Characterization of the Optically Stimulated Luminescence nanoDot for CT Dosimetry

Muhammad Yusuf[1], Abdelhamid Saoudi[2,3], Nazeeh Alothmany[4], Dheya Alothmany[1], Sameer Natto[5], Hattan Natto[6], Nurul Islam Molla[6], Noor Mail[2,3], Ahmad Hussain[1], Abdulraheem Abdulrahman Kinsara[1]

[1]Nuclear Engineering Department, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[2]King Abdullah International Medical Research Center (KAIMRC), Jeddah, Saudi Arabia
[3]Princess Norah Oncology Center (PNOC), National Guard Health Affairs (NGHA), Jeddah, Saudi Arabia
[4]Electrical and Computer Engineering Department, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia
[5]Department of Physics, Faculty of Science, Umm Al Qura University, Mecca, Saudi Arabia
[6]Center of Training and Radiation Protection, King Abdulaziz University, Jeddah 21589, Saudi Arabia
Email: myusufprajogo@gmail.com

Abstract: To characterize point dose response of optically stimulated luminescence (OSL) nano dot detector (OSLD) for computed tomography (CT) dosimetry and compare it with the data obtained with various ionization chambers. The OSLD was calibrated at 125 kVp and 15 mAs. A point dose measurement was performed on a custom-made-cylindrical-water phantom (20 cm diameter and 46 cm length) with scan length from 5 to 40 cm range using OSLD. The OSLD was characterized in terms of linearity, re-readability, signal fading, angular dependence, surface dose profile etc. The relative response of OSLD was compared with three PTW ionization chambers:Semiflex 0.125 cm^3, Farmer 0.6 cm^3 and Pencil 3.14 cm^3. The OSLD calibration was achieved to be 52.83±7 counts/mRad. The OSLD were reasonably linear with R2 of 0.9989. The average variation OSLD response during rereadability test was ±1.38%. Negligible variation has been seen after 30minutes resting. The maximum angular dependence was 2%. The variations between the PTW ionization chambers and OSLD for a scanning length of 5-10 cm and 15-40 cm were 8% and 0.5%, respectively.

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1. INTRODUCTION

A new technology which isoptically stimulated luminescence has been used as a choice in personnel dosimetry, especially in clinical application. With similar principal to thermoluminescence (TL), only the basic to induce luminescence of irradiated material where optical stimulus is used in OSL instead of thermal stimulus in TL. The signal that has been released from light-emitting diodes (LEDs) is directly proportional to the dose absorbed from OSL [1]. The other difference is that luminescence can be read anywhere between seconds and minutes, also can be read many times with less depletion signal compare with TL [2]. Some experiments were evaluated for routine used in various dosimetry applications [3], [4] and offer great advantages over than other detectors. With more accurate determination dose, by capturing high-energy photons efficiently in small size of dosimeters.

Recently, latest technology from multi-detector CT (MDCT) scans, requires renewed awareness to the patient dose. Also more accurate methodology to determine the organ dose produced from MDCT scan is needed since the air-kerma measurement techniques was quite obsolescence [5]–[7]. As we know that OSL has some potential advantages, then characterization OSL is required before using it as personnel dosimeter. Several experiments have been evaluated in CT dosimetry[8]–[10] and the results indicate that the OSL dosimetrers are good candidates for imaging dosimetry. However, still need more experimental that can be conducted to justify that OSL can be an alternative personnel dosimeter during CT dosimetry. In this paper, the examined characteristic included calibration, signal fading, linearity, re-readability, angular dependence, comparison of scan length variation with other detector.

2. MATERIAL AND METHODS

2.1 Calibration

A set of6 unexposed OSL was selected and placed to the the board with the PTWIonization chamber as the reference dose. And another set of 3 unexposed OSLD was placed out of the board as background..Then Siemenes portable X-ray was place 100 cm over the board and 20 cm of scan field for exposure was required from portable X-ray followed figure 1.OSL and PTW Ionization chamber were exposed with 125 kVp and 16 mAs using portable X-ray machine.

