The Review Of
DIABETIC
STUDIES
OPEN ACCESS

Review the application of advances in Biomedical X-ray: A Comprehensive Review

Sharifah Mohammad Awad[1], Rajaa Abdullah Mahmoud[2], Najd Mohammad Al Saadi[3], Mohamed Abdukrahman Ghali Al Otaby[4], Dawi Hanas Dawi Alotaibi[5], Omar Ahmed Saeed Alhani[6], Bandar Nasser Olyan Almutairi[7], Abulaziz Saud Abdullah alqahtani[8], Yasser Mohammed Halawi[9], Jawhara Abdulaziz Halabi[10], Saud Khalaf Sayil Alanazi[11], Mishal Saleh Al-Atani[12]

[1]Diagnostic radiology, Yanbu General Hospital, Saudi Arabia.
[2]Radiology Technician, King Abdulaziz Hospital, Saudi Arabia.
[3]Radiology Technician ,King Faisal Hospital in Makkah, Saudi Arabia.
[4]Radiology Technician Al-Dawadmi Hospital, Saudi Arabia.
[5]X-Ray, HOSPITAL SAJIR, Saudi Arabia.
[6]X-Ray technician, Erada complex for mental health- AlBaha, Saudi Arabia.
[7]X-Ray Technician, Wtheilan Hospital, Saudi Arabia.
[8]Radiology Technician, Rawda Hospital, Al-Ardh, Saudi Arabia.
[9]Radiology technician, Forensic Medical Services Center, Saudi Arabia.
[10]Radiology technician, Ministry of Health Branch in Jeddah, Saudi Arabia.
[11]Radiology Technician, Ministry of Health Public Health Departments Riyadh branch, Saudi Arabia.
[12]X-ray technology, Third Settlement, Riyadh / Dawadmi Governorate Hospital, Saudi Arabia.

Abstract

The use of X-rays for imaging has a long history, which has resulted in several well-established methods in preclinical as well as clinical applications, such as tomographic imaging or computed tomography. While projection radiography provides anatomical information, X-ray fluorescence analysis allows quantitative mapping of different elements in samples of interest. This comprehensive review aims to explore the various applications of X-ray imaging in biomedical research by analyzing existing literature and summarizing key findings. The study used secondary data sources, including research articles, reviews, and textbooks, to compile a detailed overview of the different imaging modalities and techniques available in X-ray imaging. The review covers a wide range of biomedical research areas where X-ray imaging has been employed, including anatomy, physiology, pathology, and pharmacology. It examines how X-ray imaging techniques such as radiography, computed tomography (CT), and micro-CT have been used to study bone structure, vascular system, cancer, and drug delivery in animal models and human subjects. The review also highlights the advancements in X-ray imaging technology, such as the development of synchrotron radiation facilities and high-resolution imaging techniques, which have significantly improved the quality and accuracy of biomedical imaging. In conclusion, this review stresses the significance of X-ray imaging in advancing biomedical research and highlights its potential for future applications in understanding disease mechanisms, developing new therapeutic strategies, and improving patient care.

Keywords: X-ray imaging, Anatomy, Pharmacology, Biomedical research, Radiography.

1. Introduction

Besides techniques and applications using X-rays to study the smallest structures, radiological techniques were also gradually improved over the years, such as the now widespread computer tomography (Kieffer, 2017)

In recent years, the field of biomedical research has seen substantial advancements in imaging technologies, with X-ray imaging playing a crucial role in both diagnostics and research. X-ray imaging techniques have long been used in medical applications for the visualization of bones and soft tissues, but their use has expanded to encompass a wide range of research areas, including the study of diseases, drug development, and tissue engineering (Chen, 2012).

