

Assessment of Backscattered Radiation Dose at Exposed Object's Level during X-Ray Examinations

Abdullah Taher Naji^{1,*} and Gobran N. Ali²

¹University of Science and Technology, Yemen

²Sana'a University, Yemen

Abstract: This paper estimates backscattered radiation doses at patient's positioning level (exposed object) using different X-ray tubes. The effects of different exposure sittings (X-ray tube voltage, exposure intensity, exposed area, dosimeter position, and distance between X-ray tube and imaged object surface) on backscattered radiation doses are estimated using different dosimeters and x-ray units. The quantity of recorded backscattered radiation dose -which reflects from patient's table or bucky to image receptor and exposed patient - is determined by the position of dosimeter between exposed object's table or bucky and X-ray tube according to backscatter angle, at higher backscattered angle, the dosimeter records more backscattered dose. The results showed that, increase in kVp, exposure intensity, and exposed area led to a concomitant increase in the quantity of backscattered radiation, whereas the increase in distance between X-ray tube (source) and imaged object surface reduces the amount of backscattered radiation dose. As well as, there is no remarkable difference in recorded backscattered dose due to the position of X-ray tube or the direction of incident X-ray photons.

Keywords: Backscattered radiation, X-ray, exposure parameters, exposed object's level.

1. INTRODUCTION

Medical X-ray is most common forms of radiation in medicine, and one of the largest manmade sources of radiation exposure to patients, radiology staff (workers), and the general populace, hence there exists the problem of safely delivering radiation dose when imaging biological tissues [1-3]. For example, conventional radiography accounts more than 80 % of X-ray-based imaging [4], and it is considered a responsible for the most of the radiation exposure associated with all medical imaging techniques [5].

The problem of scattered radiation exposure to patients and radiology staff during radiological examinations is imperative because of the position of the patients and radiology workers in relation to the radiation source, and the long period of X-ray exposure. Hence, scattered radiation is considered the main source of the occupational radiation exposure [6, 7]. According to ICRP Publication 103 (ICRP, 2007) the overall cancer risk coefficient has been estimated $F_{CR} = 55$ mSv for the population, while $F_{CR} = 41$ mSv for the adult workers [5]. Therefore, there is a need to reduce backscattered radiation dose to protect patients and radiology workers in an X-ray room from unnecessary radiation exposure [8, 9].

To elucidate matter interactions with radiation from X-rays, the mechanism of X-ray propagation should be

understood. When a beam of X-ray strikes any object or inner cladding of X-ray room, it is either scattered, absorbed, transmitted or reflected to backward [10]. Scattered radiation photons are radiation that changes in direction due to interaction with some materials.

The scattered photons negatively affect radiographic image contrast thereby hindering accurate representations of human anatomy, and increase radiation dose that patients and medical personnel are exposed to [11]. X-ray scatter is one of the foremost factors that negatively affect image quality by causing the underestimation of attenuation coefficient in image reconstructions. The scattered radiation reduces image sharpness and contrast, which makes the image hazy and indistinct [12, 13]. The scattered radiation is initiated by Compton interaction, which occurs when an incident photon collides with an atomic electron to produce photons that lose energy because of the scattering interaction [14]. The generated secondary photons continue to dissipate energy in different directions due to the scattering interactions [15]. Scattered radiation arises from the interaction of the primary beam photons with the exposed materials causing a portion of the primary (incident) X-rays photons to be redirected in different directions [16]. The scattered radiation photons can cause a serious radiation exposure hazard in diagnostic radiography, a large amount of X-ray photons can be scattered from the patient during radiography and fluoroscopy. Hence, scattered radiation is the source of most of the occupational radiation dose exposure that radiography's staff receive [17].

Address correspondence to this article at the University of Science and Technology, Yemen; Tel: +967771523431; E-mail: ataher8383@yahoo.com

Scattered radiation can be classified upon the direction of secondary photons, backscattered radiation consists of photons that collide with an object then reflect back at different backscattering angles, when the photons are reflected back with scattering angle greater than 90° (at different angles between 90° and 180°) with the incident photons, it is referred to as backscattered radiation, whereas side scattered radiation occurs when the radiation photon scatters to the side or changed its direction by 90° or less from the initial photon beam trajectory [18].

