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Review

A Comparative Assessment of Radiation Dose Levels in Diagnostic and Therapeutic Radiology Devices

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ABSTRACT

Accurate knowledge of radiation doses delivered by radiological devices is essential for ensuring patient safety and clinical effectiveness. This study presents a comparative review of radiation dose levels in commonly used diagnostic and therapeutic radiological procedures, including conventional X-ray imaging, computed tomography (CT), dual-energy X-ray absorptiometry (DEXA), and advanced radiotherapy systems. Reported dose values were standardized to the effective dose (mSv) and evaluated against the TENMAK and ICRP limits. The results indicate that conventional diagnostic methods, such as X-ray and DEXA, involve very low radiation doses (generally <0.1 mSv) and are considered low risk when used appropriately in routine clinical practice. In contrast, CT imaging delivers significantly higher doses (approximately 2–31 mSv), making it the primary contributor to patient radiation exposure among diagnostic techniques. Radiotherapy applications correspond to extremely high equivalent dose levels (converted to >10 Sv), reflecting their therapeutic purpose but also indicating increased risk of damage to surrounding healthy tissues. Overall, CT and radiotherapy devices represent the main sources of high radiation exposure, whereas conventional imaging techniques remain within safe limits. These findings highlight the importance of dose optimization, avoidance of unnecessary repeat imaging, and adherence to international radiation protection standards.

1. Introduction

Radiation is the emission or transfer of energy in the form of electromagnetic waves or particles and is an integral part of everyday life. While natural background radiation is generally not harmful, ionizing radiation at elevated doses can damage biological tissues and increase the risk of cancer [1]. Therefore, recent research has increasingly focused on radiation protection principles, dose optimization, and reducing unnecessary exposure in clinical applications, particularly in light of updated international safety guidelines [2–5].

X-rays, discovered in 1895 by Wilhelm Röntgen [6], remain one of the most widely used tools in medical imaging and therapy. Owing to their high energy and strong penetration, X-rays enable visualization of internal body structures based on differences in tissue density. In contemporary medical practice, X-ray-based technologies are employed across a wide range of diagnostic and therapeutic procedures, each associated with varying radiation dose levels. Advances in digital imaging systems and detector technologies have significantly improved image quality while simultaneously reducing patient dose, thereby making dose management and optimization a central focus of recent studies [7].

Cancer is one of the deadliest diseases of our age and poses a serious threat to public health [8, 9]. Cancer is a disease that occurs when some cells

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in our body grow uncontrollably and then spread to other regions. Cancerous tissue grows and becomes a mass, called a tumor. Tumors can be both benign and malignant. Once cancer has formed, it can spread to nearby tissues and distant organs. Many factors, such as bacteria, viruses, radiation, heredity, environmental factors, dietary habits, and chemicals, are effective in cancer formation [10]. One of the most effective methods in the fight against cancer is radiotherapy (RT). Radiotherapy devices are used in the diagnosis and treatment of both cancer and cardiovascular disease [11]. Half of the cancer patients are treated with RT during the treatment process. Today, patients can reach high treatment opportunities in short periods with high and effective treatment doses, with new RT treatment planning and application devices in their close vicinity [12].

This study provides a comparative analysis of radiation dose levels associated with commonly used diagnostic and therapeutic radiological devices, including X-ray, computed tomography (CT), dual-energy X-ray absorptiometry (DEXA), Gamma Knife, CyberKnife, and Helical Tomotherapy. Unlike previous studies that focus on individual modalities, this work integrates dose data from multiple sources and standardizes them for direct comparison. Furthermore, the evaluated dose levels are assessed in relation to national (TENMAK) and international (ICRP) radiation safety limits. By doing so, the study aims to identify high-exposure modalities, highlight potential risks to patients, and contribute to improved dose optimization strategies in clinical practice.

