Enhancement of MD-55-2 radiochromic film sensitivity using a multilayer film technique for applications in the low dose range

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Background: MD-55-2 is one of the Radiochromic film models with the sensitivity suitable for dose measurements ranging from 5 to 100 Gy. However, this lower limit makes the film impractical for its applications in many areas such as brachytherapy source dosimetry. ***Materials and Methods:*** In this project, the useful range of the film has been extended by using a multilayer film technique. In this technique, single, double-, and triple- layers of films were exposed to the doses ranging from 0.5 to 10 Gy using a Co-60 photon beam. Calibration curves for corresponding layers of films were obtained with a spectrophotometer using a 680nm wavelength. ***Results:*** The results indicated that the sensitivities of double and triple layers were approximately 200% and 300%, respectively, higher than a single-layer film. The impact of multilayer film arrangement on the energy dependence of the MD-55-2 Radiochromic film has also been examined using 100 kVp, 80 kVp, and 6 MV X-ray beams. The results indicated an insignificant (within 5%) change in film responses with the beam energy. ***Conclusion:*** Therefore, the multilayer technique enhances the Radiochromic film sensitivity and expands its application to the low dose range in field of brachytherapy source dosimetry. **Iran. J. Radiat. Res., 2005; 3 (1): 11-15**

Keywords: *Radiochromic film, multilayer, MD-55-2, low dose, sensitivity, low energy.*

INTRODUCTION

International Specialty Products (ISP) (ISP, Wayne, NJ) has originally designed the radiochromic film (also known as Gafchromic film) for industrial applications. However, due to their superior dosimetric characteristics to the silver halide films, such as energy independent, lower sensitivity, and no processing requirement after irradiation, their applications have been expanded in the field of radiation therapy[1-3]. The response of the MD-55-2 Radiochromic films to radiation can be determined by the change of its color from light blue to different shades of blue upon the level of radiation dose. Presently, MD-55-2 Radiochromic films are more commonly used for the measurement of therapeutic doses from radiation beams with energies higher than 200 keV[2, 3]. The low sensitivity of this film has limited its applications in low dose radiation fields such as dosimetry around the brachytherapy sources.

Cheung *et al.*[4] has demonstrated that film layering increases the sensitivity of radiochromic film for 6 MV X-ray beams. They have also shown that increase in number of layers increases the sensitivity but reduces the spatial resolution. The results of these investigations were only limited to Megavoltage X-ray beams. However, to our knowledge, multilayer film technique has not been investigated for low energy X-ray beam.

In this study, enhancement of MD-55-2 radiochromic sensitivity in low energy X-ray beam has been investigated using multilayer films technique. Moreover, the impact of the film layering on its energy dependence has been evaluated. The range of low energy X-ray beams used in these investigations is comparable to radiation emitted by I-125 and Pd-103 brachytherapy sources.

MATERIALS AND METHODS

Linearity of multilayer-film response

MD-55-2 Gafchromic films with Lot No. 39082 were cut into 2×2 cm^2 pieces and were placed in the pre-labeled plastic sleeves. Each plastic sleeve contained a multilayered film composed of 3 to 4 pieces of film and was

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irradiated to doses ranging from 50 to 1500 cGy. A series of multilayer films was put in a 15×10×2 cm^3 Perspex phantom and was irradiated with a 0.5cm build up material, using a ^{60}Co therapy unit (Theratron 780c). In these irradiations, the source to surface distances (SSD) was 80cm and output dose rate was 132.68 cGy/min. Transportation, maintenance, and analysis of films were performed according to TG-55 recommendations(2). Irradiated films were read after 24 hours using a spectrometer or a portable densitometer. A spectrophotometer (SPECTRONIC 21D) was used for measuring the absorbance and optical density (OD) of the multilayer films. This spectrometer has three modes of absorbance, transmittance and concentration measurement. The optical density in the concentration mode saturates at 4.2 levels and its spatial resolution is 1mm. However, the saturation levels of the optical densities in the other two modes are 2.0. The range of wavelength varies from 200-1000 nm with 2 nm steps. A 680 nm wavelength was producing the maximum response, which was used to read other films.

