DOSIMETRIC CHARACTERISTIC OF AL_2O_3 NANODOT® OSL DOSIMETERS FOR THE MEASUREMENT OF EFFECTIVE DOSES IN THE PRESENCE OF ANODE HEEL EFFECT IN PELVIC RADIOGRAPHY

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ABSTRACT

The Al2O3 NanoDot® OSL (OSL) dosimeters is seen as potential internal dosimeter for dosimetry studies in medical physics. The study focuses on the dosimetry characteristics of OSL dosimeters in kilovoltage x-ray energies the dosimetry on several organs during pelvic radiography. The anode heel effects on femoral head, colon, bladder and rectum were measured by using OSL dosimeters based on the pelvic radiography protocol in an anthropomorphic phantom. The effective dose of the organs was measured based on the ICRP 60 and 103 reports. The results indicated dose reduction in the anode side measured by using OSL dosimeter with the percentage difference of 32% compared to without the anode heel effect. The organ doses were significantly reduced when they were placed at anode side compared to the cathode side. The total effective dose however showed no significant change between with and without the application of the anode heel effect. The overall results indicated the ability of OSL dosimeter to detect dose reduction in organs resulted by the anode heel effect.

ABSTRAK

Dosimeter Al2O3 NanoDot® OSL (OSL) dilihat sebagai dosimeter dalaman yang berpotensi untuk kajian dosimetri dalam fizik perubatan. Kajian memberi tumpuan kepada ciri dosimetri dosimeter OSL dalam kilovoltan x-ray memberi tenaga kepada dosimetri pada beberapa organ semasa radiografi pelvis. Kesan tumit anod pada kepala femoral, kolon, pundi kencing dan rektum diukur dengan menggunakan dosimeter OSL berdasarkan protokol radiografi pelvis dalam hantu antropomorfik. Dos berkesan organ diukur berdasarkan laporan ICRP 60 dan 103. Keputusan menunjukkan pengurangan dos di bahagian anod yang diukur dengan menggunakan dosimeter OSL dengan peratusan perbezaan 32% berbanding tanpa kesan tumit anod. Dos organ telah dikurangkan dengan ketara apabila ia diletakkan di bahagian anod berbanding dengan bahagian katod. Jumlah dos berkesan bagaimanapun tidak menunjukkan perubahan ketara antara dengan dan tanpa penggunaan kesan tumit anod. Keputusan keseluruhan menunjukkan keupayaan dosimeter OSL untuk mengesan pengurangan dos dalam organ akibat kesan tumit anod.

Keywords: OSL dosimeter, anode heel effect, pelvic radiography

INTRODUCTION

Pelvic X-ray radiography involves the exposure to several radiosensitive organs located in the pelvis area. Gonad shielding is often provided to the patient with the aim to protect the gonads from harmful exposure. As low dose radiation still poses a dangerous effect, more attention shall be given to measure the dose other radiosensitive organs and to reduce them if possible. Recent studies highlighted the significance of patient orientation in achieving lower dose to these organs due to the presence of anode heel effect. The anode side of x-ray tube exhibits a drop in radiation intensity due to the presence of anode heel effect. The photons at anode side may reduce as much as 25%, while at cathode side, the photons may increase as much as 20% (Fung et. al., 2000). The impact of anode heel orientation in includes the reduction of dose for radiograph procedures such as thoracic, spine, chest and extremities, in which the tissue thickness graduates along its length (Kusk et al., 2021). By placing the x-ray tube with the anode-cathode axis runs parallel to thin-to-thick tissue, more x-rays will penetrate the thicker part of the tissue and lesser x-rays will penetrate the thinner part. This will result in even x-rays emerging out of the patient.