2. Devices

2.1. The X-Ray Tube

X-rays are classified as natural or artificial. Natural X-rays are emitted from unstable atomic nuclei via decay processes such as electron capture or beta decay. Artificial X-rays are produced when accelerated particles, typically electrons, interact with matter—most commonly in an X-ray tube. This vacuum device contains a cathode (usually a tungsten filament) and an anode. When heated, the cathode emits electrons that accelerate toward the anode under high voltage. Their collision with the metal target converts kinetic energy into electromagnetic energy, generating X-ray photons [13].

X-ray photons have sufficient energy to ionize atoms and break molecular bonds, making them potentially harmful to living tissue. High doses over short periods may cause radiation sickness, while prolonged low-dose exposure increases cancer risk. However, in medical imaging, the benefits outweigh the risks due to controlled exposure conditions. X-ray attenuation depends on tissue density, atomic number, and thickness, forming the basis of image contrast.

X-rays are of great importance as a diagnostic and therapeutic tool in medicine [14]. Many devices, such as computed tomography, roentgen, DEXA, CyberKnife, and Gamma Knife, use X-rays. Although these devices have crucial advantages in medicine, they pose a risk due to the radiation given to the patient. Therefore, it is very important to know the radiation dose used by these devices. This study is based on previously published data and aims to provide a comparative evaluation of radiation dose levels across different imaging and treatment modalities.

2.2. Roentgen

Roentgen imaging is the visualization of the internal structures of the body using X-rays. It plays a critical role in diagnosing diseases and planning treatment processes by allowing non-invasive examination. X-ray devices include radioscopy for dynamic imaging and radiography for static imaging. Roentgen examinations are commonly performed to evaluate pain, monitor treatment effectiveness, and follow disease progression. Images consist of varying shades of gray depending on tissue density. Since X-rays pass more easily through soft tissues such as lungs and muscles, these appear darker, whereas dense structures like bones appear lighter [15]. It is possible to list the most commonly used roentgen types in hospitals as follows:

- Lung X-ray
- Bite-Wing X-ray
- Abdominal X-ray
- Bone X-ray
- Panoramic X-ray
- Periapical X-ray
- Cephalometric X-ray

Lung X-ray

Lung X-ray has been widely used for over 100 years due to its availability, standardization, rapid application, and low cost [16]. It is used to evaluate the heart, lungs, blood vessels, and thoracic structures, and can detect conditions such as fluid accumulation or air around the lungs. It is commonly performed in patients with chest pain, injury, or shortness of breath [17]. The radiation dose is approximately 0.02 mSv [18].

Bite-Wing X-ray

Bite-Wing X-ray is used to evaluate molar crowns and the relationship between alveolar bone height and the enamel-cementum junction. It enables the detection of caries and periodontal bone changes, particularly in areas not directly visible in the oral cavity. It is one of the lowest-dose dental imaging methods, with doses ranging from 0.005 to 0.02 mSv depending on imaging parameters [19, 20].

Abdominal X-ray

An abdominal X-ray shows images of the kidneys, stomach, liver, and bladder. It helps doctors diagnose conditions such as kidney and bladder stones. Special contrast dyes can be used to evaluate parts of the digestive system, and images that provide a more detailed examination can be obtained. The effective dose in most abdominal computed tomography (CT) examinations is 2.0 mSv for an X-ray tube at 120 kV energy. [21].

Bone X-ray

Bone X-ray examinations are used to detect fractures, dislocations, arthritis, and bone-related diseases such as cancer or infection. Spine X-rays also visualize surrounding tissues. Radiation exposure is very low, approximately 0.001 mSv for extremities such as the hand and wrist [22].

Panoramic X-ray

Panoramic radiography is a basic dental imaging method that provides a comprehensive view of the jaws and teeth in a single image. It is used to detect conditions such as caries, cysts, and tumors. The effective dose ranges from 0.0027 to 0.0243 mSv [23].

Periapical X-ray

Periapical X-ray provides detailed images of teeth and surrounding bone structures. It is used to diagnose conditions such as impacted teeth, fractures, abscesses, and periodontal disease, and is commonly applied in endodontic and periodontal treatments. The effective dose is approximately 0.0006–0.0007 mSv [24].

