Journal of Medical Imaging

MedicalImaging.SPIEDigitalLibrary.org

Review of the current status of radiation protection in diagnostic radiology in Africa

Wilbroad Muhogora
Madan M. Rehani

Review of the current status of radiation protection in diagnostic radiology in Africa

Wilbroad Muhogora^{a,*} and Madan M. Rehani^{b,c}

^aTanzania Atomic Energy Commission, Arusha, Tanzania

^bHarvard Medical School, Massachusetts General Hospital, Boston, Massachusetts, United States

^cDuke University, Department of Radiology, Durham, North Carolina, United States

Abstract. The aim of this paper is to review the available published studies from African countries on patient doses and medical radiation protection and identify strengths, weaknesses, and challenges. Papers on radiation doses to patients published until 2016 pertaining to studies in African countries were reviewed. Radiography, interventional radiology, computed tomography (CT), and mammography modalities were covered. In radiography, the entrance surface air kerma values were below the established diagnostic reference levels (DRLs) provided by the International Atomic Energy Agency, European Commission, and National Council on Radiation Protection and Measurements. Patient and staff doses in interventional procedures were not on the higher side when compared with other published reports from developed countries. The dose length product values in CT in many situations were higher than established DRLs. In mammography, the variations of clinical image quality and dose to standard breast between African countries and other countries were insignificant. In conclusion, like in any continent, not all countries in Africa are active, but some have produced good results. The potential for optimization of radiation protection using simple and inexpensive techniques has been demonstrated. The lack of medical physicists is one of the important challenges. © 2017 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: [10.1117/1.JMI.4.3.031202](https://doi.org/10.1117/1.JMI.4.3.031202)]

Keywords: radiation protection in Africa; diagnostic radiology; medical physics; radiation doses to patients in Africa.

Paper 16274SSVR received Dec. 24, 2016; accepted for publication May 17, 2017; published online Jun. 12, 2017.

1 Introduction

There is good information available at the global level on the usage of radiology¹ and some information on inappropriate or unjustified use.^{2–4} The International Atomic Energy Agency (IAEA) has provided opportunities to strengthen radiation protection in developing countries.^{5,6} The extent to which medical physicists meet the standard of education and training requirements varies among countries.⁷ The status of radiation protection in diagnostic and interventional radiology in developing countries in various regions of the world has improved due to implementation of the International Action Plan by the IAEA.^{5,8} For African region, in the early 2000s, there was a lack of information on radiation doses to patients in various diagnostic and interventional procedures, but, in recent years, there have been a series of publications.^{9–22} The aim of this paper is to consolidate information to understand the current status of radiation protection in diagnostic and interventional procedures in African countries and identify challenges and possible strategies for improvement. The paper separately reviews situations for radiography, interventional procedures, computed tomography (CT), mammography, justification, optimization, and awareness on radiation protection.

2 Status of Radiation Protection in Africa

2.1 Radiation Protection in Radiography

Radiography in a large part of Africa continues to be conventional film based rather than digital [computed radiography (CR)

and digital radiography (DR)]. In some countries, even calcium tungstate screens with emission in the blue range and a screen speed of 200 have been used rather than rare earth screen with emission in the green range and a screen speed of 400 in x-ray cassettes.^{9–16} Accordingly, actions have been taken by the IAEA in the past to motivate and support the change of calcium tungstate screens to rare earth screens. It must be noted that this single action results in patient dose reduction by about half, and the results are definitive. The results from an IAEA project on image quality and patient dose in radiography had data from six countries, namely, Congo, Ghana, Madagascar, Sudan, Tanzania, and Zimbabwe.¹⁸ In this study, image quality was subjectively assessed by radiologists as A (clearly accepted), B (accepted with some remarks or reservations), or C (should be rejected). To reduce interobserver variability, radiologists were provided with European Commission (EC) quality criteria to keep in mind while grading.²³ The study indicated that poor image quality (B and C grade) was observed in 4% to 53% of images, and, after optimization actions, the extreme value of 53% was reduced to 37% and 4% to 2%.¹⁸ The average value of poor image quality for all five countries in Africa was 24%, which was reduced to 18%, as can be seen elsewhere.¹⁸ In contrast, the average value of poor image quality for five Asian countries participating in the project was 45%, which was reduced to 35%; for four East European countries, it was 19%, which was reduced to 12%. Thus, the situation for participating African countries was found to be better than Asian countries and closer to East European countries. For participating countries in Africa, the entrance surface air kerma (ESAK) values, taking into account the type of film–screen combination

