

Publisher's Disclaimer. E-publishing ahead of print is increasingly important for the rapid dissemination of science. **Journal of Public Health Research** is, therefore, E-publishing PDF files of an early version of manuscripts that undergone a regular peer review and have been accepted for publication, but have not been through the copyediting, typesetting, pagination and proofreading processes, which may lead to differences between this version and the final one. The final version of the manuscript will then appear in print on a regular issue of the journal. E-publishing of this PDF file has been approved by the authors.

J Public Health Res 2021 [Epub ahead of print]

Citation

Zuzana Bárdyová, Martina Horváthová, Katarína Pinčáková, Darina Budošová. **The importance of public health in radiology and radiation protection.**

J Public Health Res 2021;10:2141 doi: 10.4081/jphr.2021.2141

The importance of public health in radiology and radiation protection

Zuzana Bárdyová, Martina Horváthová, Katarína Pinčáková, Darina Budošová

Trnava University in Trnava, Faculty of Health and Social Care, Univerzitné námestie 1, 918 43 Trnava, Slovakia

Corresponding author: PhDr. Zuzana Bárdyová, PhD.

*e-mail: zuzanabardyova@gmail.com

Competing interests: The authors declare no competing interests.

Abstract

The ionizing radiation belongs to the basic physical factors that can be measured. We forget often about its risks and the possible damage to our health. The imaging methods which use the ionizing radiation increase the diagnostics quality and they have become a certainty for many medical workers. Therefore, they are being used without rational thinking many times. With this is related to increasing the cumulative dose of patients. Next problem can be radiation safety knowledge of medical workers. The enormous increase in the use of sources ionizing radiation in medicine and rapid development, there may be a disproportionate acquisition of radiation safety knowledge of healthcare workers. At the same time, constant attention must be paid to the biological effects of radiation and realize epidemiology studies. In all the areas mentioned the public health has space. However, it is sad that presently, the radiation safety is not considered important enough in Public Health. Based on many sources, it is safe to say that this is a major problem, because the public health itself can play an important role in radiation safety. It is important to point out, that safety and effectivity of using the source of ionizing radiation is one of the main components of Good Medical Practice.

Key words: Education, ionizing radiation, public health, radiation safety, radiology.

Significance for public health

The aim of all radiological methods as well as the Public Health is to lower the mortality and morbidity of individual diseases and thus elongate a patient's life. The Public Health and the Radiation Protection share many of the same aims. The main aim is patient-oriented, and it is about minimizing negative biological effects of the ionizing radiation in medical examinations. The second aim is workers-oriented, who work with the source of the ionizing radiation. This means, that it is a cooperation between Radiation Protection, Public Health and Occupational Health. Public Health can help to minimize the exposure of risk factor – ionizing radiation or to deal with quality in health care – in radiology. The can to cooperate in obtaining the necessary information for Evidence Based Medicine that is an integral part of all medical disciplines, including radiology and radiobiology.

INTRODUCTION

In this time exist many risk factors, that endanger human health: biological, chemical, physical, psychosocial, economic, and other. Physical factors include ionizing radiation, ultraviolet radiation, infrared radiation, microwave and radio radiation, noise, vibration as well.

The ionizing radiation is very important risk factor. But using the ionizing radiation has many benefits in medicine, specifically in the means of prevention, diagnostics, and therapy of various diseases. The bases of some diagnostic methods are the imaging technique that produces the ionizing radiation. On the contrary, other diagnostic methods use for visualization radioactive contrast dye that is being applied to the patient during the examination. Thanks to the advancement in radiology, the diagnostics of many diseases that are the cause of morbidity and mortality of a population, has become easier. Also, many of the therapeutic techniques are based on the methods that use the ionizing radiation, such as radiotherapy of oncological diseases.

It is well known that role of the Public Health is to minimize the impact of risk factors and, conversely, to promote the impact of protective factors. Ionizing radiation is a factor with indispensable benefits, but with its reckless use and irrational exposures, it can lead to serious health problems. The aim of all radiological methods as well as the Public Health is to lower the mortality and morbidity of individual diseases and thus elongate a patient's life. The Public Health and the Radiation Protection share many of the same aims. The main aim is patient-oriented, and it is about minimizing negative biological effects of the ionizing radiation in medical examinations. The second aim is workers-oriented, who work with the source of the ionizing radiation. This means, that it is a cooperation between Radiation Protection, Public Health and Occupational Health.