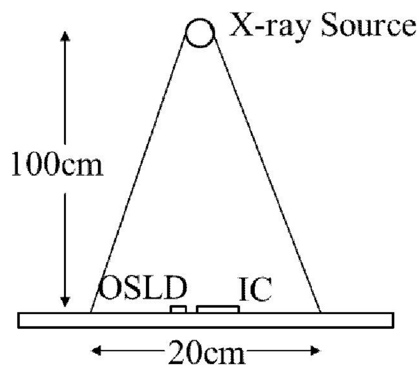

Figure 1. Schematic of OSLD calibration Set-up

The exposed OSLD were read using Microstar reader to read the amount of photons that captured by PMT from the reader. The amount of photons (PMT counts) then subtracted with the background. And the net of PMT counts were compared with the dose that measured from PTW Ionization chamber. The comparison value was defined as calibration factor and will be used for next experiments during dose calculation. The calculation for calibration factor was shown in eq 1.

$$CF = \frac{PMT\ Counts\ (Net)}{Dose\ (mRad) * Sensitivity} \quad (1)$$

Where CF is calibration factor that been using for calculating the dose from OSL, PMT counts is how many photons from OSLD that generated by Photomultiplier tube (PMT), dose is the reference dose at the same condition of OSL, sensitivity is the sensitivity of OSLD.

2.2 Signal Fading

An unexposed OSLD was irradiated with 100kVp, 150mAs, 5 scan length helical scan using CT machine was shown at figure 2. After exposure, started from 1 to 60 minutes, an exposed OSLD was read and repeated for 4 times to see the variation during fading. This purpose was to study the signal fading of OSLD and resting time that required after exposure.

Figure 2. OSL placement in free air condition

2.3 Linearity

Each of unexposed OSLD was inserted to the center of 47cm length and 20 cm diameter of water phantom and irradiated with fixed energy in different mAs (2, 4, 8, 16, 32 mAs) to study the linearity response of OSLD when exposed from CT 16 slices unit. The OSLD was put in the center of the rod of styrofoam, then exposed using fixed kVp (80 kVp) as fig 2.

2.4 Re-readability

3 random unexposed OSLD (xxx54T, xxx94F, xxx26Z) with same sensitivity were irradiated with 100kVp, 150mAs, 5cm scan length helical scan using CT machine. After exposure, each of OSLD was read up to 100 times to see the consistency during multiple readings.

2.5 Angular Dependence

The variability of OSLD response to the incident x-ray beams from various angles was studied. Four different angles were used with the CT. A stereo foam as air equivalent was made, on which the dosimeters were placed to give the angles from 0^0, 45^0, 90^0, and 135^0 followed the xz-axis. The angular dependence was tested using 16-slice CT scanner. The schematic of the OSLD orientation along x-axis was shown in figure 3.

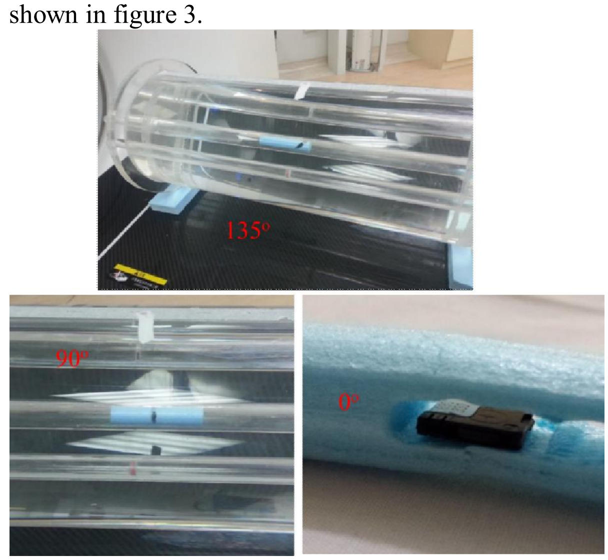

Figure 3. OSL orientation in different angular

2.6 Scan length variation for difference detectors

The relative response of OSLD for different scan lengths compared with three PTW ionization chambers (IC): Semiflex 0.125 cm^3, Farmer 0.6 cm^3 and Pencil 3.14 cm^3.

Each of OSLD was inserted into the center of water phantom alternately and exposed with fixed energy (120 kVp) and mAs (150mAs) with various scan length from 5cm up to 40cm [11].

3. RESULTS

3.1 Re-readability

The reading of a set of 6 unexposed OSL that read by using Microstar reader also Ionization Chamber was shown in table below.