*Address all correspondence to: Wilbroad Muhogora, E-mail: wmunhogora@yahoo.com

speed in use, were of the order of the diagnostic reference levels (DRLs) provided by IAEA or EC or well below the DRLs. Exceptions were observed for some chest [postero-anterior (PA)], abdomen [antero-posterior (AP)], pelvis (AP), and skull (AP) radiographic examinations. Despite that, lower ESAK variations were observed in Asian and Eastern European countries than in Africa. Further, the common assumption or opinion that radiation doses to patients in developing countries may be higher than those in developed countries is not correct. Other studies in the region corroborate this finding and fail to show higher radiation doses in radiography in Africa.^{14,15}

It should be noted that digital radiography technology (CR and DR) is also in use in the region. Examples of such applications in some African countries show that patient doses are in the range of 0.18 mGy (chest PA) to 10.8 mGy (lumbar spine lateral) for some common CR x-ray examinations, which were different from the doses in film–screen systems as they were lower than 0.3 mGy (chest PA) but higher in the case of lumbar spine Lateral of 5.9 mGy.^{14,15} Literature data in DR show that patient doses are in the range of 0.14 (chest PA) to 9.76 (lumbar spine lateral) mGy^{15,16} and, therefore, are relatively lower than in film–screen systems as expected. The potential for patient “dose creeps” was observed both in CR and DR due to the nature of the techniques. Therefore, the need to carry out optimization of variables that affect patient dose requires emphasis. Like in any continent, not all countries are active, but some have produced good results. Most studies are during the last decade only and momentum seems to be picking up.

2.2 Radiation Protection in Interventional Procedures

Are interventional procedures performed in Africa at a similar frequency as in other regions? Is the practice of radiation safety for patient and staff adequate? Are protective tools available and used? The answers to some of these questions became available through studies coordinated by the IAEA.¹⁹ The data from five countries (Algeria, Kenya, Morocco, Sudan, and Tunisia) covering 17 hospitals indicated the workload of interventional radiology and cardiology procedures of more than 1000 procedures per room in Algeria, Sudan, and Tunisia. The overall distribution in all countries combined indicated nearly 60% diagnostic procedures and 40% therapeutic procedures compared with 73% and 27%, respectively, for Asian countries and 68% and 32%, respectively, for Eastern European countries, who contributed data in the project.¹⁹ Typically, 4% to 5% are pediatric procedures. An immediate observation was that interventional cardiology facilities outnumber interventional radiology, although this is based on the type of participating facilities in the multinational study rather than national surveys.

It has been observed in the above study¹⁹ that interventional radiology and interventional cardiology procedures are currently expanding in African countries. This is in contrast to the decreasing trend in developed countries, such as the United States.²⁴ There are data showing that an increasing percentage of the US population is achieving target blood pressure and cholesterol goals, which is not likely the case in African countries. Thus, increased usage in African countries is expected as more patients need to avail the benefit.

As far as radiation protection measures are concerned, the results for staff protection show that lead aprons are commonly used in all participating hospitals (100%). Further, about 44% of hospitals had lead glass eye wear. Regarding personnel

monitoring, there were certain hospitals in Africa in which either the operator (cardiologist or radiologist) or the radiographer did not routinely have a dosimeter during interventional procedures. The practice included monitoring using one dosimeter.

