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Dosimetry of blood irradiation with radiochromic film

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SUMMARY. It has been shown that radiochromic film is an ideal dosimeter for assessment and verification of delivered dose to irradiated blood products. Using a parallel opposing two-field technique on a medical linear accelerator, blood is irradiated to diminish the risk of transfusion-associated graft vs. host disease (TA-GVHD). The blood products are irradiated in a Perspex blood box to an applied dose of 29·5–31·7 Gy. Verification of applied dose has been performed with thimble ionization chambers and radiochromic film. Radiochromic film results have matched absorbed dose measurements from ionization chambers at all sites within the 'active' treatment volume within ± 6% for a 95% confidence limit. Using a sample of 100 in-vitro measurements, radiochromic film has measured the average applied dose to blood products to be 30·95 ± 2·6 Gy for two standard deviations. Like currently available 'irradiated' film labels, the radiochromic film also serves as a visible reminder that the blood products have been irradiated.

Key words: blood products, dosimetry, Gafchromic, graft vs. host disease, radiochromic film.

Blood products are irradiated using photons to diminish the risk of transfusion-associated graft vs. host disease (TA-GVHD). The desired effect of irradiating the blood is to inhibit lymphocyte function and therefore to prevent GVHD while not causing damage to platelets and other blood fractions. The UK guidelines for blood irradiation state that all parts of the blood pack should receive at least 2500 cGy. These quidelines are based on the work of Pelszynski *et al.* (1994) and Luban & DePalma (1996) who demonstrated that 2500 cGy achieves a 5log depletion of T cells in a T-cell cologen assay. Leitman (1993) surveyed the status of blood irradiation for TA-GVHD prevention and verified that 'at least' 2500 cGy should be sufficient to prevent GVHD. Moroff *et al.* (1986) conducted a study on the in-vitro properties of stored platelets and results indicated that 5000 cGy did not significantly alter the platelet number, the mean platelet volume, the response to hypotonic stress, the extent of discharge of lactate hydrogenase from the cytoplasm or the morphological characteristics of the platelets. From these studies, and for ease of treatment, an applied mean dose of 3085 cGy was adopted by our centre for irradiation of blood products, accepting a deviation of up to 6%.

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Previous dosimetry techniques

Various dosimetry techniques are mentioned in the literature, including thermoluminescent dosimeters (TLDs), alanine, ferrous sulphate, red perspex, metal oxide semiconductor field effect transistors (MOSFETs) and chloroform/dithoizone/paraffin mixture (Hillyer *et al.*, 1993). The most prevalent method relies on TLDs. Often cases are attached to the outside of the blood bags or alternatively placed in polystyrene phantoms which are made to fit into the cylindrical geometry of the commercially available blood irradiators. Radiation-sensitive labels set to specific doses are currently available for use in blood irradiation. However, they only provide information in terms of the minimum dose given to the blood and no quantitative information concerning the actual absorbed dose to the blood products. In this note, Gafchromic MD-55-2 radiochromic film is tested as an alternative method of dosimetry.

MATERIALS AND METHODS

Blood products are irradiated using 6-MV X-rays produced by a Varian 2100C linear accelerator in a 40-cm × 40-cm × 31·5-cm Perspex 'blood box' which is entirely filled with bags containing rice during irradiation. The rice has been tested for attenuation properties and the data used to produce a computer-planned treatment sheet on a GE target series II radiotherapy planning computer using two parallel opposed fields. An irradiation volume was visibly marked on the 'blood box' to allow a variation of less than 6% for applied dose to the blood products. Standard dosimeter measurements were performed with a thimble ionization chamber attached to a Farmer 2570 dosemeter. These results are used in X-ray dosimetry as a standard and accurate method of dose measurement. Dose was mesured *in vitro* with ISP technologies Gafchromic MD-55-2 radiochromic film. In all instances, measurements were performed using two 1-cm × 1-cm square pieces of MD-55-2 Gafchromic film. A control film of the same dimensions from the same piece of film was placed in a light-tight envelope and used in all experiments as a standard for background readings. Optical density of the films was recorded using a 660-nm spot densitometer (Photon Industries, Mangerton, NSW, Australia) and used to determine the absorbed dose to the blood products. This is achieved by comparing the optical density readings to that of previously irradiated films to known doses in control conditions. The film pieces were placed perpendicular to the irradiation beam direction and within the 'active' blood volume during irradiation. The X-ray energy response of Gafchromic film has been studied in detail by Kron *et al*. (1998). These results show that the film could be used effectively in all X-ray beam energies ranging from 50 kVp up to 18 MVp.

RESULTS

Figure 1 shows the calculated applied dose variation through the 'active' region in the blood box as predicted by the GE target II planning system. Results show that up to 6% variation in dose is expected and accepted across the active volume within the blood box for treatment of blood products. Applied dose is expected to range from 29·5 Gy to 31·7 Gy. The low doses seen at the edge of the blood box are the build up characteristics of high-energy X-ray beams (Butson *et al*., 1996).