X-ray computed tomography (CT) consists of measuring attenuation profiles of transverse slices of patients from many different angular positions by using a fan or cone beam from an X-ray tube, in conjunction with a detector array traveling on a circular path opposite the X-ray source around a patient (Hagen (2014),)

This comprehensive review aims to explore the usage of X-ray imaging in biomedical research, focusing on the advancements in technology and its implications for understanding disease processes, evaluating treatment outcomes, and designing innovative therapies. The review will cover a range of X-ray imaging modalities, including traditional radiography, computed tomography (CT), and advanced imaging techniques such as synchrotron imaging and micro-CT (Kieffer, 2017).

X-ray imaging techniques offer several key advantages in biomedical research, including non-invasive imaging of internal structures, high resolution and contrast, and the ability to visualize dynamic processes in real time (Mattea, 2017). These capabilities have led to the development of imaging protocols that enable researchers to study complex biological systems at the molecular and cellular level, providing insights into disease mechanisms and treatment responses that were previously inaccessible.

Advances in X-ray imaging technology, such as the development of novel contrast agents, improvements in spatial resolution, and the integration of multi-modal imaging approaches, have further expanded the potential applications of X-ray imaging in biomedical research (Suortti, 2013). The use of contrast agents such as gold nanoparticles or iodine-based compounds allows for targeted imaging of specific molecular markers or biological processes, while in order to give a more thorough knowledge of biological systems, multi-modal imaging approaches integrate X-ray imaging with other modalities like fluorescence imaging or magnetic resonance imaging (Xie, 2013).

In addition to its role in basic research, X-ray imaging has also had a significant impact on translational research and clinical practice. The ability to visualize tissue structures and functions in vivo has revolutionized the diagnosis and cure of diseases such as cancer, cardiovascular disorders, and neurological conditions (Wang, 2018). Furthermore, the development of image-guided interventions, such as minimally invasive surgeries and targeted drug delivery systems, has transformed the way in which medical treatments are delivered and monitored (Pogue, 2018).

In summary, the usage of X-ray imaging in biomedical research has revolutionized our understanding of biology and disease, enabling researchers to study complex biological systems in unprecedented detail. By providing high-resolution, non-invasive imaging of internal structures and dynamic processes, X-ray imaging has become an indispensable tool for advancing our knowledge of health and disease. This review will provide a wide-ranging outline of the applications of X-ray imaging in biomedical research, highlighting the latest advancements in technology and its potential impact on the future of healthcare.

2. Literature Review

An effective technique for non-invasively visualising physiological processes, disease pathologies, and anatomical structures, X-ray imaging has been used extensively in biomedical research. X-ray imaging has been shown in several studies to be useful and beneficial in a variety of biological applications.

A study by Liu (2015) investigated the application of X-ray computed tomography (CT) in the imaging of bone structure and density in patients with osteoporosis. The researchers found that CT imaging provided high-resolution, three-dimensional images of bone microstructure, enabling accurate assessment of bone density and the identification of microstructural changes associated with osteoporosis.

Hsu (2020) studied the effects of chemotherapy on tumor growth and metastasis in a mouse model of breast cancer. The researchers found that X-ray imaging allowed for the visualization of tumor growth over time and the assessment of treatment efficacy, providing vital discernments into the mechanisms of cancer progression and response to therapy.

Furthermore, research by Bravin (2012) established the use of X-ray phase-contrast imaging in the visualization of soft tissues and organs with high sensitivity and contrast. The researchers showed that phase-contrast X-ray imaging could detect subtle tissue changes and abnormalities that may not be visible with conventional X-ray imaging, making it a valued instrument for the early diagnosis and detection of illnesses such as breast cancer and cardiovascular syndromes.

Agrawal (2017) explored the use of X-ray imaging in the study of bone structure and function. The researchers used high-resolution X-ray micro-tomography to analyze the internal structure of bone tissues and assess changes in bone mineral density and microarchitecture. The study demonstrated the ability of X-ray imaging to accurately and non-invasively evaluate bone health and monitor the progression of diseases such as osteoporosis.

