The Importance of the X-ray in Medicine: Evolving Applications, Challenges, and Future Directions

Dunya Ali Mustafa*
***Department of Radiological Techniques, College of Health and Medical Techniques - Baghdad, Middle Technical University, Baghdad, Iraq**
Correspondence: dunya.ali@mtu.edu.iq

(Ann Coll Med Mosul 2025; 47 (2):274-285).
Received: 29th March 2025; Revised 13th April 2025; Accepted: 26th Aug. 2025.

ABSTRACT

X-ray were discovered in 1895, the explosion of research that occurred shortly thereafter paved the way for much of the diagnostic imaging that we have today not just in medicine, but also in industrial and even scientific uses of these powerful technologies. Originally employed for examining the skeletal system, x-rays have become an integral part of modern medicine, which aids in different pathological conditions like fractures and tumors along with playing a vital role in treatment, as in the case of radiotherapy. Exploring various imaging methods such as conventional radiography, computed tomography (CT), and digital radiography suggests an ongoing pursuit to improve image quality while minimizing radiation exposure but with the risk of increasing radiation dose. Although X-rays are effective, radiation safety issues continue to arise, especially since ionizing radiation is associated with an increased risk of cancer later in life. Rapid maturity in radiology and the advent of sophisticated technologies like artificial intelligence and digital modeling systems have further redefined the radiology space and its impact in diagnostic accuracy and workflow efficiency. With the advancement of the field, an in-depth knowledge of the ethical considerations, regulatory requirements, and patient safety measures is of utmost importance. This review summarizes the historical development, the underlying concepts, and the current applications of X-ray technology and outlines the need for further investigations to develop solutions to minimize potential harms while enhancing its clinical applications. X-ray imaging is an essential diagnostic tool widely used in healthcare settings; however, translation into clinical practice is fraught with challenges that, if left untreated, can inhibit improvement of patient care and radiological safety.

Keywords: X-ray, Diagnostic imaging, Clinical application, Imaging method.

أهمية الأشعة السينية في الطب: التطبيقات المتطورة والتحديات والتوجهات المستقبلية

دنيا علي مصطفى*
*قسم تقنيات الأشعة، كلية التقنيات الصحية والطبية - بغداد، الجامعة التقنية الوسطى، بغداد، العراق

الخلاصة

اكتُشفت الأشعة السينية عام ١٨٩٥، ومهّدت الطفرة البحثية التي حدثت بعد ذلك بوقت قصير الطريق لكثير من التصوير التشخيصي الذي نستخدمه اليوم، ليس فقط في الطب، بل أيضًا في الاستخدامات الصناعية وحتى العلمية لهذه التقنيات القوية. استُخدمت الأشعة السينية في الأصل لفحص الهيكل العظمي، وأصبحت جزءًا لا يتجزأ من الطب الحديث، إذ تساعد في تشخيص حالات مختلفة مثل الكسور والأورام، إلى جانب دورها الحيوي في العلاج، كما هو الحال في العلاج الإشعاعي. يشير استكشاف أساليب التصوير المختلفة، مثل التصوير الشعاعي التقليدي والتصوير المقطعي المحوسب (CT) والتصوير الشعاعي الرقمي، إلى سعي مستمر لتحسين جودة الصورة مع تقليل التعرض للإشعاع. على الرغم من فعالية الأشعة السينية، إلا أن قضايا السلامة الإشعاعية لا تزال قائمة، لا سيما وأن الإشعاع المؤين يرتبط بزيادة خطر الإصابة بالسرطان في مراحل لاحقة من العمر. وقد أدى التطور السريع في مجال الأشعة وظهور تقنيات متطورة مثل الذكاء الاصطناعي وأنظمة النمذجة الرقمية إلى إعادة تعريف مجال الأشعة وتأثيره على دقة التشخيص وكفاءة سير العمل. مع تقدم هذا المجال، أصبحت المعرفة العميقة بالاعتبارات الأخلاقية والمتطلبات التنظيمية وتدابير سلامة المرضى ذات أهمية قصوى. تُلخص هذه المراجعة التطور التاريخي والمفاهيم الأساسية والتطبيقات الحالية لتقنية الأشعة السينية، وتُبرز الحاجة إلى مزيد من الدراسات لإيجاد حلول للحد من الأضرار المحتملة مع تعزيز تطبيقاتها السريرية. يُعد التصوير بالأشعة السينية أداة تشخيصية أساسية تُستخدم على نطاق واسع في مرافق الرعاية الصحية؛ إلا أن تطبيقها في الممارسة السريرية محفوف بالتحديات التي قد تُعيق تحسين رعاية المرضى والسلامة الإشعاعية إذا تُركت دون معالجة.

الكلمات المفتاحية: الأشعة السينية، التصوير التشخيصي، التطبيقات السريرية، طريقة التصوير.

INTRODUCTION TO X-RAY

William Roentgen presented a lecture presenting X-ray to the German Physical Society in Paris on February 21st, 1896. In February 1995, ninety-nine years later, scientists at the Stanford particle accelerator, again driven by the thirst to discover and learn, found that bacteria could be destroyed by pulses of X-ray. Together these two events heralded the realization of a powerful new tool that would forever change science, health, and industry, from cancer diagnosis to protein structure determination. X-ray machines soon became a tool in routine medical practice for imaging bones and different body tissue structures [1-3]. Since a quincunx of numerous individual X-ray device types has been constructed, so have the operating principles and instrumentations parallel to the devices [4]. Since their invention, X-ray have gained widespread applications, ranging from projection radiography to computed tomography. Their technology improved generation upon generation, year by year [5].

X-Ray Imaging: Fundamentals

Radiography, or X-ray imaging, generates a two-dimensional projection image of the internal structures, capturing an object using ionizing radiation. This technique works by shining direct x-rays through the object and creating a transmission image on a detector. How a radiographic signal is read out determines the classification of detector systems into either analog or digital. There exists a strong correlation between image quality and dose level to be used for x-ray imaging, which always had to be compromised due to the conflicting nature of the two parameters [6]. Data from an imaging X-ray tube comprising a glass bulb with filaments and an anode. Glass blowers have left the space in a state of extremely high vacuum to enable a huge voltage (approx. 30-150 kVp) to be supplied across the tube. Usually tungsten filaments, which are resistively heated to give off free electrons in the area an installation causes a gradual high voltage to accelerate the electrons and flatten them toward the anode target of millimeter squares area. When the electrons strike their targets, they release almost all their kinetic energy: which is converted to x-rays and the remaining to heat as shown in **figure 1** [7].