Unfortunately, one of the problems is that presently, the radiation safety isn't emphasized in Public Health enough. On the contrary, it is often undervalued, even negatively received. Yet, it is a major problem, because the Public Health plays an important role in Radiology and Radiation Protection.

To the potential applications of public health in radiology can be included identification the most appropriate medical imaging for prevention, diagnostic and treatment diseases. Clinical effectiveness, clinical or radiation epidemiology, biostatistics, research, quality improvement or quality improvement evaluation, overall management of patient and radiology strategies are other ways to involve public health in radiology.

The next importance of Public Health in Radiation Protection also lies in the ability to remind about the importance of radiation safety or monitor and analyse the patients' radiation dose. It can also help with optimizing individual imaging methods, minimizing the collective dose, as well as minimizing the risk coming from patient's exposition to the ionizing radiation. It should also inform the medical workers, how to shield themselves better from the exposition; help with minimizing the cumulative dose and radiation risk of medical personnel, who works with radiation source. Finally, the Public Health can educate the medical workers about radiation safety for example, as well as gen up them with recent trends regarding radiation protection in medicine and new legislation etc.

In presently the Public Health is oriented at biological, chemical or lifestyle risk factors which cause most often acute or chronic diseases. When Public Health is oriented at physical factors, they are standard physical factors of as noise, vibration, lighting etc. But the ionizing radiation belongs to the basic physical factors that can be measured and when the exposures are excessive, they influence the health negatively.

This article stresses the importance of one from more physical factors, that causes exposure of patients as well as medical worker. Because the radiation plays very significant role in our life and our health, we cannot forget it that exposure of ionizing radiation is not only problem of Radiology or Radiation protection. On the contrary, it is problem of Radiation protection and Public Health because the Public Health has a multidisciplinary character.

Role of Public Health in Radiology and Radiation Protection

Public Health is defined as “the art and science of preventing disease, prolonging life and promoting health through the organized efforts of society”¹. From the definition implies, Public Health should be involved in all areas that may have any impact on human health. It can be an effort to minimize the exposure of risk factor – ionizing radiation or to deal with quality in health care – in radiology. The can to cooperate in obtaining the necessary information for Evidence Based Medicine that is an integral part of all medical disciplines, including radiology and radiobiology.

We cannot forget on epidemiological studies and observations playing an important role of medicine. They are the only way to detect the influence of various factors, as well as ionizing radiation, to the human biological system. The multidisciplinary character of Public Health, the knowledge of concepts related to epidemiology also helps to correctly interpret research results and to prevent the formation of incorrect research conclusions.

Among other things, currently, screening programs are an integral part of healthcare and some of them (for example mammography screening...) are based on imaging methods that use X-ray. While clinical radiology deals with imaging methods for the diagnosis and treatment of diseases, public health radiology imaging deals with radiological imaging methods used in screening². The public health experience and its collaboration with experts in radiology and radiation safety can help assess the risk and benefits of the imaging methods. It can compare the radiation exposure of individual imaging methods or actively monitor compliance with diagnostic reference levels (DRLs) of patients or dose limits of medical worker as well.

Based on “*The European Directive 2013/59/Euratom*”, it is required that all of the member states of the European Union ensure justification and optimisation of radiological methods and archive the information about the exposition of patients for the purpose of analysis and assurance of quality. R. W. Loose discusses these requirements in his work “*Radiation dose management systems—requirements and recommendations for users from the ESR EuroSafe Imaging initiative*”.³ In the Slovak Republic, there requirements are defined by a specific law *101/2018 statute which defines details about ensuring radiation safety while executing medical radiation*.

