Calculation and comparison of MD-55-2 and HS radiochromic films' responses to the 60Co Gamma rays

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SUMMARY

Background: Radiochromic films are one of the useful radiation dosimeters. MD-55-2 and HS radiochromic films have been previously used in medical dosimetry applications. The aim of this study is calculation and comparison of responses of MD-55-2 and HS radiochromic films to gamma rays of 60Co radioisotope.

Methods: The sensitivity of MD-55-2 radiochromic film to 60Co gamma rays has been calculated and compared with that of HS film. The films were defined as multiple layers and different tallies of MCNPX Monte Carlo code were scored in water and Perspex phantoms.

Results: Following simulation of the radiochromic films irradiated by a 60Co source, it was evident that the sensitivity of a three-layer and a two-layer MD-55-2 film to that of a single-layer film is 2.95-fold and 1.94-fold higher, respectively. Furthermore, the sensitivity of a HS film is 1.0, 1.5 and 2.92 times higher compared to a MD-55-2 film, respectively with 3, 2 and 1 layers. Comparing the outputs of F6, *F8 and mesh tallies indicate that the F6 and mesh tallies have the same results but the differences between the results obtained by F6 and *F8 tallies are about 5.8% for the MD-55-2 film and 10.5% for the HS film.

Conclusion: Our results show that the sensitivity of MD-55-2 film increases with a relatively linear trend with the number of film layers. Besides, the sensitivity of the HS film is about 2 times higher than that of the MD-55-2 film. Our results are in agreement with the previously published experimental results.

Key words: Film Dosimetry; Radiation Dosage; Radiometry; Cobalt Radioisotopes; Gamma Rays; Monte Carlo Method; Sensitivity and Specificity

INTRODUCTION

Radiochromic film was firstly used by McLaughlin for measurement of radiation dose. The active layer in this type of film is composed of microcrystalline monomers which are sensitive to radiation and the film turns progressively blue following exposure to ionizing radiation. Nowadays Gafchromic MD-55-2 and HS film models are widely used in medical applications of dose measurements. Because of its relatively medium sensitivity, the use of Gafchromic MD-55-2 radiochromic film is restricted only to low dose range dosimetry. The HS film was designed for dosimetry of photon beams in high energy range and electron beams with energy higher than 1 MeV (1-8).

Pourbeigi, et al. has experimentally evaluated the sensitivity and optical density per dose of a multilayer MD-55-2 film to gamma rays in a Perspex phantom. This study was based on a multilayer technique and by adoption of Task Group No. 55 (TG-55) protocol in the experiments. The results have indicated that the sensitivity of this film type increases with an increase of the number of the film layers (3). In a report by International Specialty Products (ISP) company, the response of the HS radiochromic film to high energy photon beams was compared with that of the two-layer MD-55-2 radiochromic film and it was evident that the response of the HS film was about two-folds higher than that of the MD-55-2 film (5). However, to the best of our knowledge, there are limited reports on sensitivity of the MD-55-2 film to 60Co gamma photons based on multilayer technique as well as on comparing the response of this type of radiochromic film with the HS film through Monte Carlo simulation of these films. This fact has been a motivation for us to perform the current study. The aim of this study is to evaluate the sensitivity of a multilayer Gafchromic MD-55-2 film and to compare its response to 60Co gamma photons with that of the HS radiochromic film through Monte Carlo simulation of the films. Furthermore, the effect of type of MCNPX scoring tally on the response of the films was evaluated as well.

MATERIALS AND METHODS
Radiochromic films

Gafchromic MD-55-2 radiochromic film is composed of two active layers of 13 μm thickness. The active layers are coated on a 25.4 μm polyester base. Each active layer has a protective polyester coating with 67 μm of thickness. Effective atomic number of the film is 6.5 and the film is suitable for measurements in dose range of 3-100 Gy.

Gafchromic HS film was presented as a higher sensitivity and uniformity option by development of the MD-55 radiochromic film. In this film model, the active layer has a thickness of 40 μm and is sandwiched between two clear polyester layers each of 100 μm thickness. The effective atomic number of this film model is 6.5 and the useful dose range of the film is 1-50 Gy (1-8).

A summary on characteristics of the MD-55-2 and the HS radiochromic films including mass density, thickness of the active layer, thickness of the polyester layer and chemical composition of the films are listed in Table 1. More details on characteristics of these film types can be found at the webpage of International Specialty Products (5). It is notable that various film models have different sizes and thicknesses and atomic compositions.

