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The Role of Artificial Intelligence (AI) in Radiation Protection of Computed Tomography and Fluoroscopy: A Review

Emmanuel Worlali Fiagbedzi[1,2*], Philip Nii Gorleku[1], Savanna Nyarko[1], Vivian Della Atuwo-Ampoh[3], Yawo Atsu Constantino Fiagan[4], Adomako Asare[5]

[1]Uuniversity of Cape Coast, Department of Medical Imaging, Cape Coast, Ghana
[2]Department of Medical Physics, University of Ghana, Accra, Ghana
[3]University of Health and Allied Science, Ho, Ghana
[4]Faculty of Medicine and Pharmacy, Vrije Universiteit Brussel, Brussels, Belgium
[5]Department of Radiology, Komfo Anokye Teaching Hospital, Kumasi, Ghana
Email: *emmanuel2g4@gmail.com, *emmanuel.fiagbedzi@ucc.edu.gh

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Abstract

Background: The medical imaging world is currently changing with the introduction of advanced modalities to help with diagnosis. There is then the need for the application of Artificial Intelligence (AI) in areas such as radiation protection to improve the safety as far as radiations are concerned. This review article discusses the principles, some of the challenges of radiation protection and the possible role of Artificial Intelligence (AI) regarding radiation protection in computed tomography and fluoroscopy exams. **Methods:** A literature search was done using Google Scholar, Science Direct and Pubmed to search for relevant articles concerning the review topic. **Results:** Some of the challenges identified were outdated and old X-ray machines, lack of QA programs on the machines amongst others. It was discovered that AI could be applied in areas like scan planning and positioning, patient positioning amongst others in CT imaging to reduce radiation doses. With fluoroscopy, an AI enabled system helped in reducing radiation doses by selecting the region of interest of pathology and exposing that region. **Conclusion:** The application of AI will improve safety and standards of practice in medical imaging.

Keywords

Artificial Intelligence (AI), Radiations Protection, Computed Tomography, Fluoroscopy

1. Introduction

Medical Imaging, a branch of science with its rapid development is changing the scope of medical practice in the world. It is basically about the techniques applied in the creation of internal images of the human body to aid in the diagnosis and accurate prescription of treatment for diseases [1]. Medical Imaging with its image guided techniques and minimally invasive procedural methods is gradually replacing conventional surgery with speedy recovery rates and minimal post-procedural complications in patients [2]. It comprises ultrasound, conventional X-rays, computed tomography (CT), positron emission tomography (PET), mammography, fluoroscopy, single photon emission computed tomography (S-PECT) and magnetic resonance imaging [3].

Medical Imaging, with the exception of ultrasound and magnetic resonance imaging operates behind the principle of using ionizing radiations to visualize the internal organs of the human body for diagnosis, treatment plans and accurate prescription of medications to aid in treatment and speedy recovery of patients [1]. It also has a special role to play in oncology. With the help of imaging modalities such as the computed tomography, ultrasound and mammography etc, cancers developing in the body especially the breast are detected at early stages. Ionizing radiations are further used to treat cancers in the early and late stages, thus in radiotherapy [4].

Radiations although serving as useful agents in medical imaging can be very harmful when exposed unnecessarily or overexposed to the human body tissues [5]. They have the potential of causing genetic mutations to fetuses, cataracts and cancer even though they are useful agents in radiotherapy [6]. The goal therefore in every radiation-based examination is to achieve accurate diagnosis, plan and prescribe the accurate treatment methods with minimal radiation dose to the patient under examination [7].