Backscattered radiation is defined as a secondary radiation photon which deflected with scattering angle more than 90° from the primary radiation [19]. Hence, backscattered photons refer to the part of scattered radiation that reflects back toward the radiation source, or the scattered radiation opposite the incident radiation direction due to its reflection from particles of the medium traversed [20].

Therefore, backscattered radiation is an important portion of scattered radiation which can cause harm to the patients and workers in an X-ray room if their exposure exceeds the permissible value [21, 22]. Also, backscatter radiation can have a significant effect on the quality of a radiograph, increases the level of random background noise on the film, and degrades the visibility of contrast details [23, 24].

Backscatter radiation exposure to the operator can be reduced by providing external shielding or increasing distance between the operator and the X-ray unit [25]. Because the position of radiology operators which usually closer than 1 m to the unit, the exposure measurements at distances closer than those required by the Federal standard become important [26].

2. EXPERIMENTAL SECTION

2.1. Materials

The measurements of this study are conducted by utilizing some of equipments and accessories. These instruments includes different types of X-ray units, dosimeters, and accurate survey meter (Radiation detection meter) to assess backscattered radiation by monitoring area near X-ray units and recorded backscattered dose which reflects from x-ray table or bucky to image receptor or patients.

2.2. Methods

This study estimated backscattered radiation dose reflected from patient table, X-ray room floor, standing

bucky, and X-ray room wall at exposed object level during x-ray examinations. The tube of X-ray machine is a leading source of radiation, which was directed towards an exposed object. The backscattered radiation doses were measured at exposed object level using different dosimeters (ionization chambers). After calculation of correction factors the normalized exposure rate are determined. The measurements were carried out with different radiation exposure parameters sitting (kVp, field sizes, radiation intensities, distances, and backscatter angles) to evaluate the effect of exposure parameters on resultant backscattered radiation dose.

3. RESULTS AND DISCUSSION

3.1. Backscattered Radiation Dose for Different X-Ray Tubes

This section investigate backscattered radiation dose for different X-ray tubes, given that X-ray spectrum vary for different X-ray tubes, it is valuable to determine the backscatter values for different X-ray units. The results of estimated X-ray dose for compact X-ray unit compared with other X-ray tube model (swing x-ray unit). Backscattered radiation doses for the Swing X-ray unit were relatively similar compared with the compact X-ray unit at moderate exposure parameters whereas the differences in recorded doses increased at low and high investigated exposure intensity (2 mAs, and 32 mAs) which the differences between backscattered doses up to 18.80%, and 12.89 % respectively. Figure 1 shows the backscattered doses with different X-ray unit as a function of exposure sittings. This finding proved that X-ray spectrum vary for different X-ray tubes and working environments, it is valuable to assess the backscatter values for different X-ray machines.

The results showed that both X-ray units presented similar backscattered radiation dose for the different exposure sittings commonly used in clinical diagnosis. In addition, factors such as X-ray tube voltage (kVp), and exposure intensity (mAs) similarly affect the recorded backscattered radiation dose in both X-ray units.

3.2. Effect of X-Ray Tube Voltage on Backscattered Radiation Dose

The effect of incident X-ray energy on backscattered dose is evaluated by measuring backscattered dose at different applied voltage of X-ray tube (kVp) and fixing other affecting exposure parameters. Figure 2 shows the backscattered X-ray

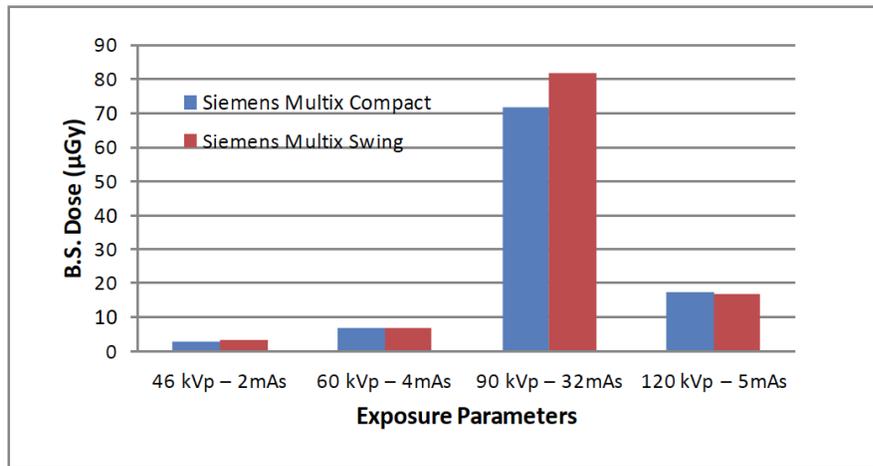


Figure 1: Backscattered dose for different X-ray units.