Even though all the radiology working sites archive the information about the level of radiation burden of patients, continual evaluation of the radiation burden of patients is a very important aspect. Because the radiological working-sites focus on offering quality health care to the patients, they don't have enough time nor experience with radiological epidemiological

and statistical processing of available data. However, modern devices and software allow automatic transferring of data, or control over the expositions with DRLs, nevertheless, it is important to process data right towards the radiation epidemiologists and consequently consult the results with the medical physics expert or medical radiological, which are responsible for correct adjustment of the devices, optimizing the examinations and applying the ALARA principle in practice. Here, it is possible to use the multidisciplinary approach of Public Health, which is capable of training radiation epidemiologists. Thanks to the multidisciplinary approach, it is possible to accomplish a higher level in radiology, because the statistical evaluation of the acquired dosimetry data is the basis for analysing, optimizing and clinical audit³. Seeing that in the modern time, the demand for the radiation imaging techniques as well as using the ionizing radiation in medicine rises, the issue of radiation safety and the multidisciplinary approach has not yet been as desirable as it appears to be nowadays.

Within the frame of the European radiological society campaign - *Eurosafe Imaging*, the *Dose Management*“work group has been created. It's aim was to ensure the implementation of the *European recommendations on the implementation of management systems in clinical practice*. One of the main activities of the European radiological society is to support the system of controlling and assessing the local, national, and European DRLs.³ Presently, only the DRLs of the national level are defined in the Slovak Republic, and they are anchored in the decree of the Department of Health of the Slovak Republic, that was updated in 2018 *Measure No. S02933-2018-OL, dated March 19th 2018, which constitutes the diagnostic reference levels of medical radiation*. The local DRLs are frequently absent and also, in many specialized radiological examinations, the DRLs are not defined.

Beside the radiation safety that is focused on the patients, we should not forget about the occupational expositions. For example, lowering the equivalent dose limit for the lens of the eye for occupational exposure. Thanks to the epidemiological studies such as the ORAMED research, we came to a conclusion that the lens of the eye is far more sensitive than we had previously assumed, which was the base for updating the equivalent dose limit^{4,5}.

Updating the DRLs, limits, legislature, guidelines, and recommendations requires conducting out quality epidemiological research. However, this can only be executed if we abide the multidisciplinary approach and collaborate with multiple disciplines. The proof of this is the novelization of *The European Directive 2013/59/Euratom*, which was established in collaboration with many specialists and their years of experience and research^{4,6}. The most important changes that occur in the guidelines were written by A. Torresin *et al.* in their *Practical recommendations for the application of DE 59/2013*.⁶

Next problem can be radiation safety knowledge of medical workers. Due the enormous increase in the use of sources ionizing radiation in medicine and rapid development, there may be a disproportionate acquisition of radiation safety knowledge of healthcare workers. It is essential that the education and training of healthcare workers working with source of ionizing radiation keep pace with new trends and knowledge of radiation protection.

Based on the above information, it follows that Public Health can play an important role in Radiation Protection and in Radiology, as well. Also, it is important implementation Radiation Epidemiology in practice and develop this special field of epidemiology in Public Health.

Role of Public Health in radiation safety of the patients

Why are exposures of ionizing radiation patient's global and public health problem? The answer to this question is very easy. In modern medicine, radiology plays an important role. Even though the benefits of medical exposures prevail over the radiation risks, there are concerns connected to the unwanted biological effects of ionizing radiation⁷.

Based on the knowledge about radiation, we know, exposure of cells to any form of ionizing radiation is connected to a potential risk of biological cell damage. The main effect of exposure is molecule ionization and actions that follow, which cause irretrievable cell damage. The target molecule of ionizing radiation is the DNA molecule, but it effects also other molecules such as proteins and lipids^{8,9}. The mechanisms of ionizing radiation are very complicated and consist of physical, physical-chemical, chemical and biological processes that cause the final radiobiological effect¹⁰.

Based on the ICRP recommendations, the negative biological effect of ionizing radiation exposure can be divided in two general categories. The first one contains the biological effects caused by the exposition to high doses, so called deterministic effects. These follow immediately after the exposition when a certain threshold of dose is crossed. The second category contains the biological effects that are caused by low doses of ionizing radiation, so called stochastic effects. For stochastic effects don't exist threshold level under which biological effect don't occur. These effects don't cause immediate clinical manifestations and they are unpredictable. They mainly damage the cell itself, and the biological effects can be seen after several years go by¹¹.