Medicine and its practice have been affected positively by the advent of artificial intelligence (AI). Artificial Intelligence is a field of computer science that gives machines the power to function and carry out human-like cognitive functions. These include; problem identification and solving, decision making amongst others [8] [9]. Basically, Artificial Intelligence (AI) involves the development of computer systems and algorithms to undertake tasks that require human intelligence [9] [10]. The AI applications have the ability to affect major areas positively when it comes to radiology. These include workflow management, image acquisition, reconstruction and interpretation, dose optimization and image quality, diagnosis and report writing amongst others [11]. AI in medical imaging has many advantages. It is often used to improve the efficiency of medical scans and minimize radiation exposure. It can also help minimize unwanted scans thereby saving patients from incurring unnecessary cost. The use of AI algorithms for scanning can help improve the efficiency of medical examinations and provide faster access to imaging for a wider variety of patients. It can also benefit both patients and the radiographers by reducing errors and improving the diagnostic process. AI could also help minimize radiation risks by estimating the risks relative to the patient's age and cumulative dose [12]. Auto-reporting of issues related to equipment maintenance can also be automated through the use of AI-based monitoring of scanners. This method allows healthcare facilities to prepare for potential issues and avoid last-minute examinations, save money and provide preventive maintenance services [13]. Furthermore the use of AI in medical imaging has created avenues for radiographers, radiologists and other imaging scientists to seek further training in order to keep abreast with the latest technological advancement. Computer-aided detection and diagnosis are two of the earliest examples of AI in medical imaging. AI-based systems are typically programmed to identify and classify signs of disease, such as cancer. It can detect the presence of disease in a specific part of the body, such as the breast tissue during a mammogram. CAD systems help radiologists interpret the severity of a mass or area of concern [12] [14] [15].

Artificial Intelligence (AI) has sub divisions. The Machine Learning (ML) and Deep Learning (DL). Machine Learning (ML) involves the training of algorithms to undertake specific tasks through the learning of patterns and inferences from datasets [16] [17]. In machine learning, programs of a specific set of logic or mathematical codes are used to turn the input data into output answers. Thus, for every desired answer, a developer has specific codes to input and follow to arrive at it. Deep Learning (DL) on the other hand makes use of neural networks with many layers of mathematical equations to carry out a specific task [7] [18]. Unlike the Machine Learning (ML) which utilizes hand-crafted features which are extracted manually as inputs, deep learning employs multiple stacks of neural layers to function as the human brain [19]. These deep learning-based technologies have the capacity to handle large and enormous datasets, carry out specific yet complex tasks which are beyond human abilities [20] [21] [22].

This review article therefore aims to discuss the principles, some of the challenges in radiation protection and the possible role of artificial intelligence (AI) in radiation protection in computed tomography and fluoroscopy.

2. Radiation Protection: The Principles and Challenges

The exposure of the human body tissues to radiations causes damage. Though radiations serve as useful agents in accurate diagnosis and treatment of various diseases by giving internal pictures and videos of the human body, caution must be taken whenever they are being used. Hence, the need for protection from these radiations [6].

Radiation protection is the art and techniques employed to ensure the safe use of ionizing radiations whiles achieving accuracy and precision. It involves the methods put in place by radiographers, oncologists, and other radiological staffs to prevent the harmful effects of ionizing radiations to patients, workers and the general public [23].

These harmful effects of ionizing radiations are categorized into two depending on the time of exposure, the strength of radiation and the region of body part exposed. Some detrimental effects may occur immediately after exposure, thus deterministic effects whiles others may not show any form of harm until several years later, thus stochastic effects [24].

2.1. Principles of Radiation Protection

For radiation protection to be achieved in every radiological examination, all these principles must be met. These principles are optimization, justification, and dose limitations [5].

2.1.1. Optimization

The principle of optimization in radiation protection means that the depth of protection should be the best, increasing the margin between benefit and harm and taking into account all economic and societal factors [25]. In optimization, the ALARA principle is employed. Thus, medical radiation exposure should always be kept as low as reasonably achievable. Shielding, Time, and Distance are also considered in optimization [26].

1) Shielding

Shielding refers to protecting the personnel and patient's vital organs susceptible to ionizing radiation and also other parts of the body that are not under examination. Some equipment used in shielding are lead aprons, lead gloves, thyroid shields, gonad shields, lead goggles amongst others [27].

2) Time

The longer the time, the higher the radiation dose to the patient. The optimum technique involving the use of high Kilo-voltage (KV) and low milli-ampere seconds (mAs) mode, beam collimation, anti-scatter grids, high-speed films, and processing are very important [28].

3) Distance

Radiation exposure is inversely proportional to the square of the distance. This means when the distance is doubled, the exposure is reduced by a factor of four [5]. According to The International Commission for radiation protection (ICRP) and the National Council for Radiation Protection (NCRP), a recommended distance of 2 m from the radiation source is safe. This will help reduce the dose of ionizing radiation the personnel will receive thereby protecting him from the harmful effects associated with it [25] [28].

