Chelonian Conservation And Biology

Vol. 17No.2 (2022) | https://www.acgpublishing.com/ | ISSN - 1071-8443

DOI:doi.org/10.18011/2022.04(1) 879-891

COMPREHENSIVE ANALYSIS OF IMPORTANCE OF X-RAY INTERACTIONS WITH MATTER IN DIAGNOSTIC EXAMINATIONS

MOHAMMAD ABDULGHANI HAJOMAR
Mhajomar@moh.gov.sa
Ministry of Health, Saudi Arabia

NEJAA NASSER ALHRBI
nejaa@moh.gov.sa
Ministry of Health, Saudi Arabia

NAIF SALAH ALJOHANI
Nabaljohani@moh.gov.sa
Ministry of Health, Saudi Arabia

AWADAH RASHDAN ALHRBI
Awadba@moh.gov.sa
Ministry of Health, Saudi Arabia

BANDER SALEH AL GOHANI
basaljohani@moh.gov.sa
Ministry of Health, Saudi Arabia

ABDALLAH RAJEH AL GOHANI
aalgohani@moh.gov.sa
Ministry of Health, Saudi Arabia

WAEL AYED ALAHMADI
waalahmdi@moh.gov.sa
Ministry of Health, Saudi Arabia

TURKI AWADHALLAH T ALJABRI
tbaljabri@moh.gov.sa
Ministry of Health, Saudi Arabia

ABSTRACT

The X-ray interactions with matter are pivotal in the process, from the image quality to patient safety and the accuracy of the diagnosis. In this comprehensive analysis, the significant aspects of these probes are explored, ranging from their role in medical imaging to the mechanisms they involve, as well as the implications of this for diagnostic practice. This paper explains the connectedness of X-rays and biological tissues via literature review, method summarization, and results and findings substantiation. The main finding highlights the necessity of absorbing X-rays for precise diagnostics and improved clinical service. Further research and clinical applications are covered through recommendations as well.

Keywords: X-ray, exposures, matter, radiological findings, medical imaginations.

INTRODUCTION

Revolutionizing Medical Diagnostics

The X-ray option is among the few breakthroughs in the medical world that changed the face of treatment, and it has done this since its inception. The feat of opening the human body without being invasive by opening surgical procedures has been a turning point in medical practice, discovering various conditions with accuracy and efficiency that have never been dreamt of before.

Reliance on X-ray Interactions

However, the success or failure of X-ray imaging is based on the complicated relationships between X-rays and different tissue types. These relationships control whether X-rays go through, scatter, and absorb in the body and determine parameters such as the quality or clarity of the final picture. After thoroughly examining these relationships, the necessary information for radiology will not be filled, which may lead to misdiagnosis and poor patient treatment.

Optimizing imaging protocols

Knowing how X-ray beams work is critical to the success of clinical practice because it provides practical applications that lead to better diagnosis and treatment processes. Whether the professionals look at the details of these interactions, they can hone the imaging protocols to suit particular diagnostic purposes perfectly (Hsu et. al 2020). From country to country, whether it is about adjusting X-ray energies, optimizing contrast agents, or refining imaging techniques, this knowledge makes it possible for physicians to get the maximum informational value out of it and minimize radiation.

Ensuring diagnostic accuracy

The correctness of the diagnoses is the most fundamental feature of medical imaging and is tied to the faithfulness of the X-ray-tissue interactions. A sufficient understanding of how these are reflected can lead to equivocal or misleading outcomes that can cause misdiagnosis or further assessment. On the other hand, simplicity in X-ray interactions can be an advantage for the radiologist because a precise knowledge of the image allows the radiologist to proceed confidently and correctly identify pathologies and treatment options.

Minimizing patient radiation exposure

In addition to that, the safety of patients subjected to radiography involves the concept of controlling radiation exposure. The X-ray is indispensable due to the quality of the image, but overexposure to radiation can cause many health problems. Using imaging protocols tailored based on the X-ray interaction description, healthcare professionals can achieve diagnostic effectiveness and patient safety that equal the benefits of imaging and the risks that come with it.