It can be noted that basic radiation protection practices, such as wearing a lead apron and a personnel dosimeter, are routine in all countries participating in this project, perhaps due to the active support of the IAEA in most developing countries in the area of radiation protection. There is a need to enhance the routine use of either lead glass eyewear or a lead protective screen in 100% of cases. As recommended by the International Commission on Radiological Protection, the use of two dosimeters, especially for the operator, is desirable (one over and one under the lead apron).^{19,25}

For patient protection, it was observed that four out of five participating countries in the above list had some machines with kerma-area product (KAP) installed in angiography machines; the exception was Sudan. Data from most centers indicated that very few patients having KAP > 300 Gy · cm² in percutaneous coronary interventions and nearly 50% patients had KAP < 100 Gy · cm².

A study from Sudan on 461 patients in a hospital indicated a higher fluoroscopy time for the percutaneous transluminal coronary angioplasty procedure as compared with European countries.¹¹ It inferred that proper selection of irradiation area, technique modes, and fluoroscopy time and conducting special training on radiation protection to the operators are the main factors for potential optimization. Another study from Kenya¹² collected data from all four Kenyan hospitals carrying out interventional radiology and cardiology procedures. Real-time measurement of radiation dose to patients and staff during these procedures was done using KAP and fluoroscopy time and peak skin dose using EDR2 films. The observations were that patient doses were not on the higher side when compared with other published reports or reference values. It is difficult to find publications from other countries in the region other than those cited above. There is a need to have KAP meters in all x-ray fluoroscopy equipment for patient dose monitoring and optimization. While there is momentum in selected countries in the region and the status of radiation protection looks good, there is lack of information from a large number of countries.

2.3 Radiation Protection in Computed Tomography

CT is a most challenging imaging modality not only for its widespread applications but also for radiation risks for which it has remained much in news.²⁶ The information available from countries in Africa on this modality is reasonable.^{9,10,13,17,20–22}

Initial studies through IAEA published in 2009 had data from seven countries in the region, namely, Algeria, Ghana, Morocco, Kenya, Sudan, Tanzania, and Tunisia.²⁰ The weighted computed tomography dose index (CTDI_w) values for CT of chest, chest high resolution, abdomen, lumbar spine, and pelvis were compared with European DRLs and with data from Asian and East European countries. Since the majority of equipment was non-helical, CTDI_w was used. The mean values of CTDI_w in Africa for adults were 9.2 to 24.3 mGy (chest), 6.8 to 25.8 (mGy) (chest high resolution), and 11.9 to 38.8 (lumbar spine). Others were 11.9 to 22.7 mGy (abdomen) and 7.3 to 26 mGy (pelvis), and all values were below the European DRLs.²⁷ Even the upper values of the range were in most cases below the DRLs. The ratio of maximum to minimum values of CTDI_w was higher than those in East European countries although they

were in a similar range as Asian countries. Thus, based on CTDI_w values and assuming that the equipment is calibrated to provide correct CTDI_w values, it was reassuring not only to rule out higher CTDI_w values than DRLs but also that they are on lower side in the range and in a similar range as Asian countries. The DLP values in many situations were higher than DRLs, indicating that scan length is not optimized. Similar findings were also observed in Asia and East European data.

A multinational study on radiation protection of children in CT examinations in 40 less resourced countries conducted by IAEA had data from Algeria, Sudan, and Tanzania.^{17,21} It showed that patient dose records were kept at 14% of the participating CT facilities in Africa, compared with 49% in Europe, 49% in Asia, and 36% in Latin America. Even though the number of hospitals included in the multinational study was limited, there is indication that such records are kept in fewer countries in Africa as compared with European and Asian countries. Fewer centers responded on the availability of medical physicists in Africa: 2/7 (29%) in Africa, 34/60 (57%) in Europe, 32/63 (51%) in Asia, and 3/11 (27%) in Latin America. There is 2 to 3 time more utilization of CT for pediatric patients in Africa as compared with Eastern Europe. Lack of access to previous images was reported more from African participating centers than from other regions. Furthermore, an overview of global situation is available in publications.^{3,28}

Some national initiatives are also reported in the literature. For example, a study in Nigeria by Garba et al.¹³ on 54 adult patients undergoing head CT showed the third quartile values of CTDI_w and DLP to be 77 mGy and 985 mGy · cm, respectively. These values were significantly higher than most of the reported data in the literature. Another study on pediatric patients⁹ indicated that imaging protocols were not adapted to the patient's weight in certain CT machines for head, abdomen, and chest procedures. The respective DLP values of 772, 446, and 178 mGy cm were obtained and found to be higher than those available in other countries. A study by Korir et al.¹⁰ in Kenya found variable DLP values among the facilities with 50% being above DRLs in the literature. Such a situation was attributed to human factors, i.e., selection of suboptimal protocols, inappropriate uses of slice thickness, and extended scan length. Despite such achievements, there is paucity of published information on optimization actions.