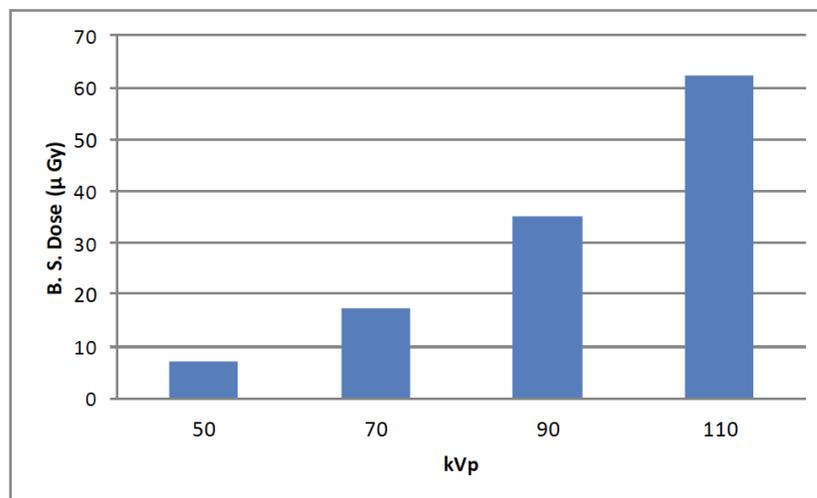


Figure 2: Backscattered radiation at different X-ray tube voltages.

dose versus kVp. The dose of backscattered radiation increased with increasing X-ray tube voltage (kVp) due to the fact that more scatter photons occur at higher energy.

More backscattered dose was recorded for high X-ray energy, X-ray photons interaction with matter increases by increasing photon energy (kVp). The backscattered dose increased more than eight times with increase in X-ray tube voltage from 50 to 110 kVp. This finding in agree with Vlachos *et al.* (2015) [27] and Chiang *et al.* (2020) [28] who illustrated the effect of X-ray tube voltage on dose rate due to the scatter radiation.

3.3. Effect of Radiation Exposure Intensities on Backscattered Radiation Dose

The effect of radiation exposure intensity which referred to as mAs (product of X-ray tube current and

exposure time) on the backscattered radiation dose was evaluated. Figure 3 shows direct proportionality between backscattered radiation dose and exposure intensity (mAs) due to the number of incident photons increased proportionally with mAs increase, so there is a clear relationship between the backscattered radiation dose and mAs. Chiang *et al.* (2020) [28] similarly reported the dependence of backscattered dose on the radiation exposure intensities.

Therefore, one of the most effective method to reduce backscattered radiation dose is by reducing radiation intensity.

3.4. Contribution of Exposed Object in Backscattered Radiation Dose

The effect of exposed object on backscattered dose is assessed by estimating backscattered dose with and without imaged object, Figure 4 shows that more

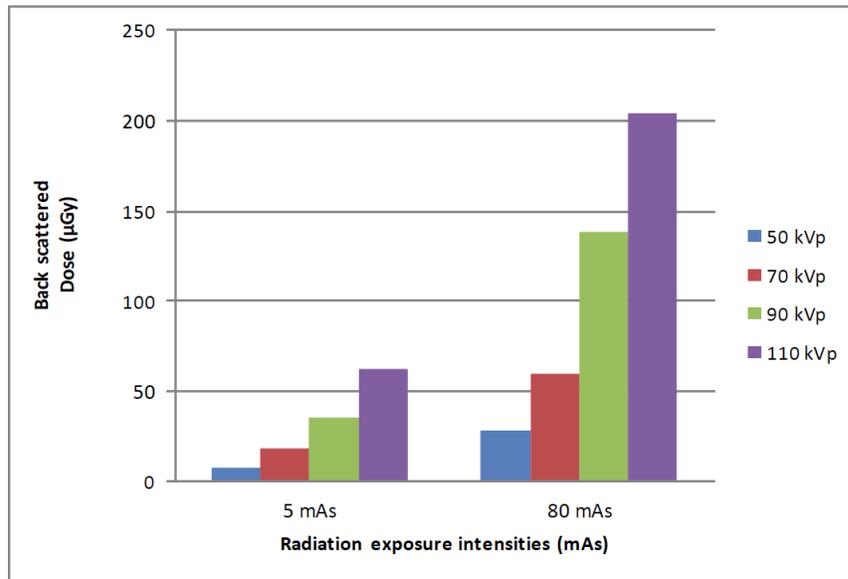


Figure 3: Backscattered radiation at different X-ray tube voltages.