2.1.2. Justification

Justification is the weighing and evaluation of decisions that, the radiation exposure will do better than harm. The risk-to-benefit analysis is done to ensure that the benefits of the radiation exposure outweighs the harm involved [29]. This means that when giving radiation exposure to a patient or aiming to minimize an existing exposure or a potential exposure, sufficient benefits to offset the harm it causes should be accomplished [30]. For instance; an X-ray of the broken bone of a young girl will help diagnose and treat the site of fracture than refusing to expose the girl which would be more detrimental to her health [31].

2.1.3. Dose Limitations

Dose limits principles are in place to ensure that individuals in the radiology department are not exposed to any unnecessary amount of radiation. They give standard doses for various examinations and exposures. This is to ensure that the threshold of certain tissues and organs is not exceeded to prevent the harmful effects of ionizing radiations [29].

The dose limitation principle states that the total dose to an individual from regulated sources in planned exposure situations other than medical exposure of patients should not be more than the acceptable limits approved by the Commission [25].

2.2. Challenges in Radiation Protection

Some of the challenges identified in the protection of patients, workers and general public and ensuring the safe use of ionizing radiations are discussed below.

2.2.1. Old and Outdated Diagnostic Imaging Equipment

The world and everything in it including the practice of medicine has changed and still changing. Due to this, there must be constant upgrade in order to match and meet the requirements of this changing world. The use of old and obsolete diagnostic imaging equipment leads to frequent breakdowns, malfunctions and consequently leakages of radiation to patients, workers, and the general public [32].

The age of conventional film and screen imaging has passed and therefore it is essential that hospitals and diagnostic facilities have all old machine replaced with the modern digital X-ray machines. These digital X-ray machines have the ability to reduce repeats and patient doses because of their increased latitudes and dynamic ranges. They are built with highly sensitive image receptors which respond speedily even to low levels of radiation as compared to the conventional screen and film machines [33]. Due to this lower quantity of radiation are required to produce an image.

2.2.2. Lack of Quality Control (QC) Programs on the Diagnostic Equipment

Proper servicing and maintenance of the diagnostic equipment is very key to ensure the safe, effective and prolonged use of the machine. Routine checks, servicing and maintenance of the machine helps the machine function effectively. It also makes it user-friendly as issues such as possible radiation leakage could be identified and the necessary corrective measures put in place before it causes harm to patients, workers and the general public [32]. According to Bwanga *et al.* the maintenance and servicing of their diagnostic equipment were not routinely done which was the major cause of the consistent and frequent machine breakdowns. This challenge could also be as a result of the inadequate medical physicists and biomedical engineers in our hospital [32].

2.2.3. Inadequate and Worn out Personal Radiation Protective Equipment (PRPE)

The PRPE consist of all the apparel and accessories used by radiographers, radiation therapists, and patients to prevent the harmful effects of ionizing radiations. However, these protective clothing are not always available in large quantities and even those available are old and worn out. Examinations like fluoroscopy and theatre radiography which require the radiographer staying in the radiation field becomes a great challenge due to inadequate protective equipment. This protective equipment is made up of lead aprons, thyroid shields, lead gloves, lead-lined goggles, gonad shields, lead caps amongst others [28].

2.2.4. Inadequate Radiation Protection Awareness and Knowledge amongst Practitioners

Continuous education and training are key aspects in any profession. In this changing world, new discoveries come up day in and day out therefore it is important radiographers and radiation therapists constantly upgrade their knowledge as far as the profession, imaging is concerned. In a study by Maina *et al.* [34] to investigate radiation protection and safety measures, a large percentage of the practitioners had unsatisfactory results when their knowledge about radiation protection measures and awareness was assessed.

The above listed challenges and many others give a justification that the implementation of Artificial Intelligence (AI) in radiology and even in oncology will have a positive impact especially with matters concerning radiation protection.

3. Artificial Intelligence: The Possible Role in Radiation Protection

The advent of Artificial Intelligence (AI) is radically changing the practice of medicine as far as radiology is concerned. Though there has not been a total implementation of Artificial Intelligence (AI) but the few implemented sections in radiology have and are still impacting this branch of medicine positively.

The goal of every examination involving radiations is to achieve accuracy and precision in diagnosis and prescription of treatment plans with less radiation doses to the patients. Thus, optimization of the doses the patients receive.