2.4 Radiation Protection in Mammography

A multinational study through IAEA included some countries from Africa and was focused on the potential for optimization in mammography.²⁹ Under this study, which involved the evaluation of clinical and physical image quality as well as patient dosimetry using standard methods,^{29,30} three African countries, namely, Ghana, Uganda, and Tanzania, had the opportunity to participate. Clinical image quality evaluation was graded as A, B, or C with European quality criteria³⁰ acting as a guiding tool for grading.

Common features in need of corrective measures in many facilities were mainly film processing, damaged or scratched image receptors, film–screen combinations that are not spectrally matched, inappropriate radiographic techniques, and lack of training.²⁹ Dose to standard breast as average glandular dose in two phases was evaluated using a standard 45-mm block of Perspex as a breast substitute and suitable conversion factors. For practical reasons, only 24 facilities out of 54 facilities

(44.4%), including one facility in Africa, managed to participate in the second phase that assessed the impact of optimization.

The results of both clinical image quality and dose to standard breast between 3 African countries and 14 countries from other regions, mostly Eastern Europe, were reported.²⁹ Overall, after optimization, the frequency of poor quality images decreased, but the relative contributions of the various causes remained similar. Image quality improvements following appropriate corrective actions varied in different centers and were up to 50% in some facilities in all countries, with no specific findings for African countries. The study concluded that poor image quality was a major source of unnecessary radiation dose to the breast. The study demonstrated how simple and low-cost measures can be a valuable tool in improving image quality in mammography.

3 Challenges Facing Radiation Protection in Diagnostic Radiology

3.1 Justification of Diagnostic Procedures

It is imperative that diagnostic procedures be well-justified to avoid unnecessary radiological examinations. In limited studies conducted in less resourced countries, including those in the African region, appropriateness criteria for referral for CT examinations in children varied among different countries and did not always follow guidelines set by the agencies.¹⁷ One reason is the inadequate number of physicians as is also evident from a UNSCEAR report that indicates that for health care levels III and IV, in which the majority of African countries fit, one physician serves a population of 3000 to 10,000 for health care level III and more than 10,000 for health care level IV,¹ whereas for healthcare level II, the number is one physician for 1000 to 3000 and for level I, it is at least one physician for 1000. As indicated, the number of physicians could just be one element but not the only one.

3.2 Limited or Absent Optimization of Radiation Protection and Safety

It can be noted that many publications from a number of countries already cited above deal with survey of doses. Despite that, regular patient dosimetry and image quality assessment are uncommon while optimized protocols and DRLs are still underdevelopment.^{28,31,32} There is also evidence that simple but inexpensive measures, such as use of appropriate exposure parameters, immobilization of patients, proper collimation, and shielding of sensitive organs, are not always applied.^{17,20,28,33,34} Limited availability of protective tools contributes to lack of optimization as well as lack of use of optimization methods. Non-availability of national or local DRLs also contributes to this lack of optimization as few countries have developed such tools.³⁵

3.3 Inadequate Radiation Protection for Pediatric Patients

The lack of appropriateness of the procedures, nonuse of pediatric protocols, and nonuse of immobilization devices have been reported in a number of African countries.^{10,11,13,20}

3.4 *Inadequate Number or Lack of Medical Physicists*

This challenge is likely to be a major causative factor of other challenges described earlier. In studies conducted, among other things to know if hospitals have access to the services of qualified physicists in diagnostic radiology or not, very few African countries indicated availability of these professionals.^{11,17} Actions to increase the number of qualified and skilled medical physicists are needed.