Table 1. Characteristics of Gafchromic MD-55-2 and HS radiochromic films including density, thickness and chemical composition of the films

Film model	Layer	Density (g/cm³)	Thickness (μm)	Composition (%)			
				H	C	N	O
MD-55-2	Active	1.08	2×13.2	56.8	29.1	6.9	7.1
	Polyester	1.35	25.4+2×67	36.4	54.4	-	2.18
HS	Active	1.10	40	9.2	56.2	10.4	24.2
	Polyester	1.35	2×100	4.2	62.5	-	33.3

Monte Carlo simulations

For determination of radiochromic film response in high energy range, it is useful to utilize calculation models. Among the calculation methods, Monte Carlo technique is one of the most accurate methods. In this technique the source particles are tracked based on statistical transport of the particles in a user-defined geometry. In complex geometries it can be a useful tool for scoring the radiation quantities which is advantageous over the other methods. In this method, each source particle is tracked and its history and interactions with other particles and media are recorded from production up to a final absorption of the particle. There are several Monte Carlo codes but in the present study, the MCNPX code (version 2.4.0) was used in the simulations of the source and radiochromic films [9]. The average absorbed energy (MeV) in the radiochromic film per ^{60}Co source photon was taken into account as the sensitivity of the film.

Geometry of Monte Carlo simulations

MD-55-2 film was defined as a 12 cm×12 cm sheet at 5 cm and 10 cm depths in water phantom in the simulations. In another situation, the film was defined as a 4 cm×4 cm sheet at 0.5 cm depth in Perspex phantom. The HS film was defined as a 12 cm×12 cm sheet located at 10 cm depth in water phantom (Figure 1). The figure is schematic and the dimensions are not shown as the real scale. The thickness of the film is of the order of micron but it was drawn at a larger scale. ^{60}Co source was an isotropic point source located at the distance of 80 cm from the surface of the phantom. The deposited energy per source particle (MeV/photon) was then scored by running a number of 2×10^9 histories by using *F8, F6 and meth tallies. The corresponding statistical Monte Carlo error was in the range of 2%-6%. A phantom should provide full scatter condition. To provide this condition, a phantom should be large enough depending on the energy of the source particles. In the present study a 40 cm×50 cm×50 cm water phantom was defined in the simulations by considering the full scatter conditions needed for ^{60}Co gamma rays. In this study, the Perspex phantom had dimensions of 15 cm×10 cm×2 cm and the dimensions were defined in accordance with the study by Pourbeigi, *et al.* [3].
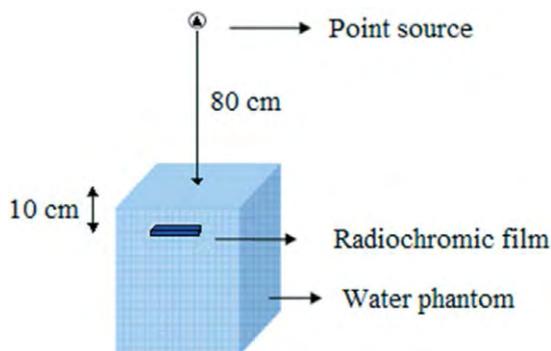

Figure 1. Geometry of the simulation illustrating position of the source, phantom and radiochromic film

RESULTS AND DISCUSSION

The average absorbed energy (MeV) per source particle for ^{60}Co gamma photons for the HS and the MD-55-2 films for three different tallies is plotted in Figure 2. The data was scored at 10 cm depth of a water phantom. The results indicate that there is no significant difference between the results obtained by F6 and mesh tallies. The difference between the results obtained by F6 and *F8 tallies for the MD-55-2 and the HS films are equal to 5.8% and 10.5%, respectively.

The response of radiochromic film depends on the tally type and the *F8 tally shows more accurate dosimetric values than F6 and mesh tallies. Thus, *F8 tally was used in the simulation of the films. *F8 tally values versus the number of the film's active layers for the MD-55-2 film at 10 cm depth in water phantom and at 0.5 cm in Perspex phantom were plotted in Figures 3 and 4.

It is evident from the data that the sensitivity of the film increases with the increase of the number of film's active layers. The sensitivity of three-layer and two-layer films is higher than that of a single-layer film respectively by 295% and 194%.

