Measurement of energy dependence for XRCT radiochromic film

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Gafchromic XRCT, radiochromic film is assessed over a broad energy range, from kilovoltage to megavoltage x rays for variations in reflected optical density to dose response. A large energy dependence was found with reflected optical density output for the same delivered dose varying from 7.8±0.35 at 25.5 keV (50 kVp) peaking at 12.1±0.5 at 54 keV (125 kVp) to 0.975±0.03 at 2300 keV (10 MV) when normalized to 1 at 1400 keV (6 MV) energy. The response is constant (within 3%) in the 36–69 keV equivalent photon energy range, which corresponds to x-ray tube generating potentials of approximately 100–150 kVp. This matches well with beam qualities for diagnostic computed topography applications. *© 2006 American Association of Physicists in Medicine*. [DOI: 10.1118/1.2219330]

Key words: radiochromic film, Gafchromic XRCT, radiation dosimetry, energy dependence, dose response

INTRODUCTION

Dose assessment in computed topography (CT) applications requires detectors, which are highly sensitive to radiation due to the lower level of applied doses during these procedures.[1] This has in the past minimized the use of radiochromic films in CT and diagnostic applications in general. Historically, radiochromic films have required large doses (of the order of 1 Gy or more) to produce a measurable result.[2–4] Recently a product called Gafchromic XRCT has been developed (ISP) which has significantly enhanced the sensitivity of this radiochromic film product in the kilovoltage energy range. The manufacturer states that in the low energy range doses as low as 0.01 cGy are measurable with this film. Gafchromic XRCT and Gafchromic XR-T (older commercially available film model) films are quite different film models. Whereas the XR-T film was a Gafchromic film model having a sensitive layer with the same composition as HS model doped with high Z components, the sensitive layer of XRCT film has the same basic composition of EBT Gafchromic doped again with high Z elements. For accurate dose assessment, however, we must know the energy to dose conversion factors or the energy dependence of the film to assess variations in measured reflective optical density with dose at various applied energies. In this work, we have investigated the dependence of XRCT reflective optical density to dose response at various photon beam energies in a broad range from kilovoltage to megavoltage energies.

MATERIALS AND METHODS

Gafchromic XRCT radiochromic film (ISP Corp., Wayne, NJ) contains an active, radiation-sensitive, polymer between two protective layers of polyester, which allows the film to be easily handled and minimizes effects of ultraviolet exposure.[5] The film is constructed with a top transparent yellow polyester cover, 97 μm thick. Beneath lies two active layers, 25 μm thick each held together with two 5 μm surface layers. The backing layer is a reflective white 97 μm thick polyester sheet. This allows the film to be analyzed with a reflective type scanner. Our measurements are made using a reflective mode desktop scanner and results are quoted as a reflective optical density (ROD). The ROD is defined as the log of the initial light intensity (I_0) over the transmitted light intensity ($I_{(t,r)}$) which has been reflected off the opaque white backing sheet of the XRCT film, i.e., $\mathrm{ROD}=\log(I_0/I_{(t,r)})$. The film changes color to green/brown upon irradiation. The overall film thickness is approximately 250 μm. In this study, the 3/4 in. $\times$ 5 in. film pieces are irradiated to the following doses: 10, 20, and 200 cGy. These values were chosen to produce an adequate degree of darkening for the x-ray beam qualities tested for energy response. Irradiations up to 200 cGy at 100, 125, 150, 250, and 6 MV were also delivered for dose response assessment of XRCT film. Irradiations were performed in a $30\times30\times30$ cm^3 solid-water phantom[6] using a GULMAY D3300 orthovoltage machine and a Varian 2100C linear accelerator. The absorbed dose calibrations were performed with a Farmer thimble-type ionization chamber according to the IPEMB protocol for kilovoltage x rays[7] and IAEA TRS-398 protocol for megavoltage x rays.[8] The delivered doses were dose to water and no corrections were applied for the influence of solid water or Gafchromic XRCT film material on absorbed dose. The equivalent photon energy[9] of each beam was calculated from half value layer (HVL) measurements. These values are quoted within the results.

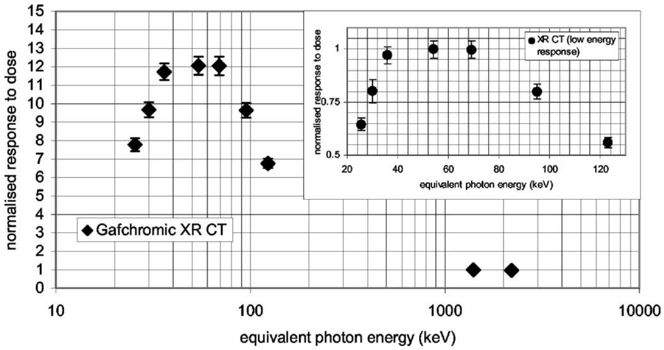

FIG. 1. Energy dependence of XRCT radiochromic film over kilovoltage and megavoltage energy range.