The use of Optically Stimulated Luminescence (OSL) dosimeter in radiation dosimetry has recently increased due to its promising properties, which includes stable sensitivity, high precision, high accuracy and fast readout (Yukihara et. al., 2008; Scarboro et. al., 2015). OSL dosimeter is applied in various field and studies, including beam output verification, patient surface, in vivo, and phantom measurements. Several studies described the basic characteristics of OSL dosimeter and its capability for clinical applications. These include energy dependence measurements, angular dependence measurements, procedure for calibration, procedure for annealing and measurement using anthropomorphic phantom (Endo et al., 2012). Recent studies demonstrated the characterization of OSL dosimeter for clinical dosimetric measurements. It is proven that OSL dosimeter exhibits high accuracy, excellent precision, and negligibly small dependence on energy in diagnostic x-ray examinations (Okazaki et. al., 2016). The measurement of organ dose is vital in order to estimate the relative risk of cancer occurrence that is associated with diagnostic photons. To achieve this, a dosimeter is embedded in tissue-equivalent anthropomorphic phantom to estimated organ dose.

This study focused on the measurement of dose to several organs in Antero-posterior (AP) projection of pelvic radiography using OSL dosimeter type nanoDot ®, with the aim to determine the sensitivity of OSL dosimeters on the anode heel effects in radiography.

METHODOLOGY

Assessment of Dose Profile across the Anode and Cathode

The OSL dosimeters were exposed to 77 kV and 18.0 mAs with source-to-image distance (SID) at 102 cm based on the AP pelvic radiography protocol as shown in Figure 1. The OSL dosimeters were first arranged at the central axis along the anode-cathode line of the x-ray tube. The OSL dosimeters were placed at both cathode and anode side, while 1 OSL dosimeters was placed at the centre of the cathode-anode axis. It was ensured that every OSL dosimeter were at equal distance towards each other. An exposure was made. The OSL dosimeters were then read out using microSTAR reader to obtain the absorbed dose. 5 readings were taken for each OSL dosimeter and the value was averaged.

The percentage change of the radiation dose relative to the central point to the central point was calculated based on the study by Mraity et. al., (2016):

$$Percentage\ of\ change = \frac{Dose\ at\ anode\ or\ cathode\ side}{Dose\ at\ central\ axis\ beam} \times 100\% \quad (1)$$