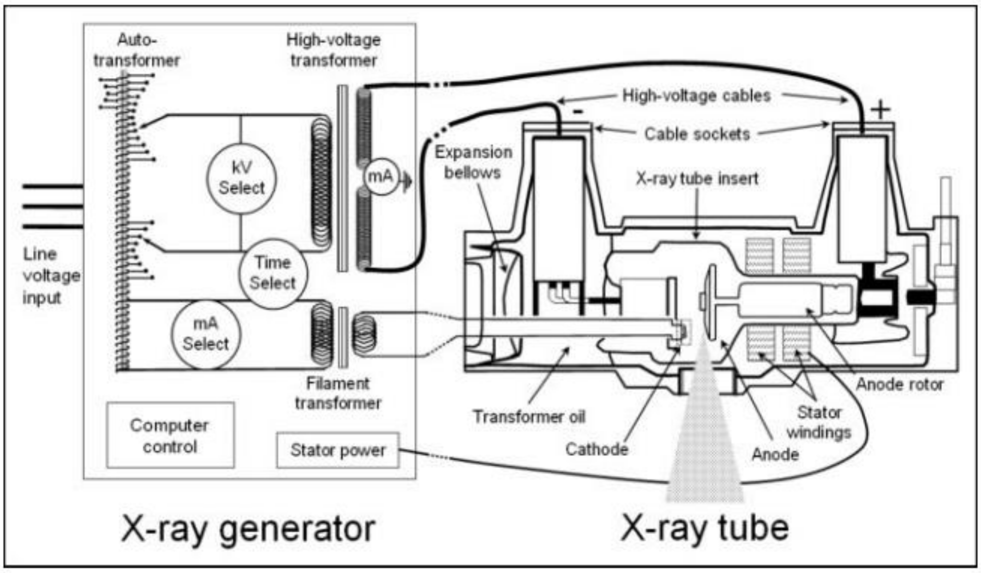

Figure 1. components of the x-ray generator and x-ray tube are shown. The x-ray generator supplies electricity to the x-ray tube and gives the operator control over radiography procedures, such as tube voltage (kVp), tube current (mA), and exposure duration. The x-ray tube supplies the following: an environment (high-voltage cable sockets and an evacuated x-ray tube insert), an electron source (cathode), an x-ray source (anode), an induction motor to rotate the anode (rotor/stator), transformer oil and expansion bellows to prevent electrical and thermal buildup, and a tube housing to support the insert and shield it from radiation leaks. [8].

Different Types of X-Ray Imaging Methods

Many X-ray imaging techniques are available, but the most popular is screen-film radiography, which uses radiographic plates that are photographic plates [9]. This method contributes to about 90% of all the diagnostic radiographs. Conventional X-ray or radiology, known as film-screen systems, is highly accessible [10]. Fluoroscopy is the combination of an X-ray emitting source and a fluorescent screen yielding real-time- and sequentially non-stop imaging recorded via digital imaging sensors [11-12].

Such a technique has been applied in many applications of medical imaging for example intravenous urography. Another method for imaging is computed tomography. In computed tomography (CT), multiple views are acquired plus multiple XR tube detectors at varying angular distributions to form multi depth-resolved image at various sections and planes. In the projection stage, an X-ray source and detector rotate around the object to create a three--dimensional data cube, which is computed using filtering methods [13].

Use of X-Rays In Medicine

The x-ray used in preventative, diagnostic, therapeutic, and research settings, X-rays are a mainstay of diagnostics in medicine. Applications — new and old — are always changing. Well-known examples of preventative medicine include mammograms, dual energy X-ray absorptiometry (DEXA), and low-dose lung cancer screening. Bone density can be diagnosed by DEXA scans, which can be performed in wide range of patients without self-report [14].

Bone Fractures Imaging

Bone fractures top list of trauma conditions. By visualizing the fracture, radiology has a significant role in the diagnosis, healing stages, post-treatment complications, and follow-up of fracture complications. Imaging modalities are primarily routine projection radiography, CT, and MRI. Routine projection radiography is the initial screening test and is generally performed as the plain X-ray examination of the affected area, such as of antero-posterior and lateral [15]. The main information obtained is presented as fracture, interruption of the cortex.

This type of imaging allows better assessment of fracture fragment rotation and detection of concave cortical bone in hidden fracture and radiological assessment of bone union; plain radiography is almost always sufficient for fracture management. But, there are a few selected cases where the evaluation of deformity and complexity of fracture is considerably limited by amino bony mix-up in basic projection view; CT can come to aid. MRI is not only useful in detecting the occult fracture but also in characterizing the soft tissue injury associated with fracture [16-17].

Tumors Imaging

Tumors are malignant or benign masses with a diameter of a few micrometers up to several centimeters. Any tissue abnormality would affect by x-ray attenuation either quantitatively or qualitatively. X- ray play role in detect tumor such as tumor of breast which can be presented by fluorescence x-ray examination find a little malignant tumor with x-ray find but the dose of x-ray less than mammography. Fluorescence X-ray analysis identifies the carcinoma from the breast by analyzing the secondary x-rays that are originated from the breast tissue when exposed to the primary x-rays. It helps in element mapping that can help to locate it more precisely with the tumors [18].

Cardiovascular Imaging

Cardiovascular imaging includes several noninvasive visualizing modalities such as X-ray radiography, echocardiography, ultrasound, Doppler imaging, computed tomography (CT), nuclear imaging, and interventional radiology [19]. There are unique features concerning the duration and what is outputted for each method. X-ray imaging is based on the attenuation of X-ray the smaller the amount of radiation reaching the detector based on the density and thickness of the material, the brighter of a spot the pixel will become, since certain planes in the human body may absorb more based on the presence of the heart or location of the lungs. Because of its safety, availability, and versatility, echocardiography continues to be the workhorse of cardiovascular disease assessment. It is composed of multiple modalities: M-mode, 2D transthoracic, Doppler, contrast, and transesophageal echocardiography. Temporal resolution for dynamic structures is often possible with M-mode, while 2D transthoracic echocardiography allows assessment of cardiac chambers and valves to visualize structural abnormalities. Doppler echocardiography is vital for assessing the direction and velocity of blood flow, especially in valvular diseases. Transesophageal echocardiographic views of the cardiac structures are more detailed and are essential in evaluating valvular heart disease and excluding thrombus before procedures [20, 21]. Piezoelectric crystals are utilized in ultrasound systems to create sound waves that differentiate tissues through acoustic impedance.