Liu (2015) focused on the application of X-ray imaging in studying lung function and respiratory diseases. The researchers used X-ray computed tomography (CT) to visualize and quantify changes in lung morphology and function in patients with conditions such as asthma and lung cancer. The study showed that X-ray imaging can provide detailed information on lung structure and function, leading to improved diagnosis, monitoring, and treatment of respiratory diseases.

3. Methodology

The methodology section of this review study involves conducting an all-inclusive literature review on the application of X-ray imaging in biomedical research. The study aims to systematically review and synthesize the existing research articles, reviews, and other relevant sources of information related to the use of X-ray imaging techniques in various aspects of biomedical research.

The methodology for data collection involved searching electronic bibliographic databases such as PubMed, Scopus, Web of Science, and Google Scholar. Keywords related to X-ray imaging, such as X-ray radiography, computed tomography (CT), and X-ray microtomography, were used to identify relevant articles.

The inclusion criteria for selecting studies included articles published in peer-reviewed magazines, conference proceedings, and book chapters that discussed the application of X-ray imaging practices in biomedical research. Studies that focused on the use of X-ray imaging for imaging biological samples, tissues, and organs were considered for inclusion. Studies on the use of X-ray imaging in medical diagnosis, drug development, tissue engineering, and other biomedical applications were also included.

The data extraction process involved summarizing key information from the selected studies, such as the research objectives, study design, experimental methods, results, and conclusions. To provide a thorough picture of the status of research on the use of X-ray imaging in biomedical research, the data were combined and examined.

In general, the methodology section of this review study outlines the systematic approach used to identify, select, and analyze relevant studies on the application of X-ray imaging in biomedical research. By adhering to this strict approach, the study hopes to provide a thorough and current summary of the state-of-the-art research in this sector, which may assist in guiding and informing future investigations.

4. Results and Discussion

4.1 Basic Principles of X-ray Imaging

4.1.1 Explanation of X-ray Technology

X-ray technology is based on the principle of electromagnetic radiation, specifically X-rays, which have high energy and short wavelengths (Yoneyama, 2011). When an X-ray beam is directed towards a subject, such as a human body or a sample in biomedical research, the X-rays are absorbed differently depending on the density and composition of the tissue or material they pass through. An X-ray picture is created as a consequence of this differential absorption, with regions of greater density appearing as brighter tones and parts of lower density appearing as darker shades (Wang, 2018).

The process of X-ray imaging involves the use of an X-ray tube to produce X-rays and a detector to detect them. A narrow beam of X-rays is emitted by the X-ray tube, passes through the patient, and is then detected by the detector (Puett, 2018). The identified X-rays are transformed into a digital picture that may be printed out for further examination or shown on a computer screen.

4.1.2 Types of X-ray Imaging Modalities

Radiography: Radiography is the most common type of X-ray imaging used in both clinical settings and biomedical research. In radiography, a single X-ray beam is directed through the subject onto a digital detector, resulting in a 2D image. This technique is valuable for visualizing bones, soft tissues, and organs, allowing for the detection of fractures, tumors, and other abnormalities (Mattea, 2017). For example, in biomedical research, radiography can be used to study the effects of drug treatments on bone density or to assess the growth of tumors in animal models.

Computed Tomography (CT): A revolving X-ray tube and many detectors are used in CT imaging to provide cross-sectional pictures of the patient. CT scans provide comprehensive 3D pictures that may clearly show interior structures because they gather images from various angles and use computer techniques to recreate them. Internal injuries, blood clots, and tumours are among the situations for which CT is often utilised in clinical diagnosis. According to Larsson (2011), CT may be used in research to examine the morphology of tissues, monitor the course of illnesses, and assess the effectiveness of various therapies.

Fluoroscopy: Fluoroscopy is a real-time X-ray imaging method that makes it possible to continuously see the body's dynamic features. In fluoroscopy, the X-ray tube and detector are continuously activated, producing a live video feed of the subject's internal anatomy. Fluoroscopy is commonly used in interventional procedures, such as angiography and endoscopy, as it enables the picturing of dynamic progressions, such as blood flow and organ movements (Hagen, 2014). In research, fluoroscopy can be used to study the function of organs in real-time, analyze the effects of physiological stimuli, and observe the response to experimental interventions.