At first an absorbance spectrum for single, double and triplet layers films irradiated to 1500 cGy ^{60}Co irradiation were measured and then the optical density for these layer of films were measured in dose range of 50-1000 cGy. The linearity of optical density of the films with the absorbed dose has been evaluated using graphical method. The sensitivity of the multilayer film at a given dose was calculated using the slope of this curve.

Energy dependence of the multilayer-film

To evaluate the energy dependence of the multilayered films, samples of films were irradiated with X- ray beams of 80 kVp, 100 kVp and 6 MV. The irradiation of the films to the 6 MV X-ray beam Clinac 2100c/D (Varian oncology system, Palo Alto, CA) were performed in a 10 cm thick Solid WaterTM (Radiation Measurements Inc. Middleton, WI) phantom material with 1.5 cm build up materials. An optical densitometer was used to read these films and the results were compared to these of ^{60}Co gamma ray beam and read with spectrophotometer. However, the irradiation to the 80 and 100 kVp X-ray beams from a superficial unit (Oldest Therapaxhf 150T, Oldest/Nucletron, Columbia, MD) was performed using the Solid Water™ phantom material without a build up material. These films were irradiation to doses ranging from 50-1000 cGy. The optical density of the single, double and triple layer films were obtained using a portable densitometer. Effective energy and half value layer (HVL) for each beam was correspondent to the energy and HVL of the ^{125}I and ^{103}Pd brachytherapy sources, which are shown in table 1.

Table 1. Nominal energy, HVL and effective energy of beams used in this part of the study.

Nominal Energy	HVL (mm Al)	Effective Energy (KeV)
80 KVp	1.2	25
100KVp	4.8	41
6 MV	-	2000
^{60}Co	-	1250

RESULTS

Figure 1 shows the measured optical density of single-, double- and triple-layer Gafchromic films exposed to the same dose as a function of input wavelength. The results indicate that for each of these film groups, the maximum response occurs at 680 nm. It was noted that for the selected dose the response peak of the triple-layer film falls in the saturation region (OD> 4.2), which could not be observable in figure 1. Figure 2 shows a comparison of the sensitivities (i.e. optical density per unit dose) of the three different film layers measured with two wavelengths of 660 nm and 680 nm. These results indicate

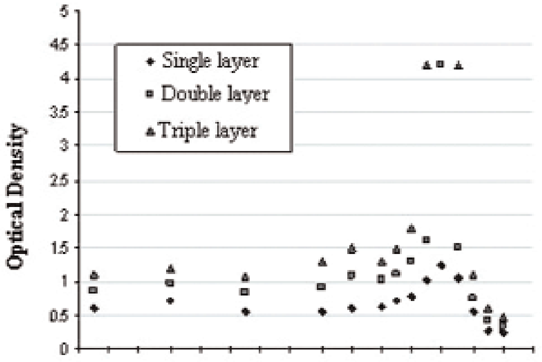

Figure 1. Optical Density spectra for 15Gy irradiated single-layer, double-layer and triple-layer of MD-55-2 Gaf-chromic film.

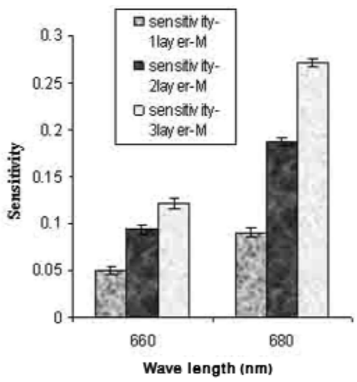

Figure 2. Comparison of sensitivity between 680nm and 660 nm using the spectrophotometer.

that a minor change in wavelength near the peak value (680) results in a significant variation in the film sensitivity. Figure 3 represents the measured OD of the above-mentioned film groups for a dose range of 50-1000 cGy exposed to ^{60}Co gamma rays. These results show that in low dose regions, multilayer film-response varies linearly with absorbed dose.