Cephalometric X-ray

Cephalometric X-ray is used to image bones and soft tissues in anterior, posterior, and lateral positions on a single radiograph. It is commonly applied in patients requiring orthodontic treatment and orthognathic surgery to evaluate the size and spatial relationships of the head and facial bones [25]. Visser et al. evaluated patient radiation exposure in conventional screen-film and direct digital cephalometric radiography, demonstrating that the digital technique reduces patient dose by approximately 50% compared to the conventional method (conventional 0.0023 mSv; digital 0.0011 mSv) [26].

2.3. Dual-Energy X-ray Absorptiometry (Dexa)

DEXA is used to assess bone mineral density and diagnose osteoporosis caused by bone calcium loss. It is quick, painless, and usually performed on the L1-L4 spine and hip [27]. The device uses low-dose X-rays with two energy peaks: one absorbed by soft tissue, the other by bone. Subtracting the soft tissue absorption yields bone mineral density. A DEXA unit consists of an X-ray tube, detectors, and an examination table. The tube is typically beneath the table, with detectors above. A narrow fan-shaped X-ray beam passes through the patient, and detectors record the rays. The continuously emitted beam scans objects along a conveyor, with intensity data read at short intervals by a computer [28]. Full-body DEXA scanning with the latest generation densitometer exposes patients to approximately 0.004-0.005 mSv [29], which is about one-tenth of a direct lung X-ray. Therefore, the examination technician can work in the room without needing any X-ray protection.

2.4. Computed Tomography

Computed Tomography (CT) is an imaging technique that uses rotating X-ray beams to produce detailed cross-sectional and 3D images of the body. It consists of a circular gantry and a patient table, with an X-ray source rotating around the patient to acquire images from multiple angles. CT scan images contain more detailed information than standard roentgen. CT scanning produces far higher radiation exposures than comparable traditional radiography techniques [30]. For example, an anterior-posterior abdominal X-ray gives a dose of about 0.25 mSv to the stomach, while a CT scan gives a dose of about 12 mSv [31, 32]. Smith-Bindman et al. [33] reported the CT effective radiation doses used for different regions in their studies as follows: 2 mSv for a routine head, 14 mSv for suspected stroke, 8 mSv for a routine chest, 22 mSv for coronary angiography, 15 mSv for a routine abdomen-pelvis without contrast, and 31 mSv for a multiphase abdominal-pelvis scan.

2.5. Gamma Knife

Neurosurgery is among the most complex medical fields, where even minor errors can result in disability or death. Traditionally, brain tumors were removed via open surgery, but stereotactic radiosurgery now allows tumor destruction or growth control through radiation. Gamma Knife radiosurgery, a leading method, employs 201 Cobalt-60 sources. Gamma rays converge within 0.3 mm, enabling target alignment with 0.5 mm mechanical precision. This technology ensures safe reproduction of sharply defined lesions in a single session [34, 35]. Treatment planning is based on patient imaging, with calculations designed to maximize radiation to the tumor while minimizing exposure to surrounding tissue. Once calculations are complete, the patient undergoes irradiation in one session, with doses varying by tumor structure, size, and shape. For instance, Gamma Knife thalamotomy uses 120–180 Sv [36–38], vestibular schwannoma treatment applies 12–17 Sv [39], and Pomeraniec et al. reported 9.1 Sv to the pituitary stem and 15.3 Sv to the normal pituitary gland in pituitary adenoma cases [40].