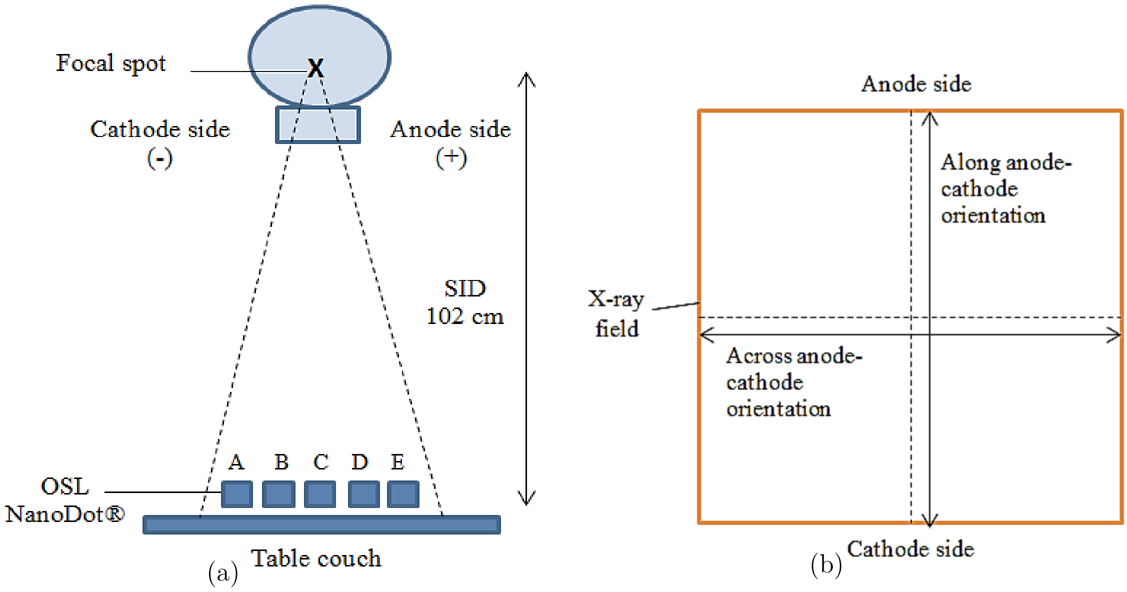

Figure 1: (a) Diagram set-up for dose profile assessment along the anode-cathode axis and (b) the orientation of along the anode-cathode and across the anode-cathode.

Measurement of Organ Doses

The doses in several critical organs during pelvic radiography were measured in the anthropomorphic ART phantom. The phantom was first scanned by using a CT scanner at abdominal CT protocol to locate the position of the critical organs of femur, bladder, rectum and colon. A number of three OSL dosimeters were the place on the centre of the identified organs. The ART phantom was exposed to X-rays using the pelvic radiography protocol at two orientations; head on anode side and head on the cathode side as shown in Figure 3.

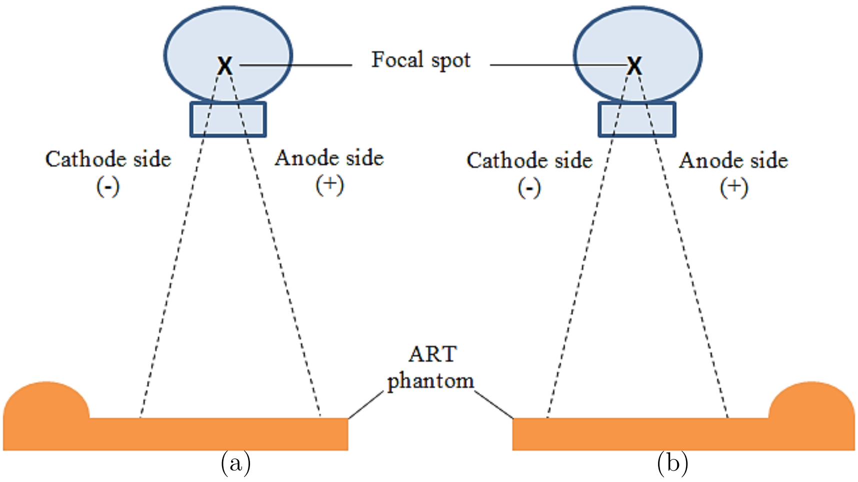

Figure 2. The positioning of ART phantom at anterior-posterior (AP) pelvic radiography at (a) head towards cathode side and (b) head towards anode side.

The equivalent dose, H_T for each organ was calculated based on International Commission on Radiological Protection (ICRP) Report 103 (Valentin, 2007):

$$H_T = \Sigma_R W_R . D_{T,R} \qquad (2)$$

With D_T, is absorbed dose averaged over the tissue or organ, T due to the incident radiation, R and W_R is radiation weighting factor. The effective dose, E for each organ was calculated based on ICRP 103:

$$E = \sum W_T \cdot H_T \qquad (3)$$

With E is effective dose absorbed by entire body, W_T is tissue weighting factor, and H_T is equivalent dose absorbed by tissue T. A number of five exposures were made and the average dose in each OSL dosimeter in the organs were calculated. The dose in OSL dosimeters were measured by using the MicroStar OSL reader at diagnostic X-ray set up in the Secondary Standard Diagnostic Laboratory (SSDL), Malaysian Nuclear Agency.

RESULTS AND DISCUSSION

The doses across the X-ray beams at the orientations of across the anode-cathode and along the anode-cathode are illustrated in Figure 3. The results showed the decrease in the dose at position across the beam between OSL dosimeter A to E in the across the anode-cathode orientation. It was also showed the reduction of dose away from the central axis and the reduction of dose dramatically increased at anode side of the X-ray tube with position A, B, D and E measuring absorbed dose of 0.654 mGy, 0.952 mGy, 1.112 mGy and 0.984 mGy respectively. All four positions recorded an absorbed dose lower than the central position C (1.169 mGy).

