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PHYSICS CONTRIBUTION

ASSESSMENT OF LARGE SINGLE-FRACTION, LOW-ENERGY X-RAY DOSE WITH RADIOCHROMIC FILM

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Purpose: To investigate the accuracy of *in vivo* dosimetry using radiochromic film for large single-fraction, low-energy irradiations.

Methods and Materials: Gafchromic MD-55-2 radiochromic film and LiF thermoluminescent dosimeters (TLDs) were placed *in vivo* on 25 patients to ascertain their effectiveness for assessment of dose. All patients received 10 Gy single fractions at energies ranging from 100 kVp (half-value layer [HVL] = 3.5 mm Al) up to 250 kVp (HVL = 2.3 mm Cu). Effects of small air gaps were also investigated using LiF TLDs and radiochromic film.

Results: Radiochromic film adequately measured applied dose for 25 patients *in vivo* with a standard deviation of 5.5% from prescribed dose. LiF TLDs recorded a standard deviation of 4.1% from measured to applied dose. Small air gaps which can be created under the film or TLDs during *in vivo* dosimetry were shown to have a measurable but minimal effect on results for gaps less than 5 mm.

Conclusions: Gafchromic film has adequately measured applied dose *in vivo* at low energy for large 10 Gy single-fraction irradiation. © 2000 Elsevier Science Inc.

Radiochromic film, *In vivo* dosimetry, Single-fraction irradiation, X-rays, Low energy.

INTRODUCTION

In vivo measurement of applied dose during superficial and orthovoltage X-ray treatment (1, 2) is important when the dose is delivered in one large fraction of 10 Gy. Traditionally thermoluminescent dosimeters (TLDs) are used for dose assessment (3, 4) in these regions due to their small size which allows the closed-end orthovoltage cones to be placed directly on the patient's skin for the treatment. The development of the newer, more sensitive MD-55-2 Gafchromic film (I.S.P. Technologies, Wayne, NJ) means this type of film could also adequately measure applied doses *in vivo* for the range of single 10 Gy fractions. Radiochromic film's near water equivalence also reduces the possible perturbations caused by primary and backscatter fluence. Radiochromic film also has the ability to measure dose over an area which could create an improvement over TLD dosimetry especially in areas of high dose gradients. This report presents data from *in vivo* measurements using radiochromic film of single fractions of 10 Gy.

METHODS AND MATERIALS

Measurements were performed on 25 patients who received large single fractions of 10 Gy. The X-rays were produced by a Pantak DXT-300 orthovoltage machine (Pantak Pty Ltd, East Haven, CT) with energies of 100 kVp (half-value layer [HVL] = 3.5 mm Al) to 250 kVp (HVL = 2.3 mm Cu). For each patient, LiF TLDs and Gafchromic MD-55-2 radiochromic film were placed on the patient's skin close to the central axis of the beam.

Lithium fluoride (LiF:Mg:Ti) extruded ribbons (Solon/Harshaw, Solon, OH) were used with a nominal thickness of 0.89 mm. The TLDs were held in a thin plastic foil container ("glad wrap") thickness 0.02 mm and taped to the patient's skin during irradiation. The TLDs were individually calibrated and grouped into sets in which all TLDs shared the same thermal history. In parallel to the *in vivo* measurement, four TLDs from each set were irradiated to a known dose close to the estimated applied patient dose for comparison. The unknown patient dose was then calculated using the individual calibration factors of the chips and relating the readings to the readings of the detectors that had received the known dose. With this procedure, using a NE technology Rialto TLD reader with a two-step readout cycle of 160°C for 10 sec and 300°C for 10 sec, uncertainties from fading, thermal treatments, and variations of dose response due to radiation quality can be minimized, produc-

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ing a reproducibility of ±4% (2 standard deviations of the mean) (5).