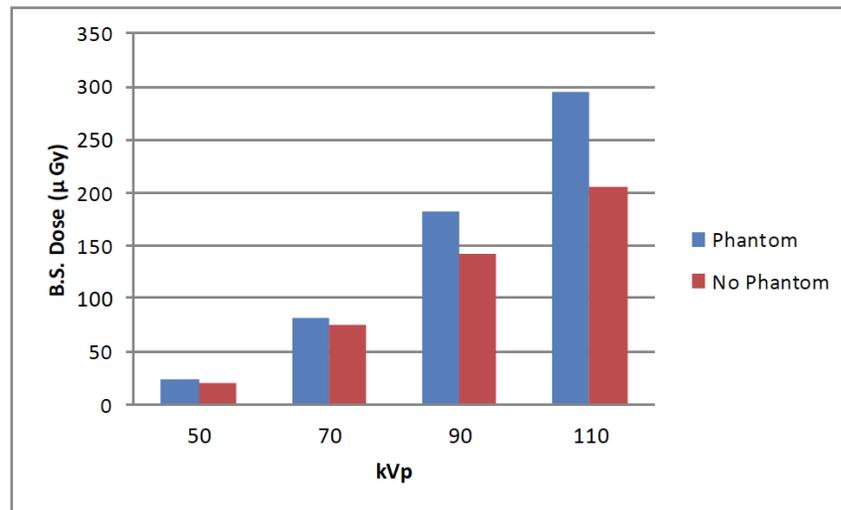


Figure 4: Backscattered radiation dose with and without exposed object.

backscattered radiation dose recorded in the existence of exposed object (Phantom) because of more interactions occur between incident radiation and phantom components hence more backscattered photons are produced. This result is consistent with Ghafarain *et al.* (2007) finding, who reported strongly dependence for the quantity of scattered radiation dose on the exposed object [29].

3.5. Effect of Exposed Area on Backscattered Dose

The effect of irradiated area on backscattered dose is evaluated by measuring backscattered radiation dose at different field sizes. Figure 5 illustrates the backscattered radiation dose as a function of exposed area. The backscattered radiation doses were

estimated at different field sizes of incident X-ray with 60 kVp X-ray tube voltage and 5 mAs.

The backscattered radiation dose for large field size is much greater than backscattered dose for small field size. On the other hand, the effect of radiation field size on backscattered dose at different exposure sittings (90 kVp, 128 mAs) was also investigated by increasing exposed area the backscattered radiation dose is increased much more at higher exposure factors as shown in Figure 6. It is evident from Figures 5 and 6 that backscattered radiation dose is directly proportional to the field size of incident radiation (exposed area). This result is consistent with Bushberg *et al.* (2012), who reported that scattered radiation is proportional to the field size of incident X-ray [30].

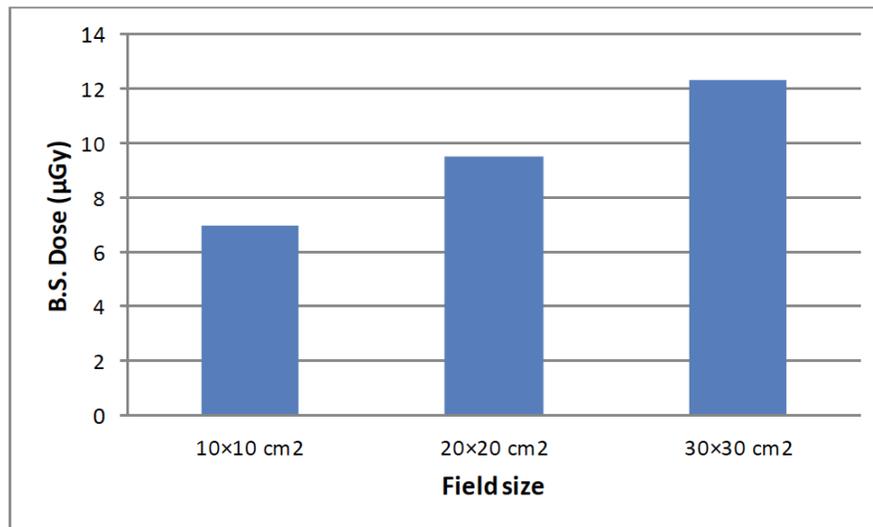


Figure 5: Backscattered radiation dose at different exposed areas.