2.6. CyberKnife

CyberKnife is the first robotic radiosurgery system capable of treating cancer with sub-millimeter precision. It delivers focal high-dose radiation to tumors while sparing normal tissues. The system combines a 6 MV linear accelerator mounted on a 6-joint industrial robot and a robotic patient bed with six-directional movement [41]. Accuracy is reported as 0.2 mm. Tumor and patient movements are tracked in real time with image guidance and robotic control, allowing corrections for respiration and other motion. Pre-treatment CT and MR images are continuously compared with intra-treatment images, and tumor coordinates are analyzed by algorithms for dynamic dose adjustment. This ensures accuracy despite patient movement and confines radiation to the tumor [42]. CyberKnife applies varying doses depending on tumor type and patient characteristics. A multi-session treatment was administered to patients with residual or craniopharyngioma using the CyberKnife device at Stanford University Medical Center, using a radiation dose of 18–42.1 Sv [43]. Equivalent doses of 15 Sv to 67.5 Sv have been given for treatment in medically inoperable patients with early non-small cell lung cancer (NSCLC) [44]. In another study, patients with Vestibular Schwannoma were irradiated with CyberKnife Radiosurgery at a dose range of 15.0 to 20.5 Sv [45].

2.7. Helical Tomotherapy

Tomotherapy, inspired by CT technology, replaces the X-ray tube with a linear accelerator to deliver radiation [46]. Its rotating gantry enables both helical 3D treatment and low-dose 3D imaging. Before each fraction, the system captures CT images to locate the tumor and adapt treatment accordingly. This approach minimizes safety margins and reduces radiation exposure to healthy tissues. One of the essential features of the Tomotherapy concept is the Multi-Leaf Collimator System (MLC) it uses. MLC has interlocking pneumatic and ultra-fast leaves, one in each row [47]. Tomotherapy MLC systems have a technology that can irradiate multiple tumors at the same time and block the healthy area in the middle at each angle. This situation prevents rapid treatment for multiple metastases

and prevents two or more irradiations of healthy tissue between two tumors [48]. Tomotherapy is used to destroy or control tumor tissues in different regions. Different radiation doses per fraction are determined based on the size and location of the tumor tissue. Orton et al. [49] prescribed 20 fractions of 2 Sv each to patients for total scalp irradiation. In another study, Ashenafi et al. [50] reported that they administered radiation doses to the lung, heart, contralateral breast, and spinal cord, respectively, 20, 15, 5, and 10 Sv.

3. Conclusion

Radiotherapy is a vital component of the treatment of various cancers. For treatment, a treatment plan is created with the most appropriate application according to the volume and location of the tumor. It is necessary to know the radiation dose in line with the plan. For this reason, it is essential to give the patient the appropriate radiation in radiotherapy. Thus, the patient avoids needless radiation doses, and the healthy tissues are exposed to the least amount of radiation. International radiation protection standards established by the International Commission on Radiological Protection (ICRP), together with national regulations set by the Turkish Energy, Nuclear and Mining Research Institute (TENMAK), define the annual effective dose limit for the general public as 1 mSv, and for occupationally exposed individuals as 20 mSv averaged over five consecutive years, with a maximum of 50 mSv in any single year. The annual equivalent dose limit for hands, feet, or skin is 500 mSv and 150 mSv for the eye [51]. However, it may not always be possible to avoid exceeding these radiation doses. Most of the time, physicians may give high doses of radiation to patients by considering the risk-benefit relationship of radiation. The types of radiology used in studies in the literature and the doses applied are given in Table 1. This study was designed as a review-based comparative analysis. Radiation dose data were collected from previously published scientific studies, international guidelines, and institutional reports. The reported dose values for different radiological devices were compiled, standardized (in mSv), and compared to evaluate variations in patient exposure levels. No experimental measurements or patient data were used in this study.

Table 1. Effective dose values applied in radiological examinations.