Although safe and inexpensive, deep thoracic structures pose a challenge due to high attenuation and poor identification of the heart. In fact, intracoronary ultrasound, a tiny ultrasound transducer mounted to a catheter, offers a resolution superior to conventional X-ray angiograms for studying the heart. Doppler imaging techniques identify blood flow speed and direction and are used in ultrasound and laser methods, typically in the form of color Doppler, which is the basis of non-invasive vascular imaging. These techniques can also obviate the need for invasive procedures and provide complete vascular evaluations in pediatric patients [23]. Interventional radiology uses fluoroscopy, ultrasound, CT, and MRI to guide minimally invasive procedures. Although radiologists perform these image-guided interventions that include percutaneous drainage and tumor ablation, fluoroscopy requires extensive prior preparation and coordination among radiologists [24,25]. These developments have made echocardiography an essential modality in cardiovascular evaluation as compared with other imaging modalities in terms of safety and availability for patients [26].

Pediatric Imaging

X-ray imaging systems and X-ray equipment for imaging of newborns and children clearly need to be designed and constructed with special emphasis on minimizing the radiation dose to the small patient. Age dependency of the radiation sensitivity was convincingly demonstrated in a nationwide cohort of cardiac CT examinations of children and adolescents. In 2010, 36 million CT examinations were performed in pediatric hospitals and clinics in Germany, which related to an effective dose of approximately 4631 terabecquerel. Taking all CT examinations extrapolated an estimated 700 excess cancer risk in 0.76% [27], however X-rays are crucial for the detection of a medical condition, such as a fracture, an infection, or a tumor [28]. Radiation exposure risks must be minimized, specifically concerning the remaining lifespan of children and adolescents who are more sensitive to radiation-induced cancers than adults . So it is important to keep radiation doses low, if possible, but in an adequate quality of the image. Children are more likely to be harmed by radiation because they have a less developed immune system. Therefore, it is essential to weigh the benefits of diagnostic X-ray against the risks in children [29]. CT examination should be avoided when possible and alternative imaging with ultrasound should be offered as appropriate, in order to minimize unwarranted radiation exposure to the healthcare provider. In addition, practitioners should always make sure to apply the lowest possible settings of radiation appropriate to the size of children [30].

Researches has indicated that CT scans do increase radiation exposure in children – possibly by too much. But practitioners need to recognize where this is safe across age groupings and body types, therefore CT examination should only be done after careful consideration of the indication and alternative imaging modalities used first [31]. Communication Without Rhetoric for Radiation Risk Parents should be made aware of child cancer risk potential. Moreover, innovations such as automatic exposure control systems can decrease doses in a way where image quality is not compromised but such technology is still not used in full potential. Advanced image processing methods could then be integrated to further minimize exposure. Further exploration of different methods of detection will help to make both safety and diagnosis more accurate. In the end, only by working healthcare providers and manufacturers together can ensure that the needs of pediatric patients come first [32].

Geriatric Considerations

The elderly patients usually need multiple complex overlapping diagnostic modalities to control their diseases, like X-ray tests, which are the key in identifying fractures like those of the osteoporosis bone and assessing joint status in conditions like osteoarthritis and rheumatoid arthritis. CT scans are also often used for chest imaging for pneumonia and heart failure and for abdominal imaging for bowel obstructions or tumors. But a lot of patients have radio phobic due to historical and cultural perceptions of X-ray examinations. Assessment of patient-reported concerns should be done in a professional manner by medical practitioners to decrease anxieties and optimize the effectiveness of therapy. Resources to provide to patients and families to clarify the fairly low risk of these types of examinations would also be useful [33].Other imaging methods comprise CT, which provides cross-sectional views for complex fractures, lung evaluations, and rapid stroke assessment. Magnetic resonance imaging (MRI) is useful for evaluating soft tissue, identifying tumors, and neuroimaging when there is suspicion for dementia. Ultrasound is used to assess the heart, perform abdominal imaging, and also detect deep vein thrombosis (DVT). Some other exams include bone scans for metastases and thyroid evaluations (for that, we use nuclear medicine).

Moreover, Doppler ultrasound plays an essential role in the evaluation of blood flow in arteries and veins, and fluoroscopy is used in gastrointestinal imaging and in non-invasive procedures [34, 35].

Radiotherapy

Neoplastic cells have an increased susceptibility to irreversible mitotic catastrophe induced by DNA-damaging events (e.g., in contrast to their normal counterparts). The major cause of this sensitivity is an inability to recover after DNA damage, allowing this to result in a survivable state post-irradiation. The likelihood (30% to 34%) of direct DNA break induction by low-energy X-rays and γ-irradiation is similar, and surviving cells, especially in the G2/M phase, fail to undergo lobulation as required, leading to irreversible DNA damage. This mechanism leads to the selective killing of cancer cells compared to normal cells [36].

Artificial intelligence (AI) has multiple applications, such as surgical assistance, drug discovery, radiology, disease diagnosis, pathology, and treatment follow-up. Automated systems based on human resources management (HRM) technology are becoming increasingly prevalent in numerous medical domains used for cancer screening, including X-ray, CT, MRI, and PET. Example: Low-Dose CT Lung Cancer Screening Lower downstage tumors are detected two years earlier than with conventional imaging, benign lesions are identified, and mortality is decreased by ~20%. Source. Training of Computer Aided Diagnosis (CADx) systems using AI technologies such as artificial neural networks (ANN), traditional AI approaches, deep learning (DL), radio frequency (RF), and support vector machine (SVM) approaches [37]. The first models, based on image feature classification, were sensitive to image noise. Advancements in transfer learning, particularly with deep learning architectures that are pre-trained on large datasets, have improved feature extraction and reduced the time needed to develop a model. Most current HRM models focus exclusively on image-based diagnosis, though others supplement them with lesion characteristics with predictive analytics. Now there are high hopes for digital-style systems such as cancer diagnosis using CADx systems have been developed but in a controlled environment, which faces challenges in their ability to generalize into real-world use. Models serving high-throughput applications are being built to scan the mass images, classify the mass types, and suggest actions to take in a cancer diagnostic system [38].