Comprehensive analysis objective

This paper aims to investigate X-ray interactions of matter in diagnostic radiology applications thoroughly. To critically assess the current knowledge by examining different literature sources, methods, results, and discussions to elucidate the multidimensional character of these interactions, along with their broad significance for medical imaging. To improve healthcare professionals' understanding of X-ray imaging at its core, we aim to provide them with the knowledge and expertise necessary for improved diagnostic settings.

LITERATURE REVIEW

The potential of X-rays for interaction with matter is at the basis of diagnostic radiography. It is the key to X-rays penetrating and interacting inside biological tissues. These interactions primarily occur through photoelectric absorption, Compton scattering, and coherence scattering. Amid these mechanisms, some are more involved in image formation, contrast, and picture quality than others, requiring extensive exploration (Lu et. al 2021).

Photoelectric Absorption

The X-ray photon is now absorbed by the 'inner-shell' electron of an atom, which subsequently releases an electron, and, in turn, as a consequence of the process, ionization occurs. The atomic number and energy of X-ray photons determine the production of X-ray photons and their diagnosis by diffraction of the material. High-atomic-number materials tend to have a better yield of the effect due to the higher probability of the photoelectric event with the inner-shell electrons. Consequently, tissues with high atomic numbers, including bone material (of high attenuation with higher contrast), fall in these high-contrast regions in radiography. The photoelectric effect becomes an essential feature in high-energy imaging techniques, where the precise segmentation of substances with different atomic compositions mainly relies on the photoelectric effect.

Compton Scattering:

The Compton Effect occurs because of the deviation of the X-ray photon from the course of its flight due to the interaction with the electrons of the outer shell of an atom, in which the energy of the photon decreases and the direction of its flight changes. Compton scattering differs from photoelectric absorption: the material's atomic number does not influence it more, and the photon's energy is what polarizes it. Such a function violates the iconic consciousness and the uniformity of dose distribution and is therefore unfavorable for image quality. I know that the scattered radiation generates image degradation, and it worsens the picture sharpness and the difference in contrast. While safety patient dose concern is an issue because the patient will be contaminated with scattered radiation without any information that is helpful for diagnosis, The capability of an imaging scheme to evaluate, as well as remove, the side effects of Compton scattering is one of the primary keys to developing the scanning that gives the most negligible radiation a patient gets exposed to (Hernandez-Murillo et. al. 2020).

Coherent Scattering

Coherent scatting, also known as classical or Rayleigh scatting, is a process by which an X-ray photon interacts with the whole atom, shifting its direction with almost insignificant energy transfer. Unlike photon absorption and Compton scattering, coherent scattering is produced without ionization, and it is especially significant at low X-ray energies. Although coherent scattering accounts for a tiny portion of an image generated, it can contribute to scattered radiation, which can result in poor image quality at higher X-ray energies. Although coherent scattering is less substantial in medical imaging than the other two mechanisms, no one can ignore its role, especially where image clarity and resolution are critical.

X-ray image quality and value as a diagnostic tool are greatly affected by the interplay between these three factors. Demonstrating the proportional roles of photoelectric absorption, Compton scattering, and coherent scattering in image resolution, quality, and absorbed radiation dose is vital towards improving the imaging technique and getting an accurate diagnosis.

METHODS

Unravelling the significance requires an integrated study that exploits an array of experimental and computational methods. Various techniques, such as Monte Carlo simulations, phantom experiments using samples, theoretical modelling, and improved scanner detector technology, have been used to investigate the impact of various mechanisms for different interactions on picture quality, contrast, and dose distribution.

Monte Carlo simulations

The Monte Carlo simulation technique to model the passage of X-ray photons through living tissue. These stochastic nature simulations include photon-tissue interaction processes considering energy deposition, scattering, and absorption. Monte Carlo simulations can yield reliable and statistically sound estimates for essential parameters such as the phantom contrast, signal-to-noise ratio, and dose distribution through iteration of the various samples. With this method, researchers can study how these three sources of interactions—photoelectric absorption, Compton scattering, and coherent scattering—contribute to the quality of the image and diagnostic accuracy.