Figure 2 shows the measured dose vs. applied dose in control conditions for MD-55-2 Gafchromic film between the dose range 20–40 Gy. An error of 2·9% (two standard deviations of the mean) was recorded using 10 films for measurement of applied dose. These results show that Gafchromic film can adequately measure dose for most irradiaton procedures involving blood products.

Figure 3 shows the measured applied dose for 100 consecutive blood irradiations over an 8-month period using radiochromic film cut from the same batch and placed in a light-tight box for storage. Negligible effects were recorded in film dosimetry deterioration as the age of the film increases.

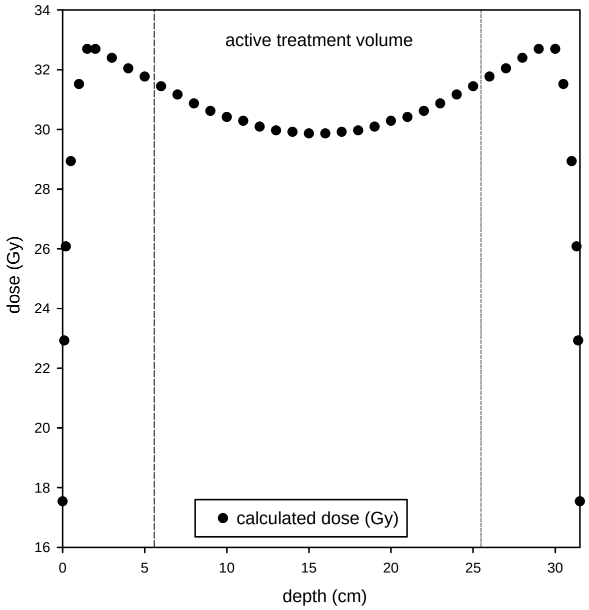

Fig. 1. Dose distribution across the 'blood box' used for the irradiation of blood products. The 'active' area indicates the region in which blood bags are placed during irradiation.

Figure 4 shows a frequency histogram for the measured dose results in vitro for 100 blood irradiations. The Gafchromic film was placed either on top, in the middle or below the blood bags on each occasion. The mean dose measured was 30·95 ± 2·6 Gy for two standard deviation. The applied dose ranged from 29·5 Gy to 31·7 Gy with a mean applied dose of 30·85 Gy.

Figure 5 shows a frequency histogram of the percentage deviation from the mean applied dose at isocentre for measurement with Gafchormic film. Less than ± 5%

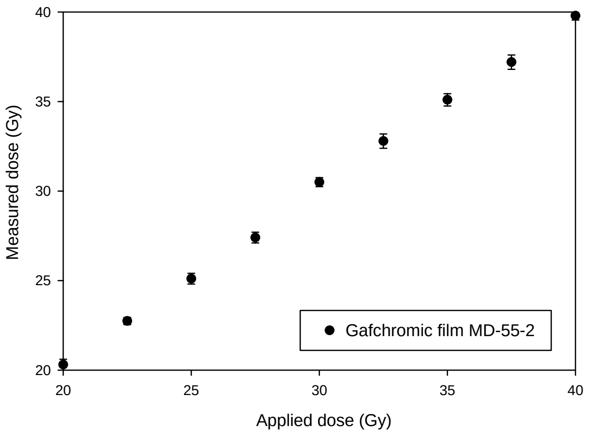

Fig. 2. Measured dose vs. applied dose for MD-55-2 Gafchromic film in control conditions between the dose levels of 20 Gy and 40 Gy.

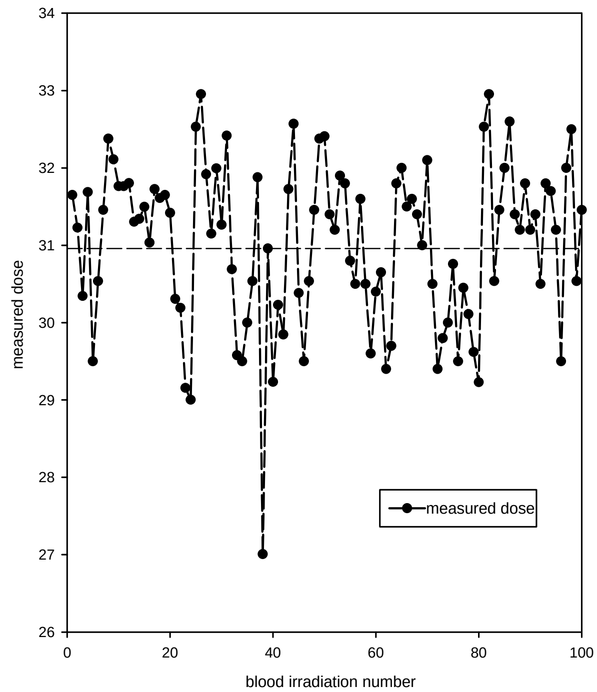

Fig. 3. Measured dose *in vitro* for 100 consectutive blood irradiations. The Gafchromic film tags are placed within the active region during the irradiation process.