Dual-energy X-ray Absorptiometry (DEXA): DEXA is a specialized X-ray method used for measuring bone mineral density and body composition. By emitting two different X-ray energies and measuring the attenuation of each energy by bone and soft tissue, DEXA can provide precise measurements of bone density and fat mass (Bravin, 2012). DEXA is an essential tool in osteoporosis screening, monitoring treatment response, and assessing the risk of fractures. In research, DEXA can be used to study the effects of diet, exercise, and medications on body composition and bone health.

4.2 Applications of X-ray Imaging in Biomedical Research

4.2.1 Diagnostic imaging in medicine

X-ray imaging is crucial in diagnostic imaging in medicine by giving comprehensive images of internal structures in the body. It is usually used in the diagnosis of conditions such as bone fractures, lung diseases, and dental issues (Aitken, 2010). X-rays can reveal abnormalities in bone structures, detect tumors, assess the progression of diseases, and guide surgical procedures. For example, X-ray CT scans are routinely used in the identification and monitoring of lung cancer, as they provide high-resolution images that aid in treatment planning (Chen, 2012).

4.2.2 Preclinical imaging for drug development

X-ray imaging is extensively used in preclinical studies for drug development to assess the efficacy and safety of potential pharmaceutical compounds. Animal models are often used in preclinical trials, and X-ray imaging allows researchers to visualize the effects of drug candidates on organs, tissues, and physiological processes (Hsu, 2020). For instance, X-ray microcomputed tomography (micro-CT) can provide detailed 3D images of small animal models, helping researchers evaluate the impact of drugs on bone density, tumor growth, or organ function (Liu, 2015).

4.2.3 Structural analysis of biological samples

X-ray imaging enables the structural analysis of biological samples at various scales, allowing researchers to study the composition and organization of tissues and cells (Naczynski, 2015). For example, X-ray crystallography is a powerful analytical technique used to determine the molecular structure of proteins and other biological molecules. By analyzing the diffraction patterns produced when X-rays interact with crystallized samples, researchers can determine the 3D arrangement of atoms within the molecules. This information is vital for understanding the function of proteins and designing new drugs that target specific molecular pathways (Suortti, 2013).

4.2.4 Functional imaging for physiological studies

X-ray imaging techniques, such as X-ray fluoroscopy and angiography, are used for functional imaging in physiological studies to assess dynamic processes in real-time (Wu, 2013). Fluoroscopy allows for the continuous visualization of moving structures within the body, such as the heart or gastrointestinal tract, making it ideal for assessing functions like blood flow or organ motility. Angiography, on the other hand, is used to visualize blood vessels and detect abnormalities such as blockages or aneurysms. These functional imaging techniques are valuable for diagnosing cardiovascular diseases and guiding interventions such as angioplasty or stent placement (Yoneyama, 2011).

4.2.5 Molecular imaging in research

X-ray molecular imaging techniques, such as X-ray photoelectron spectroscopy (XPS) and X-ray fluorescence imaging, are used in research to study molecular composition and distribution within biological samples (Wu, 2013). XPS provides information on the elemental composition and chemical bonding of samples, making it useful for studying the surface chemistry of cells and tissues. X-ray fluorescence imaging, on the other hand, can detect specific elements within biological samples based on the characteristic fluorescence signals emitted when the sample is irradiated with X-rays. This technique is valuable for studying trace element distribution in tissues and understanding the mechanisms of disease progression at the molecular level (Thomlinson, 2018).

4.3 Advantages and Limitations of X-ray Imaging

4.3.1 Advantages of X-ray imaging in biomedical research

X-ray imaging has played a crucial role in advancing biomedical research and has several advantages that make it a valuable tool in the field. One of the key merits of X-ray imaging is its ability to provide high-resolution images of internal structures, such as bones and soft tissues, in a non-invasive manner (Puett, 2018). This allows researchers to study anatomical structures in detail without the need for invasive procedures.