Our results are in agreement with the experimental results obtained by Pourbeigi, *et al*. His results indicate that in the energy range of ^{60}Co gamma rays, the sensitivities of two-layer and three-layer MD-55-2 films relative to that for a single layer film, are respectively equal to 290% and 200%. The study by Pourbeigi, *et al*. was performed on the basis of the TG-55 protocol [3]. The results of normalized sensitivity as obtained by Monte Carlo simulations in this study and the experimental results by Pourbeigi, *et al*. are plotted in the Figure 5. In this figure, Monte Carlo data were normalized at the maximum value and then multiplied by 10^8. As it is evident from this figure, there is an agreement between the Monte Carlo and the experimental results. The data in this figure also indicate that the sensitivity of the film is independent of film dimensions and the phantom material. The relative difference between our Monte Carlo results and the results of Pourbeigi, *et al*. is in the range of 0%-4%. It can also be noted from the Figures 2 and 3 that the sensitivity of the HS film with thickness of 40 μm in relation to that of a three-layer, two-layer and a single layer MD-55-2 film is respectively equal to 1.0, 1.5 and 2.92 folds. The differences between the sensitivities originate from the difference between the structures and compositions of the two film models. In the report by ISP, which has been performed on the dosimetry of high energy photons by HS radiochromic film, it has been noted that the response of the HS film is higher than that of the two-layer MD-55-2 film by an order of about two folds [5]. The results of the present study show that the sensitivity of the HS film is two times higher than that of the MD-55-2. Thus, when considering the fact that usage of a single layer film is more comfortable when compared to a two-layer film, the HS film can be more comfortable in film dosimetry when compared to an MD-55-2 film. It should be also noted that the negligible difference between our theoretical results and the experimental results can be related to the potential difference between the geometries in these two methods. Thus, our results are in agreement with the experimental results.
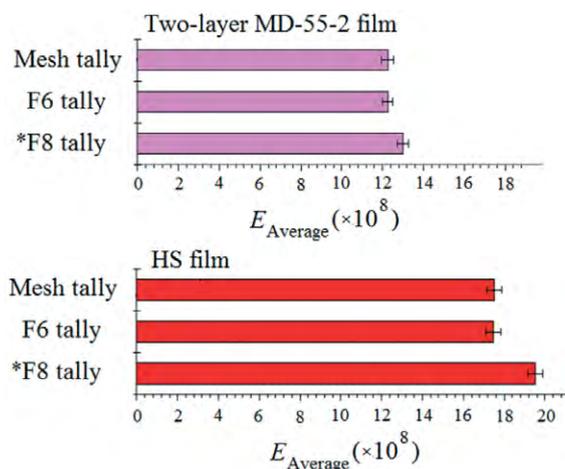
Figure 2. The effect of tally type on the response of the MD-55-2 and the HS radiochromic films
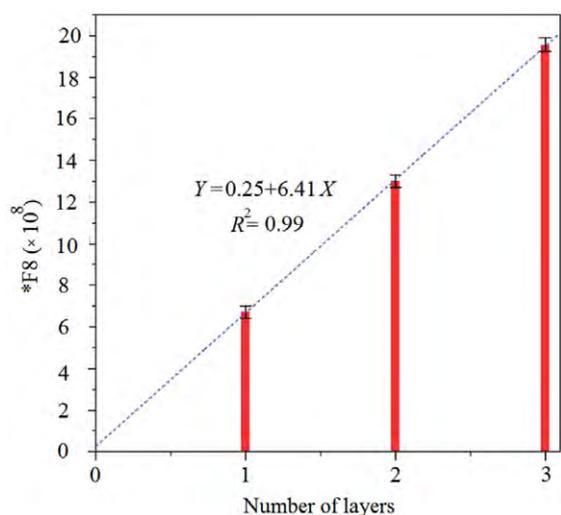