3.5 *Limited Awareness on the Need for Radiation Protection in Diagnostic Radiology*

Studies done in several parts of world, especially in high resource countries, indicate that there are strong education and training programs in medical physics and professional organizations that support and promote training. In the African region, a similar situation is still in the formative stage for its Federation of African Medical Physics Organization (FAMPO). Consequently, limited activities are reported in the region and, hence, limited appropriate awareness on radiation protection issues. This is evidenced in some studies where simple and inexpensive tools could be effective for improving the radiation protection of patients but were not being implemented.^{17,19,22,29}

4 Discussion

Many success stories on radiation protection in Africa are the results of the positive impact of IAEA activities in the region.^{5,8,17–22,28,29,32–34} Such positive developments are mainly reflected from the IAEA regional projects implemented from 2005 to to-date. Together with these projects, the administrative support of African governments, hospital managements, and regulatory authorities has also contributed to the achievements.

The achievements of radiation protection programs in diagnostic radiology in Africa can be seen if the current status is compared with the situation in the early 2000s. First, there is greater awareness of radiation protection issues with regards to justification, optimization, and/or use of dose constraints as evidenced from publications after 2000.^{5,36} This awareness has resulted in high enthusiasm among major interested parties. Second, basic information on radiation protection in diagnostic radiology, including patient dose and image quality, is now available.^{9–24} Third, the potential for optimization of radiation protection using simple and inexpensive techniques has been demonstrated, upon which further developments can be made.^{5,28,29,33,34} Fourth, a number of staff have been trained in radiation protection principles, justification of medical procedures, and medical exposure control.^{5,8} This is evidenced in studies undertaken in African countries in general radiography, fluoroscopy, mammography, CT scanning, and interventional procedures.^{9–22,29,33,34} As a result of the mentioned achievements, there is a potential for improved outreach of radiation protection in diagnostic radiology that can contribute to related sustainable programs.³⁶

Despite the aforementioned achievements, some challenges have been discussed in this paper. It can be observed that these challenges are largely due to economy-related factors rather than willingness to implement radiation protection programs. Probably, such impeding factors can also be found in other regions of world, excluding Europe, North America, Australasia, and other specific individual countries. Within the constraints of economic factors and based on success

achieved so far, there is a bright future for Africa if awareness campaigns on radiation protection in diagnostic radiology are strengthened and readily accepted by key interested parties. For sensitization purposes, the IAEA website dedicated to address various issues related to radiological protection of patients³⁷ can be useful.³⁶

An inadequate number or lack of clinical medical physicists is mainly responsible for ineffective radiation protection programs in diagnostic radiology in Africa. In other parts of world, there is active involvement of medical physics organizations. Some of these organizations are the European Federation of Organization in Medical Physics, the Asia-Oceania Federation of Organization for Medical Physics, the Southern Asian Federation of Organizations of Medical Physics, and the American Association of Physicists in Medicine. Such a situation in Africa is developing, and joint efforts by FAMPO and other national organizations can bring hope to the future of medical physics and, thus, of radiation protection in diagnostic radiology in Africa.

Unjustified imaging is a global problem, not only in Africa, and its magnitude cannot be inferred to be higher in Africa. The reasons for unjustified imaging vary from defensive medicine in a legal conscious society, such as the United States, to the lack of active participation of radiologist in decision making in many other countries as examinations are simply performed based on referral by referring physician and radiologists hardly refuses or changes the prescribed imaging by referring physician.

Despite the good achievements and challenges discussed in this review, the main limitation of this study is that only some of the African countries were involved, with the number of these countries varying between radiography, interventional radiology, CT, and mammography practices. Such limited coverage and variation among diagnostic applications might not fully give information related to the specific covered populations. Despite this limitation, the study provides insight on the desirable navigation toward which radiation protection can be improved.

5 Conclusion

Information on radiation dose to patients is available in many African countries, despite the common perception of a lack of information and, hence, the need to create awareness. The potential for optimization of radiation protection using simple and inexpensive techniques has been demonstrated; upon these, further developments can be made. The activities conducted under the support of IAEA have significantly contributed to the improvement of radiological protection in diagnostic radiology in Africa. There is a need to strengthen actions to have more qualified and skilled medical physicists as well as to improve standards.

