using reconstruction tools such as the iDose 5 algorithm led to a significant reduction in dose and noise [33]. In all explored studies in radiotherapy, the limitation in dose reduction was the patients' constitution. The higher the body mass, the lower the possibility of reducing radiation dose while maintaining adequate image quality without significant noise [32-35].

Low Dose CT in the Diagnosis of Cardiovascular Diseases

Cardiovascular and cerebrovascular diseases are the leading cause of death worldwide according to the Global Burden of Disease (GBD) 2019 statistics. It is estimated

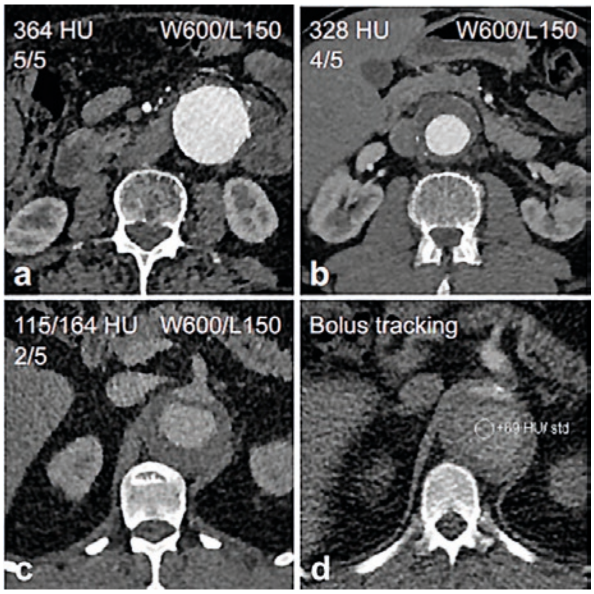

Figure 5. The LD protocol CTA demonstrates sufficient diagnostic quality except in image d), where the tracking of aortic dissection is impeded. *(Source:* https://pubmed.ncbi.nlm.nih.gov/35328228/)

that cardiovascular disease-related mortality exceeded 18 million people in 2019 [36]. Given these numbers, we can conclude that the need for diagnostic methods in the diagnosis of cardiovascular diseases is also rapidly increasing. CT as a diagnostic method is crucial in detecting atherosclerotic changes. Zhao et al. conducted a prospective study due to the increasing demand for the diagnostic method of Computed Tomography Angiography (CTA). By using CTA, they implemented a protocol aimed at drastically reducing the dose while maintaining sufficient diagnostic quality [37]. The results showed a significant reduction in effective dose by 59% with the ULD protocol and lower application of iodine contrast by 51%, with satisfactory image quality. All explored studies in the diagnosis of cardiovascular diseases in this paper indicate that with newer generations of devices, even greater improvements in quality and dose reduction are expected (Figure 5) [37, 38].

Biological effects of Low-Dose CT on the human body

Despite the promising results of studies demonstrating reduced radiation doses or decreased mortality through early detection of pathologies such as lung cancer screening, they do not provide a concrete answer to the biological harm that LDCT radiation leaves on the human body. In a prospective study, Sakane et al. attempt to determine the biological effects of LDCT lung screening on DNA [39]. The study involved 209 patients (105 women and 104 men) with an average age of 67. Patients were equally divided into two groups, with 107 patients undergoing LDCT and 102 patients undergoing standard CT. Blood samples for assessment were examined 15 minutes before and after imaging. It was found that the mean effective dose for LDCT was significantly lower, ranging from 1.4 to 1.7 mSv, while for standard CT, it ranged from 4.2 to 6.3 mSv. The DLP, effective, and calculated blood doses were approximately 30% lower with LDCT. Evaluation of the results revealed no increase in double-strand DNA breaks or chromosomal aberrations with LDCT, whereas their numbers increased with standard CT. The study showed no harm to human DNA using LDCT protocols, whereas potential DNA damage was observed with high doses of standard CT protocols [39]. Another study conducted by Maarten et al. to assess cell survival after exposure to low and high doses of Linear Energy Transfer (LET) radiation in radiotherapy also indicates different radiation effects [40]. High doses resulted in low cell survival but high cell apoptosis (programmed cell death), unlike lower doses, which showed contradictory results (Figure 6.) [40].