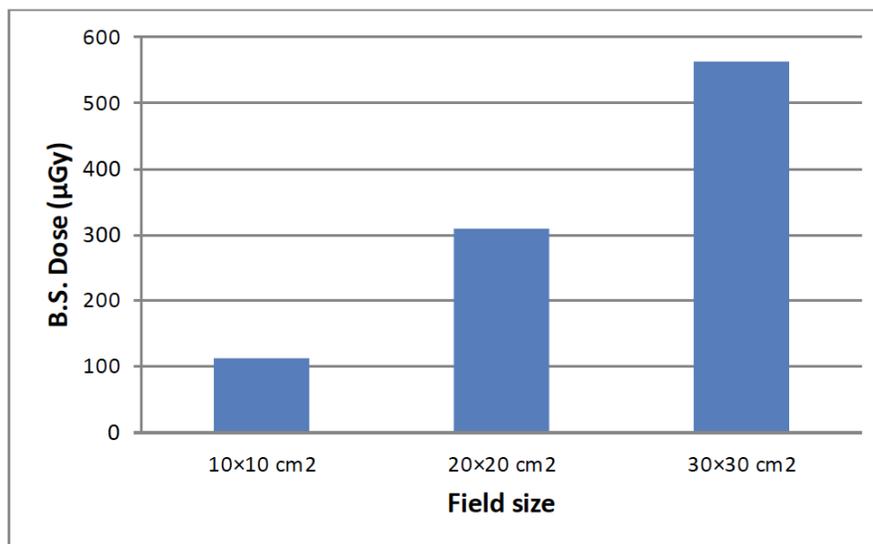


Figure 6: Backscattered dose at different exposed areas and higher exposure factors.

3.6. Effect of Dosimeter Position on Measuring of Backscattered Radiation Dose

The effect of dosimeter position on the recorded backscattered radiation dose was evaluated. The backscattered radiation doses were measured at different backscatter angles between incident and backscattered X-ray beam. The measurements of backscattered radiation dose as a function of backscatter angles are shown in Figure 7. The result shows clearly the dependence of recorded backscattered radiation doses on the position of dosimeter (backscatter angle), so that the higher backscattered radiation doses were recorded at 160° backscattered angle with incident beam while lower backscattered radiation doses were recorded at 90°

angle with central ray of incident beam. The higher backscattered radiation doses which recorded at 160° can be attributed to the higher volume of backscattered photons that reach to the ionization chamber flat position at this angle, and vice versa (less recorded backscattered dose obtained at 90° angle between incident and backscattered radiation). This result is in consistent with the study by Binger *et al.* (2014), who similarly reported the dependence of backscattered dose on the angle between central beam axis and scattering material position [31]. The dosimeter reading is evaluated the amount of backscattered photons per unit area of ionization chamber flat, and the flounces of backscattered photons depend on ion chamber position (backscatter angle), thus, at higher backscattered angle, the dosimeter records more backscattered dose.

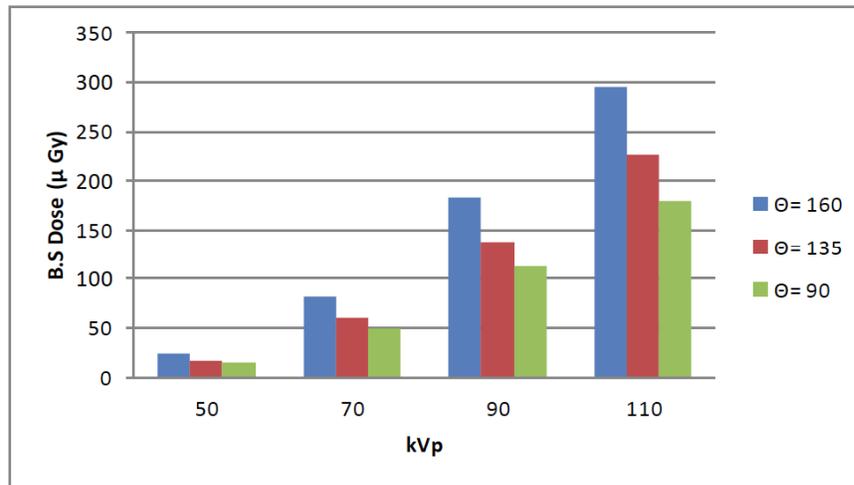


Figure 7: Backscattered radiation doses at different backscattered angles.