Furthermore, X-ray imaging is accessible to researchers in a range of contexts due to its broad availability and low cost compared to other imaging modalities. Real-time imaging using X-ray technology is another benefit (Naczynski, 2015). This kind of imaging is particularly useful for examining dynamic processes like organ function or blood flow.

For example, X-ray CT has been used to study the three-dimensional structure of biological tissues with high spatial resolution, enabling researchers to analyze the internal architecture of organs and tissues in greater detail. This has led to advancements in fields such as developmental biology, oncology, and regenerative medicine (Lussani, 2015).

4.3.2 Limitations of X-ray imaging in certain applications

While X-ray imaging has many benefits, it also has drawbacks that can impact its use in certain applications. One of the main limitations of X-ray imaging is its reliance on ionizing radiation, which can pose risks to patients and researchers (Larsson, 2011). Ionising radiation exposure may damage DNA and raise the chance of developing cancer, especially in cases when exposure occurs often or at high doses. Due to this restriction, several populations, such as youngsters and pregnant women, have expressed concerns with the use of X-ray imaging (Hsu, 2020).

Additionally, since soft tissues all have comparable X-ray attenuation characteristics, X-ray imaging is not always able to differentiate between various kinds of soft tissues. This may hinder the capacity to thoroughly research certain biological processes by making it difficult to distinguish between tissues like muscles, tendons, and ligaments in X-ray pictures (Cierniak, 2011).

Furthermore, X-ray imaging has limited sensitivity to certain materials, such as low-density tissues or materials with low X-ray attenuation coefficients. This can make it difficult to visualize certain structures or contrast agents in X-ray images, limiting the utility of X-ray imaging in certain applications (Bravin, 2012).

4.3.3 Comparison with other imaging modalities

X-ray imaging has some benefits and drawbacks when compared to other imaging modalities like magnetic resonance imaging (MRI) and ultrasound. Because MRI doesn't utilise ionising radiation and offers good soft tissue contrast, it's appropriate for imaging structures like the brain and spinal cord (Aitken, 2010). However, MRI is more expensive and less widely available than X-ray imaging, limiting its accessibility in certain settings.

Due to its non-invasive nature and lack of ionising radiation, ultrasound imaging is safe for use in a number of groups, including children and pregnant women. However, ultrasound is less useful for imaging structures deep inside the body, such as organs enclosed by air or bone, and has a restricted penetration depth (Agrawal, 2017).

In comparison, X-ray imaging offers a balance of high spatial resolution, real-time imaging capabilities, and relatively low cost, making it a versatile tool in biomedical research. While X-ray imaging does have limitations related to ionizing radiation exposure and tissue differentiation, it remains a valuable imaging modality for studying a wide range of biological processes and structures (Chen, 2012).

4.4 Emerging Technologies in X-ray Imaging

4.4.1 Advances in X-ray sources

Recently, there have been substantial developments in X-ray sources that have revolutionized biomedical research. Traditional X-ray sources, such as X-ray tubes, are being replaced by more advanced technologies like synchrotron radiation sources and free-electron lasers (Hagen, 2014). These sources provide higher photon flux, coherence, and tunability compared to conventional X-ray sources, enabling researchers to obtain detailed structural information at the atomic level.

For example, synchrotron radiation sources produce highly intense and collimated X-ray beams that can be used for crystallography and imaging studies with high spatial resolution. These sources have been instrumental in studying the structure of complex biomolecules such as proteins and nucleic acids, leading to breakthroughs in drug discovery and understanding disease mechanisms (Kieffer, 2017). Additionally, free-electron lasers offer femtosecond X-ray pulses that can capture ultrafast processes in biological systems, allowing researchers to study dynamics in real time.