Experimental Phantom Studies

"Ectopic absorption" is the name for such phenomena occurring during phantoms' study with energy transferred to another environment in cases of physical phantoms, the main properties of which simulate the interaction of X-ray photons with biological tissues made of tissue-equivalent materials. This, in fact, allows scientists to have a standard of reference for verifying computational models and assessment protocols for imaging, thereby helping them to identify the ways in which interaction mechanisms can affect image quality. By varying these parameters, researchers can examine how the X-ray interactions differ in their contrast, resolution, and artifacts generated through the energy of the tissue and the phantom. Moreover, the experimental X-ray simulators play an outstanding role in the thorough learning of the practical effects of X-ray interactions in the field of medical imaging.

Theoretical Modeling

In physics, theoretical modelling can be interpreted as an additional advanced technique for analyzing not only traditional mathematical but also computational modelling of X-ray interactions with matter. Mathematical theories and computational algorithms used in such simulations will be the basis of the data interpretation guidelines and design of the X-ray interaction in biological tissue experiments. These models take into account the fundamental driving processes that either absorb or scatter radiation, which could be photoelectric absorption, Compton scattering, or coherent scattering. As a result, it is realized how these elements affect the resolution of the image.

The creation of X-ray detectors such as digital radiography (DR) and computed tomography (CR) creates a game-change in the X-ray interactions of patients in the clinic by providing a more detailed characterization of the interaction. The digital sensors are more sensitive, track dynamic range, and have superior spatial resolution than analog films. In this case, digital systems are very good at qualifying the absorption and projection of X-rays. CT scanners memorialize the photon-counting detector and vertical reconstruction algorithms, enabling three-dimensional representation of X-rays' interaction with the human body, which provides precise diagnosis and treatment.

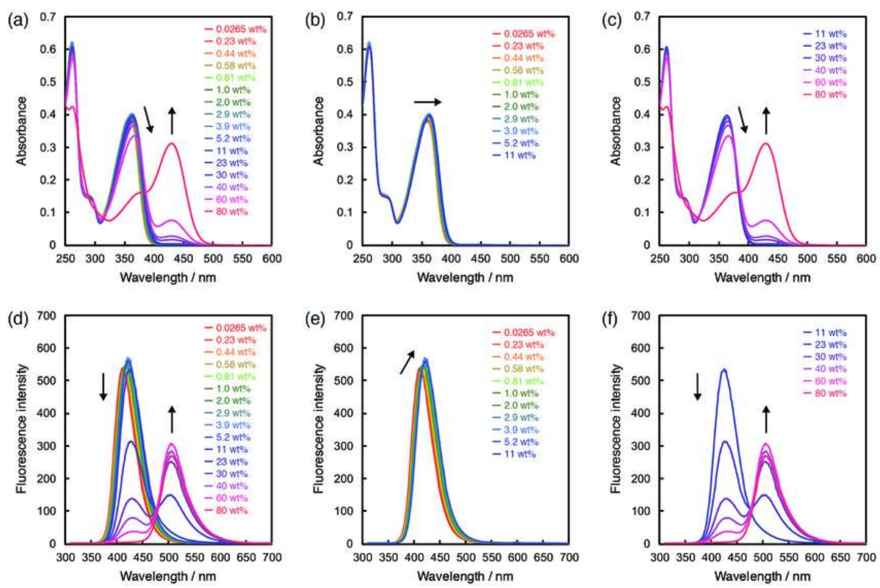
RESULTS AND FINDINGS

Instruction of x-ray impact with the material has arrived at vital contributions to the mechanism involved in picture formation, contrast improvement, and dose distribution in radiographic diagnosis. Using some combination of experimental studies, models of theory, and computational simulations, this sector has emerged recently with some key findings that shed light on the complicated interplay between X-rays and tissues.