In medical imaging, Computed Tomography (CT) and Fluoroscopy are the two major areas where high radiation doses are produced and as such measures must be put in place to ensure safety and one of such measures is the implementation of Artificial Intelligence (AI) methods [35].

In CT examinations, Artificial Intelligence (AI) techniques can be applied in these stages to reduce radiation doses and its effects.

3.1. In Patient Positioning

The Computed tomography system is designed in such a way that the detector of the X-ray tube which are pairs rotate around a fixed center. This is the isocenter where all patients must be centered. Once a patient is not centered on the isocenter, radiation doses are exposed to other parts of the body. The positioning of patients is done manually by the radiographers and there is the high probability of a mismatch with the isocenter [36]. In a study conducted Booij *et al.*, a manufacturer incorporated a three-dimensional infrared camera and with the use of AI algorithms, specific landmarks on the patient's body to be scanned were detected and all the anatomical areas were captured so as not to miss any pathology in the region of interest. There is also an automatic movement of the couch vertically by the system so that most of the anatomical regions of interest are located at the isocenter. This helps prevent the wrong centering of patients thereby reducing radiation doses patients receive [37].

3.2. In Scan Positioning

Once the patient is centered at the isocenter and a scout image (topogram) is taken, the radiographer manually positions the scan line from a starting point to the ending point. Mostly for the fear of cutting an anatomical region of interest out and missing a possible pathology, the scan fields are normally opened beyond range thereby increasing radiation exposure to the patient. Making references to the clinical indications, AI algorithms have been trained to choose automatically the scan range covering all the anatomic regions of interest and preventing overexposure. This has been evidenced to make the scanning process safer, faster and easier [7]. This is demonstrated in **Figure 1** below where the AI algorithm can select the scan range to cover the lung anatomy (grey box) on both Anterior-Posterior (left) and lateral projections (right) of the chest or the algorithm can select the scan range to cover the cardiac region (dark box) based on clinical indications and history of patient.

3.3. In Image Reconstruction

Image reconstruction involves the selection of parameters by the radiographers manually to refine the images acquired. A greater challenge occurs in low dose setting where the patient is thick and has a large body habitus. Images are deteriorated

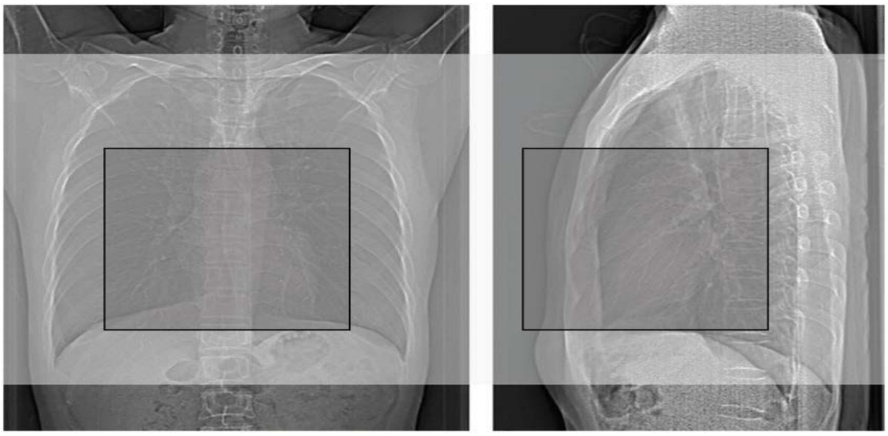

Figure 1. Shows a scout image (topogram) ready for planning with the use of AI to cover the scan range [7].

with a low quality as noise ratio is high [18]. With the help of AI, deep learning (DL) based-algorithms can produce high diagnostic quality images with high reconstruction speed and a reduced radiation dose. An AI based algorithm can therefore remove the all the noise produced on the image in a process known as denoising. A convolutional Neural Network (CNN) based deep learning algorithm help to remove the noise, improving image quality and reducing radiation dose [38]. This is demonstrated in **Figure 2** below.

In **Figure 3**, there is a reduced noise and increased sharpness in B as compared to A. This is possible because of the use of the AI deep learning-based reconstruction to subtract the noise in the images during reconstruction to produce sharp images.

Fluoroscopy is an integral part of radiology and medicine in general. It is

Figure 2. Shows the noise subtraction from the two images (up and down) with a convolutional neural network (CNN) based deep learning algorithm to minimize the noise on the images during reconstruction [7].