The readings of OSLD were in PMT Count. To obtain the exact reading (Net), the readings of OSL were deducted with the background readings from unexposed OSLD.

Table I. OSLreading compare with Ionization Chamber reading

PMT Counts (Net)	Ave. PMT Counts (Net)	Std Dev PMT Counts (Net)	Ionization Chamber (mGy)	Ave. Ionization Chamber (mGy)
1298.667	1205.867	9.22%	0.279	0.278
1190.667			0.278	
1261.667			0.278	
1019.667			0.279	
1258.667			0.279	

With the sensitivity of each OSLD is 0.82. The generated calibration was obtained from this experiment was 52.83 counts/mRad with ±3.68 counts/mRad.

3.2 Signal fading

The result of OSLD response for different elapsed time was shown in figure 4. The OSLD was read after getting rest for various elapsed times from 0 to 60 minutes. The readings were already deducted with the background reading.

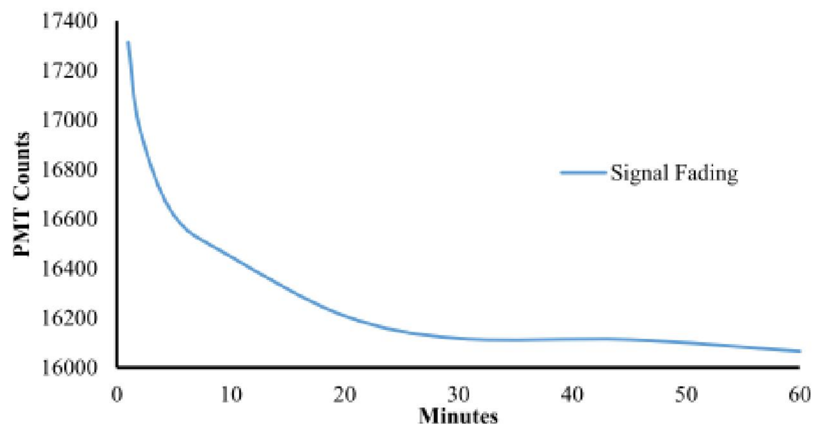

Figure 4. Signal fading after 60 minutes resting

3.3 Linearity

The linearity of OSLD response that exposed using fixed energy (80 kVp) with various mAs, was plotted in fig 5.

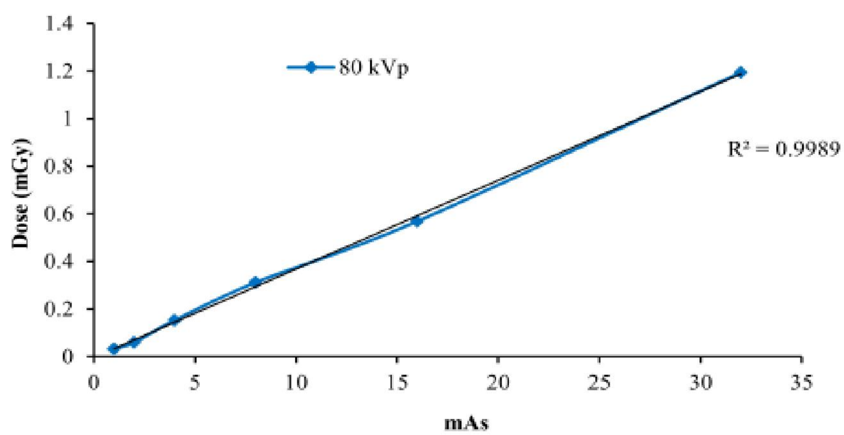

Figure 5. Linearity of OSLD response in 80 kVp

3.4 Re-readability

The re-readability response after exposure was obtained by repeating 3 OSLD for 100 times. Dosimeter's reproducibility during re-readability was found and shown in figure 6.