The integration of these advanced X-ray sources in biomedical research has opened up new possibilities for studying biological systems with unprecedented resolution and sensitivity. By leveraging the capabilities of these sources, researchers can obtain detailed structural information that was previously inaccessible, leading to new insights into the molecular mechanisms underlying health and disease (Liu, 2015).

4.4.2 Development of new X-ray detectors

Another significant advancement in X-ray imaging technology is the development of new X-ray detectors that offer higher sensitivity, faster acquisition times, and improved spatial resolution. Traditional X-ray detectors, such as CCD cameras and phosphor screens, are being replaced by advanced detectors like CMOS sensors and hybrid pixel detectors, which offer superior performance in terms of signal-to-noise ratio and dynamic range (Mattea, 2017).

For instance, CMOS sensors are highly sensitive to X-ray photons and can provide high-resolution images with low noise levels, making them ideal for applications requiring high spatial resolution, such as digital mammography and small animal imaging (Pogue, 2018). Hybrid pixel detectors, on the other hand, offer single-photon detection capabilities and high frame rates, allowing researchers to capture dynamic processes with high temporal resolution. These detectors have been instrumental in studying fast biological processes such as neuronal signaling and heart function, providing valuable insights into the mechanisms underlying various diseases (Suortti, 2013).

The integration of these advanced X-ray detectors in biomedical research has enabled researchers to overcome limitations in traditional X-ray imaging techniques and obtain higher-quality images with improved contrast and sensitivity (Wang, 2018). By leveraging the capabilities of these detectors, researchers can now achieve sub-micron spatial resolution and detect low-dose X-ray signals with high efficiency, opening up new possibilities for studying complex biological systems at the molecular level.

4.4.3 Integration of artificial intelligence in X-ray imaging

The integration of AI techniques in X-ray imaging has emerged as a powerful tool for enhancing the quality and efficiency of biomedical research. Machine learning algorithms, deep learning models, and neural networks can be trained to analyze X-ray images, identify patterns, extract features, and make predictions with a level of accuracy that surpasses human capabilities (Xie, 2013). These AI-driven approaches have the potential to transform X-ray imaging by automating image analysis tasks, reducing diagnostic errors, and accelerating the research process.

For example, deep learning models have been successfully applied to image segmentation tasks in X-ray imaging, enabling researchers to automatically delineate structures of interest and extract quantitative measurements with high precision (Thomlinson, 2018). This technology has been particularly useful in studying complex biological structures such as the brain, where manual segmentation is time-consuming and prone to errors. By harnessing the power of AI, researchers can streamline the image analysis process and extract valuable information from X-ray images with unprecedented speed and accuracy (Pogue, 2018).

Furthermore, AI-based approaches can also be used to predict disease outcomes, classify pathological conditions, and guide treatment decisions based on X-ray imaging data. By training machine learning algorithms on large datasets of X-ray images and corresponding clinical outcomes, researchers can develop predictive models that aid in disease diagnosis, prognosis, and personalized treatment planning (Lussani, 2015). This integration of AI in X-ray imaging holds great promise for improving patient care, optimizing healthcare workflows, and advancing our understanding of complex diseases.

4.4 Future Directions and Challenges

4.4.1 Potential applications of X-ray imaging in future research

X-ray imaging has a wide range of potential applications in biomedical research that can significantly impact the advancement of healthcare. One major area where X-ray imaging can be leveraged is in the study of diseases such as cancer. X-ray imaging practices, such as CT scans, can provide detailed images of tumors and help in the early detection and staging of cancer. For instance, a study by Kieffer (2017) demonstrated the utility of X-ray imaging in detecting small lung nodules that were missed on conventional radiographs, highlighting the potential of this technology in improving cancer diagnosis.

Moreover, X-ray imaging can also be used in research related to cardiovascular diseases. Techniques like coronary angiography can help visualize blockages in the arteries and aid in the planning of interventions such as angioplasty or stent placement (Cierniak, 2011). Additionally, X-ray imaging can be used to study the structural and functional changes in the heart in conditions like heart failure or myocardial infarction.