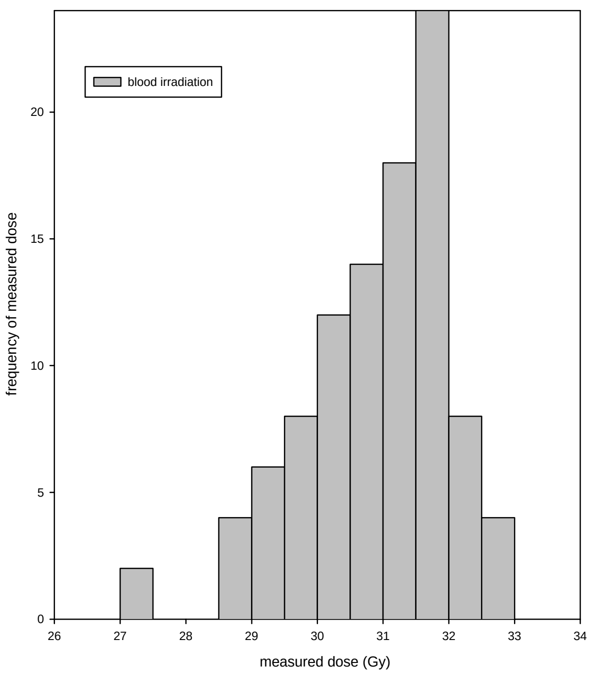

Fig. 4. Histogram for the measured applied dose to blood products.

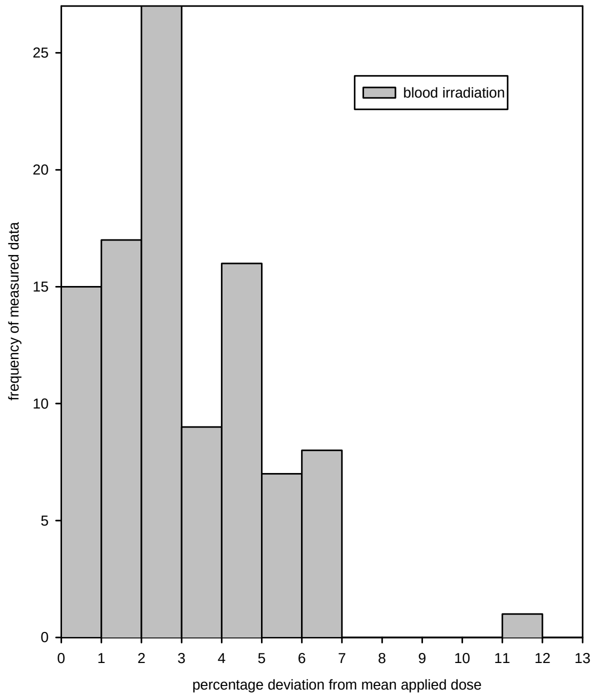

Fig. 5. Histogram of percentage deviation of measured dose from the mean applied dose for the irradiated blood products.

deviation from the applied dose at isocentre was measured in 90% of all cases.

DISCUSSION

This study has shown that Gafchromic MD-55-2 film can adequately measure dose for blood product irradiation. The film can also serve as a visual marker for irradiated blood products due to its distinctive blue colour following irradiation. No reproducible differences were measured when the films were placed either on top, in the middle or below the blood bags during irradiation. However, we recommend that the film tags be placed at all three sites during irradiation to fully assess the 2500 cGy to midplan and no less than 15 cGy recommendation. The main considerations which must be taken into account when using radiochromic film as a blood irradiation dosimeter include its slight response to ultraviolet light and scratching/contamination of the film. Butson *et al.* (1998) have shown the effect of ambient/ultraviolet light on Gafchromic MD-55-2 film. The placement of the film on the blood during irradiation will not affect the measured results; however, prolonged exposure (weeks of exposure) to fluorescent lights could affect the accuracy of the measured dose. As the film is measured in the visible region, effects such as scratches and contaminations, e.g. blood or fingerprints, could affect the optical density reading recorded. However, with careful handling these effects do not pose a problem with Gafchromic film. A suggestion could be to wrap the film pieces in opaque plastic during use to eliminate the above mentioned effects if contamination is considered to be a problem. With our centre, negligle effects were seen on all films used due to the above mentioned problems. Meigooni *et al.* (1996) showed that Gafchromic film could have a response nonuniformity of up to 12% on one piece of Gafchromic film. Variations of this size can affect the accuracy of results if corrections are not applied. However, Butson *et al.* (1998) also have shown that the nonuniformity of Gafchromic film can be as small as 1% over an entire film. To assess the extent of nonuniformity for the film before use, two thin strips can be cut from the sheet in both directions of the films axis and irradiated to a known, uniform dose and tested. Corrections can then be applied to dose response if necessary. Radiochromic film is a useful and accurate dosimeter in the measurement of absorbed dose for the irradiation of blood products. Not only can it measure dose but also can provide a visible marker for irradiated blood products.

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