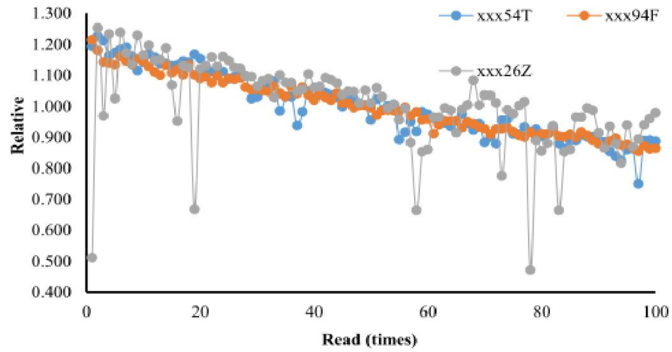

Figure 6. The Relative response of OSLD after repeating the reading up to 100 times

3.5 Angular Dependence

Doses from angled OSL nanoDots were normalized to the 00 dose, in which the detector's serial number was facing the beam. The normalized dose to $0^0$was described in figure 7. 4 angles were varied due to the similar results found at 180^0 that was similar to 0^0 and 270^0 that was similar to 90^0.

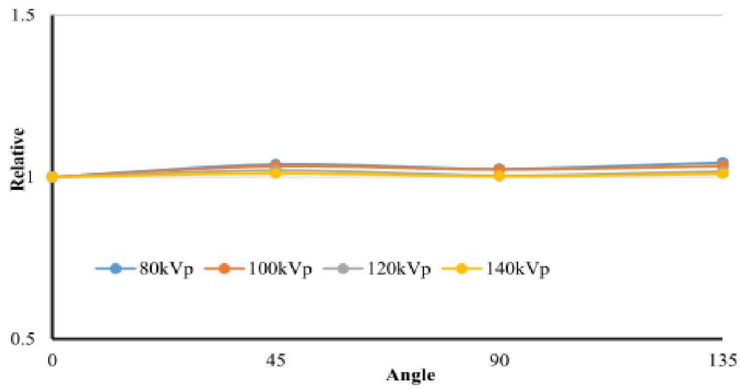

Figure 7. OSL Orientation response in different energy

3.6 Scan length variation for difference detectors

The comparison of OSL response, that were inserted into the center of water phantom alternately and exposed with fixed energy (120 kVp) and mAs (150mAs) with various scan length from 5cm up to 40cm, with various PTW ionization chamber was described on fig 8. All dose were normalized with the dose at 40 cm scan length as the maximum scan length during the experiment.