The radiation used in medicine, represents the biggest part of the radiation that comes from artificial resources. The reason is an increasing demand for X-ray with an accent on the computed tomography (CT) and the multidetector computed tomography, which represents 50% of the medical' expositions¹². The yearly rate of carried out X-ray examinations is more than 3,600 million (of which approximately 10% represent the children's expositions), 37 million examinations in nuclear medicine and 7,5 million procedures of radiotherapy¹³. It is assumed, that this number will increase due to population aging that is affected by multiple diseases and injuries. Simultaneously, ionizing radiation is being increasingly used in diagnostics in children. Child population is more sensitive to the oncogenic effects of ionizing radiation. This leads to higher risk of acute leukaemia and solid cancers. In comparable exposition parameters, the effective doses and their risks are 50% higher in children than in adults. This risk is higher especially because of the smaller bodies of children and the number of proliferating cells that are sensible to radiation exposure. Thanks to the longer living, the children have a higher risk of cancer caused by exposure of ionizing radiation than the adults^{14,15}.

Many studies assumed that the wider use of CT can cause small, but appreciable abundance of cancer risk. The problem occurs with the repeating radiation examinations, whereas the patient cumulative dose is increased and so the risk of biological damage also increases. The increase of the cumulative dose of patients, radiological workers, and the population lead to an effort to systemically lower the radiation dose by developing the tools for its decrease and optimizing sources of ionizing radiation. Including the audits that focus on the betterment of radiation safety among the medical workers⁷.

Along with the increasing cumulative dose of population, the cancer risk also increases during life. The European Commission has dealt with this issue in 1997 and it has published several recommendations. There is possible to integrate the competencies of Public Health in the process of radiation safety. The public health worker can realize campaign and thus to remind the indicating doctors of the fact, that indicating X-rays or CT isn't the only option in diagnostics and it shouldn't become the first choice. Since a high amount of indicated and carried out CT examinations often isn't the result of their rational use, it is important to remind of the principle of justification.

Due to irrational use of CT, and in many cases groundless indication of CT by the doctors, some countries have created clinical guidelines to support rational usage of CT. In the USA, The National Institute for Health and Clinical Excellence has published guidelines about proper usage of CT and magnetic resonance imaging. With the aim to lower the number of groundless medical expositions, the campaign with name *Choosing Wisely* has been launched in Canada and the USA¹⁶. Similarly, the FDA had started a campaign with the same aim, which was mentioned in *The National Council on Radiation Protection and Measurements Report NO.160*. Some studies show, that a third of all CT examinations are carried out unnecessarily. Among these are the cases when X-ray or CT examinations were indicated without adequate reasoning, improperly, controversially, or repeatedly due to insufficient communication among the doctors¹⁷.

A similar campaign - *3A-AUDIT, APPROPRIATENESS AND AWARENESS*, was launched by the IAEA. Its aim was to better the principles of justification in radiological examinations which is an effective tool for primary cancer prevention^{18,19}. With the aim to ensure and support the radiation safety, the IAEA created action plans, for example *The International Action Plan for the Radiological Protection of Patients* or *The International Action Plan on Occupational Radiation Protection*". In the Slovak Republic, this issue is dealt with by the Standard diagnostic procedures that are being prepared consecutively and they regulate the indicating criteria as well as the terms of radiological examinations. For example, *Standard procedure for executing the medical X-ray examinations – Computed tomography*; *Standard procedure for executing the medical X-ray examinations – Skiagraphy and fluoroscopy*; *Standard procedure for executing the medical X-ray examinations – standard operating process for diagnostic mammography*; *Standard procedure for executing the medical X-ray examinations for prophylaxis – screening mammography*; *Standard procedure for executing the medical examinations in nuclear medicine*.

But setting standards and norms is not enough in this area. It is very important that the public health professional or radiation protection worker has an active attitude to the issue, to constantly monitor the radiation exposure of patients and to support the rational use of radiation imaging methods.