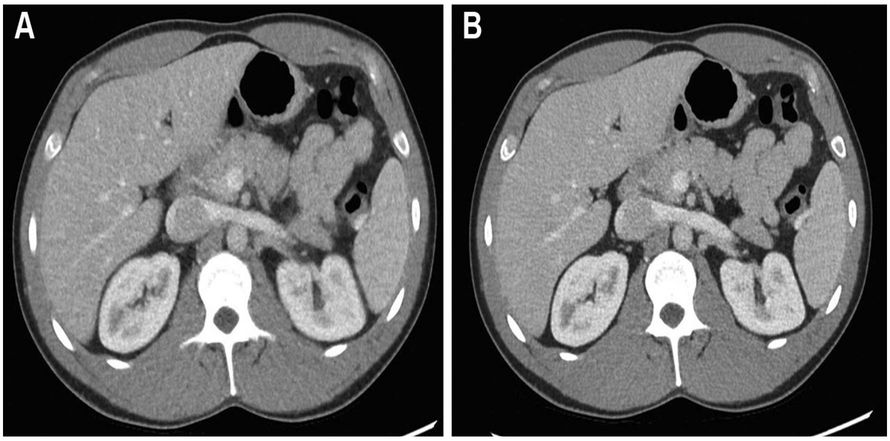

Figure 3. Is a CT axial plane image of the portal venous phase depicting the use of AI to reduce noise and image sharpness [18].

mostly used in advanced surgical examinations such as trauma and orthopedics, cardio, gastrointestinal endoscopy procedures among others. Fluoroscopy facilitates the easy diagnosis and prescription of pathologies as it gives a real time imaging (video) of the internal organs of the body [39].

During fluoroscopy, there is the continuous screening and as such radiation doses are high. This then calls for the high demand for safety measures to operate under during such examinations with the fluoroscopy [40].

A study conducted by Bang *et al.*, on using AI to reduce radiation doses in fluoroscopy, it was discovered that Fluoroshield, a type of fluoroscopy system has AI technology embedded in it for the purposes of radiation protection. Unlike the conventional technology, this Fluoroshield uses ultrafast collimation to reduce radiation exposure during examinations [40]. During fluoroscopic examinations, usually a small anatomical region is of interest to the endoscopists or surgeons. The larger field of view around however is needed for orientation and reference purposes [26] [41]. Usually large doses of radiations are received by the organs in the surrounding area aside the region of interest. With the help of the AI technology, exposures are minimized in the Fluoroshield using secondary collimators to adjust the amount of radiation dose that is received by the organs in the larger area aside the small region of interest. These secondary collimators are embedded with auto region of interest (ROI) processors alongside the AI technology which also regulates the radiation dose from the primary collimator. They help images of the region of interest overly the surrounding area image to give a better view and also enable references to be made easily unlike the conventional E-view system [26] [41]. In **Figure 4**, (A) is a normal conventional E-view of the body part with both the region of interest and surrounding area exposed. (B) is an AI enabled fluoroscopic image with only the site of intervention in profile to reduce radiation doses. (C) is an optimal AI enabled fluoroscopic image with collimations to the region of interest (grey square box) overlying on the surrounding areas for references and orientation purposes.

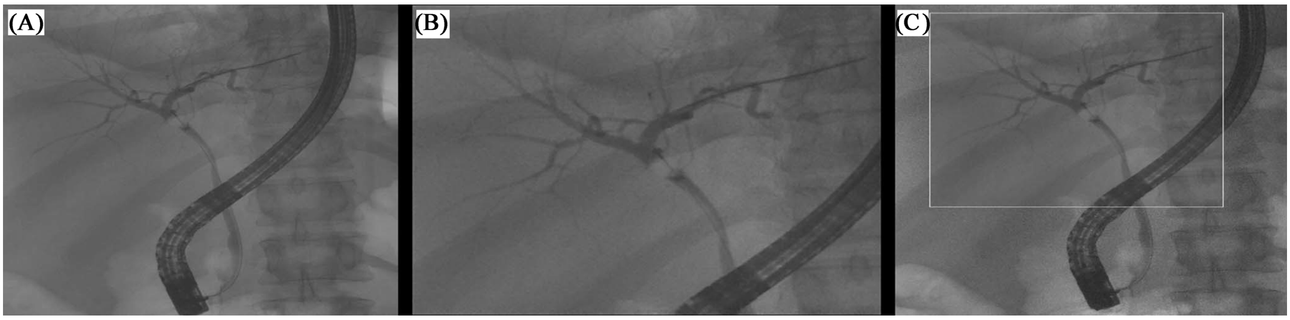

Figure 4. Shows a comparative analysis of three fluoroscopic images [40].