The film used was Gafchromic MD-55-2 with batch number 970116. Following the American Association of Physicists in Medicine (AAPM) TG-55 (6) recommendations, appropriate precautions in handling, calibration, and scanning the radiochromic film were taken. The film results were analyzed using a double-exposure technique (7). This is performed by giving each film an initial dose of 5 Gy to ascertain if any corrections are needed due to nonuniformity in dose response (8). A variation of ±3% (2 SD of the mean) was recorded in optical density for the films used in the experiment. The film was analyzed with a 660-nm, 3000-mcd, GaAlAs ultra-bright light-emitting diode (LED) which had been integrated into a Scanditronix RFA300 densitometer (9). Negligible polarization effects (10) were observed using this densitometer. A set of standard films were irradiated at each energy used in dose increments of 0.5 Gy to produce an optical density versus dose calibration curve from 0 Gy to 20 Gy. A third-order polynomial function was then applied to the data to produce the calibration curve. It is important that a calibration curve be produced at each beam quality used due to the steep change in energy response dependence for radiochromic film around 100 keV (11). The film was left for a period of 24 hours before optical density measurements were performed to reduce the effects of postirradiation coloration (12). The effective depth of measurement in MD55-2 is 0.17 ± 0.03 mm water equivalent (13). The Gafchromic film was placed perpendicular to the beam's path for *in vivo* and phantom experiments. Gafchromic film should be handled either using soft gloves or tweezers to avoid fingerprints and other contaminants that affect readout. To avoid contact with the patient's skin during *in vivo* dosimetry, the Gafchromic film was wrapped in 0.02-mm-thick plastic which was removed prior to film dose evaluation. By attaching a paper or plastic tab on the side of the film with sticky tape, it can also be easily handled without touching the film. Gafchromic film is prone to scratching, which can also affect the optical density readout. Care should be taken not to slide the film on surfaces with any force. Assessment of measured dose using this technique for an applied dose of 10 Gy was found to have a variance of ±5%.

Clinical measurements were performed on 25 patients with various sites of treatment. Fifteen patients received 10 Gy single-fraction applied doses at 250 kV energy, 5 patients received 10 Gy at 125 kV, and 5 patients received 10 Gy at 100 kV. All applied doses from the 300DXT machine were calibrated using a Thimble ionization chamber using International Atomic Energy Agency (IAEA) protocol. For the 250 kV beam, 50-cm Focal Service Distance (FSD) cones were used which have a 2-mm perspex front cover. For the other energies, 30 cm FSD cones were used and are open-ended cones. The TLDs and radiochromic film were placed side by side during *in vivo* measurements.

Testing was performed in a 30 cm × 30 cm × 30 cm solid water slab phantom for the effects of backscatter. This test was performed as clinically, TLDs and radiochromic film can not always be placed flat on the patient's skin during *in vivo* measurements and slight gaps sometimes exist.

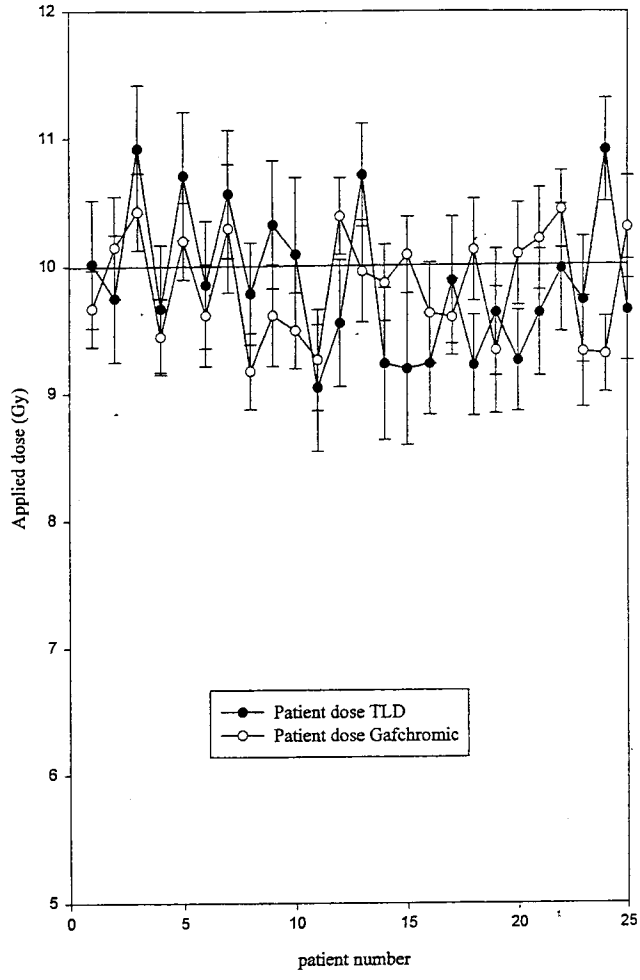

Fig. 1. Measured *in vivo* data for 25 irradiation using low-energy X-rays in 10 Gy single fractions. Results show measurements for TLDs and radiochromic film.