Role of Public Health in radiation safety of the medical workers

Another risk group except the patients are the medical workers who work with the ionizing radiation. They are exposed to the ionizing radiation on daily basis because of various radio-diagnostic and therapeutic interventions. These expositions are connected to various acute

or late effects²⁰⁻²⁴. With the aim to prevent the deterministic effects and minimizing the stochastic effects, the IRPA has created several recommendations and set dose limits that should not be exceeded. In the legislation of the Slovak Republic, these norms are defined in the Law No. 87/2018 about the radiation safety and changes and completing of some laws.

Presently, with the increase in the number of examinations using the radiation, it is important for the medical workers to know about the ways they can shield themselves effectively²⁵⁻²⁷. One of the components that can contribute to the correct way of shielding the workers is a measure of knowledge about the radiation safety, which has a big influence on the correct actions and performance in the field of radiation safety. Within this context, R.Behzadmehr conducted a systematic review. Its aim was to map the knowledge, access, and experience of medical workers in the field of radiation protection. Specifically, 41 scientific studies were chosen based on defined criteria that evaluate the adequacy of the research. The results of the research gather valuable information and scientific proofs that education of medical workers is the most important method of applying the fundamentals of radiation safety. From the analysed studies, 13 studies recommend incorporating the subject of radiation safety into the curriculum, 12 studies recommend implementing completing the training and direct acquiring of practical knowledge in the hospital, 11 studies recommend providing programmes of further education and 8 studies recommend providing adequate safety tools²⁸.

Even though the medical imaging tools advanced and ionizing radiation is more commonly used in medicine, the knowledge about radiobiology, radiation safety and optimizing criteria has lessened. Knowledge has a direct impact on implementing the safety measures of radiation safety and the focus on this issue is necessary²⁹. Professional preparation and education in the field of radiation safety is considered one of the basic components of optimizing programmes focused on medical expositions. Many international organizations, such as ICRP, WHO, IAEA, together with the EC emphasize the importance of education and professional preparation of medical workers, which is necessary to lower the radiation dose that comes from medical expositions and to lower the risk associated with the expositions¹⁴.

One of the most important challenges that the WHO deals with contains professional preparation, provide guidelines, technical messages and keeping up with the principles of radiation safety, which are all mentioned in the document *Global Initiative on Radiation Safety in Healthcare Setting*". The WHO assumes that a great investment is necessary for minimizing the risks and insuring a safe and effective healthcare, so that the medical workers can gain the necessary knowledge, views, and professional experiences. The medical workers often lack the necessary knowledge of the risks associated with the exposition to ionizing radiation.

This can be explained by the fact that the medical workers often have negative or neutral views about radiation safety, which leads to lower ability of applying knowledge about radiation protection in practice. The importance of radiation safety in medicine and the measures for supporting radiation protection were defined in 10 points which are part of the document *Bonn call for action*.^{30,31}

During the last decade, many studies in different countries have been conducted that analysed the knowledge of medical workers about the issue of radiation safety³²⁻³⁸. Many of them showed unsatisfying results. For example, there was realized an Italian study that used the questionnaire method. 780 radiologists completed the questionnaire. 12% of radiologist confirmed that they

regularly attend trainings that focus on this issue and 56% of radiologist rarely. On the contrary 32% of radiologist have never attended course about radiation protection.

Even though 90% of the respondents of this study marked that they have enough knowledge about radiation safety, the average success rate of the questionnaire was only 53%¹². In another study, the average answer score of the medical workers was 50%, of whom 48% answered more than half of the questions. Only 23% of the respondents connected radiation dose and radiation exposure with the X-ray examination, 50-70% of them undervalued radiation exposure and 50-75% of them undervalued the potential radiation risk of dying of secondary induced cancers³⁹. The questions concerning the radio-sensitivity of tissues and organs, as well as defining the imaging methods that use or don't use ionizing radiation (for example magnetic resonance imaging, ultrasonography, CT, mammography) also showed surprising results.^{7,12,40,41}

An interesting study in this field is S. K. Hagi's study, which focused on evaluating the knowledge of medical students in Saudi Arabia. The students attended a didactic presentation about radiation protection. They completed the same questionnaire before and after the presentation. In the questionnaire before the presentation, only 17% of students scored more than 60%. When comparing their knowledge before and after the presentation, there was an improvement in their knowledge. The average score before the presentation had been 47% and after the presentation, the score improved by 31%, therefore the average score was 78% ($p=0,01$). The results of the study confirmed that as little as one presentation can help improve the knowledge about general principles considering ionizing radiation and radiation safety⁴⁰. It is necessary to continue this trend and to bring forward the issue of radiation safety.