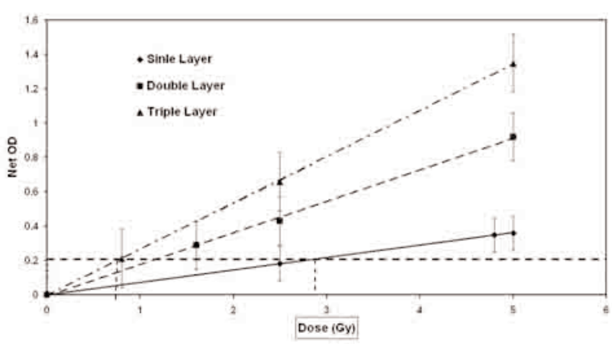

Figure 3. Sensitivity of Multi-layer MD-55-2 films at 680 nm wavelengths, using Co-60 photon beam.

From the data in figure 3, the sensitivity of single, double- and triple- layer films was found to be 0.09, 0.18 and 0.271 OD/Gy, respectively Thus, the sensitivity of the layered MD-55-2 Gafchromic films increases by increasing the number of layers (e.g. 295% for triple-layer film relative to single layer). Similar results were obtained for 6MV, 80 keV, and 100 keV X-ray beams. In addition, Figure 3 shows that, the radiation dose required producing a net optical density of 0.2 decreases from 300 cGy for a single-layer film to 80 cGy for a triple-layer film. Therefore, the multilayer technique enhances the film sensitivity and expands its application to lower dose regions (table 2). Reproducibility of the dosimetry with the multilayer film technique using the MD-55-2 Gafchromic film in the dose range of 50-1000 cGy from a ^{60}Co beam is shown in figure 4.

Table 2. Comparison of the sensitivity and low-dose-limit of a single-, double- and triple- layer MD-55-2 Gafchromic films.

Layer	Sensitivity (OD/Gy)	Lower limit of dosimetry (Gy)
Single	0.09	4.80
Double	0.18	1.60
Triple	0.27	0.80

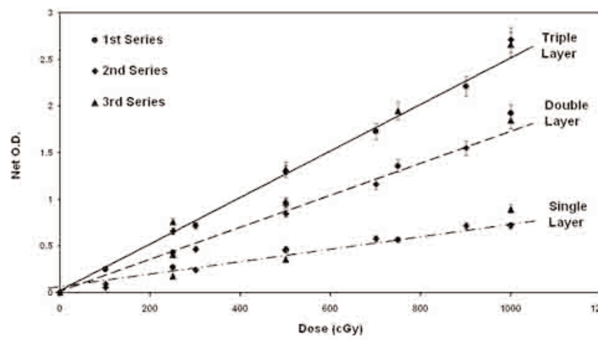

Figure 4. Reproducibility of this technique in three separate series for dose range of 50-900cGy.

Figure 5 shows a comparison of the optical density response of the triple-layered film exposed to 6 MV X-ray beams with the response of the film expose to ^{60}Co gamma rays. The 10% differences between the slopes of these two sets of the data could be partially due to the non-uniformity of the films response presented in TG-55[2].

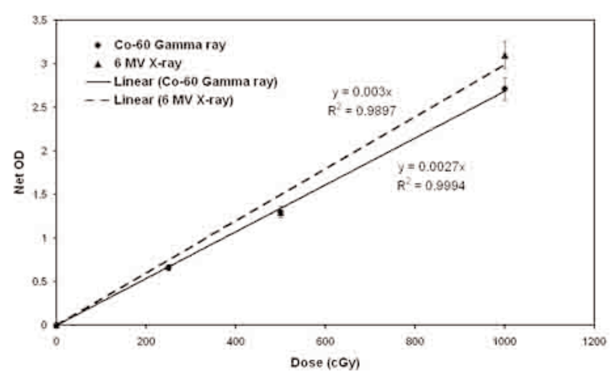

Figure 5. Optical density response due to high energy x- ray (6 MV) for triple-layer films and compare with ^{60}Co photon beam.

In addition, the energy dependence of the multilayer MD-55-2 Gafchromic film response exposed as a function of absorbed dose to the low energy (80, 100 kVp) X-ray and high energy photon (^{60}Co gamma rays and 6 MV X-ray beam) is shown in figure 6. Table 1, shows the half value layers and effective energy of the beams used in this investigation.