3.7. Effect of Distance between X-Ray Source and Exposed Object Surface (SSD) on Backscattered Radiation Doses

The effect of the distance between the surface of exposed object (Phantom) and X-ray source on backscattered radiation dose was evaluated by assessment backscattered radiation doses at different SSD with exposure sitting 90 kVp and 128 mAs. The relation between backscattered radiation dose and SSD is illustrated in Figure 8. Based on the inverse square law, the increase of SSD lead to reduce the intensity of incident radiation, which in turn reduced the backscattered radiation. Higher backscattered radiation doses were obtained at short SSD and vice versa. This deduction is consistent with studies by Wagner *et al.* (2000) [32] and Sharma *et al.* (2015) [33] who reported inverse proportionality between SSD or the position of X-ray device and overall radiation exposure dose

delivered to patients and operators as well as backscatter factor.

In addition, Bushong (2013) reported reduction of X-ray quantity by increasing the distance from X-ray source and target (SSD) because X-ray intensity varies inversely with the square of the distance from the X-ray tube [7]. As a result, the reduction of incident X-ray intensity by increasing SSD lead to less backscattering photons.

3.8. Effect of Incident Radiation Direction on Backscattered Radiation Dose

The impact of X-ray tube position and incident photons direction (vertical, horizontal) are investigated for several exposure sittings commonly used in clinical diagnoses, for each exposure sitting the incident radiation are directed vertically on X-ray tube table and

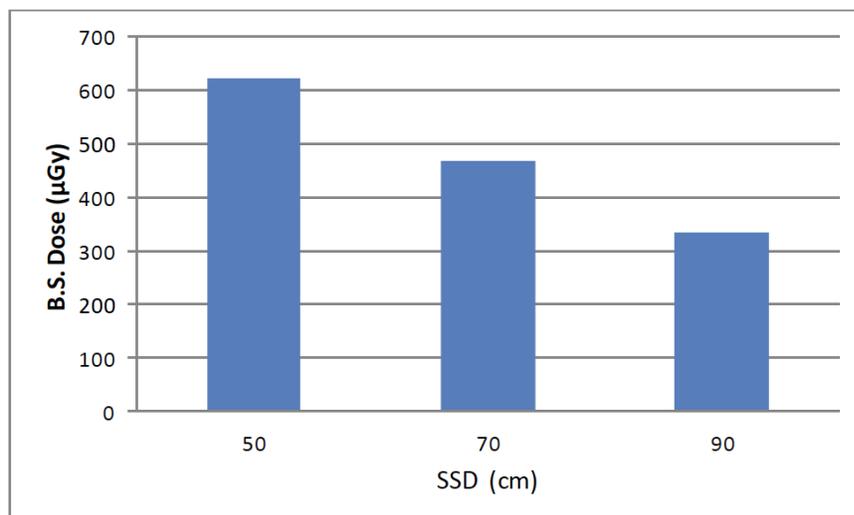


Figure 8: Backscattered dose at different distance between exposed object and X-ray source.

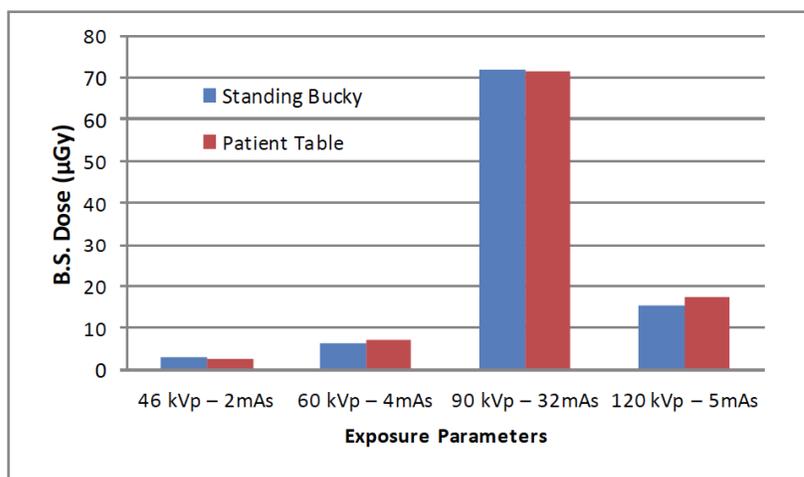


Figure 9: Backscattered dose for different X-ray tube positions.

horizontally on standing bucky, and the backscattered radiation doses are estimated for both directions and compared as illustrated in Figure 9, the results show that, there is no remarkable difference in recorded backscattered dose due to the position of X-ray tube or the direction of incident X-ray photons.