The X-Ray Risks

The efficacy of X-ray imaging is quantified by measuring the X-ray attenuation between the source and the detector [39]. Despite its benefits, exposure to X-rays brings the risk of free radical production that can trigger cancer, and adverse effects likely increase with exposure levels [40].

It is well established that ionizing radiation can cause cancer but is also associated with a spectrum of non-cancer health effects, similar to environmental agents [40]. It is possible that cancer and non-cancer risks could be due to radiation exposure in natural attenuation tests (NAT) of related radioactive waste disposal projects [41].

The main proven long-term risks from exposure to artificial and augmented natural sources of ionizing radiation are increased incidence of leukemia, breast cancer, and thyroid cancer. Though there are some associated with other cancers and risks from non-cancer effects, the data behind these assertions are now poorer or absent. Crucially, existing evidence tends to suggest that the long-term detriments of ionizing radiation are likely to be underestimated, and in few studies can there be seen any strong grounds to imagine that the available evidence dramatically underestimates actual long-term risks.

The knowledge about low-dose radiation exposure effects has improved considerably over the last years due to advances in radiobiological research [42].

Radiation Exposure

Radiation is classified into two types: ionizing and non-ionizing. Ionizing radiation being the source of radiation that has sufficient energy to displace electrons, generating secondary radiations capable of causing biological damage. The absorbed energy per kilogram, measured in grays (Gy), indicates potential effects on health. Medical imaging, known for diagnostic and therapeutic purposes, has been categorized as a non-occupational concern, and some estimates in the United States (US) indicate that this practice is responsible for around 1.5% to 2% of all cancers, particularly among developing countries.

This has been proven to be harmful even at the lower and high doses, and a united Kingdome (Uk) study indicated that up to 20% of medical X-rays performed may provide no clinical value, potentially resulting in about 1,000 cancer cases annually so the radiologists are suffering from the serious health issues because they exposed to mount of x-ray which caused dermatoses, and hematological disorders [43].

The X-Ray Safety

X-ray imaging is a widely used diagnostic tool in medicine, valued for its ability to provide rapid and effective visualization of internal structures. However, the safety of X-ray exposure is a critical concern due to the potential health risks associated with ionizing radiation [44].

While X-ray imaging is essential for diagnosing various conditions, it is associated with certain health risks. To mitigate these risks, radiation safety protocols were established, setting dose limits to protect individuals working with radiation, including those using X-ray equipment. It is vital to adhere to the principle of keeping exposure levels as low as reasonably achievable (ALARA). The recommended limits include a whole-body dose of 50 millisieverts (mSv), a lens dose of 150 mSv, and a shallow skin dose of 500 mSv. These measures are crucial in minimizing health risks associated with radiation exposure and reducing cancer risk. [45].

Increased awareness of the risks associated with X-rays, especially from CT scans, is essential, as these procedures can expose patients to harmful radiation levels. CT colonography may also carry undisclosed risks, and unprotected X-ray fluoroscopy poses significant dangers, particularly for defense personnel. Urgent risk assessments are required to mitigate these exposures and enhance protective measures [46].

Encouraging dialogue between patients and healthcare providers is essential for improving care quality.

Protective Equipment

The proper understanding of safety profile of X-ray and the relevant protective measures applicable will prevent the non-desired exposure to radiation to patients and health profession. Controlling the exposure Doses is it is very important especially for CT doing patients where the radiation leakage is often observed from malfunctioned X-ray machines. Medical staff should use protective devices that protect patients from radiation and not just lead aprons that do not have total protection. Protective eyewear (including lead glasses with additional shields) should be worn by staff operating equipment from outside the room to minimize scatter radiation exposure [47]. Even though modern panoramic dental X-ray devices absorb more than 90% of leakage radiation, the cumulative exposure can be considerable. Placeholder image. Ergonomics have lessened the requirement for operator protective devices, but others pregnant women, nursing mothers and young children need to continue using them [48], patient dose control, and the use of methods like X-ray beam collimation and gonadal shielding are critical to protect the patient and to optimize radiological quality. This minimal radiation dose is further enhanced by strict criteria for retakes and image processing, thus strengthening the efforts to safeguard the patients and the health care personnel [49].

Imaging-Based Artificial Intelligence

Artificial intelligence in medical imaging is at an explosive growth stage. It is analysis software has been created to help radiologists with repetitive work or where AI has been demonstrated to be valuable. AI can assist radiologists in performing this task as a second reader and flagging cases of interest [50]. Machine learning (ML) is a specialized subdomain of AI that focuses on the creation of predictive data models. ML is simply a set of statistical and mathematical algorithms that are designed for analyzing data to discover patterns that allow for the prediction of data that is not seen. After training a model and validating its accuracy, it can be turned towards analysis of out-of-sample data to make predictions, which we can then act on or use to further direct patient follow-up care [51]. Deep learning (DL) is a subclass of ML that requires massive datasets and requires computational architectures to capture the inherent complexity of the existing data. DL is founded upon neural networks—networks of mathematical functions organized in a numeric graph that try to convert data in layers. A supervised convolutional neural network (CNN) can be trained on tens to hundreds of thousands, or even millions, of data items without any further knowledge of that task and thereafter perform a particular task [52].

Comparison with Other Imaging Modalities

Digital X-Ray

X-ray examinations should produce high-level radiographic quality images with optimized surgery using as little radiation as multiple images exchange minimum time and effort with minimum radiation.

Film-screen systems, which have long represented the standard in imaging, are being succeeded by all-digital platforms [53].

Digital technology allows for long, high-speed image acquisition generally just taken in seconds and rapid control of brightness and contrast, unlike old-style systems [54]. X-ray is one of the most commonly used clinical diagnostic tools to identify and treat patients. Thus, appropriate protections (e.g., directing away from unnecessary obstacles, increasing the distance of examination, and using advanced digital detectors) are critical aspects of effective protective measures to ensure that this safety standard molecule is effective.

Due to its high atomic number (Z = 56) and excellent X-ray attenuation properties, barium, in particular barium sulfate, has been used as a contrast agent for many years.

For the gastrointestinal (GI) tract examination, it provides a safe, cost-effective, and simple-to-perform technique with a high diagnostic yield when performed by experienced personnel. Barium studies are also used to identify and characterize lesions such as small bowel obstructions, Crohn's disease, diverticula, tumors, and fistulas [55].