4. Conclusion

The full implementation and the application of Artificial Intelligence (AI) in medical imaging will improve the quality of care, quality and standards of practice and ensure safety as far as radiations are concerned. AI has the potential of giving lasting solutions to some of the challenges concerning radiation protection thereby ensuring effective, improved and a better working environment in the various radiology departments in hospitals and facilities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Laal, M. (2013) Innovation Process in Medical Imaging. *Procedia*: *Social and Behavioral Sciences*, **81**, 60-64. https://doi.org/10.1016/j.sbspro.2013.06.388

[2] Comaniciu, D., Engel, K., Georgescu, B. and Mansi, T. (2016) Shaping the Future through Innovations: From Medical Imaging to Precision Medicine. *Medical Image Analysis*, **33**, 19-26. https://doi.org/10.1016/j.media.2016.06.016

[3] World Health Organization (2016) Communicating Radiation. http://apps.who.int/iris/bitstream/handle/10665/205033/9789241510349_eng.pdf;jsessionid=6CC99F2DA846C12CD10A1DBB6EE42186?sequence=1

[4] Parkinson, C., Matthams, C., Foley, K. and Spezi, E. (2021) Artificial Intelligence in Radiation Oncology: A Review of Its Current Status and Potential Application for the Radiotherapy Workforce. *Radiography*, **27**, S63-S68. https://doi.org/10.1016/j.radi.2021.07.012

[5] Abuzaid, M.M., Elshami, W., Shawki, M. and Salama, D. (2019) Assessment of Compliance to Radiation Safety and Protection at the Radiology Department. *International Journal of Radiation Research*, **17**, 439-446.

[6] Forouharmajd, F., Azam, S. and Ebrahimpour, K. (2021) Effect of Exposure to Ionizing Radiation on Biomarker of Oxidative Damage of DNA. *Journal of Health and Safety at Work*, **11**, 252-264.

[7] Mccollough, C.H. and Leng, S. (2020) Use of Artificial Intelligence in Computed Tomography Dose Optimization. *Annals of the ICRP*, **49**, 113-125. https://doi.org/10.1177/0146645320940827

[8] Seah, L.M.J., Brady, Z., Ewert, K. (2021) Artificial Intelligence in Medical Imaging: Implications for Patient Radiation Safety. *The British Journal of Radiology*, **94**, 1124. https://doi.org/10.1259/bjr.20210406

[9] Avanzo, M., Trianni, A., Botta, F., Talamonti, C., Stasi, M. and Iori, M. (2021) Artificial Intelligence and the Medical Physicist: Welcome to the Machine. *Applied Sciences*, **11**, Article No. 1691. https://doi.org/10.3390/app11041691

[10] Tang, X. (2020) The Role of Artificial Intelligence in Medical Imaging Research. *BJR Open*, **2**, Article ID: 20190031. https://doi.org/10.1259/bjro.20190031

[11] Larson, D.B. and Boland, G.W. (2019) Imaging Quality Control in the Era of Artificial Intelligence. *Journal of the American College of Radiology*, **16**, 1259-1266. https://doi.org/10.1016/j.jacr.2019.05.048

[12] Colvin, K. (2020) Artificial Intelligence and the Future of Radiography. *EMJ Radiology*, **1**, 23-25. https://doi.org/10.33590/emjradiol/20F0901.

[13] Oren, O., Gersh, B.J. and Bhatt, D.L. (2020) Artificial Intelligence in Medical Imaging: Switching from Radiographic Pathological Data to Clinically Meaningful Endpoints. *The Lancet Digital Health*, **2**, e486-e488. https://doi.org/10.1016/S2589-7500(20)30160-6

[14] HCIAC Corporate Roundtable Subcommittee on Artificial Intelligence (2020) The Artificial Intelligence Era: The Role of Radiologic Technologists. American Society of Radiologic Technologists, Albuquerque.