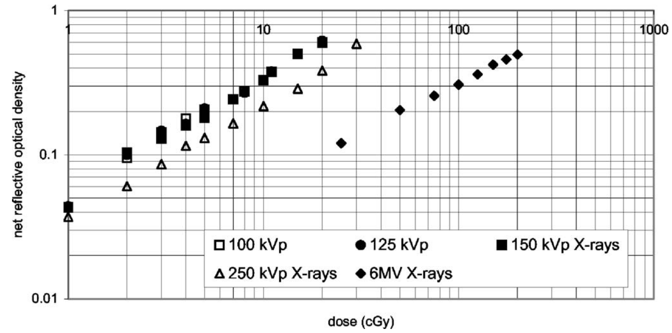

FIG. 2. Dose response of XRCT at various x-ray energies.

All XRCT Gafchromic films were analyzed using a personal computer (PC) desktop scanner and Image J software on a PC workstation at least 24 h after irradiation to minimize effects from post irradiation coloration.[10,11] The scanner used was a Hewlett Packard ScanJet with scanning resolution of up to 1200 pixels per inch. The films were scanned over an area of 2 cm $\times$ 1 cm in the center of each film piece. The images produced were 16 bit red, green, blue (RGB) color images. These images were analyzed with the full RGB components. Net RODs (subtraction of film fog levels from the results) for all films were calculated and compared to evaluate the variations in ROD to dose response with respect to beam energy. These results are compared to measure the variations in ROD change with applied dose as a function of x-ray beam energy.

RESULTS AND DISCUSSION

Figure 1 shows the relative energy response curve for Gafchromic XRCT radiochromic film when normalized to 1 at the equivalent photon energy of 1.4 MeV which corresponds to a 6 MV x-ray beam. The beam qualities used were 50, 75, 100, 125, 150, 200, 250 kVp, 6 MV, and 10 MV. These energies were found to have equivalent photon energies of 25.2, 30, 36, 54, 69, 95, 123, 1400, and 2200 keV using HVL measurements. The results shown for relative energy response are the average of responses found using 10, 20, and 200 cGy applied doses. Presented results show that a markedly higher ROD to dose response is seen at lower energies which produces a peak in energy response at 54 keV (125 kVp). The error bars on the graph represent a 2SD of the measurement and show uncertainties in calculated values up to ±5%. The low energy relative response can be up to 12 times larger than the ROD to dose response at 1.4 MeV (6 MV), showing approximately 7.8 times relative response at 25.5 keV (50 kVp). The shape of this energy response curve is similar to other radiochromic films in the low energy range, however, the magnitude is different. A similar response is seen with radiographic film as well (e.g., Kodak X-Omat V) which is a silver-halide based film. Radiographic type films produce even larger relative energy response with values rising up to approximately 15 times[12,13] higher response at low energy as compared to high energy x rays. The inset in Fig. 1 represents the same data now normalized to 1 at the peak energy sensitivity. Relatively uniform energy response is seen for the energy range 36–69 keV, which corresponds to x-ray tube generating potentials of 100–150 kVp with a variation in energy response of 3% seen. That is, the average relative responses calculated for 100, 125, and 150 kVp were within 3% of each other with a ±5% uncertainty. Since in general, CTs produce an x-ray output within this range, XRCT radiochromic film produces an energy independent dosimeter relative to most other film type detectors. This feature allows the films dosimetry accuracy to be increased for dose assessment compared to other radiochromic film types such as Gafchromic HS that has an approximate 15% variation over a similar energy range and radiographic film types such as Kodak X-omat V that has a 30% variation over the similar energy range.[13] Figure 2 shows the dose response of Gafchromic XRCT film to x-ray beams at different equivalent photon energies. As shown in the figure the sensitivity of the film is higher at kilovoltage energies and only requires a few cGy of dose to produce a significant darkening. At higher energies, more dose is required to produce an equivalent degree of film darkening. As an example, to produce a net ROD of 0.3 doses of approximately 8.5, 16, and 90 cGy are required from 150 kVp, 250 kVp, and 6 MV x rays, respectively.

CONCLUSION

Gafchromic XRCT radiochromic film produces a relatively constant (3% variation) energy response in the equivalent photon energy range of 36–69 keV, which relates to generating potentials of 100–150 kVp. Thus the film is well suited in terms of energy response for dose assessment in diagnostic CT applications. Its relative energy response over the broad energy range from 25.5 keV to 2.2 MeV (50 kVp to 10 MV) is significantly larger and ranges from 0.97 to 12.1 when normalized to 1 at 6 MV photon beam quality. Due to its high sensitivity and low energy dependence at CT x-ray energies the film is well suited as a dosimeter at Diagnostic energies.

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