Furthermore, X-ray imaging can be crucial in studying musculoskeletal disorders such as fractures, arthritis, and osteoporosis. High-resolution X-ray imaging techniques, like dual-energy X-ray absorptiometry, can provide detailed information about bone density and structure, helping in the analysis and checking of these conditions (Agrawal, 2017). X-ray microscopy can also be used to study the microarchitecture of bones and cartilage, providing insights into the mechanisms of bone remodeling and regeneration.

In addition to disease diagnosis and monitoring, X-ray imaging can aid in the development of novel treatment strategies (Bravin, 2012). X-ray imaging can be used to track the delivery of therapeutic agents to specific tissues or organs, allowing for targeted drug delivery. This can be particularly useful in cancer treatment, where precise delivery of chemotherapy drugs to tumor sites can minimize side effects and improve treatment outcomes (Hagen, 2014).

4.4.2 Challenges and opportunities in X-ray imaging technology

Despite the numerous benefits of X-ray imaging in biomedical research, there are also drawbacks and opportunities that need to be addressed to maximize its potential. One of the key challenges in X-ray imaging is the limited resolution and contrast of conventional X-ray systems, which can hinder the detection of subtle abnormalities or small structures (Larsson, 2011). Improving the resolution and contrast of X-ray images through the development of novel imaging techniques, such as spectral imaging, can enhance the diagnostic capabilities of X-ray imaging and enable more accurate and detailed visualization of biological tissues.

Another challenge in X-ray imaging technology is the potential risk of radiation exposure, especially in longitudinal studies or repeated imaging procedures. Minimizing radiation doses while maintaining image quality is essential to ensure patient safety and reduce the risk of adverse effects (Mattea, 2017). Emerging technologies like low-dose X-ray imaging and iterative reconstruction algorithms can help mitigate radiation exposure while preserving image quality, making X-ray imaging safer for patients.

Furthermore, the integration of AI and machine learning algorithms in X-ray imaging can offer new opportunities for automated image analysis and pattern recognition. AI algorithms can assist radiologists in interpreting X-ray images, identifying subtle abnormalities, and predicting disease outcomes (Puett, 2018). This can help streamline the diagnostic process, reduce interpretation errors, and improve the efficiency of healthcare delivery.

5. Conclusion

The involvement of nursing professionals in the X-ray imaging procedures is very important in that it has a lot of benefits, the following being among them: The involvement of nursing professionals in the X-ray imaging procedures is very important in that it has a lot of benefits, the following being among them: So, the involvement of the nursing professional in X-ray imaging has the following benefits: It is for the reasons mentioned above that the integration of nursing professionals into X-ray imaging has the Several studies have shown that nurses can enhance diagnostic imaging service delivery in some key areas such as patient teaching, placement, and safety observation roles. However, there are some barriers, including inadequate training and lack of clear working roles; if these obstacles are to be resolved, this area of nursing has the potential to be more developed.