Figure 3. Dependence of *F8 tally on the number of active layers in the MD-55-2 radiochromic film. The film was positioned at 10 cm depth of a water phantom
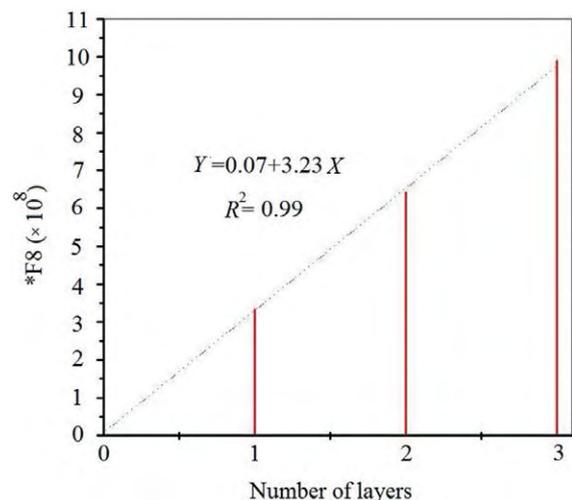

Figure 4. Variation of *F8 tally versus the number of active layers of the MD-55-2 film positioned in 0.5 cm depth of a Perspex phantom
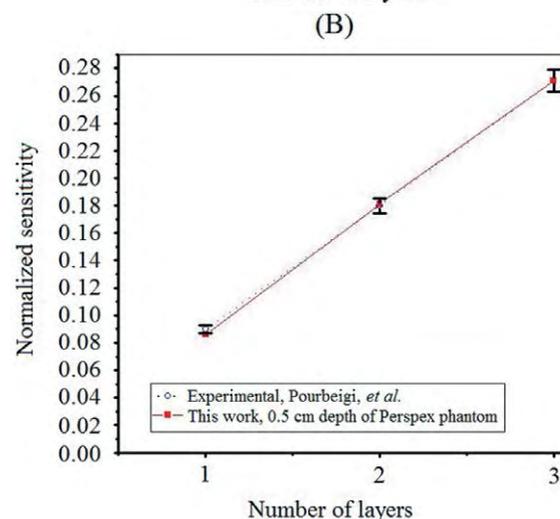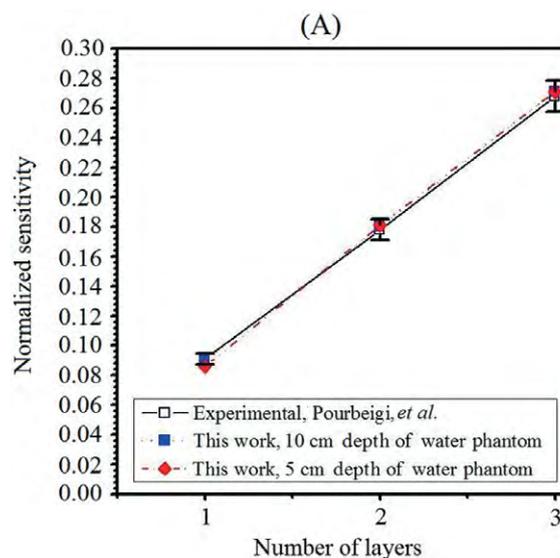

Figure 5. Normalized sensitivity versus the number of layers of the MD-55-2 film. Monte Carlo results were compared with the results of Pourbeigi, *et al*.
(A): For 12 cm×12 cm film. (B): For 4 cm×4 cm film

CONCLUSION

In this study, sensitivity (tally value per average photon energy) of the MD-55-2 radiochromic film to ^{60}Co gamma photons was evaluated on the basis of the multilayer technique and the response of this film type was compared with that of the HS radiochromic film. Our Monte Carlo simulations using various tallies have indicated that the sensitivities of three-layer and two-layer films were higher than that of a single-layer film respectively by 295% and 194%. It can be concluded that the multilayer technique can enhance the sensitivity of a radiochromic film dosimeter considerably and can extend the useful dose measurement range of a film also for the low dose range values.

It was also observed that the HS film has about two times higher response than a two-layer MD-55-2 film. Therefore, it has a better response and is more comfortable than a two-layer MD-55-2 radiochromic film. The results are in agreement with the results reported by Pourbeigi, *et al*. and ISP company on Gafchromic HS dosimetric characteristics. It was also noted that *F8 tally has more accurate results when compared with

F6 and mesh tallies. The effect may be because of inclusion of electron transport in this tally. Mesh tally has similar results when compared to F6 tally.

Our results will provide for radiochromic film users a tool for selection of a suitable dosimeter for medical applications. It can be also concluded that MCNPX code may be useful in dose calculations in situations when using an experimental tool for dose measurement in medical radiation dosimetry may not be easily feasible.

Conflict of interest

We declare no conflicts of interest.

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