

Measurement of backscatter factor for kilovoltage x-ray beam using ionization chamber and Gafchromic XR-QA2 film

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Abstract. Backscatter factor (BSF) is an important parameter in the determination of surface dose for kilovoltage X-ray beam. The purpose of this study was to measure the BSF for kilovoltage diagnostic X-ray beam, and compare the measured BSF between Gafchromic XR-QA2 film and shadow free (SFD) ionization chamber (IC). The parameters that may affect the BSF, such as tube voltage (kVp) and field size, were also studied. The results were in good agreement with the TRS 457, with deviation of less than 12 %. Based on the film study, the BSF obtained from the film measurement were found to be lower than that of the IC, with average difference of 26 %. It was also found that smaller field size resulted in lower effective energy, and the amount of photons which scattered back onto the surface were also smaller. This study demonstrated that the Gafchromic XR-QA2 film was not suitable for the application of small field size.

1. Introduction

Backscatter factor (BSF) is defined as the ratio of the collision kerma of a phantom material; at the surface of a full scatter phantom located at a point in the beam axis, to the collision kerma of the same material; at the same point in the primary beam, with no phantom present [1][7]. Alternatively, BSF is defined as the ratio of a tissue [e.g. water, ICRU tissue or poly (methyl methacrylate) (PMMA)] kerma on the surface of a phantom consisting of the same material, to the tissue kerma at the same point in space, in the absence of the phantom [1][2][3][7]. The numerical values of BSF vary depending on both the definition used, and the chosen reference phantom material. Values of BSF were provided by ICRU-74 and IAEA TRS 457, for 21 diagnostic beam qualities with kilovoltages of between 50.0 and 150.0 kV, and for different types of filtration (2.5 mm aluminum (Al); 3.0 mm Al; 3.0 mm Al + 0.1 mm copper (Cu)). For each kV and filtration, the BSF were given in three field sizes and phantoms (i.e. 15.0 cm thick water, ICRU tissue and PMMA), respectively. The data obtained in these reports were taken from published studies [2][3]. The BSF is an important parameter in the determination of dose for kilovoltage X-ray beam. Equation (1) represents the definition of the BSF in radiodiagnostic dosimetry:



$$BSFair(Q) = \frac{(Kair, Q)_w}{(Kair, Q)_{air}} \quad (1)$$

where $(Kair, Q)_{air}$ is the incident air kerma free-in-air for the primary incident beam of quality, Q , at the point of measurement. This is achieved by multiplying the free-in-air ionization reading in the Q beam, $Mair, Q$ (corrected for the influenced quantities; pressure, temperature and recombination), by the corresponding calibration coefficient NK, Q . On the other hand, $(Kair, Q)_w$ is the air kerma at the surface of the water phantom [3].

Unfortunately, BSF data for beams in the diagnostic range were not as widely available, compared with the beams in the therapeutic range. The importance of BSF in determining the absorbed dose at the phantom's surface was clear, but achieving an accurate measurement has not been simple [4]. BSF measurement using an ionization chamber (IC) has always been a challenge, due to: (i) the effect of the displaced material inside the chamber volume, which results in the lack of scatter radiation being produced within the chamber; (ii) more scattering event occurring at the posterior of the chamber, as a result of lower attenuation; (iii) extra scatter radiation produced within the wall, due to the physical size of the apparatus. Gafchromic XR-QA2 films possess several appealing features, which might be suitable for the measurement of BSF. The film was designed specifically as a quality assurance (QA) tool for radiological applications. It is suitable for application in the energy range of between 20.0 and 200.0 kVp, with sensitivity to the dose range of between 0.1 and 20.0 cGy. As opposed to its predecessor, i.e. XR-QA film with Caesium Bromide (CsBr) sensitive layer, the sensitive layer of the XR-QA2 film contains Bismuth(III) Oxide (Bi₂O₃), which is intended to boost the photoelectric effect at lower energies. A previous study found that the sensitivity of the XR-QA2 film increased at the energy range of 18.0 to 39.0 keV, with maximum variation of about 170 %, and decreased at the energy range of 38.0 to 46.5 keV [5]. The film was well suited for the kilovoltage X-ray beam study, with the effective energy range from 33.7 to 39.0 keV. Currently, there is no general consensus amongst published literature pertaining to the accuracy of this type of film for BSF measurement.