Currently, the majority of barium studies are performed using digital X-ray (DXR) systems. The growing use of digital X-ray and barium in GI imaging further improves image quality and accuracy in diagnosis. Nevertheless, there are still obstacles; generating diagnostically acceptable images typically necessitates a high detector gain, which increases the noise and reduces the sharpness of the images. Solving these technical problems is necessary to optimize digital barium studies and make them clinically useful [56].

MRI

Magnetic Resonance Imaging (MRI) are medical imaging techniques used to visualize the internal structure in the body. An MRI machine lines up hydrogen atoms in the body using a strong magnet. These atoms subsequently emit energy when subjected to a second applied magnetic field, which is detected and transformed into images that enable differentiation between types of tissue with far greater soft tissue contrast than CT, MRI scans a non-invasive machine provide a detailed view of soft tissues like organs, muscles, and nerves and are regarded as non-invasive and fairly thorough examinations. MRI has been utilized considerably in the qualitative assessment and diagnosis of diverse central nervous, musculoskeletal, cardiovascular, and abdominal diseases, Unlike X-rays and CT scans, MRI does not use ionizing radiation, reducing the risk of radiation-related health issues. This makes MRI a safer option, especially for repeated imaging and for sensitive populations like children and pregnant women [57] .

MRI is a non-invasive procedure, meaning it does not require incisions or invasive techniques, which reduces patient discomfort and recovery time. So it does not effect on body system like urinary system , but some MRI procedures may use gadolinium-based contrast agents. While these agents are usually safe, they can affect kidney function in individuals with pre-existing renal issues. This is particularly important for patients with severe renal impairment, as it may lead to a condition called nephrogenic systemic fibrosis (NSF) [57].

Ultrasound

Ultrasound is a non-invasive medical imaging modality that utilizes mechanical sound waves to visualize internal organs. It allows real-time images, better spatial resolution compared to CT and MRI, and no use of ionizing radiation. Its usefulness is somewhat limited by the attenuation of the sound waves during transmission through gas-filled lungs and dense bones, which restricts its application mainly to the soft tissues. There are some recent proposals for handheld probes and multi-transducer designs to better handle the motion. However, this design usually needed external cameras to be portable [58,59].

Doppler imaging is a focused ultrasound approach that tracks the motion of echogenic scatters, particularly red blood cells, in blood vessels, This approach allows for measuring blood flow velocity and volume, and is often combined with traditional grey-scale B-mode imaging by commercial scanners. Doppler imaging can produce two-dimensional color maps showing the direction and velocity of moving scatters by processing the same data of echo signals. Doppler frequency-shift spectra which show the power-density spectral distribution of the blood flow in a volume of tissue are generated using pulsed-wave or continuous-wave ultrasound. Haemodynamically-dependent is shown to be effective, but this is limited by the requirement of correct orientation of the transducer with the assumed blood-flow direction as well as the transducer's scanning prowess [60].

Yet, another highly important imaging method is elastography, which is a non-invasive technique measuring the speed of the mechanical wave propagation as an indirect measure of tissue elasticity (stiffness) [61]. The use of sound wave propagation through soft biological tissues for clinical application is emerging, covering different properties like tissue micro- vessel density and elastic or viscoelastic properties of tissues. Other modalities are aimed at the discovery of biochemical or molecular markers of disease. Such techniques mainly extract features by analyzing the amplitude, temporal or spectral properties of radiofrequency echo signals, with some existing protocols using image-based information obtained from multiple 2D planes with time-multiplexed transducer arrays. Such progress in these imaging modalities provides excitement for earlier, less invasive and more accurate identification and tracking of soft tissue pathologies [62].

X-Ray Ethical Issues

Educating the public with a balanced view on the benefits and risks of X-ray-centered risk awareness can change the attitudes of the public away from hostility and towards X-ray-centered risk awareness. The concern that communities have with respect to health problems due to X-ray exposure is always greater, and their responses are based on what they know about possible risks. This is because X-ray exposure can lead to cancer, especially due to the ionizing radiation involved, which is known for causing DNA destruction, which is one of the common points of fear: carcinogenic effect. Radiation risk (cumulative) risks kids & parents.

The potential risks of X-ray exposure to the children are a significant concern for parents since children are at a higher level of radiation. One way to do this is to improve public understanding of these issues so as to fight against radiophobia (irrational fear of radiation). This will help diminish fears and stimulate discussions on safe and healthy practices by raising awareness about the actual risks as opposed to the diagnostic gain associated with X-ray imaging. For previously untreated conditions, physicians often face this difficult dilemma of balancing the value of diagnostic imaging against the risk of exposure to radiation.

As such, improving awareness of the risks associated with X-ray use may contribute to more even-handed attitudes towards their use [63].

Guidelines and Regulatory Standards

The patient safety responsibility resides with healthcare providers managing places with radiation sources. Medical and health authorities, by establishing standards or, to the extent appropriate, providing education, should support relevant parties with radiological protection, including for the application of radiopharmaceuticals. It should run a national radiation protection service with local divisions to aid implementation of standards, provide expert advice, and suggest annual updates on surveys and training. Facilities need to be appropriately shielded, with protection criteria defined for each type and the shielding calculated by recognized methods. Shielding designs should be tested during the planning and on-site phase in order to verify conformity [64].

Preparing A Patient for an X-Ray

As long as the X-ray is important, the physician provides the patients with the restrictions they have to follow as mentioned by the physician or radiologist.

Patients need to be aware of the rationale, benefits, and risks of the procedure and have the ability to ask questions and give consent.

X-ray films are a permanent part of the medical record, and as such, confidentiality must be preserved.

These include ensuring patient awareness of cooperation and cost, scheduling follow-up appointments, and special preparation requirements, including any arrangements for assistance with transportation. For instance, the amount of radiation absorbed during the examination depends on one's age, the specific anatomical area studied, and the technology used. The lack of information available for patients about safe radiation doses may contribute to reduced adherence to safety precautions.

Doctor confirmation of low-dose values in X-rays and non-radiation techniques as diagnosis measures is the main area of concern.

This ignorance is troubling, especially because X-rays have potential side effects, but with large area exposure.

Physicians should be well aware of the X-ray facility protocols and should prefer regular quality control to have maximum quality with minimum exposure. It is also important that underexposed images be detected and adjusted by radiologists and that the imaging be optimized according to body size [65,66].