[15] Mun, S.K., Wong, K.H., Lo, S.C.B., Li, Y. and Bayarsaikhan, S. (2021) Artificial Intelligence for the Future Radiology Diagnostic Service. *Frontiers in Molecular Biosciences*, **7**, Article ID: 614258. https://doi.org/10.3389/fmolb.2020.614258

[16] Naqa, I., Giger, M.L. and Ten Haken, R.K. (2020) Artificial Intelligence: Reshaping the Practice of Radiological Sciences in the 21st Century. *The British Journal of Radiology*, **93**, 1106. https://doi.org/10.1259/bjr.20190855

[17] Korreman, S., Eriksen, J.G. and Grau, C. (2021) The Changing Role of Radiation Oncology Professionals in a World of AI—Just Jobs Lost—Or a Solution to the Under-Provision of Radiotherapy? *Clinical and Translational Radiation Oncology*, **26**, 104-107. https://doi.org/10.1016/j.ctro.2020.04.012

[18] Kambadakone, A. (2020) Artificial Intelligence and CT Image Reconstruction: Potential of a New Era in Radiation Dose Reduction. *Journal of the American College of Radiology*, **17**, 649-651. https://doi.org/10.1016/j.jacr.2019.12.025

[19] Barragán-Montero, A., Javaid, U., Valdés, G., Nguyen, D., Nguyen, D., Macq, B., *et al.* (2021) Artificial Intelligence and Machine Learning for Medical Imaging: A Technology Review. *Physica Medica*, **83**, 242-256. https://doi.org/10.1016/j.ejmp.2021.04.016

[20] Peeken, J.C., Bernhofer, M., Wiestler, B., Goldberg, T., Cremers, D., Rost, B., *et al.* (2018) Radiomics in Radiooncology—Challenging the Medical Physicist. *Physica Medica*, **48**, 27-36. https://doi.org/10.1016/j.ejmp.2018.03.012

[21] Kortesniemi, M., Tsapaki, V., Trianni, A., Russo, P., Maas, A., Källman, H.-E., *et al.* (2018) The European Federation of Organisations for Medical Physics (EFOMP) White Paper: Big Data and Deep Learning in Medical Imaging and in Relation to Medical Physics Profession. *Physica Medica*, **56**, 90-93. https://doi.org/10.1016/j.ejmp.2018.11.005

[22] Vandewinckele, L., Claessens, M., Dinkla, A., Brouwer, C., Crijns, W., Verellen, D., *et al.* (2020) Overview of Artificial Intelligence-Based Applications in Radiotherapy: Recommendations for Implementation and Quality Assurance. *Radiotherapy and Oncology*, **153**, 55-66. https://doi.org/10.1016/j.radonc.2020.09.008

[23] Sharma, M., Singh, A., Goel, S. and Satani, S. (2016) An Evaluation of Knowledge and Practice towards Radiation Protection among Radiographers of Agra City. *Scholars Journal of Applied Medical Sciences*, **4**, 2207-2210. https://doi.org/10.21276/sjams.2016.4.6.70

[24] Aras, S., Tanzer, I.O. and Ikizceli, T. (2020) A Survey Study of Radiation Protection Awareness among Radiology Technicians in Mogadishu, Somalia. *Radiation Protection Dosimetry*, **192**, 36-40. https://doi.org/10.1093/rpd/ncaa191

[25] López, P.O., Dauer, L.T., Loose, R., Martin, C.J., Miller, D.L., Vañó, E., *et al.* (2018) ICRP Publication 139: Occupational Radiological Protection in Interventional Procedures. *Annals of the ICRP*, **47**, 1-118. https://doi.org/10.1177/0146645317750356

[26] Nir, G., Machan, L.S., Donnellan, F., Brounstein, A.B.M., Singh, K., Gordon Wait, D., *et al.* (2021) Automatic Detection and Tracking of the Region of Interest during Fluoroscopy-Guided Procedures for Radiation Exposure Reduction. *Proc. SPIE*, **11598**, Article ID: 1159828. https://doi.org/10.1117/12.2580729

[27] Marsh, R.M. and Silosky, M. (2019) Patient Shielding in Diagnostic Imaging: Discontinuing a Legacy Practice. *American Journal of Roentgenology*, **212**, 755-757. https://doi.org/10.2214/AJR.18.20508

[28] Lakhwani, O.P., Dalal, V., Jindal, M. and Nagala, A. (2019) Radiation Protection and Standardization. *Journal of Clinical Orthopaedics and Trauma*, **10**, 738-743. https://doi.org/10.1016/j.jcot.2018.08.010

[29] Lukoff, J. and Olmos, J. (2017) Minimizing Medical Radiation Exposure by Incorporating a New Radiation "Vital Sign" into the Electronic Medical Record: Quality of Care and Patient Safety. *The Permanente Journal*, **21**, 1-8.