2. Materials and methods

This study was carried out at the Satellite X-ray Unit in the Radiology Department, Hospital Universiti Sains Malaysia using a static X-ray machine (Optimus 80, Philips Healthcare, MA, USA) with three-phase power supply

2.1 Determination of effective energy

The effective energy of the kilovoltage X-ray machine was measured by determining the half-value layer (HVL) of the nominal X-ray energies, i.e. 70, 81, 90, 102 and 117 kVp. A shadow free (SFD) IC (PTW, Freiburg, Germany) was connected to an electrometer (Unidose E, PTW, Freiburg, Germany), and placed on the surface of a solid water phantom. The distance of measurement between the X-ray tube and the IC was 100 cm, with 10 × 10 cm² field size. Al sheets were placed under the collimator and broad focus setting was used. The measurements were made in an open field, and the Al sheets were added until the IC reading was reduced to half of its initial value. The HVL value was obtained from the graph generated from the relationship of the electrometer reading versus the Al thickness used [6]. The value of linear attenuation coefficient for the energy can be calculated using equation (2) as follows:

$$\mu = \frac{0.693}{HVL} \quad (2)$$

where, μ/ρ was calculated and converted to the corresponding effective energy, by using the X-ray mass attenuation coefficient table for Al (National Institute of Standard and Technology, 2000).

2.2 Measurement of backscatter factor

The SFD IC with a sensitive volume of 6 cm^3 was used for the BSF measurement. In-air measurements for no-scatter condition were carried out, by placing the IC at 85 cm distance from the surface of the light beam diaphragm of the X-ray machine. This IC was placed on top of a polystyrene slab which was positioned hanging at the height of 15 cm (supported by a pair of retort stands), from the top of the X-ray table. This resulted in a source to image-receptor distance (SID) of 100 cm, as recommended by the TRS 457. The field sizes chosen were 10×10 , 15×15 and $20 \times 20 \text{ cm}^2$. The IC and Gafchromic XR-QA2 films (Lot # 02201501, Ashland Inc., KY, USA) with field size of $5 \times 5 \text{ cm}^2$, were placed at the centre of the polystyrene, and perpendicular to the beam direction (figure 1). For the phantom measurement setup, solid water phantoms with 15 cm thickness (constructed by stacking several solid water slabs) were placed on top of the X-ray table. Next, the IC and film were each placed on the surface of the solid water phantom (figure 2), followed by the placement of a bolus on top of the detectors. Similar SID and field sizes were used, with all the measurements taken at 70, 81, 90, 102 and 117 kVp, and 20 mAs.



Figure 1. In air measurement setup.

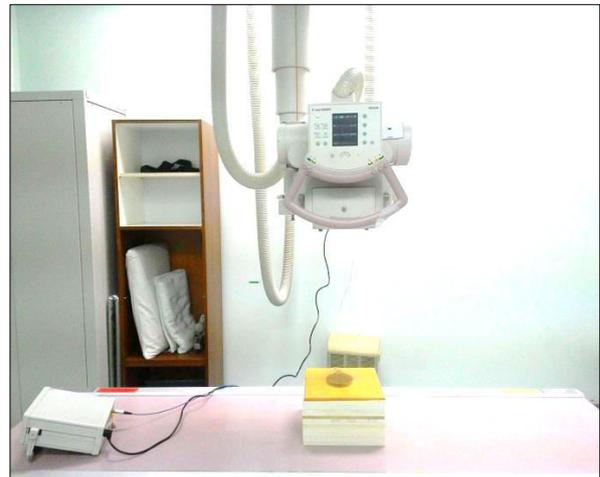


Figure 2. Phantom measurement setup.

The exposed films were read using a flatbed film scanner (Epson Expression 10000XL, Seiko Epson Corporation, Owa, Japan) with Verisoft software (PTW, Freiburg, Germany) at 24 hours post-irradiation, to ensure that the film chemicals have been stabilised. The images were scanned using a scanning resolution of 300 dots per inch (dpi), and saved as 16 bit grayscale in tagged image file (TIF) format. Each film's response in pixel value was taken using the 'Film Calibration' option, as provided by the Verisoft software. The BSF for these conditions were then calculated using equation (1).