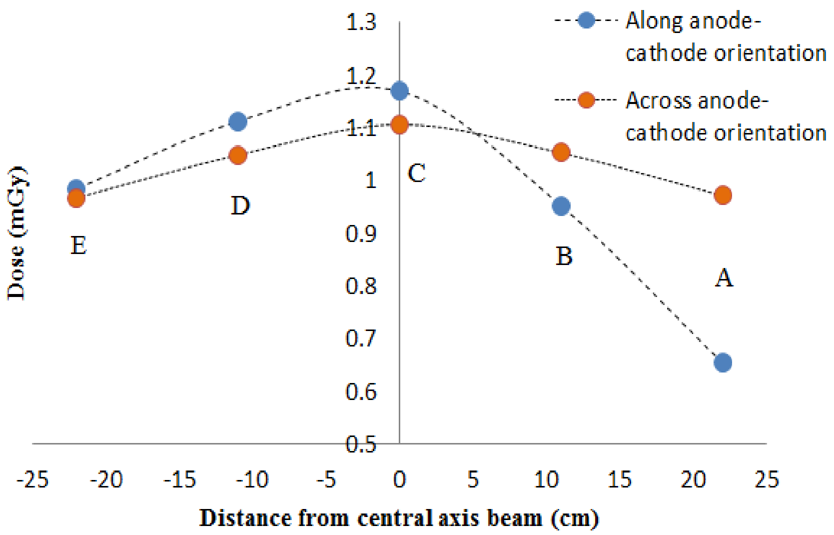

Figure 2. Dose profile (mGy) at across anode-cathode and along anode-cathode orientations by using pelvic radiography protocol.

Table 1 and 2 shows the dose to critical organs for position of head towards anode and head towards cathode respectively. A number of 3 OSL dosimeters were placed in each critical organ and a total of 5 readings were obtained from each organ. The average readings were calculated from the OSL dosimeter readings. The equivalent doses for all critical organs were calculated using Equation 2 while the radiation weighting, W_R of 1 as X-rays were used. The tissue weighting factor was referred to ICRP 60 and ICRP 103. The effective dose for each organ was then calculated using Equation 3. The colon received an average dose of in head towards cathode orientation was higher than the head towards anode orientation by 9.6% percentage of difference. In contrast, the mean dose received by femoral head, bladder and colon were slightly less when the phantom head at the anode side of the x-ray tube, owing to the anode heel effect. In any of the two anode-cathode orientation, there will always be a projection in which organs on one side receive higher dose while organs on the other side receive lower dose.

Table 1. Dose to several organs with position of head towards anode in pelvic radiography.

Organ	Average dose (mGy)	Equivalent dose (mSv)	Tissue weighting factor		Effective doe (mSv)	
			ICRP 60	ICRP 103	ICRP 60	ICRP 103
Femoral head	0.558	0.558	0.05	0.12	0.028	0.067
Bladder	1.639	1.639	0.05	0.04	0.082	0.066
Rectum	0.213	0.213	0.05	0.12	0.011	0.026
Colon	1.397	1.397	0.12	0.12	0.168	-
Total effective dose					0.288	

Table 2. Dose to several organs with position of head towards cathode in pelvic radiography.