[30] Clement, C., Rühm, W., Harrison, J., Applegate, K., Cool, D., Larsson, C.-M., *et al.* (2021) Keeping the ICRP Recommendations Fit for Purpose. *Journal of Radiological Protection*, **41**, 1390-1409. https://doi.org/10.1088/1361-6498/ac1611

[31] European Society of Radiology (ESR) and European Federation of Radiographer Societies (EFRS) (2019) Patient Safety in Medical Imaging: A Joint Paper of the European Society of Radiology (ESR) and the European Federation of Radiographer Societies (EFRS). *Insights into Imaging*, **10**, Article No. 45. https://doi.org/10.1186/s13244-019-0721-y

[32] Bwanga, O. and Chanda, E. (2020) Challenges in Radiation Protection in Healthcare: A Case of Zambia. *EAS Journal of Radiology and Imaging Technology*, **2**, 7-14.

[33] International Atomic Energy Agency (2015) Worldwide Implementation of Digital Imaging in Radiology. Human Health Series No.28, International Atomic Energy Agency, Vienna. http://www.iaea.org/Publications/index.html

[34] Maina, P.M., Motto, J.A. and Hazell, L.J. (2020) Investigation of Radiation Protection and Safety Measures in Rwandan Public Hospitals: Readiness for the Implementation of the New Regulations. *Journal of Medical Imaging and Radiation Sciences*, **51**, 629-638. https://doi.org/10.1016/j.jmir.2020.07.056

[35] Zhang, Z. and Seeram, E. (2020) The Use of Artificial Intelligence in Computed Tomography Image Reconstruction—A Literature Review. *Journal of Medical Imaging and Radiation Sciences*, **51**, 671-677. https://doi.org/10.1016/j.jmir.2020.09.001

[36] Meineke, A., Rubbert, C., Sawicki, L.M., Thomas, C., Klosterkemper, Y., Appel, E., *et al.* (2019) Potential of a Machine-Learning Model for Dose Optimization in CT Quality Assurance. *European Radiology*, **29**, 3705-3713. https://doi.org/10.1007/s00330-019-6013-6

[37] Booij, R., van Straten, M., Wimmer, A. and Budde, R.P.J. (2021) Automated Patient Positioning in CT Using a 3D Camera for Body Contour Detection: Accuracy in Pediatric Patients. *European Radiology*, **31**, 131-138. https://doi.org/10.1007/s00330-020-07097-w

[38] Gupta, R.V., Kalra, M.K., Ebrahimian, S., Kaviani, P., Primak, A., Bizzo, B., *et al.* (2021) Complex Relationship between Artificial Intelligence and CT Radiation Dose. *Academic Radiology*. (In Press) https://doi.org/10.1016/j.acra.2021.10.024

[39] Shalom, N.E., Gong, G.X. and Auster, M. (2020) Fluoroscopy: An Essential Diagnostic Modality in the Age of High-Resolution Cross-Sectional Imaging. *World Journal of Radiology*, **12**, 213-230. https://doi.org/10.4329/wjr.v12.i10.213

[40] Bang, J.Y., Hough, M., Hawes, R.H. and Varadarajulu, S. (2020) Use of Artificial Intelligence to Reduce Radiation Exposure at Fluoroscopy-Guided Endoscopic Procedures. *The American Journal of Gastroenterology*, **115**, 555-561. https://doi.org/10.14309/ajg.0000000000000565

[41] Sethi, S., Barakat, M.T., Friedland, S. and Banerjee, S. (2019) Radiation Training, Radiation Protection, and Fluoroscopy Utilization Practices among US Therapeutic Endoscopists. *Digestive Diseases and Sciences*, **64**, 2455-2466. https://doi.org/10.1007/s10620-019-05564-z