RESULTS AND DISCUSSION

Figure 1 shows the measured applied dose for both the radiochromic film and the TLDs for each of the 25 patient irradiations. The standard deviation of measured dose for the TLDs was 4.1% and the standard deviation for the radiochromic film was 5.5%. This equates to a mean error in measurement of 0.45 Gy for radiochromic film and 0.4 Gy for TLDs for 10 Gy applied dose *in vivo*. Both dosimetry media are shown to adequately measure applied dose *in vivo* on patients.

Figure 2 shows a histogram of percentage deviation from applied dose for both detectors. The *y*-axis shows the percentage of results that show a percentage deviation greater than the values quoted on the *x*-axis; for example, 80% of Gafchromic film results, and 70% of TLD results have a greater than 2% deviation of measured dose to applied dose. These results show that TLDs are slightly more accurate

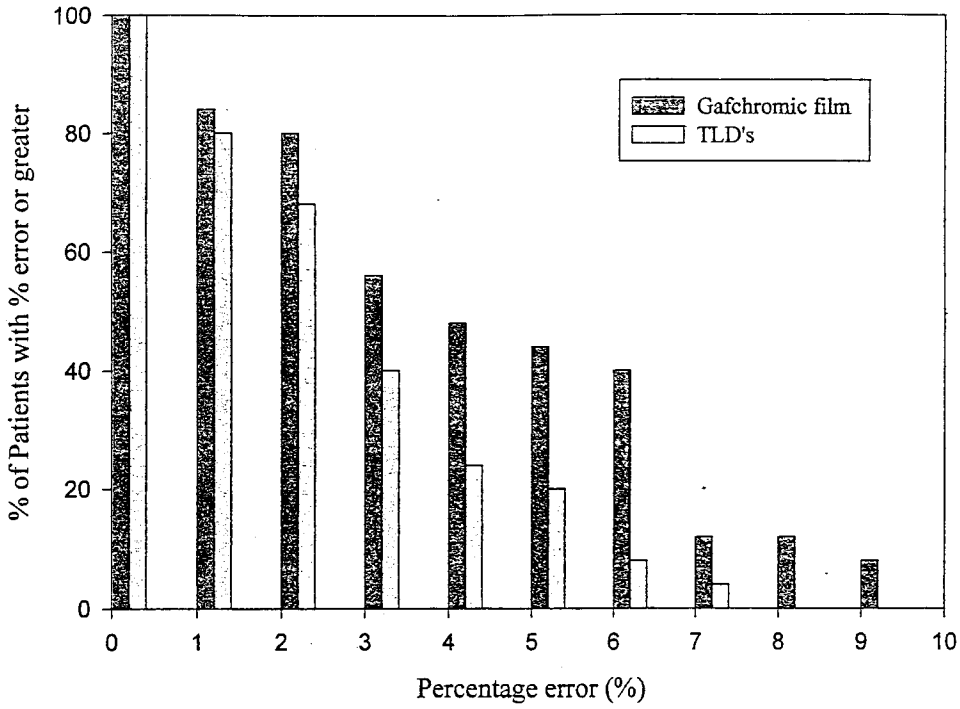

Fig. 2. Histogram of percentage deviations of measured results from applied doses for both radiochromic film and TLD measurements. TLDs are shown to provide slightly more accurate point doses.