Although we compare the results of studies that were performed on different samples with different occupational and age range (radiologists, emergency physicians medicine, students of radiology, students of medicine), we can see that the topic of education of health professionals cannot be underestimated. As mentioned above, the knowledge of some medical workers about radiation protection and ionizing radiation are in some cases insufficient. It has been the result of several studies.^{7,12,29,32,40,42-44} Because a medical worker plays a crucial role in radiation safety, it is very unsettling that these people don't have enough knowledge in the field of radiation safety many times. It follows that they don't know in many causes how to adequately implement the basic principles of radiation protection into their medical practice. Based on that, it is necessary to say that this is a serious problem of public health, which should be the Public Health dealt with. It is of utmost importance, that the medical workers have enough knowledge about radiation and the risks that are a big part of the exposition. Considering radiation safety, the medical workers should regularly attend courses lead by a qualified person that can offer the workers new information considering the legislation and other guidelines.

Underestimation of significance of education in the field of radiation safety of the medical workers can have dangerous effects, which can lead to higher number of unnecessary X-ray examinations, higher expositions of patients, wrong usage of safety tools, insufficient covering of radiosensitive organs and many other substantial consequences.

CONCLUSIONS

The radiobiological imaging methods offer valuable information in diagnostics and therapy. However, if they're used irrationally or if the safety measures integrated into the

principles of radiation protection are not respected, the exposition to the ionizing radiation can lead to higher number of health risks for the patients as well as medical workers.

The specific aim of the study was to point out the importance one physical factor from more physical factors, which play very important role in medicine as well in public health. This importance can we see in the fact that ionizing radiation affects patients as well as healthcare professionals themselves. In order minimize the negative effects of ionizing radiation and increased its benefit, every healthcare professional must have adequate knowledge of ionizing radiation. Because the ionizing radiation is significance physical factor, we cannot forget the field of public healthcare system, who's main aim is safety, support, and development of the population's health. These are also aiming of the radiation safety. It is necessary to emphasize, that safe and effective usage of the ionizing radiation in medicine is one of the basic components of Good Medical Practice. To be able to prevent unwanted biological effects of radiation in the human body, realize epidemiology studies, regular education of the medical workers, as well as informing them about the effects and the mechanisms of this radiation on human cells is necessary. Hereby, it is inevitable to know the sources of the ionizing radiation and the ways for lowering the exposition to the lowest possible level, while keeping the maximum of its benefits.

Funding information

This work was supported by Grant of University of Trnava number 11/TU/2020.

References

1. WHO. Public health services. Accessed: January 28, 2021. Available from: <https://www.euro.who.int/en/health-topics/Health-systems/public-health-services>
2. Pongpirul K, Lungren MP. Public Health and International Epidemiology for Radiology. Radiology in Global Health. Springer, New York: NY; 2014.
3. Loose, RW, Vano E, Mildemberger P. et al. Radiation dose management systems—requirements and recommendations for users from the ESR EuroSafe Imaging initiative. European Radiology. 2020. Available from: <https://doi.org/10.1007/s00330-020-07290-x>
4. Guglielmi G, Pinto A, Salerno, S. Editorial from guest editors current Euratom legislation (DE 59/2013): new patient management in radiation protection. La radiologia medica. 2019; 124(8): 711–713.
5. Vanhavere F, Carinou E, Gualdrini G et al. ORAMED: Optimization of Radiation Protection of Medical Staff. EURADOS Report 2012-02.
6. Torresin A, Evans S, Lizio D. et al. Practical recommendations for the application of DE 59/2013. La radiologia medica. 2019; 124(8): 721–727.
7. Faggioni L, Paolicchi F, Bastiani L et al. Awareness of radiation protection and dose levels of imaging procedures among medical students, radiography students, and radiology residents at an academic hospital: Results of a comprehensive survey. European Journal of Radiology. 2017; 86(1): 135-142.
8. Cabaneková H. [Ionizing radiation and health risk]. XI. Banskóštiavnické dni: Banská Štiavnica, 2009. Accessed: January 28, 2021. Available from:

https://inis.iaea.org/collection/NCLCollectionStore/_Public/41/122/41122251.pdf .
Slovak