Organ	Average dose (mGy)	Equivalent dose (mSv)	Tissue weighting factor		Effective doe (mSv)	
			ICRP 60	ICRP 103	ICRP 60	ICRP 103
Femur head	0.525	0.525	0.05	0.12	0.026	0.063
Bladder	1.434	1.434	0.05	0.04	0.072	0.057
Rectum	0.179	0.179	0.05	0.12	0.009	0.021
Colon	1.545	1.545	0.12	0.12	0.185	-
					0.292	

ICRP 60 was published in 1991 while ICRP 103, which is also known as 2007 recommendations, has tissue weighting factor updated due to the latest scientific information of physics and biology of radiation exposure (Obed et. al., 2015). The ICRP 60 differs to the ICRP 103 on the tissue weighting factor of organs. Based on the results, it can be concluded that the effective dose calculated using ICRP 103 for femoral head and rectum is higher compared to ICRP 60 due to the higher tissue waiting factor for ICRP 103. The total effective dose showed reduction in head towards anode orientation compared to head towards cathode orientation by 1.5% indicating no significant different of total effective dose when the anode heel effect is utilized (Mraity et. al., 2020; Mraity et. al., 2017). This study however indicated the ability of the OSL dosimeters to measure a small change of doses due to the anode heel effect.

CONCLUSION

The dose profile along the anode-cathode axis showed a rapid fall towards the anode, due to the presence of anode heel effect. There is a relative dose reduction in several organs when anode heel was utilized in the AP pelvis radiography. There was no significant difference in total effective dose in the pelvic area when anode heel effect was utilized. This study however also provides evidence of the ability of OSL dosimeters to detect small changes of organ doses in diagnostic range of X-ray energies and can be potentially utilized in many dosimetric studies in radiography.

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REFERENCES

[1] Fung K K and Gilboy W B 2000 Anode heel effect on patient dose in lumbar spine radiography. *Br. J. Radiol.,* 73(869), 531–536.

[2] Kusk M W, Jensen J M, Gram E H, Nielsen J and Precht H. 2021 Anode heel effect: Does it impact image quality in digital radiography? A systematic literature review. *Radiography*, 27(3), 976–981.

[3] Yukihara E G, and McKeever S W 2008 Optically stimulated luminescence (OSL) dosimetry in medicine. *Phys. Med. Biol.,* 53(20), 351–379.

[4] Scarboro S B, Cody D, Alvarez P, Followill D, Court L, Stingo F C, Zhang D, McNitt-Gray M. and Kry S F 2015 Characterization of the nanoDot OSLD dosimeter in CT. *Med. Phys.,* 42(4), 1797–1807.

[5] Endo A, Katoh T, Kobayashi I, Joshi R, Sur J, and Okano T 2012 Characterization of optically stimulated luminescence dosimeters to measure organ doses in diagnostic radiology. *Dentomaxillofac. Radiol.,* 41(3), 211–216.

[6] Okazaki T, Hayashi H, Takegami K, Okino H, Kimoto N, Maehata I, and Kobayashi I 2016 Fundamental Study of nanoDot OSL Dosimeters for Entrance Skin Dose Measurement in Diagnostic X-ray Examinations. *J. Radiat. Prot. Res.,* 41(3): 229-236.

[7] Mraity H A A B, England A, Cassidy A, Eachus P, Dominiguez A and Hogg P 2016 Development and validation of a visual grading scale for assessing image quality of AP pelvis radiographic images. *Br. J. Radiol.,* 89(1061), 20150430.

[8] Mraity H A A B, Walton L, England A, Thompson J, Lanca L, and Hogg P 2020 Can the anode heel effect be used to optimise radiation dose and image quality for AP pelvis radiography? *Radiography* ,26(2), 103–108.

[9] Valentin J 2007 The recommendations of the International Commission on Radiological Protection, *ICRP Report 103*, Elsevier

[10] Obed R, Ogbole G. and Majolagbe S 2015 Comparison of the ICRP 60 and ICRP 103 Recommendations on the Determination of the Effective Dose from Abdominopelvic Computed Tomography. *IJMPCERO*, 4, 172-176.

[11] Mraity H A A B, England A, and Hogg P 2017 Gonad dose in AP pelvis radiography: Impact of anode heel orientation. *Radiography*, 23(1), 14-18.