Challenges in X-Ray Imaging

The difficulties arising in X-ray imaging, extends from understanding of X-ray astronomy, cesium iodide scintillators, and nanocrystalline diamond films in security and medical imaging. The challenges applied to medical X-ray imaging, tapping into their X-ray interactions and image formation process, and highlights the crucial role detection media play in the image formation process.

Detector structure optimization and choice of scintillator are highlighted for X-ray image enhancement. However, 3D imaging can have a major influence on clinical outcome for life-threatening disorders, and this letter addresses some advances in the area of digital X-ray tomosynthesis (DXT). There are considerable hurdles that DXT is being assessed through in imaging centers.

The problems in scintillator-based X-ray imaging development [67].

The usefulness of x-ray imaging in screening for individuals who are probably at risk of a disease (for example, a family history or exposure to an environment that raises the risk of a life-threatening disease) but have not yet displayed the clinical signs or symptoms is limited by this trade-off [68].

As expertise grows (particularly in synchrotron x-ray-based imaging), it may be possible to reduce the x-ray dosage and improve contrast resolution by using x-ray imaging of certain effects of a tissue's x-ray refractive index rather than x-ray attenuation.[68]

This method might significantly increase the use of x-ray imaging for screening and follow-up investigations of asymptomatic patients of all ages, even if it poses significant technological challenges for whole-body 3D imaging [68].

CONCLUSION

X-ray imaging continues to be one of the most important modalities for our modern-day medical diagnostics and references, as there are specific techniques created for different clinical necessities. Although screen-film radiography is the dominant technique, other X-ray modalities, including computed tomography (CT) and fluoroscopy, have developed over the years. Some of them are good to visualize bone fractures, tumors, and cardiovascular conditions but have relatively lower resolution and diagnostic power. However, the risk of low-dose ionizing radiation still needs to be taken into account, especially among those sensitive groups like very young children and older people, and safety measures must be followed. Artificial intelligence helps in faster imaging and improves the accuracy of imaging depending on the application and prevents the risks involved. Moreover, more utilities of imaging technologies like digital X-ray systems and elastography enhance the quality of imaging and reduce radiation exposure, which is projected to improve patient outcomes.

However, ethical concerns of X-ray as a carcinogen with cumulative effects must be emphasized, and public awareness and education of this issue should be widespread. Healthcare providers should always follow guidelines and other standards to optimize the balance of risks and benefits of X-ray imaging and to ensure that clinical and screening uses of X-ray imaging contain meaningful information for patients that are informed by appropriate consent. Through research and innovation of imaging techniques, the importance of X-rays in medical diagnosis will be improved and will always be a great tool to ensure early diagnosis and treatment of the disease.

.

REFERENCES

1. Karanam, Santoshachandra Rao, Y. Srinivas, and S. Chakravarty. "A systematic approach to diagnosis and categorization of bone fractures in X-Ray imagery." International Journal of Healthcare Management (2022): (15) 4 1-12. https://doi.org/10.1080/20479700.2022.2097765.
2. Wong, Liang Jie, and Ido Kaminer. "Prospects in x-ray science emerging from quantum optics and nanomaterials." Applied Physics Letters (2021): (119)13: 130502-13 . https://doi.org/10.1063/5.0060552
3. Staufer, Theresa, and Florian Grüner. "Review of development and recent advances in biomedical X- ray fluorescence imaging." International Journal of Molecular Sciences (2023): 24(13), 10990. https://doi.org/10.3390/ijms241310990
4. Pandey, A., Dalal, S., Dutta, S., & Dixit, A. "Structural characterization of polycrystalline thin films by X-ray diffraction techniques." Journal of Materials Science: Materials in Electronics (2021):32(2), 1341-1368. https://doi.org/10.1007/s10854-020-04998-w
5. Kim, N., at al. An engineering view on megatrends in radiology: digitization to quantitative tools of medicine. Korean journal of radiology, (2013): 14(2), 139-153. https://doi.org/10.3348/kjr.2013.14.2.139
6. Kim, B. J., et al. "A flexible active-matrix X-ray detector with a backplane based on two-dimensional materials." Nature Electronics (2025): 8, 147–156. https://doi.org/10.1038/s41928-024-01317-7
7. Isler, Y., Egeli, S. S., & Manalp, A. (2019). New-Age Pyroelectric Radiographic X-Ray Generators. Natural and Engineering Sciences, 4(2), 125-132. DOI:10.28978/nesciences.567072
8. Seibert, J. A. X-ray imaging physics for nuclear medicine technologists. Part 1: Basic principles of x-ray production. Journal of nuclear medicine technology (2004): 32(3), 139-147. PMID: 15347692
9. Peters, C. E., et al. Exposure to low-dose radiation in occupational settings and ischaemic heart disease: a systematic review and meta-analysis. Occupational and environmental medicine, (2023). 80(12), 706-714. https://doi.org/10.1136/oemed-2023-108865
10. Zhou, Y., Wang, X., He, T., Yang, H., Yang, C., Shao, B., ... & Mohammed, O. F. Large-area perovskite-related copper halide film for high-resolution flexible X-ray imaging scintillation screens. ACS Energy Letters, (2022): 7(2), 884-46 https://doi.org/10.1021/acsenergylett.2c00075