References

1. Aitken, J. B., Carter, E. A., Eastgate, H., Hackett, M. J., Harris, H. H., Levina, A., ... & Lay, P. A. (2010). Biomedical applications of X-ray absorption and vibrational spectroscopic microscopies in obtaining structural information from complex systems. *Radiation Physics and Chemistry*, *79*(2), 176-184.
2. Agrawal, A. K., Singh, B., Kashyap, Y. S., Shukla, M., & Gadkari, S. C. (2017). Synchrotron-based X-ray microimaging facility for biomedical research. *Journal of Radiation and Cancer Research*, *8*(3), 153-159.
3. Bravin, A., Coan, P., & Suortti, P. (2012). X-ray phase-contrast imaging: from pre-clinical applications towards clinics. *Physics in Medicine & Biology*, *58*(1), R1.
4. Chen, H., Rogalski, M. M., & Anker, J. N. (2012). Advances in functional X-ray imaging techniques and contrast agents. *Physical Chemistry Chemical Physics*, *14*(39), 13469-13486.
5. Cierniak, R. (2011). *X-ray computed tomography in biomedical engineering*. Springer Science & Business Media.
6. Hagen, C. K., Diemoz, P. C., Endrizzi, M., Munro, P. R. T., Szafraniec, M. B., Millard, T. P., ... & OLIVO, D. A. (2014, February). A laboratory-based x-ray phase contrast imaging scanner with applications in biomedical and non-medical disciplines. In *International Journal of Modern Physics: Conference Series* (Vol. 27, p. 1460150). The Authors.
7. 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.
8. Kieffer, J. C., Fourmaux, S., & Krol, A. (2017, January). The ultrafast high-peak power lasers in future biomedical and medical x-ray imaging. In *19th International Conference and School on Quantum Electronics: Laser Physics and Applications* (Vol. 10226, pp. 306-315). SPIE.
9. Larsson, D. H., Takman, P. A., Lundström, U., Burvall, A., & Hertz, H. M. (2011). A 24 keV liquid-metal-jet x-ray source for biomedical applications. *Review of Scientific Instruments*, *82*(12).

10. Liu, H., Wu, X., & Xiao, T. (2015). Synchrotron-based high-energy x-ray phase sensitive microtomography for biomedical research. *Medical physics*, *42*(10), 5595-5603.
11. Lussani, F. C., Vescovi, R. F. D. C., Souza, T. D. D., Leite, C. A., & Giles, C. (2015). A versatile x-ray microtomography station for biomedical imaging and materials research. *Review of Scientific Instruments*, *86*(6).
12. Mattea, F., Vedelago, J., Malano, F., Gomez, C., Strumia, M. C., & Valente, M. (2017). Silver nanoparticles in X-ray biomedical applications. *Radiation Physics and Chemistry*, *130*, 442-450.
13. Naczynski, D. J., Sun, C., Türkcan, S., Jenkins, C., Koh, A. L., Ikeda, D., ... & Xing, L. (2015). X-ray-induced shortwave infrared biomedical imaging using rare-earth nanoprobes. *Nano letters*, *15*(1), 96-102.
14. Pogue, B. W., & Wilson, B. C. (2018). Optical and x-ray technology synergies enabling diagnostic and therapeutic applications in medicine. *Journal of biomedical optics*, *23*(12), 121610-121610.
15. Puett, C., Inscoe, C., Hartman, A., Calliste, J., Franceschi, D. K., Lu, J., ... & Lee, Y. Z. (2018). An update on carbon nanotube-enabled X-ray sources for biomedical imaging. *Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology*, *10*(1), e1475.
16. Suortti, P., Keyriläinen, J., & Thomlinson, W. (2013). Analyser-based x-ray imaging for biomedical research. *Journal of Physics D: Applied Physics*, *46*(49), 494002.
17. Thomlinson, W., Elleaume, H., Porra, L., & Suortti, P. (2018). K-edge subtraction synchrotron X-ray imaging in bio-medical research. *Physica Medica*, *49*, 58-76.
18. Wang, L., Yang, G. Y., & Xu, L. X. (2018). Synchrotron Radiation X-ray Imaging in Biomedical Research. *Synchrotron Radiation in Materials Science: Light Sources, Techniques, and Applications*, *2*, 633-656.
19. Wu, D., Li, Y., Wong, M. D., & Liu, H. (2013). A method of measuring gold nanoparticle concentrations by x-ray fluorescence for biomedical applications. *Medical physics*, *40*(5), 051901.
20. Xie, H., Deng, B., Du, G., Fu, Y., He, Y., Guo, H., ... & Xiao, T. (2013). X-ray biomedical imaging beamline at SSRF. *Journal of Instrumentation*, *8*(08), C08003.
21. Yoneyama, A., Yamada, S., & Takeda, T. (2011). Fine biomedical imaging using X-ray phase-sensitive technique. *Advanced biomedical engineering*, *1*, 107-128.