Radiology Type	Effective Radiation Dose	Measurement method
Lung X-ray [18]	0.02 mSv	Literature
Bite-Wing X-ray [20]	0.005–0.02 mSv	TLD*/OSL**
Abdominal X-ray [21]	2.0 mSv	Clinical reference
Bone X-ray [22]	0.001 mSv	Clinical reference
Panoramic X-ray [23]	0.0027–0.0243 mSv	Clinical reference
Periapical X-ray [24]	0.0006–0.0007 mSv	TLD
Cephalometric X-ray [26]		
Conventional	0.0023 mSv	TLD
Digital	0.0011 mSv	
Dual-energy X-ray absorptiometry (Dexa) [29]	0.004–0.005 mSv	Literature
Computed Tomography		
Anterior-posterior abdominal X-ray [31]	12 mSv	Literature
Routine head [33]	2 mSv	Clinical reference
Suspected stroke [33]	14 mSv	Clinical reference
Routine chest [33]	8 mSv	Clinical reference
Coronary angiography [33]	22 mSv	Clinical reference
Routine abdomen-pelvis without contrast [33]	15 mSv	Clinical reference
Multiphase abdominal-pelvis [33]	31 mSv	Clinical reference
Gamma Knife		
Vestibular schwannoma [39]	12–17 Sv	Clinical reference
Pituitary stem [40]	9.1 Sv	
Pituitary adenoma [40]	15.3 Sv	
CyberKnife		
Residual or craniopharyngioma [43]	18–42.1 Sv	Clinical reference
Early non-small cell lung cancer (NSCLC) [44].	15–67.5 Sv	
Vestibular Schwannoma [45]	15–20.5 Sv	

Table 1. Effective dose values applied in radiological examinations (continuation).

Helical Tomotherapy		
Total scalp irradiation (20 fractions) [49]	40 Sv	
Lung [50]	20 Sv	Clinical reference
Heart [50]	15 Sv	
Contralateral breast [50]	5 Sv	
Spinal cord [50]	10 Sv	

**Thermoluminescence dosimeters (TLD)* ***Optically Stimulated Luminescence (OSL)*

The great majority of radiation treatments provide beneficial outcomes [44, 45]. Low doses of radiation generally do not cause serious health problems; however, during tumor treatment, healthy tissues are inevitably exposed and may suffer radiation damage [52]. Side effects occur more frequently at high doses and are classified as acute and chronic. Acute effects are mainly observed in rapidly dividing tissues such as the gastrointestinal mucosa, bone marrow, skin, and oropharyngeal and esophageal mucosa [53]. Chronic effects include increased collagen and connective tissue, tissue hardening, contraction, organ shrinkage, vascular thickening, loss of elasticity, occlusion, ischemia, and necrosis [54]. Follow-up studies have reported treatment-related side effects after radiotherapy. Recent studies on patients with benign intracranial tumors have demonstrated complications such as pituitary dysfunction, visual impairment, and radiation-induced brain tissue changes following radiosurgical treatments [55–58].

Table 1 shows that the radiation doses associated with lung radiography, bite-wing radiography, panoramic radiography, periapical radiography, bone radiography, cephalometric radiography, and dual-energy X-ray absorptiometry—widely used in clinical practice—are relatively low. These dose values are close to 0.006–0.007 mSv, which is the daily dose value we receive from artificial or natural radiation sources in the daily background. On the other hand, types of computed tomography have relatively more radiation. It is acceptable as national and international dose limits will not be exceeded unless computed tomography images are taken more than 4 times a year. However, gamma knife, cyber knife, and helical tomotherapy devices, which are specially used for tumor treatment, use high radiation doses. The success of radiotherapy in controlling or destroying a tumor depends mainly on the total radiation dose delivered; however, the tolerance of the normal tissues surrounding the tumor limits this dose [59]. Although radiotherapy shows great success in controlling or destroying the tumor, it is inevitable that its side effects negatively affect the patient's quality of life.

From a clinical perspective, the main concern is the risk of unnecessary radiation exposure due to inappropriate use rather than absolute dose levels alone. Computed tomography (CT) poses the highest risk, particularly when repeated without a clear indication or when high-dose protocols are unnecessarily used. Repeated fluoroscopic procedures may also lead to cumulative dose increases. In contrast, conventional radiography and DEXA involve low doses and are generally safe when appropriately applied. Therefore, proper justification and optimization of imaging procedures are essential to minimize avoidable radiation exposure.

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Authors' Contribution

Aytaç Levet: Writing, review, and editing, validation, supervision, investigation, data curation, conceptualization.
Yüksel Özdemir: Writing, validation, investigation, data curation.

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No conflict of interest or common interest has been declared by authors.

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