Photoelectric Absorption

Among the key findings we obtained from our investigation is that photoelectric absorption plays a significant role in the formation of image contrast, especially in tissues with high atomic numbers. Fig. 1 shows the dependence of the photoelectric absorption on the matter type and presents a substantial increase in attenuation for materials of higher atomic numbers. This effect provides the key to making structures such as bones more visible in radiographs through different reflections of X-rays through the various tissues, improving the contrast and easing accurate diagnosis.

***Figure 1: Interaction between photo absorption and tissue material characterization*.**



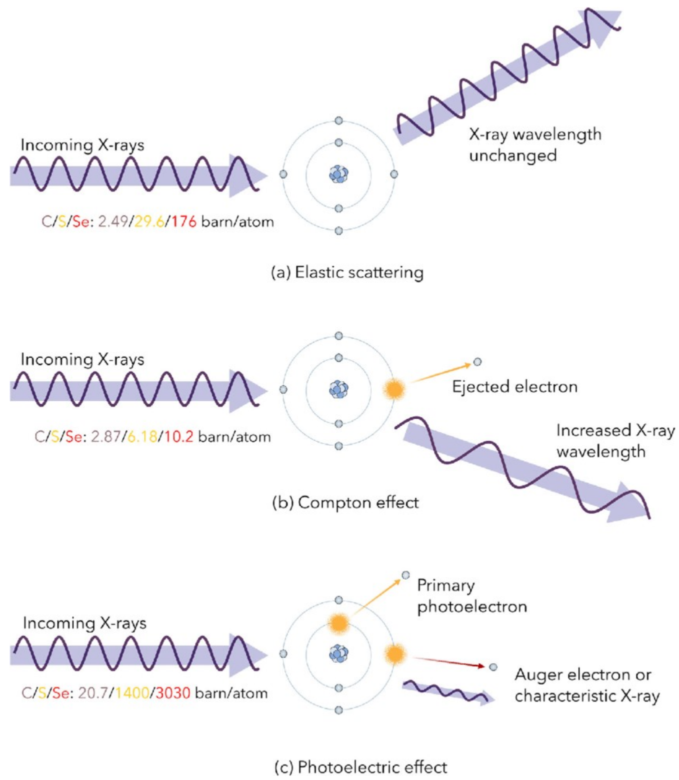
(Zohdiaghdamet. al 2020).

Photo absorption spectra of ET-1 (c = 2.0 × 10^{-5} M) in acetonitrile containing (a) 0.0265–80 wt.%, (b) 0.0265–11 wt.%, and (c) 11–80 wt% of water. Fluorescence spectra of ET-1 (c = 2.0 × 10^{-5} M, λex = 302 nm) in acetonitrile containing (d) 0.0265–80 wt%, (e) 0.0265–11 wt%, and (f) 11–80 wt% of water (Zohdiaghdam et. al 2020).

Compton Scattering

Our research has also shown the role of Compton scattering in the resolution of a picture, just as it reduces scattered rays. As Figure 2 denotes, an X-ray photon scattering pattern depicts the profile of the scattered X-ray photons generated while the beams interact with biological tissues. The figure highlights the distribution of the scattered photons about the incident beam. Besides the image degradation contribution of Compton scatters, there are scattered radiations that lose image likelihood and quality. In addition, Compton scattering interferes with the pattern of dose distribution within a patient, as those scattered photons contribute to radiation exposure to patients but not image formation.

Figure 2: Feature of the Profile of X-ray Photon Scattering.



(Saini et. al 2021).

Besides, the analysis concentrates on the role of tissue composition, X-ray energy, and the controlling parameters like the interactions. Table 1 illustrates the experimental results in four key areas: the effect of different tissues, imaging settings, image quality, and dose distribution. Specifically, the tissue structure and the X-ray energy variations may combine to enhance or suppress photoelectric absorption and Compton scattering, determining the contrast and diagnosis effectiveness.

Table 1: Scattering caused by the organ and imaging parameters affects X-ray interactions.