Disclosures

The authors declare that there is no potential of conflict related to this paper.

Acknowledgments

The authors are grateful to the IAEA for supporting various Technical Cooperation projects on radiological protection of patients. Project counterparts of these projects from participating member states are also thanked for their cooperation during the projects implementation.

References

- United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and effects of ionizing radiation: report to the General Assembly," Annex D, Medical Radiation Exposures, United Nations, New York (2000).
- D. P. Frush, "Deciding why and when to use CT in children: a radiologist's perspective," *Pediatr. Radiol.* **44**, 404–408 (2014).
- M. M. Rehani, "Looking into future: challenges in radiation protection in medicine," *Radiat. Prot. Dosim.* **165**, 3–6 (2015).
- H. Oikarinen et al., "Unjustified CT examinations in young patients," *Eur. Radiol.* **19**, 1161–1165 (2009).
- M. M. Rehani and V. Tsapaki, "Impact of the International Atomic Energy Agency (IAEA) actions on radiation protection of patients in many countries," *Radiat. Prot. Dosim.* **147**, 34–37 (2011).
- International Atomic Energy Agency, "Radiation protection and safety of radiation sources: international basic safety standards," General Safety Requirements, Part 3, IAEA, Vienna (2014).
- International Atomic Energy Agency, "Roles and responsibilities and education and training requirements for clinically qualified medical physicists," IAEA Human Health Series No. 25, IAEA, Vienna (2013).
- M. M. Rehani et al., "International Action Plan of the radiation protection of patients," *Radiat. Prot. Dosim.* **147**, 38–42 (2011).
- A. Sulieman, "Establishment of diagnostic reference levels in computed tomography for paediatric patients in Sudan: a pilot study," *Radiat. Prot. Dosim.* **165**, 91–94 (2015).
- G. K. Korir et al., "National diagnostic reference level initiative for computed tomography examinations in Kenya," *Radiat. Prot. Dosim.* **168**, 242–252 (2016).
- N. A. Ahmed, S. B. Ibraheem, and F. Habban, "Patient doses in interventional cardiology procedures in Sudan," *Radiat. Prot. Dosim.* **153**, 425–430 (2013).
- G. K. Korir et al., "Radiation exposure in interventional procedures," *Radiat. Prot. Dosim.* **152**, 339–344 (2012).
- I. Garba et al., "Computed tomography dose index for head CT in northern Nigeria," *Radiat. Prot. Dosim.* **165**, 98–101 (2015).
- E. Babikir et al., "Radiation dose levels for conventional chest and abdominal x-ray procedures in selected hospitals in Sudan," *Radiat. Prot. Dosim.* **165**, 102–106 (2015).
- E. Elshiekh, I. I. Sulliman, and F. Habban, "A comparative study of adult patient doses in film screen and computed radiography in some Sudanese hospitals," *Radiat. Prot. Dosim.* **165**, 402–405 (2015).
- S. Inkoom et al., "Retrospective patient dose analysis of Ghana's first direct digital radiography system," *Health Phys.* **103**, 133–137 (2012).
- J. Vassileva et al., "IAEA survey of pediatric CT practice in 40 countries in Asia, Europe, Latin America, and Africa: Part 1, frequency and appropriateness," *Am. J. Roentgenol.* **198**, 1021–1031 (2012).
- W. E. Muhogora et al., "Patient doses in radiographic examinations in 12 countries in Asia, Africa, and Eastern Europe: initial results from IAEA projects," *Am. J. Roentgenol.* **190**, 1453–1461 (2008).
- V. Tsapaki et al., "Radiation exposure to patients during interventional procedures in 20 countries: initial IAEA project results," *Am. J. Roentgenol.* **193**, 559–569 (2009).
- W. E. Muhogora et al., "Patient doses in CT examinations in 18 countries: initial results from International Atomic Energy Agency projects," *Radiat. Prot. Dosim.* **136**, 118–126 (2009).