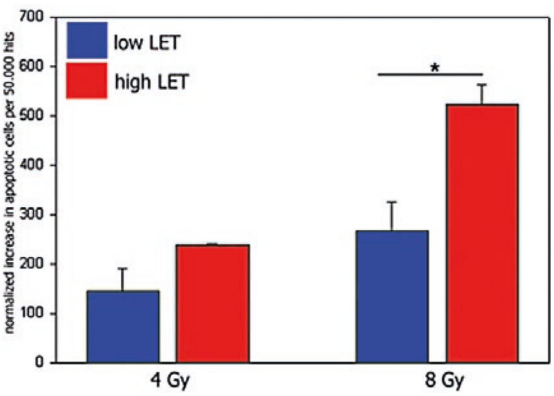

Figure 6. Relationship between high and low doses of Linear Energy Transfer (LET) radiation on human cell.
(Source: https://www.redjournal.org/action/showPdf?pii=S0360-3016%2811%2903330-X)

The influence of Low-Dose CT radiation on animals

Exposure of animals to doses of ionizing radiation poses a problem for scientists involved in daily research. Molins et al. estimate that scientists are exposed to an average dose of 3 mSv annually, considering the amount of studies they conduct [41]. They consider optimized dose reduction protocols necessary for studies conducted in this case on PET (Positron Emission Tomography) CT devices to minimize the doses to which both humans and animals are exposed [41]. For this reason, Molins et al. conducted a study using a Si78 PET/CT device from Gruker Biospin, employing LD protocols on phantoms and animals, confirming excellent image quality with four times lower doses compared to standard protocols. Scientists operating the device are thus predicted to experience a drastic reduction in their annual dose. The device enabled doses of less than 10 mGy for exposed mice with nearly identical image quality to the standard protocol (Figure 7.), [41].

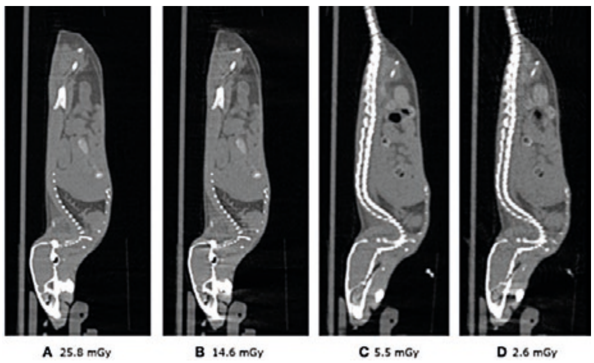

Figure 7. Above are shown four sagittal views of a mouse with dose reduction protocols.
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6509903/)

Advantages and disadvantages of Low-Dose CT

All the mentioned research and studies highlight the advantage of significantly reducing the dose with LDCT protocols while minimizing the loss of image quality, recommending it as the method of choice in the diagnosis of adults, especially in pregnant women, children, and cancer patients. This certainly favors LDCT as the primary method of choice, but most studies also mention some significant drawbacks. One of the most significant drawbacks of LDCT, according to most studies, especially those related to lung cancer screening, is false-positive findings resulting from various factors [42]. Poorly prepared protocols leading to high image noise are certainly among them, so every healthcare facility using CT as the method of choice should align protocols to achieve the lowest dose possible while maintaining satisfactory diagnostic quality with the agreement of radiologists interpreting the images. False-positive findings lead to additional negative aspects such as additional imaging and procedures needed to detect or refute pathology. Additional imaging leads to additional doses to which the patient is exposed, while false-positive findings in procedures such as lung cancer screening lead to uncomfortable biopsies and further complications [42]. Finally, we come to the drawback that is actually the greatest general problem of CT devices, which is the relationship between LDCT and the occurrence of cancer. Lin [1] states that doses up to 100 mSv do not cause significant consequences. The emphasis is on “significant” because potential harm is never completely ruled out with 100% certainty in all studies reviewed in this paper. In conclusion, studies suggest that the potential association between cancer development and LDCT exposure would only be possible if the follow-up period began 10-20 years after exposure [43]. It should be noted that overestimating risks can lead to incorrect assessments by physicians, and due to the fear of the consequences of radiation, avoiding LDCT as the method of choice could produce more harm than benefit.