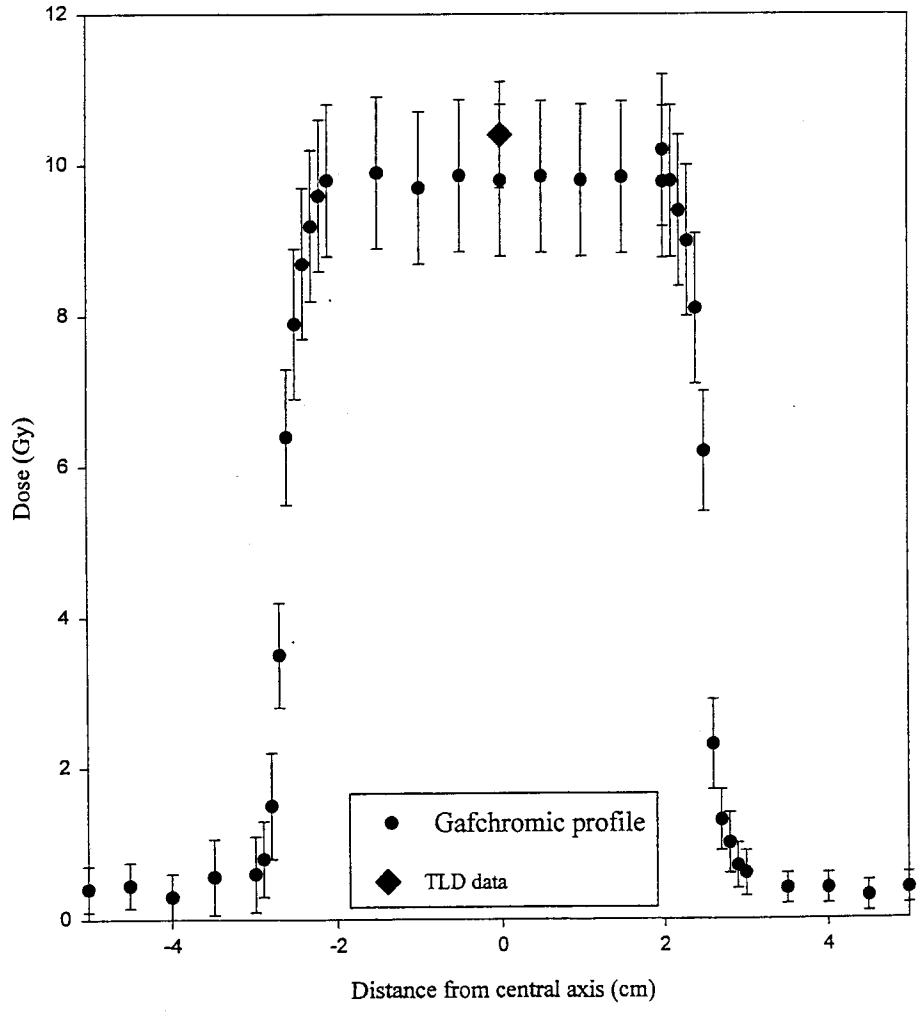

Fig. 3. Dose profile measurement *in vivo* using radiochromic film across a patient treatment field. Also shown is a TLD point dose measurement on the central axis.