11. Geng, D.,et al. "Thin-film transistors for large-area electronics." Nature Electronics (2023): 6 (12), 936-72. https://doi.org/10.1038/s41928-023-01095-8
12. Mirza, W. A., Aslam, M., Ali, A., Mirza, K., & Ahmad, N. "Film retakes in digital and conventional radiography." Journal of the College of Physicians and Surgeons--Pakistan: JCPSP (2008): 18(3),151-153. https://ecommons.aku.edu/pakistan_fhs_mc_radiol/103
13. Shi, Lin, and Satoshi Tashiro. "Estimation of the effects of medical diagnostic radiation exposure based on DNA damage." Journal of radiation research (2018): 59 (2),121-129. https://doi.org/10.1093/jrr/rry006
14. Wong, S. B., & Peh, W. C. The role of magnetic resonance imaging in the evaluation of scaphoid fractures. Journal of Medical Radiation Sciences(2019): 66(1), 3-4 doi: 10.1002/jmrs.316
15. Kutsal FY, Ergani GO. Vertebral compression fractures: still an unpredictable aspect of osteoporosis. Turkish journal of medical sciences. (2021):51(2),393-9. DOI:10.3906/sag-2005-315
16. Miyahara, L., et al. Fractures of the appendicular skeleton and criteria for their surgical management: pictorial essay. Radiologia Brasileira, (2022):. 55 (2), 120-127. https://doi.org/10.1590/0100-3984.2021.0039
17. Minehara, H., et al., (2023). Open fractures: Current treatment perspective. OTA International, 6(3), e240 DOI: 10.1097/OI9.0000000000000240
18. Hayashi, Yasuhiko, and Fumio Okuyama. "New approach to breast tumor detection based on fluorescence x-ray analysis." GMS German Medical Science (2010): (8) 18,1-7 doi: 10.3205/000107
19. Achenbach, S., et al., Non-invasive imaging as the cornerstone of cardiovascular precision medicine. European Heart Journal-Cardiovascular Imaging, (2022): 23(4), 465- 75. https://doi.org/10.1093/ehjci/jeab287
20. Manzo, R., et al.,. Echocardiographic evaluation of aortic stenosis: a comprehensive review. Diagnostics, (2023): 13(15), 1-19 https://doi.org/10.3390/diagnostics13152527
21. Al-Assaf, A. M., et al., An Overview for Echocardiography Techniques-An Updated Review for Modern and Advanced Techniques and Innovations. Journal of Medical and Life Science, (2024). 6(4), 611-632. DOI: 10.21608/jmals.2024.413169
22. Kellar, A., et al.,. Intestinal ultrasound for the pediatric gastroenterologist: a guide for inflammatory bowel disease monitoring in children: expert consensus on behalf of the International Bowel Ultrasound Group (IBUS) Pediatric Committee. Journal of Pediatric Gastroenterology and Nutrition, (2023): 76(2), 142-148. https://doi.org/10.1097/MPG.0000000000003649
23. Avery, J. C., et al.,. Noninvasive diagnostic imaging for endometriosis part 1: a systematic review of recent developments in ultrasound, combination imaging, and artificial intelligence. Fertility and sterility, (2024):121(2), 164-188. https://doi.org/10.1016/j.fertnstert.2023.12.008
24. Tibana, T. K., et al., What the radiologist should know about the role of interventional radiology in urology. Radiologia brasileira, (2019): 52(5) 331-336. https://doi.org/10.1590/0100-3984.2018.0035
25. Rogers, T., et al., Interventional cardiovascular magnetic resonance: state-of-the-art. Journal of Cardiovascular Magnetic Resonance, (2023): 25(1), 2-21. https://doi.org/10.1186/s12968-023-00956-7
26. Pastore, M. C., et al. Speckle tracking echocardiography in primary mitral regurgitation: should we reconsider the time for intervention?. Heart Failure Reviews(2022): 27(4), 1247–1260 https://doi.org/10.1007/s10741-021-10100-1
27. Renz, D. M., et al. Röntgenuntersuchungen des Thorax bei Kindern und Jugendlichen. Zeitschrift für Pneumologie, (2022): 19(5), 296-304. doi: 10.1007/s00117-021-00954-9
28. Morgan, H., et al. Indications for chest X-rays in children and how to obtain and interpret them. Nursing Children and Young People, (2025): 37(1),30-37. doi: 10.7748/ncyp.2018.e1141
29. Bernhardt P, Lendl M, Deinzer F. New technologies to reduce pediatric radiation doses. Pediatric radiology. (2006):(36)2, 212-5. DOI 10.1007/s00247-006-0212-4
30. Cohen, M. D. (2016). Understanding the problem of a parent’s fear of their child getting cancer from CT scan radiation. Journal of Pediatric Surgery, 51(7), 1222-1227. https://doi.org/10.1016/j.gpedsurg.2016.04.003
31. Karavas, E., et al. Are we aware of radiation: A study about necessity of diagnostic X-ray exposure. World Journal of Methodology, (2022): 12(4), 264-273. doi: 10.5662/wjm.v12.i4.264

32. Hauptmann, M., et al. Brain cancer after radiation exposure from CT examinations of children and young adults: results from the EPI-CT cohort study. The lancet oncology, (2023): 24(1), 45-53. : https://www.sciencedirect.com/science/article/pii/S1470204522006556.
33. Oakley, P. A., & Harrison, D. E. X-ray hesitancy: patients' radiophobic concerns over medical X-rays. Dose-Response, (2020): 18(3),1-10 https://doi.org/10.1177/1559325820959542
34. Sanz-Cánovas, J., et al. Management of type 2 diabetes mellitus in elderly patients with frailty and/or sarcopenia. International journal of environmental research and public health, (2022): 19(14), 1-13. https://doi.org/10.3390/ijerph19148677
35. Dutta, C., et al. Urinary tract infection induced delirium in elderly patients: A systematic review. Cureus, (2022): 14(12). DOI: 10.7759/cureus.32321
36. Vainshelbaum, N. M., et al. Role of the circadian clock "death-loop" in the DNA damage response underpinning cancer treatment resistance. Cells, (2022): 11(5), 1-23. https://doi.org/10.3390/cells11050880
37. Mathew CJ, David AM, Mathew CM. Artificial Intelligence and its future potential in lung cancer screening. EXCLI journal. (2020): (11)19,1552-62. doi: 10.17179/excli2020-3095
38. Alyehya, A. A., et al. Advancements in Radiographic Imaging Techniques for Early Cancer Detection. International journal of health sciences,(2022): 6(10), 2075-2086. DOI: 10.53730/ijhs.v6nS10.15325
39. Naqvi, S. T., et al. "Awareness of hazards of X-ray imaging and perception regarding necessary safety measures to be taken during X-ray imaging procedures among patients in public sector tertiary hospitals of Karachi, Pakistan." Cureus (2019): 11(5),1-7. DOI: 10.7759/cureus.4756
40. Halboub, E. S., et al. "Radiation-induced thumbs carcinoma due to practicing dental X-ray." Contemporary clinical dentistry (2015):6(1), 116-118. DOI: 10.4103/0976-237X.149306
41. Stephens, J., et al. A systematic review of human evidence for the intergenerational effects of exposure to ionizing radiation. International Journal of Radiation Biology, (2024). 100(9), 1330-1363. https://doi.org/10.1080/09553002.2024.2306328
42. Halboub, E. S., et al. Radiation-induced thumbs carcinoma due to practicing dental X-ray. Contemporary clinical dentistry, (2015). 6(1), 116-118. DOI: 10.4103/0976-237X.149306
43. Bastiani L., et al. Patient perceptions and knowledge of ionizing radiation from medical imaging. JAMA Network Open. (2021):4(10),1-13. doi:10.1001/jamanetworkopen.2021.28561
44. Little, M. P., et al.. A historical survey of key epidemiological studies of ionizing radiation exposure. Radiation Research, (2024): 202(2), 432-487. https://doi.org/10.1667/RADE-24-00021.1
45. Hu, Y., et al. Assessment of cumulative cancer risk attributable to diagnostic X-ray radiation: a large cohort study. European Radiology, (2023): 33(3), 1769-1778. https://doi.org/10.1007/s00330-022-09178-4
46. Gu, Y., et al. Association of low-dose ionising radiation with site-specific solid cancers: Chinese medical X-ray workers cohort study, 1950–1995. Occupational and Environmental Medicine, (2023): 80(12), 687-693. https://doi.org/10.1136/oemed-2023-108875
47. Cho, J. Y., & Han, W. J. The reduction methods of operator's radiation dose for portable dental X-ray machines. Restorative Dentistry & Endodontics, (2012): 37(3), 160-164. https:// dx. doi.org/10.5395/rde.2012.37.3.160
48. Naqvi, S. T., et al. Awareness of hazards of X-ray imaging and perception regarding necessary safety measures to be taken during X-ray imaging procedures among patients in public sector tertiary hospitals of Karachi, Pakistan. Cureus, (2019): 11(5),1-7. DOI: 10.7759/cureus.4756
49. Chida, K. What are useful methods to reduce occupational radiation exposure among radiological medical workers, especially for interventional radiology personnel?. Radiological Physics and Technology, (2022): 15(2), 101-115. https://doi.org/10.1007/s12194-022-00660-8
50. Santos, M. K, et al. "Artificial intelligence, machine learning, computer-aided diagnosis, and radiomics: advances in imaging towards to precision medicine." Radiologia brasileira (2019): 52(6), 387-96. https://doi.org/10.1590/0100-3984.2019.0049
51. Takura, Tomoyuki, Keiko Hirano Goto, and Asao Honda. "Development of a predictive model for integrated medical and long-term care resource consumption based on health behaviour: application of healthcare big data of patients with circulatory diseases." BMC medicine (2021): 19, 1-16. https://doi.org/10.1186/s12916-020-01874-6
52. Alzubaidi, Laith, et al. "Review of deep learning: concepts, CNN architectures, challenges, applications, future directions." Journal of big Data (2021): 8, 1-74. https://doi.org/10.1186/s40537-021-00444-8