The results showed that all exposure settings for X-ray tube presented similar backscattered radiation dose for the different X-ray unit positions and incident X-ray directions.

4. CONCLUSION

Backscattered X-ray depends on various exposure factors, such as X-ray tube voltage, exposure intensity, the distance between X-ray source and imaged object surface. The reduction of backscattered radiation dose can be achieved by adequate changes of radiation exposure factors to reduce backscattered radiation as low as possible. The backscattered radiation is an undesirable dose should be kept at lowest level within the permissible occupational dose.

REFERENCES

- [1] Foffa MC, Andreassi MG. Health risk and biological effects of cardiac ionising imaging: from epidemiology to genes. *International Journal of Environmental Research and Public Health* 2009; 6: 1882-1893. <https://doi.org/10.3390/ijerph6061882>
- [2] Mittone A. Development of X-ray phase-contrast imaging techniques for medical diagnostics: towards clinical application; PhD Thesis, Ludwig-Maximilians-Universität 2015.
- [3] Health Physics Society. Radiation Exposure From Medical Exams and Procedures. Health Physics Society Fact Sheet [online]. 2020; Available at https://hps.org/documents/Medical_Exposures_Fact_Sheet.pdf
- [4] NAEC, National Atomic Energy Commission Statistics of Ionizing Radiation Sources Used in Medical Diagnostic in Yemen, technical report; Ministry of Health, Yemen 2015.
- [5] Amaoui, Bouchra, Semghouli, Slimane, El Kharras, Abdennasser, El Fahssi, Mohamed, Hakam, Oum Keltoum & Choukri, Abdelmajid. Medical exposure and risk estimation during routine radio-diagnostic examinations in Agadir City in 2012. *Journal of Radiation Research and Applied Sciences*, 2020; 13(1): 68-72. <https://doi.org/10.1080/16878507.2019.1695382>
- [6] Naryshkin S. On methods for assessing radiation load on medical personnel during an endourologic intervention. *Biomedical Engineering* 2007; 41(5): 228-231. <https://doi.org/10.1007/s10527-007-0053-y>
- [7] Bushong SC. Radiologic science for technologists: physics, biology, and protection. 10th edition, ISBN 978-0-323-08135-1, Elsevier Health Sciences 2013.
- [8] Nicholas J. Principle of patient radiation protection. 2006; Retrieved 04-03, Vol. Available: www.ceessential.net
- [9] IAEA, International Atomic Energy Agency. Radiation Protection and Safety in Medical Uses of Ionizing Radiation; Specific Safety Guide, No. SSG-46, IAEA, Vienna 2018.
- [10] Holmes K, Elkington M, Harris P. Clark's Essential Physics in Imaging for Radiographers, CRC Press 2013. <https://doi.org/10.1201/b15383>
- [11] Denise, O. Scatter control and grid use. 2007; Retrieved 05-09, 2012, from www.unisanet.unisa.edu.au/Resources/.../Scatter%20Control.
- [12] Langmack KA. Portal imaging. *The British Journal of Radiology* 2001; 74(885): 789-804. <https://doi.org/10.1259/bjr.74.885.740789>
- [13] Katalin K. The clinical significance of diagnostic modalities X-rays. Budapest, Semmelweis University, Department of Radiology and Oncotherapy 2012.
- [14] Alzoubi AS, Bauk S, Alam MS. Precision of low-dose response of LiF:Mg, Ti dosimeters exposed to 80 kVp X-rays. *Journal of Physical Science* 2011; 22: 125.
- [15] White SC, Pharoah MJ. Oral radiology: principles and interpretation; Elsevier Health Sciences 2014.
- [16] Carlton RR, Adler AM. Principles of radiographic imaging: an art and a science, 5th edition; Cengage Learning 2012.
- [17] Theocharopoulos N, Damilakis J, Perisinakis K, Manios E, Vardas P, Gourtsoyiannis N. Occupational exposure in the electrophysiology laboratory: quantifying and minimizing radiation burden. *The British Journal of Radiology* 2014; 79(944). <https://doi.org/10.1259/bjr/76128583>