9. Domenech H. Radiation Safety. Management and Programs. Switzerland: Springer International Publishing; 2017.
10. Podzimek F. 2015. [Radiological physics. Physics of ionizing radiation]. Praha: ČVUT; 2015. Czech
11. Franco A, Ciccarelli M, Sorriento D et al. Rays Sting: The acute cellular effects of ionizing radiation exposure. *Translation Medicine*. 2016; 14(8): 42-53.
12. Paolicchi F, Miniati F, Bastiani L et al. Assessment of radiation protection awareness and knowledge about radiological examination doses among Italian radiographers. *Insights Imaging* 2016; 7(2): 233-242.
13. WHO. Global Initiative on Radiation Safety in Healthcare Settings. 2008.100 p. Accessed: January 28, 2021. Available from: https://www.who.int/ionizing_radiation/about/GI_TM_Report_2008_Dec.pdf
14. Ivanov VK, Kasjcheev VV, Chekin SY et al. Estimation of risk from medical radiation exposure based on effective and organ dose: How much difference is there? *Radiation Protection Dosimetry*. 2013; 155(3):317-328.
15. Ivanov VK, Tsyb AF, Mettler FA et al. Methodology for estimating cancer risk of diagnostic medical exposure: with an example of the risks associated with computed tomography. *Health Physics*. 2012; 103(6): 732-739.
16. OECD. Health at a Glance 2017. OECD Indicators. Paris: OECD, 2017.
17. Štubňa M. [Radiation risks potentially associated with CT]. České Budějovice: Jihočeská univerzita v Českých Budějovicích, 2013. Czech.
18. Carpeggiani C, Kraft G, Caramella D et al. Radioprotection (un)awareness in cardiologists, and how to improve it. *Journal of Cardiovascular Imaging*. 2012; 28(6):1369-1374.
19. Malone J, Guleria R, Craven C et al. Justification of diagnostic medical exposures, some practical issues. Report of an International Atomic Energy Agency (IAEA) Consultation. *The British Journal of Radiology* 2012; 85(1013): 523-538.
20. Gerić M, Popić J, Gajski G et al. Cytogenetic status of interventional radiology unit workers occupationally exposed to low-dose ionising radiation: A pilot study. *Mutation Research - Genetic Toxicology and Environmental Mutagenesis*. 2019; 843: 46-51.
21. Coppeta L, Pietroiusti A, Neri A et al. Risk of radiation-induced lens opacities among surgeons and interventional medical staff. *Radiological Physics and Technology*. 2018; 12(323): 26-29.
22. Ko S, Kang S, Ha M et al. Health effects from occupational radiation exposure among fluoroscopy-guided interventional medical workers: A systematic review. *Journal of Vascular and Interventional Radiology*. 2018; 29(3): 353-366.
23. Picano E, Vano E, Domenici L et al. Cancer and non-cancer brain and eye effects of chronic low-dose ionizing radiation exposure. *BMC Cancer*. 2012; 12:157.
24. Reeves RR, Ang L, Bahadorani J et al. Invasive cardiologists are exposed to greater left sided cranial radiation: The BRAIN Study (Brain radiation exposure and attenuation duringinvasive cardiology procedures). *JACC: Cardiovascular Interventions*. 2015; 8(9): 1197-1206.