53. Oborska-Kumaszyńska, D., & Wiśniewska-Kubka, S. Analog and digital systems of imaging in roentgenodiagnostics. Polish journal of radiology, (2010): 75(2), 73-81. https://www.polradiol.com/fulltxt.php?CID=878520
54. Semghouli S, Amaoui B, Maamri A. Estimated radiation exposure from medical imaging for patients of radiology service of Al Faraby Hospital, Oujda Morocco. International Journal of Cancer Therapy and Oncology. (2015): 3(3),1-5 . DOI: 10.14319/ijcto.33.25
55. Kilian, H. I., et al. Barium sulfate and pigment admixture for photoacoustic and x-ray contrast imaging of the gut. Journal of Biomedical Optics, (2023). 28(8),1-10. https://doi.org/10.1117/1.JBO.28.8.082803
56. Kutlu, A. Z .,et al. A multimodal phantom for visualization and assessment of histotripsy treatments on ultrasound and x-ray imaging. Ultrasound in medicine & biology, (2023). 49(6), 1401-1407. https://doi.org/10.1016/j.ultrasmedbio.2023.01.019
57. Kumar, Komal, et al. "Weakly supervised learning based bone abnormality detection from musculoskeletal x-rays." Multimedia Tools and Applications (2024): 84(2). 1-26. https://doi.org/10.1007/s11042-024-19716-5
58. Law, Jennifer, and Paul B. Macbeth. "Ultrasound: from Earth to space." McGill Journal of Medicine: MJM (2011): 13(2), 59. PMID: 22399873; PMCID: PMC3296555.
59. Reda, Rodolfo, et al. "Ultrasound imaging in dentistry: a literature overview." Journal of Imaging (2021): 7(11), 238. https://doi.org/10.3390/jimaging7110238
60. Meola, M., et al. Basics for performing a high-quality color Doppler sonography of the vascular access. The Journal of Vascular Access, (2021). 22(1), 18-31. https://doi.org/10.1177/11297298211018060
61. Solomon, C., et al. Role of Ultrasound Elastography and Contrast-Enhanced Ultrasound (CEUS) in Diagnosis and Management of Malignant Thyroid Nodules—An Update. Diagnostics, (2025) 15(5), 599. https://doi.org/10.3390/diagnostics15050599
62. Rizzoni, D., et al. New noninvasive methods to evaluate microvascular structure and function. Hypertension, (2022). 79(5), 874-886. https://doi.org/10.1161/HYPERTENSIONAHA.121.17954
63. Heo Y., et al. Relating factors to wearing personal radiation protectors among healthcare professionals. Annals of occupational and environmental medicine. (2016) 28(60), 1-6. DOI 10.1186/s40557-016-0144-x
64. Torresin, Alberto, et al. "Practical recommendations for the application of DE 59/2013." La radiologia medica (2019): 124 ,721-27. https://doi.org/10.1007/s11547-019-01031-x
65. Farzanegan, Zahra, et al. "Evaluating the principles of radiation protection in diagnostic radiologic examinations: collimation, exposure factors and use of protective equipment for the patients and their companions." Journal of medical radiation sciences (2020): 67(2), 119-27. https://doi.org/10.1002/jmrs.384
66. Binay, Songul, et al. "Does periodic lung screening of films meets standards?." Pakistan Journal of Medical Sciences (2016): 32(6), 1506. doi: 10.12669/pjms.326.11267
67. Samaila, B., Maidamma, B., & Danyaro, R. M. Identification of Common Urological Disorders and Radiation Dose Assessment among the Patients Attending Intravenous Urographic X-Ray Procedure in Kebbi State. Int. J. Sci. Res. in Physics and Applied Sciences (2025): 13(1).16-24. Available online at: www.isroset.org.
68. Ritman, Erik L. "Medical x-ray imaging, current status and some future challenges." Advances in X-ray analysis (2006): 49, 1-12. Available online at: www.dxcicdd.com.