3. Results and discussions

Table 1 shows the measured effective energies (keV) for the X-ray machine, in comparison with the energies obtained from the study by Petoussi-Henss *et. al.* [2]. Based on the results, the difference between the effective energies obtained from both studies were about 20.91 %. The effective energies of the current study were found to be lower, due to the difference in the energy spectra used [4]. As a consequent, the effective energy affects the BSF in these studies. Table 2.0 shows that the BSF increase linearly with increased kVp. The BSF also increase with increased field size, since bigger field size results in the increase number of photons that scattered back from the phantom. The BSF obtained from the current study were found to be lower by an average of $\pm 12 \%$, as compared with the previous study [2]. Since the effective energy of the X-ray spectrum, i.e. monoenergetic photon beams, were lower, the tendency for the photons to be scattered in the forward direction was also lower, thus decreasing the backscatter. The scattered photons were only able to reach the detector in a limited distance (due to less penetrating power), which would then decrease the backscatter.

Table 1. The effective energy (keV) obtained in this current study, compared with the study by Petoussi–Henss et al. [2] as published in the TRS 457.

Tube Voltage (kVp)	Effective Energy (keV)		
	Current study	TRS 457	Difference (%)
70	33.7	39.3	14.24
81	35.5	42.9	17.24
90	35.8	46.3	22.60
102	37.9	48.1	21.20
117	39.0	55.4	29.60
Average difference (%)			20.91

Table 2: The BSF (measured using the IC) obtained in this current study, compared with the study by Petoussi-Henss et al. [2] as published in the TRS 457.

Tube Voltage (kVp)	Backscatter Factor			
	10 × 10 cm ²		20 × 20 cm ²	
	Current study	TRS 457	Current study	TRS 457
70	1.059	1.300	1.216	1.340
81	1.089	1.320	1.265	1.370
90	1.127	1.340	1.300	1.400
102	1.145	1.340	1.316	1.400
117	1.147	1.370	1.354	1.460

Table 3 shows that the BSF increase with increased field size, for both the IC and films. The BSF increased by about 11.50 and 15.82 %, for 15 × 15 and 20 × 20 cm² field sizes, respectively. This was due to more X-ray photons detected as the field size increase, reflecting the increased number of photons that scattered back from the phantom. From this study, the BSF measured using the Gafchromic XR-QA2 films were found to be lower than the BSF measured using the IC, by an average of ± 26.17 %, for all field sizes. At 10 × 10 cm² field size, the BSF were observed to be fluctuated, with the average difference of 46.7 %. As the field size gets bigger, the BSF become closer to the BSF obtained using the IC, by an average difference of 17.4 and 14.42 %, for 15 × 15 and 20 × 20 cm² field sizes, respectively. The results showed that the Gafchromic XR-QA2 film was not a suitable dosimeter for the measurement of BSF in small field size, since lesser effective energy passes through the collimator, and the probability of photons to scatter back to the surface will be lower than that of a bigger field size. From this study, we also found that the Gafchromic XR-QA2 film was energy dependent, since even a small increment in the beam qualities may lead to the variation in the film response by ± 12 %.

Table 3. The comparison between the BSF obtained using the IC and Gafchromic XR-QA2 films, at various field sizes.

Tube Voltage (kVp)	Backscatter Factor (BSF)					
	10 × 10 cm ²		15 × 15 cm ²		20 × 20 cm ²	
	IC	Film	IC	Film	IC	Film
70	1.059	0.800	1.167	0.840	1.216	1.120
81	1.089	0.472	1.229	0.984	1.265	1.161
90	1.127	0.594	1.237	1.028	1.300	1.389
102	1.145	1.120	1.270	1.132	1.316	1.156
117	1.147	0.611	12.87	1.163	1.354	1.389

4. Conclusion

As a conclusion, the BSF for kilovoltage X-ray beam increased linearly with the kVp and field size. In comparison with the TRS 457, the BSF obtained from this study were found to be lower by an average of $\pm 12\%$. Based on the film study, the BSF measured by the Gafchromic XR-QA2 films were found to be lower than that of the IC by an average of $\pm 26.17\%$, for all field sizes. The Gafchromic XR-QA2 film was found to be energy dependent and thus, not suitable to be used as a dosimeter for the measurement of BSF for small field size. This was due to lower effective energy passes through the collimator, and the probability of photons to scatter back onto the surface was lower than that of a bigger field size.

5. References

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