- J. Vassileva et al., "IAEA survey of paediatric computed tomography practice in 40 countries in Asia, Europe, Latin America and Africa: procedures and protocols," *Eur. Radiol.* **23**, 623–631 (2013).
- W. E. Muhogora et al., "Paediatric CT examinations in nineteen developing countries: frequency and radiation dose," *Radiat. Prot. Dosim.* **140**, 49–58 (2010).
- European Commission, "European guidelines on quality criteria for diagnostic radiographic images," Publication EUR 16260 EN, European Commission, Brussels, Belgium (1996).
- M. M. Rehani et al., "Radiological protection in fluoroscopically guided procedures performed outside the imaging department," *J. Ann. ICRP* **40**(6), 1–102 (2010).
- R. F. Riley et al., "Trends in coronary revascularization in the United States from 2001 to 2009," *Circ. Cardiovasc. Qual. Outcomes* **4**, 193–197 (2011).
- M. M. Rehani, "What makes and keeps radiation risks associated with CT a hot topic?" *Am. J. Roentgenol.* **204**, W234–W235 (2015).
- European Commission, "European guidelines on quality criteria for computed tomography," EUR 16262 EN, Luxembourg (1999).
- M. M. Rehani, "CT imaging in a large part of the world: what we know and what we can learn," *Pediatr. Radiol.* **44**(Suppl. 3), 511–514 (2014).
- O. Ciraj-Bjelac et al., "Image quality and dose in mammography in 17 countries in Africa, Asia and Eastern Europe: results from IAEA projects," *Eur. J. Radiol.* **81**, 2161–2168 (2012).
- European Commission, "European protocol on dosimetry in mammography," EUR 16263 EN, European Communities, Luxembourg (1996).
- M. M. Rehani, "Multi-national findings on radiation protection of children," *Pediatr. Radiol.* **44**(Suppl. 3), 475–478 (2014).
- M. M. Rehani, "International Atomic Energy Agency study with referring physicians on patient radiation exposure and its tracking: a prospective survey using a web-based questionnaire," *BMJ Open* **2**, 1–10 (2012).
- J. Vassileva et al., "A study to establish international diagnostic reference levels for pediatric computed tomography," *Radiat. Prot. Dosim.* **165**, 70–80 (2015).
- J. Vassileva and J. M. Rehani, "Patient grouping for dose surveys and establishment of diagnostic reference levels in paediatric computed tomography," *Radiat. Prot. Dosim.* **165**, 81–85 (2015).
- S. Meyer, W. A. Groenewald, and R. D. Pitcher, "Diagnostic reference levels in low- and middle-income countries: early 'ALARA' bells?" *Acta Radiol.* **58**(4), 442–448 (2017).
- M. M. Rehani and O. Holmberg, "IAEA experience in communicating radiation risks through the RPOP website," *Radiat. Prot. Dosim.* **165**, 22–24 (2015).
- International Atomic Energy Agency, "Radiation Protection of Patients," 2013, <https://rpop.iaea.org/RPOP/RPOP/Content/index.htm> (29 May 2017).

Wilbroad Muhogora obtained his doctorate degree in physics at the University of Dar es Salaam, Tanzania, under IAEA/ICTP Sandwich Education and Training Program. He received a considerable professional development boost from participating in training events organized by IAEA and ICTP. He is a member of professional organizations, SRP (UK), IRPS and Science Committee of IOMP. Currently, he is employed by the Tanzania Atomic Energy Commission as a principal radiation health physicist and has published over 30 papers in medical imaging and radiation protection.

Madan M. Rehani is a director in the Global Outreach for Radiation Protection at the Massachusetts General Hospital, Harvard Medical School, and an adjunct professor in medical physics at Duke University, USA. Formerly, he is a radiation safety specialist at the International Atomic Energy Agency for 11 years and prior to that professor and head of the medical physics at the All India Institute of Medical Sciences, New Delhi, India. He has been a member of the International Commission on Radiological Protection since 1997. He is an associate editor of BJR and vice president of IOMP. He has published 200 publications.