- [18] Mohamed AHH. Determination of scattered radiation to the testis during pa chest X-ray procedures. Distance education Project Report; Distance education Project Report, Universiti Sains Malaysia 2007.
- [19] Farlex, Medical Dictionary for the Dental Professions 2012; Available at Website:<http://medical-dictionary.thefreedictionary.com/backscatter+radiation> "> backscatter radiation.
- [20] Merriam-webster Dictionary, Definition of backscatter, 2016; available at <http://www.merriam-webster.com/dictionary/backscatter>.
- [21] Engel-Hills P. Radiation protection in medical imaging. *Radiography* 2006; 12: 153. <https://doi.org/10.1016/j.radi.2005.04.008>
- [22] Tsapaki V, Tsalafoutas I, Chinofoti I, Karageorgi A, Carinou E, Kamenopoulou V, Yakoumakis E, Koulentianos E. Radiation doses to patients undergoing standard radiographic examinations: a comparison between two methods. *The British Journal of Radiology* 2014; 80: 107-112. <https://doi.org/10.1259/bjr/87150291>
- [23] Martin C. Optimisation in general radiography. *Biomedical Imaging and Intervention Journal* 2007; 3(2). <https://doi.org/10.2349/bij.3.2.e18>
- [24] NDT, Non-Destructive Testing, Resource Center 2016; Backscatter Radiation, available at https://www.nde-ed.org/Teaching/Resources/NDT_Tips/X-ray/Backscatter.htm.
- [25] US Food and Drug Administration; USA 2013.
- [26] CDRH, Guidance for Industry and FDA Staff, Radiation Safety Considerations for X-ray Equipment Designed for Hand-Held Use; Center for Devices and Radiological Health, U.S. Department of Health and Human Services 2008.
- [27] Vlachos I, Tsantilas X, Kalyvas N, Delis H, Kandarakis I, Panayiotakis G. Measuring scatter radiation in diagnostic X rays for radiation protection purposes, *Radiation protection dosimetry* 2015. <https://doi.org/10.1093/rpd/ncv093>
- [28] Chiang HW, Chiang HJ, Li JH, Tsang LL. Evaluation of scattered radiation dose received by medical staff during uterine artery embolization in the operating room. *Technology and health care : official journal of the European Society for Engineering and Medicine* 2020; 28(S1): 3-11. <https://doi.org/10.3233/THC-209002>
- [29] Ghafarain P, Ay M, Sarkar S, Ghadiri H, Zaidi H. Impact of X-ray tube voltage, field size and object thickness on scattered radiation distribution in diagnostic radiology: A Monte Carlo investigation. *IEEE Nuclear Science Symposium Conference Record* 2007; 5: 3830-3834. <https://doi.org/10.1109/NSSMIC.2007.4436956>
- [30] Bushberg JT, Boone JM. *The essential physics of medical imaging*, Third edition; Lippincott Williams & Wilkins 2012.
- [31] Binger T, Seifert H, *et al.* Dose inhomogeneities on surfaces of different dental implants during irradiation with high-energy photons; *Dentomaxillofacial Radiology* 2014.
- [32] Wagner LK, Archer BR, *et al.* Management of patient skin dose in fluoroscopically guided interventional procedures. *Journal of Vascular and Interventional Radiology* 2000; 11(1): 25-33. [https://doi.org/10.1016/S1051-0443\(07\)61274-3](https://doi.org/10.1016/S1051-0443(07)61274-3)
- [33] Sharma R, Sharma SD, Pawar S, Chaubey A, Kantharia S, Babu DA. Radiation dose to patients from X-ray radiographic examinations using computed radiography imaging system. *Journal of Medical Physics* 2015; 40(1): 29-37. <https://doi.org/10.4103/0971-6203.152244>

Received on 05-11-2020

Accepted on 02-12-2020

Published on 31-12-2020

DOI: <https://doi.org/10.31875/2410-4701.2020.07.10>

© 2020 Naji and Ali; Zeal Press

This is an open access article licensed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted, non-commercial use, distribution and reproduction in any medium, provided the work is properly cited.