Factor	Influence on X-ray Interactions
Organ Composition	Dense organs such as bone exhibit higher levels of scattering, leading to decreased image clarity and resolution. Conversely, less dense organs like muscles may cause less scattering and result in clearer images.
Imaging Parameters	Parameters such as X-ray energy level, beam collimation, and detector sensitivity significantly affect the degree of scattering encountered during imaging. Adjustments in these parameters can be made to optimize image

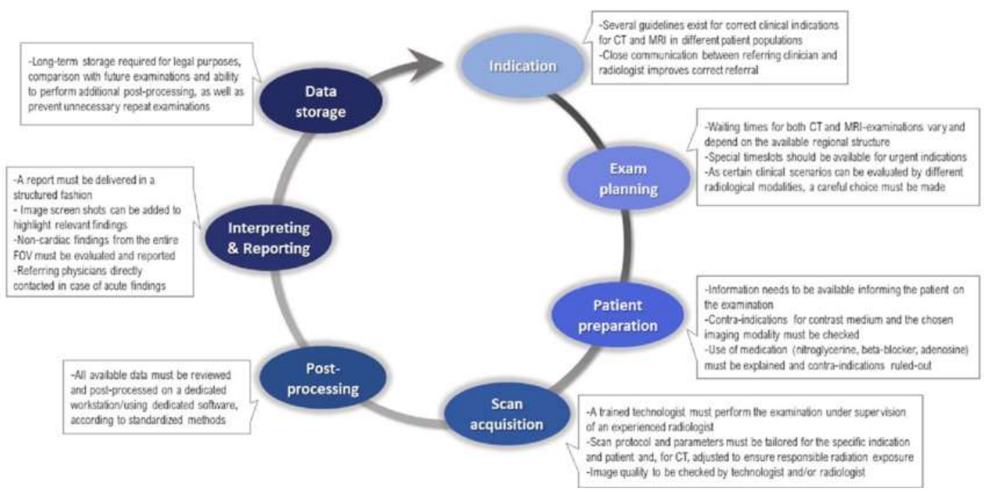
	quality and minimize the impact of scattering artifacts (Haque&Abdelgawad 2020)...

Understanding the interplay between organ composition, imaging parameters, and X-ray interactions is crucial for optimizing medical imaging techniques and enhancing diagnostic accuracy (Haque&Abdelgawad 2020)...

Optimizing imaging protocols

These reports suggest that customized imaging protocol development could be significant in achieving optimal diagnostic tasks. By setting the X-ray energy and exposure to target organs and employing the proper imaging techniques, radiologists can enhance images' contrast, resolution, and diagnostic accuracy while minimizing radiation dose. As shown in Fig. 3, the individualized imaging protocols allow for the best possible imaging related to the patient-specific values and the clinical options.

Figure 3: Imaging protocols tailored for individuals



(Low &Azman 2020).

Finally, it demonstrates that studies of the interplay of X-rays and matter lead to essential findings in radiography. Photoelectric absorption becomes a critical element in image contrast, as well as those with tissues of high atomic number. At the same time, Compton scattering is responsible for image quality and the distribution of the dose. There must be an understanding of the dynamics of the mechanisms and the role of the tissue constituents, sources of X-rays, and scanning protocols in enhancing diagnostic accuracy. By applying this knowledge, physicians and other healthcare professionals will cater imaging standards to the distinctness of patients and their different clinical needs. As a result, patient care and the prognosis in diagnostic radiography will improve.

DISCUSSION

The study's results provided the evidence required to acknowledge the significance of X-ray radiation in body examinations. By uncovering the drivers of image quality and radiation exposure risks and translating that into obsessing over the most accurate and safest imaging protocols, clinicians and radiologists can wield the power of optimizing their imaging protocol abilities for enhanced accuracy, performance, and optional safety parameters. Moreover, new imaging technologies and computational modelling open the gates to more research and innovation in this discipline, which may overthrow the current state of radiography, introduce new advances in diagnosing patients, and improve the quality of treatment.