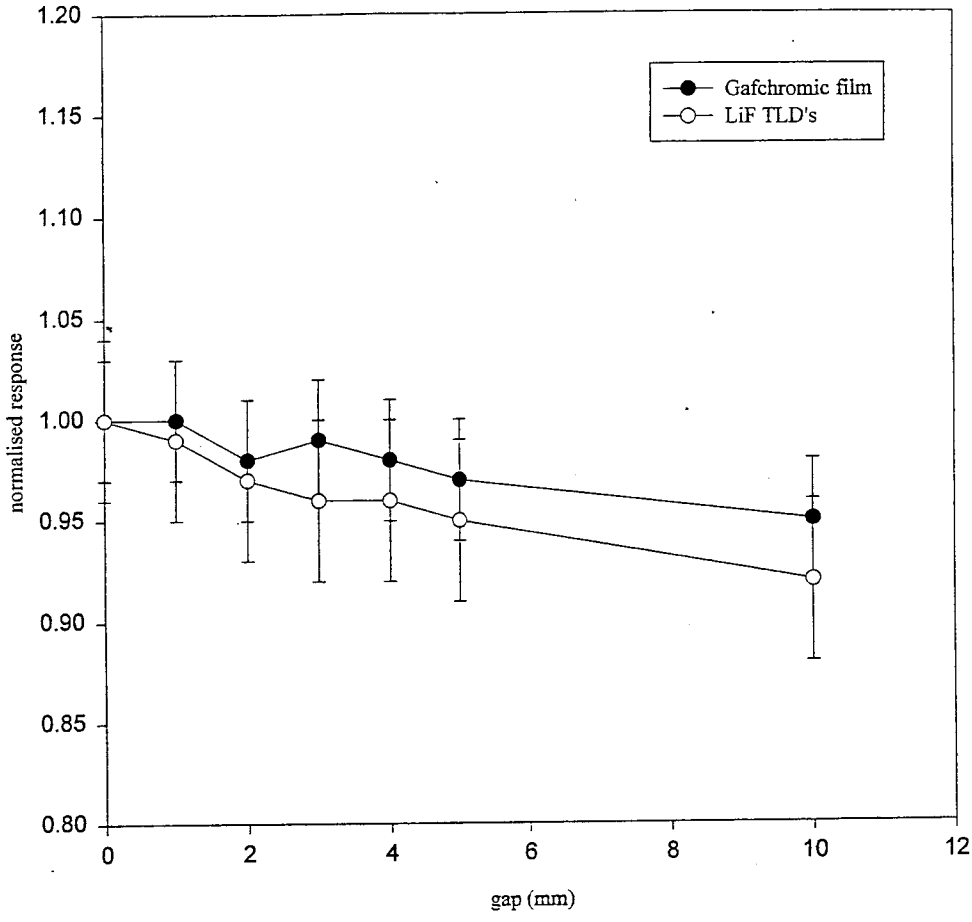

Fig. 4. The effects of air gaps under TLDs and radiochromic film for 250 kVp X-ray irradiation. For clinically relevant air gaps as might be created during *in vivo* measurement a negligible effect is seen.

point dosimeters than Gafchromic film in this study. The radiochromic film, however, has an advantage as it could be used to measure dose in a region of high dose gradient such as the penumbral region of a field or a two-field junction. This is shown in Fig. 3 as a dose profile across a patient's treatment field using radiochromic film and TLDs at the central axis. The field was an irregular shape most similar to an ellipse with a diameter across the point of measurement of 5.2 cm. The reproducibility of radiochromic film at lower applied doses is a limiting factor as the color changes produced are not substantial. However, any dose above 5 Gy could be measured within reasonable limits using Gafchromic film.

One aspect of patient *in vivo* dosimetry at low energy is the effect of backscatter for dosimeters. Due to the sensitivity of some patients' treatment areas, TLDs or film cannot be taped firmly to the skin, often leaving a small air gap under the dosimeter. Figure 4 shows the effect of the lack of backscatter for TLD chips and for radiochromic film for typical clinical situations. This was performed by lifting the chips and film away from the phantom using a thin plastic (0.02-mm thickness) suspension sheet by up to 10 mm. Results show that a less than 3% drop in measured dose occurred with Gafchromic film and less than 5% with TLDs due to lack of backscatter at 250 kV with up to a 5-mm gap. These values are within normal uncertainty limits for these detectors when performing *in vivo* dosimetry. All air gaps should be removed if possible but if they are unavoidable, measured results show that only minimal effects occur.

TLD dosimetry requires approximately 15 minutes preparation and 30 minutes readout time following *in vivo* dosimetry. A TLD system is initially expensive to purchase but requires only small maintenance costs afterwards. Gafchromic film requires similar preparation and readout time to TLDs. The film, however, should be left for 24 hours after irradiation to improve accuracy of results (11). Initial costs can be minimal as a small inexpensive densitometer can be used accurately for spot measurements. Each *in vivo* measurement only requires a small piece of Gafchromic film if point doses are required, or a thin strip may be necessary for a profile or area measurement.

CONCLUSION

Radiochromic film provides an alternative dosimeter of similar accuracy to TLDs for measurement of large single-fraction doses at orthovoltage and superficial energies. The film's advantages lie especially in its ability to measure dose

over a region in the beam as well as peripheral areas at the same time. Small air gaps generated by not taping the radiochromic film (or TLD chips) firmly to the patient seem to not significantly affect the measured dose.

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