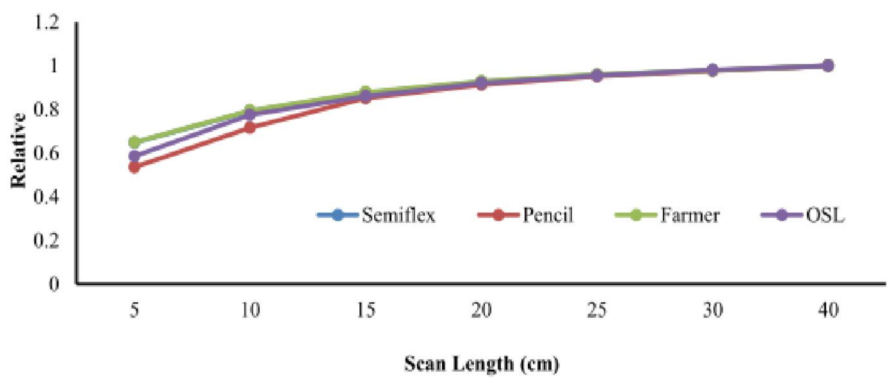

Figure 8. OSL Orientation response in different energy

4. DISCUSSION

The generated calibration factor from this experiment was 52.83counts/mRad with ±3.68 counts/mRad. It represents that every 52.83 photons that generated from PMT tube is equal with 1 mRad. The fading data might attributed to systematic uncertainties, which were not taken into consideration, including inaccuracy in the time elapsed since irradiation and readout sessions. This is in agreement with the recommendation that OSL should be read at least 8 min after exposure [12]. The first 20 minutes elapse that created fading can be attributed to the thermal instability of shallow trap at room temperature. As expected, the response of OSLD was linear during linearity test. With regression coefficient was very close to value of one, the OSLD showed good linear response for different current time (mAs) during CT examination. This result showed same statements with the published result of the manufacture and other publications [8], [13]–[15]. Figure 6 illustrates the plot of the 100 repeated measurement from 3 OSL with last three serial numbers were 54T, 94F and 26Z. The average of reading sequence depletion was found to be 0.27% for 54T, 0.32% for 94F and 0.59% for 26Z. The average depletion signal per readout was found to be 177 counts for 54T, 144 counts for 94F and 225 for 26Z. The advantages of OSLD against TLD is the re-readability process, OSLD are stimulated in very short time, which allows the dosimeter to retain the dose record. Based on manufacture, it was found that only 0.05% signal was depleted at the high dose mode [8], [16]. But during this experiment, the depletion was found up to 0.59% which is 10 times higher than the depletion during high dose mode. Considering the uncertainties factor such as statistical fluctuation or sensitivity of OSL that been used, the amount of depletion might be considered small [9] also it was much better than some experiments which has average depletion to be 2.5% using high beam energy [17]. From fig 7, the variation of each angular was close to 5%. This might be explained by the orientation itself. When the OSL was rotated along xz-axis, the volume area was playing role for receiving the photon. The bigger volume will receive more dose than the smaller one. In 45^0 and 135^0, the volume that received the photon was more because it received in 1 cm^2 area of front and back plastic case of OSL and also received almost each 0.2 mm of the OSL thickness in top and bottom. When for 0^0, the volume that received the photon was only in 1 cm^2 area of front and back plastic case of OSL, and only less that reached to top and bottom side of OSL. And for 90^o, the volume that received the photon was less than 0^o since only in the top and bottom side that received the photon from the CT [8], [18]. From figure 13, the doses were relative with the dose with 40 cm scan length from each detector. The 40 cm scan length was chosen since during this scan length, the dose that received to the detectors is the highest than the doses from other scan length. The dose relatives from 5 to 10 cm scan length are different on each detectors. From fig 13, Semiflex with 0.125 cm^3 volume and Farmer 0.6 cm^3 volume have higher relative than OSL with 1 cm^3 and Pencil with 3.14 cm^3 due to the detector volume. The detector volume is taking account during these scan lengths. When the detector volume is small, the photon that been received to the detector is more concentrate so the scattered radiation that coming to the detector is less than the primary [19]–[21]. In other hand, when the volume is higher, the scattered radiation is taking account and interfering the primary radiation as noise. The noise will reduce the dose because it also be included during dose calculation on the detector itself. The dose relatives from 15 to 40 cm scan lengths are almost same on each detectors. Since the scattered radiation produced during this length is quite high, so the scattered will interfere the primary as noise during dose calculation on the detector. Because of the scattered radiation is quite high as noise, the accumulated dose of primary and noise cannot be distinguished and filtered by the detector volume.

5. CONCLUSION

The linearity and re-readability for OSLD was found reasonably good. A 30 minutes resting is recommended to minimize the reading variation. Angular dependence for OSLD was found very negligible. OSLD was found to be a very good candidate for point dose measurements.

6. FUTURE RECOMMENDATIONS

To improve energy dependence was required by increasing the variation ofenrgy and mAs from the CT. Also for angular dependence, need to improve the angular dependence in the surface of the phantom.

7. ACKNOWLEDMENT

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Abbreviations

CT--Computed Tomography
OSL--Optically Stimulated Luminescence
OSLD--Optically Stimulated Luminescence Detector
PMT--Photo Multiplier Tube
TL--Thermo Luminescence

Corresponding Author:
Muhammad Yusuf
Department of Nuclear Engineering
King Abdulaziz University
Jeddah 21589
Kingdom of Saudi Arabia
E-mail: myusufprajogo@gmail.com

REFERENCES

[1] C. Ruan, E. G. Yukihara, W. J. Clouse, P. B. R. Gasparian, and S. Ahmad, "Determination of multislice computed tomography dose index (CTDI) using optically stimulated luminescence technology.," *Med. Phys.*, vol. 37, no. 7, pp. 3560–3568, 2010.

[2] M. S. Akselrod, L. Bøtter-Jensen, and S. W. S. McKeever, "Optically stimulated luminescence and its use in medical dosimetry," *Radiat. Meas.*, vol. 41, pp. S78–S99, Dec. 2006.

[3] H.Becquerel, "OPTICALLY STIMULATED LUMINESCENCE : FUNDAMENTALS," vol. 147, no. 4, pp. 619–622, 2011.

[4] L. Karsch, E. Beyreuther, T. Burris-Mog, S. Kraft, C. Richter, K. Zeil, and J. Pawelke, "Dose rate dependence for different dosimeters and detectors: TLD, OSL, EBT films, and diamond detectors," *Med. Phys.*, vol. 39, no. 5, p. 2447, 2012.