Conclusion

Comparing LDCT protocols with standard CT protocols in this study, we can conclude that LDCT protocols demonstrate satisfactory diagnostic accuracy in almost all studies, and even superiority over standard CT protocols, with a drastic reduction in dose, ultimately leading to the avoidance of unwanted consequences on the human body. The greatest application is seen in screening methods such as national lung cancer screening, where LDCT firmly holds its place as the “gold” method of choice in diagnosing lung cancer pathology. Certainly, LDCT should be the method of choice even for populations most sensitive to radiation, such as children and pregnant women, when MRI as a non-ionizing radiation method is not available. In such situations, LDCT shows a drastic reduction in dose compared to standard CT protocol with high diagnostic accuracy, and according to the mentioned studies, the risk of harmful effects of ionizing radiation is minimized. Some drawbacks, such as false-positive findings due to reduced image quality and the presence of noise, as well as radiologist inexperience in interpreting images, which may arise, for example, from attempts to reduce the current parameters of individual devices to achieve a satisfactory LDCT protocol, will certainly be reduced with further and increasing advances in the IT industry, leading to significant improvement in devices and algorithms such as the mentioned iDOSE-5, Flash scan technique, or the use of filters. Attention should also be paid to regular education of all professionals who work daily with doses of ionizing radiation through webinars, scientific papers, etc., directing them towards creating quality protocols to make LDCT a more reliable diagnostic method, thereby protecting all exposed individuals and eliminating all possible risks during the examination. The doses we use during LDCT protocols, although very low, must not be underestimated, considering that there is no harm to the human body. Overestimating and/or underestimating the risks associated with LDCT doses can cause more harm than benefit, especially in the diagnosis of children and pregnant women. Although studies show no direct link between low doses of ionizing radiation and the development of cancer or damage to human DNA, studies still leave a statistical possibility that we must not ignore. A review of the literature concludes that further research is not only necessary but also essential to obtain more accurate data on the advantages and disadvantages that low doses of ionizing radiation during CT scanning potentially cause.

All data in this paper are part of the results of the master’s thesis “Impact of low dose CT radiation on the human body: systematic literature review” written at the University Department of Health Studies, University of Split [44]. ■

Sažetak

Tehnološkim napretkom došli smo do velikog broja inovativnih i korisnih metoda u korištenju CT uređaja. Suvremenu upotrebu niskodoznog CT-a (low dose CT, LDCT), kako u odrasloj, tako i u dječjoj dobi, danas smatramo zlatnim standardom zbog vrlo širokog spektra različitih indikacija. Svakodnevno korištenje LDCT-a u praksi postavlja brojna pitanja o njegovoj štetnosti i utjecaju na ljudski organizam zato je nužno prepoznati te definirati pozitivne i negativne utjecaje koje LDCT predstavlja za ljudsko tijelo. Pronalazimo različita mišljenja unutar same znanstvene zajednice postoji li povezanost između LDCT-a i razvoja karcinoma. Kako bismo povezanost mogli dovesti u korelaciju, iznimno je važno detaljno proučiti: populaciju uključenu u istraživanje o navedenoj povezanosti, karakteristike zračenja LDCT-a te različite dijelove tijela izloženima zračenju prije primjene zračenja. Usprkos velikom broju provedenih istraživanja koja zagovaraju korištenje LDCT-a, njegova upotreba te razvoj potencijalnih posljedica ne mogu biti u potpunosti isključeni. Zato je jedan od nužnih preduvjeta za stručno korištenje CT-a kao metode izbora u dijagnostici, poznavanje znanstvenih istraživanja i njihovih rezultata u skladu sa suvremenim razvojem CT uređaja. Ono što ostaje ključno u svakodnevnoj praksi jest da je iskorišteno znanje uvijek znanstveno utemeljeno te na kraju — razumno.

Ključne riječi: CT; LDCT; doza zračenja; zračenje

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