25. Burns S, Thornton R, Dauer LT et al. 2013. Leaded eyeglasses substantially reduce radiation exposure of the surgeon's eyes during acquisition of typical fluoroscopic views of the hip and pelvis. *The Journal of Bone & Joint Surgery*. 2013; 95(14): 1307-1311.
26. König AM, Etzel R, Thomas RP et al. Personal radiation protection and corresponding dosimetry in interventional radiology: An overview and future developments. *Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren*. 2019; 191(6): 512-521.
27. Meisinger QC, Stahl CM, Andre MP et al. Radiation protection for the fluoroscopy operator and staff. *American Journal of Roentgenology*. 2016; 207(4): 745-754.
28. Behzadmehr R, Doostkami M, Sarchahi Z et al. Radiation protection among health care workers: knowledge, attitude, practice, and clinical recommendations: a systematic review. *Reviews on Environmental Health*. 2020. Accessed: January 28, 2021. Available from: <https://www.degruyter.com/view/journals/reveh/ahead-of-print/article-10.1515-reveh-2020-0063/article-10.1515-reveh-2020-0063.xml?language=en>
29. Marwe B. Standardised training and assessment in radiation safety for diagnostic radiographers. Thesis: Faculty Of Health Sciences, University Of The Free State Bloemfontein, 2014. Accessed: January 28, 2021. Available from: <http://scholar.ufs.ac.za:8080/xmlui/bitstream/handle/11660/802/vanderMerweB.pdf;sequence=1>
30. European Commission. Radiation Protection 116. Guidelines on education and training in radiation protection for medical exposures. EC, 2000.
31. International Atomic Energy Agency, World Health Organization. [Bonn call for action. 10 principles of strengthening radiation protection in healthcare for the next decade]. IAEA, WHO, 2012. Accessed: January 28, 2021. Available from: <https://www.health.gov.sk/Clanok?10-zasad-posilnenia-radiacnej-ochrany-v-zdravotnictve-na-najblizsiu-dekdu> Slovak
32. O'Sullivan J, O'Connor J, O'Regan K et al. An assessment of medical students' awareness of radiation exposures associated with diagnostic imaging investigations. *Insights Imaging* 2010; 1(2): 86-92.
33. Ng SE, Sa, F. Assessment of awareness and practice of ionizing radiation protection procedures among exposed health care workers. *Egyptian Journal of Occupational Medicine*. 2020; 44:529-44.
34. Alavi SS, Dabbagh ST, Abbasi M et al. Medical radiation workers' knowledge, attitude, and practice to protect themselves against ionizing radiation in Tehran Province, Iran. *Journal of Education and Health Promotion* 2017. 6:58.
35. Alzubaidi MA, Mutairi HH, Alakel SM et al. Assessment of knowledge and attitude of nurses towards ionizing radiation during radiography in Jeddah city. *The Egyptian Journal of Hospital Medicine*. 2017; 69(7): 2906-2909.
36. Söylemez H, Sancaktutar AA, Silay MS et al. Knowledge and attitude of European urology residents about ionizing radiation. *Urology* 2013; 81:30-6.
37. Shabani F, Hasanzadeh H, Emadi A et al. Radiation protection knowledge, attitude, and practice (KAP) in interventional radiology. *Oman Med J* 2018;33(2):141.

38. Ihle IR, Neibling E, Albrecht K et al. Investigation of radiation-protection knowledge, attitudes, and practices of North Queensland dentists. *J Investig Clin Dentistry* 2019;10:e12374.
39. Ramanathas S, Ryan J. Radiation awareness among radiology residents, technologists, fellows, and staff: where do we stand? *Insights Imaging* 2014;6:133-39.
40. Hagi SK, Khafaji MA. Medical student's knowledge of ionizing radiation and radiation protection. *Saudi Med J* 2011;32:179-83.
41. Campanella F, Rossi L, Giroletti E et al. Are physicians aware enough of patient radiation protection? Results from a survey among physicians of Pavia District– Italy. *BMC Health Serv Res* 2017;17:406.
42. Enabulele JE, Igbiniedion BO. An assessment of dental students' knowledge of radiation protection and practice. *J Educ Ethics Dentistry* 2014;3:54-5.
43. Kim TH, Hong SW, Woo NS et al. The radiation safety education and the pain physicians' efforts to reduce radiation exposure. *Korean J Pain* 2017; 30:104-15.
44. Foley SJ, Evanoff MG, Rainford LA. A questionnaire survey reviewing radiologists' and clinical specialist radiographers' knowledge of CT exposure parameters. *Insights Imaging* 2013;4:637-46.