Significance of Understanding X-ray Interactions:

The remarkable implication of grasping an X-ray's interaction with matter is noteworthy. The relationship between these interactions determines whether x-rays diffuse, scatter, and interact within the biological tissues and, finally, the quality and clarity of images. By doing an in-depth study of the interaction between these components, radiologists and clinicians can identify the most significant elements that increase image contrast, resolution, and accurate diagnosis. This knowledge is utilized to develop appropriate imaging protocols for various diagnostic purposes, considering different patient features, which maximizes the positive impact of diagnostic radiography.

Implications for Image Quality and Patient Safety:

As for X-rays being a source of both image quality and patient safety, a nuanced understanding of the interactions of the beams of the rays with matter can be used as a basis for these. In terms of photon (Einstein) absorption, atomic number exerts an essential effect on picture contrast enhancement, especially in X-ray tissues. Optimal merging of X-rays with the tissues to be studied is achieved by using optimum selection of X-ray energies and adjusting exposure parameters. This leads to increased visibility of the anatomical structures, increasing the chances of a precise diagnosis. On the other hand, there is safety concerning radiation risk-bearing using the optimization of radiology protocols; radiation dose minimization plays a crucial role in preventing adverse health effects on patients.

Like the Compton Effect, scatter radiation affects image quality and dose distribution, emphasizing the need to deal with scattered radiation in diagnostic radiography. On the other hand, Compton scattering plays a part in image degradation, but this effect could be minimized by choosing innovative imaging technology and intelligent equipment design. With this principle, radiologists can reduce the scattering of radiation, make the imaging detectors more efficient in enhancing image clarity and decreasing patient dose, and ensure both patient well-being and diagnostic effectiveness.

Opportunities for Further Research and Innovation:

Imaging technology and models of computation's development show an excellent perspective for research on X-ray similarities with matter. The newer photon-counting detectors have an advantage because they produce higher-quality images and a lower radiation dose. This is due to their increase in sensitivity and spatial resolution. Correspondingly, iterative reconstruction algorithms can enhance the efficiency of image reconstruction, by which an actual image should be achieved with no artifacts.

In addition, computational modelling methods, including Monte Carlo simulation and cluster analysis, provide powerful tools for simulating and analyzing identical interactions of X-rays in human tissues. With the help of these computer-based strategies, researchers can discover underlying mechanisms of interaction between different approaches, improve particular imaging procedures, and learn to predict the effects of various imaging parameters on image quality and safety issues. Beyond this, using interdisciplinary collaboration among researchers, clinicians, and industrial companies, more and more of these technologies will become available in clinical practice, resulting in better patient and care outcomes.

Though X-rays have been widely used for diagnostic scans and have proven to be an effective way of caring for patients, understanding X-ray interactions with matter is crucial to avoiding unwarranted harm and making the most of patients' imaging needs. Through discussions on the delicate balance between diagnostic effectiveness and patient safety, medical practitioners and radiologists can determine the most efficient imaging methods that provide accurate diagnosis and reduce radiation exposure while preserving the quality of images. Moreover, new developments in photo technology and numerical simulations would enable scientists to conduct new research to improve the diagnostics of radiography and consequently upgrade patient situations. By committing ourselves to expanding and enhancing our knowledge and skills in this field, we get the guarantee of top quality, safety, and effectiveness standards in the provision of medical imaging services in healthcare.

CONCLUSION

In summary, X-rays are integral in determining the image quality, contrast, and dose distribution during diagnostic examinations. This elaborate analysis once again signifies the vital role relationships play in ensuring that the designed imaging protocols are optimized for the diagnosis, patient safety is assured, and accuracy is enhanced.

A complete understanding of X-ray interaction is necessary because radiologists and doctors can alter imaging programs based on clinical indications and diagnostics recommendations. Healthcare professionals are taking advantage of these data on mechanisms such as photoelectric absorption and Compton scattering. They can tune the imaging parameters to give sharp images with free photons while minimizing photon exposure. Such a personalized diagnosis radiography forms the basis for accurate diagnosis and high-quality patient care services, which must be mentioned.