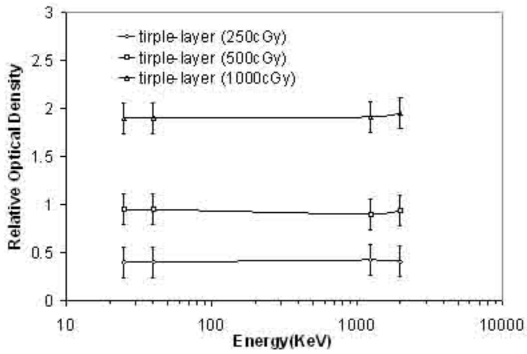

Figure 6. Energy dependence for triple layer films in the range of 50-1000 cGy.

Figure 7 shows the variation of the single-, double-, and triple-layered MD-55-2 film sensitivity as a function of the effective beam energy. These results indicate that the film sensitivity is approximately independent of the photon beam energy (within 5%) and it increases linearly with the number of films layers.

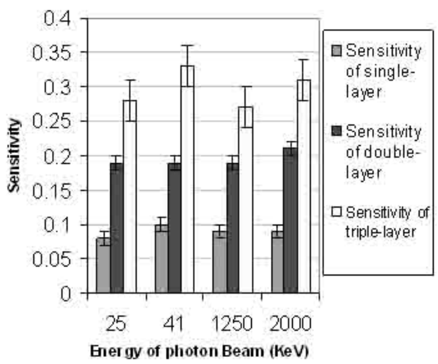

Figure 7. Sensitivity enhancement for 21 keV (80 kVp-1.2 mm Al), 41 keV (100 kVp - 4.8 mm Al), 2000 keV (6 MV, X-ray) and 1250 KeV (^{60}Co photon beam).

DISCUSSION

With the advancement of radiation therapy techniques, such as IMRT and brachytherapy, two- dimensional radiation dosimetry has become highly desirable. Radiographic film dosimetry is a well-established technique for the measurement of radiation intensity for quality assurance (QA), verification of treatment delivery, and localization of brachytherapy sources. The high energy-dependence and low dose saturation level of the silver halide radiographic film are among the limiting parameters for their applications in many clinical setups, particularly for low energy X-ray beam dosimetry. In addition, chemical processing of the radiographic film is another source of uncertainty in radiation dosimetry with this film[6, 7]. As a result, the clinical applications of various models of radiochromic film have been investigated within the past several years to bypass the shortcomings of the radiographic films[8]. The tissue equivalent base material of the radiochromic film eliminates the energy dependence of the film response. Moreover, these film types do not require chemical processing. For these reasons radiochromic film has achieved considerable popularity in recent years[3].

Despite the above mentioned superiority of the radiochromic film over the radiographic films, the low sensitivity of the radiochromic film has severely limited its utilization in low dose applications such as brachytherapy source dosimetry. In this study, we have shown that with a multilayer radiochromic film technique, the range of application of MD-55-2 radiochromic film can be extended to include the radiation dosimetry in low dose range using both low and high energy X-ray beams.

The results of these investigations show that for both low and high-energy X-ray beams the sensitivity of the MD-55-2 Gafchromic film increases by increasing the number of film layers. In addition, the data indicates that the sensitivities of a double and triple-layer film were approximately 200% and 290%, respectively, of the sensitivity of a single-layer film (figure 3 and table 2). These results were in good agreement with the data published by Cheung *et al.*[4], who have also shown that for high-energy X-ray beam, an approximately 430% increase in the sensitivity of a five-layer film compared to the single layer film.

The enhancement of the MD-55-2 film sensitivity, using the multilayer technique, has allowed us to extend the lower dose limit of this film from 480 cGy to approximately 80 cGy, using the triple-layer film (figure 4 and table 2). Using larger number of the films in the layer we can further reduce the lower dose limit.

The present results showed in figures 6 and 7 shows that the response and sensitivity of the multilayer MD-55-2 radiochromic film response are independent of beam energy (within 5%).

In summary, the MD-55-2 radiochromic

film response can be enhanced using multilayer film technique. Moreover, the enhancement of the film sensitivity can be utilized to reduce the low dose range of the radiochromic film. Due to the energy independence of the radiochromic film, their applications can be extended to low energy beam dosimetry, such as I-125 and Pd-103 brachytherapy source dosimetry.

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