[5] E. G. Yukihara, P. B. R. Gasparian, G. O. Sawakuchi, C. Ruan, S. Ahmad, C. Kalavagunta, W. J. Clouse, N. Sahoo, and U. Titt, "Medical applications of optically stimulated luminescence dosimeters (OSLDs)," *Radiat. Meas.*, vol. 45, no. 3–6, pp. 658–662, Mar. 2010.

[6] R. L. Dixon and B. Gray, "The CTDI Paradigm: A Practical Explanation for Medical Physicists Deriving the CTDI Equation," no. November 2010, pp. 1–7.

[7] J. M. Boone, "The trouble with CTDI[sub 100]," *Med. Phys.*, vol. 34, no. 4, p. 1364, 2007.

[8] R. M. Al-Senan and M. R. Hatab, "Characteristics of an OSLD in the diagnostic energy range.," *Med. Phys.*, vol. 38, no. 7, pp. 4396–4405, 2011.

[9] L. Lavoie, M. Ghita, L. Brateman, and M. Arreola, "Characterization of a commercially-available, optically-stimulated luminescent dosimetry system for use in computed tomography.," *Health Phys.*, vol. 101, no. 3, pp. 299–310, Sep. 2011.

[10] S. W. S. McKeever, L. Bøtter-Jensen, N. Agersnap Larsen, and G. a. T. Duller, "Temperature dependence of OSL decay curves: Experimental and theoretical aspects," *Radiat. Meas.*, vol. 27, no. 2, pp. 161–170, Apr. 1997.

[11] AAPM Task Group 111, "Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography," 2010.

[12] A. A. Omotayo and J. E. Cygler, "The effect of different bleaching wavelengths on the sensitivity of Al 2 O 3 : C optically stimulated luminescence detectors (OSLDs) exposed to 6 MV photon beams," vol. 39, no. 9, pp. 5457–5468, 2012.

[13] P. a. Jursinic, "Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements," *Med. Phys.*, vol. 34, no. 12, p. 4594, 2007.

[14] M. A. Charlton, K. F. Thoreson, and J. A. Cerecero, "Determining the Applicability of the Landauer nanoDot as a General Public Dosimeter in a Research Imaging Facility," pp. 217–226, 2012.

[15] J. R. Kerns, S. F. Kry, and N. Sahoo, "Characteristics of optically stimulated luminescence dosimeters in the spread-out Bragg peak region of clinical proton beams.," *Med. Phys.*, vol. 39, no. 4, pp. 1854–63, Apr. 2012.

[16] P. a Jursinic, "Changes in optically stimulated luminescent dosimeter (OSLD) dosimetric characteristics with accumulated dose.," *Med. Phys.*, vol. 37, no. 1, pp. 132–140, 2010.

[17] a Viamonte, L. a R. da Rosa, L. a Buckley, a Cherpak, and J. E. Cygler, "Radiotherapy dosimetry using a commercial OSL system.," *Med. Phys.*, vol. 35, no. 4, pp. 1261–1266, 2008.

[18] J. R. Kerns, S. F. Kry, N. Sahoo, D. S. Followill, and G. S. Ibbott, "Angular dependence of the nanoDot OSL dosimeter.," *Med. Phys.*, vol. 38, no. 7, pp. 3955–3962, 2011.

[19] J. Wang, X. Duan, J. a Christner, S. Leng, L. Yu, and C. H. McCollough, "Attenuation-based estimation of patient size for the purpose of size specific dose estimation in CT. Part I. Development and validation of methods using the CT image.," *Med. Phys.*, vol. 39, no. 11, pp. 6764–71, Nov. 2012.

[20] G. X. Ding and A. W. Malcolm, "An optically stimulated luminescence dosimeter for measuring patient exposure from imaging guidance procedures.," *Phys. Med. Biol.*, vol. 58, no. 17, pp. 5885–97, Sep. 2013.

[21] E. G. Yukihara, C. Ruan, P. B. R. Gasparian, W. J. Clouse, C. Kalavagunta, and S. Ahmad, "An optically stimulated luminescence system to measure dose profiles in x-ray computed tomography.," *Phys. Med. Biol.*, vol. 54, no. 20, pp. 6337–52, Oct. 2009.

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