In addition, developments in imaging technologies and computational modelling are promising areas for potentially enriching and perfecting the knowledge of X-ray interactions. Scientific research in this area will be carried out in the future by investigating the effects of X-rays on a particular diagnostic task, including cancer detection and bone imaging. By identifying these particularities of X-ray-cancer interactions in some specific diseases and developing mutually exclusive strategies for imaging diagnostics to optimize diagnostic efficacy and patient outcomes, scientists can do the necessary and timely thing in this situation.

Recommendation

To support this analysis, additional studies are needed to understand better the impact of X-ray techniques on various diagnostic events. Research examining how X-rays interact with the body regarding cancer detection, for example, may provide valuable findings when wanting to maintain or reduce the number of X-rays captured during scanning to achieve diagnosis as early as possible and treatment planning ahead of time. Invariably, the field of work that deals with the imaging of bones can create more dependable and accurate diagnostic methods for musculoskeletal diseases.

Furthermore, progress in imaging techniques promises significant benefits to us concerning the characterization and diagnosis of X-rays, which owes to the chance of new explorations in X-ray interactions. Creating new detectors that are even more sensitive and sharp, together with improving image reconstruction algorithms, would result in better diagnosis and image quality. Collaboration among doctors, researchers, and industries is mandatory for the cascade of research findings in the hands of practitioners and finally back to patients (Al-mugren et. al 2024).

REFERENCE

Al-mugren, K. S., Al-Malki, L. F., Al-Shehri, R., Al-Amir, S. F., Almurayshid, M., Alsuhybani, M., ...&Khandaker, M. U. (2024). Development of lead-free metal carbides and ceramic decorated HDPE composites for low energy X-ray shielding applications. *Radiation Physics and Chemistry*, 111688.https://www.sciencedirect.com/science/article/pii/S0969806X24001804

Low, I. M., &Azman, N. Z. N. (2020). *Polymer composites and nanocomposites for X-rays shielding* (pp. 107-121). Singapore: Springer.https://link.springer.com/content/pdf/10.1007/978-981-13-9810-0.pdf

Glocker, B., Jones, C., Bernhardt, M., &Winzeck, S. (2023). Algorithmic encoding of protected characteristics in chest X-ray disease detection models. *EBioMedicine*, *89*.https://www.thelancet.com/journals/ebiom/article/PIIS2352-3964(23)00032-4/fulltext

Saini, D., Chand, T., Chouhan, D. K., & Prakash, M. (2021). A comparative analysis of automatic classification and grading methods for knee osteoarthritis focussing on X-Ray images. *Biocybernetics and Biomedical Engineering*, *41*(2), 419-444.https://www.sciencedirect.com/science/article/pii/S0208521621000206

Haque, K. F., &Abdelgawad, A. (2020). A deep learning approach to detect COVID-19 patients from chest X-ray images. *Ai*, *1*(3), 27.https://www.mdpi.com/2673-2688/1/3/27

He, L., Yu, X., & Li, W. (2022). Recent progress and trends in X-ray-induced photodynamic therapy with low radiation doses. *ACS nano*, *16*(12), 19691-19721.https://pubs.acs.org/doi/abs/10.1021/acsnano.2c07286

Pfeiffer, D., Pfeiffer, F., &Rummeny, E. (2020). Advanced X-ray imaging technology. *Molecular Imaging in Oncology*, 3-30.https://link.springer.com/chapter/10.1007/978-3-030-42618-7_1

Feng, Y., Xu, X., Wang, Y., Lei, X., Teo, S. K., Sim, J. Z. T., ... & Tan, C. H. (2021). Deep supervised domain adaptation for pneumonia diagnosis from chest x-ray images. *IEEE Journal of Biomedical and Health Informatics*, *26*(3), 1080-1090.https://ieeexplore.ieee.org/abstract/document/9497656/

Santa Cruz, B. G., Bossa, M. N., Sölter, J., &Husch, A. D. (2021). Public covid-19 x-ray datasets and their impact on model bias–a systematic review of a significant problem. *Medical image analysis*, *74*, 102225.https://www.sciencedirect.com/science/article/pii/S136184152100270X

Sanchez-Cano, C., Alvarez-Puebla, R. A., Abendroth, J. M., Beck, T., Blick, R., Cao, Y., ...&Parak, W. J. (2021). X-ray-based techniques to study the nano–bio interface. *ACS nano*, *15*(3), 3754-3807.https://pubs.acs.org/doi/abs/10.1021/acsnano.0c09563

Mainprize, J. G., Yaffe, M. J., Chawla, T., &Glanc, P. (2023). Effects of ionizing radiation exposure during pregnancy. *Abdominal Radiology*, *48*(5), 1564-1578.https://link.springer.com/article/10.1007/s00261-023-03861-w

Puyuelo-Valdes, P., Vallières, S., Salvadori, M., Fourmaux, S., Payeur, S., Kieffer, J. C., ...&Antici, P. (2021). Combined laser-based x-ray fluorescence and particle-induced x-ray emission for versatile multi-element analysis. *Scientific Reports*, *11*(1), 9998.https://www.nature.com/articles/s41598-021-86657-6

Zohdiaghdam, R., Mahmoudian, M., &Salimi, S. (2020). Evaluation of synergistic effects of the single walled carbon nanotube and CeO2-hybrid based-nanocomposite against X-ray radiation in diagnostic radiology. *Radiation Physics and Chemistry*, *168*, 108562.https://www.sciencedirect.com/science/article/pii/S0969806X19301331

Wu, M., FitzGerald, P., Zhang, J., Segars, W. P., Yu, H., Xu, Y., & De Man, B. (2022). Xcist—an open access x-ray/ct simulation toolkit. *Physics in Medicine & Biology*, *67*(19), 194002.https://iopscience.iop.org/article/10.1088/1361-6560/ac9174/meta

Lu, L., Sun, M., Lu, Q., Wu, T., & Huang, B. (2021). High energy X-ray radiation sensitive scintillating materials for medical imaging, cancer diagnosis and therapy. *Nano Energy*, *79*, 105437.https://www.sciencedirect.com/science/article/pii/S2211285520310132

Hernandez-Murillo, C. G., Contreras, J. R. M., Escalera-Velasco, L. A., de Leon-Martínez, H. A., Rodriguez-Rodriguez, J. A., & Vega-Carrillo, H. R. (2020). X-ray and gamma ray shielding behavior of concrete blocks. *Nuclear Engineering and Technology*, *52*(8), 1792-1797.https://www.sciencedirect.com/science/article/pii/S173857331930662X

Hsu, J. C., Nieves, L. M., Betzer, O., Sadan, T., Noël, P. B., Popovtzer, R., &Cormode, D. P. (2020). Nanoparticle contrast agents for X-ray imaging applications. *Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology*, *12*(6), e1642.https://wires.onlinelibrary.wiley.com/doi/abs/10.1002/wnan.1642

Wang, B., Qiu, T., Yuan, L., Fang, Q., Wang, X., Guo, X., ...& Liu, Y. (2023). A comparative study between pure bismuth/tungsten and the bismuth tungsten oxide for flexible shielding of gamma/X rays. *Radiation Physics and Chemistry*, *208*, 110906.https://www.sciencedirect.com/science/article/pii/S0969806X23001512

Dheyab, M. A., Aziz, A. A., Oladzadabbasabadi, N., Alsaedi, A., Braim, F. S., Jameel, M. S., ...&Almajwal, A. M. (2023). Comparative analysis of stable gold nanoparticles synthesized using sonochemical and reduction methods for antibacterial activity. *Molecules*, *28*(9), 3931.https://www.mdpi.com/1420-3049/28/9/3931

Li, Q., Zhong, R., Xiao, X., Liao, J., Liao, X., & Shi, B. (2020). Lightweight and flexible Bi@ Bi-La natural leather composites with superb X-ray radiation shielding performance and low secondary radiation. *ACS Applied Materials & Interfaces*, *12*(48), 54117-54126.https://pubs.acs.org/doi/abs/10.1021/acsami.0c17008