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Skin dose assessment in unmodulated and intensity-modulated radiation fields with film dosimetry

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HIGHLIGHTS

- ► The surface dose was found 19.8% of maximum dose in unmodulated field for 6 MV.
- ► It was 10% of maximum dose for 18 MV photon beams.
- ► Sweeping contaminated electron by dipole magnet reduced surface dose.
- ► EDR2 and EBT2 films measured dose in good agreement in build-up region.
- ► This study demonstrated the capability of EDR2 film to measure skin toxicity.

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ABSTRACT

Superficial dose from 6- and 18-MV photon beams has been studied by measuring surface dose and shallow build-up dose using radiographic film EDR2, radiochromic film EBT2 and plane-parallel chamber. Measurements have been made for intensity- and non-intensity-modulated beams.

The results show that the surface dose was found to be 19.8% and 10% of maximum dose in unmodulated fields for 6 and 18 MV photon beams, respectively. The study further showed that intensity modulation decreased surface dose by 1.1% and 0.7% for the same field size at 6 and 18 MV, respectively, and surface dose was dropped by magnetically sweeping contaminating electrons. EDR2 and EBT2 films show in good agreement in shallow build-up region.

This study demonstrated the capability of EDR2 film, in addition to radiochromic film, to measure surface and build-up dose in case of treatment planning system uncertainties with regard to skin toxicity or shallow target coverage.

1. Introduction

Higher surface dose from photon beams is undesirable in many clinical situations because it enhances skin toxicity while the advantage of high-energy photon beam should be the skin-sparing effect. Skin reactions, such as erythema and desquamation, occur for instance in quite a number of patients undergoing intensity-modulated radiation therapy (IMRT) or radio chemotherapy for head-and-neck cancer (Lee et al., 2002). On the other hand, tumour or cervical lymph nodes may extend into the build-up regions. Therefore, it is clinically important to have a precise knowledge of the superficial depth dose profile. This knowledge is not always provided by current treatment planning systems. Mutic and Low (2000), for instance, reported that although the IMRT dose computed by the treatment planning system PEACOCK (version 1.12, NOMOS Corp., Sewickley, PA) at the surface and in the first few millimetres below it, was overestimated at 6 MV, the calculated dose beyond 3 mm was 15% lower than the measured dose. Dogan and Glasgow (2003) observed that the IMRT dose calculated for 6 MV by the inverse planning system FOCUS (version 3.2.1, Computerized Medical Systems Inc., St. Louis, MO), was 25% higher at the surface and 5% at 1 mm below the surface as compared to measurements conducted with a plane-parallel chamber. Moreover, Ding (2002) reported significant dose discrepancies between Monte Carlo calculation and measurements for 18 MV in the build-up region (5% at 1 cm depth) in a 40 × 40 cm^2 open field with lead foil. Butson et al. (2004) showed that the surface percentage dose can be estimated within ±3% of parallel plate ionization chamber results with radiographic film using a series of film layers to produce extrapolated results. Chen et al. (2010) measured IMRT

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surface dose using Markus chamber and results of chamber measurement compared against radiographic film.

In physics terms, surface and superficial doses are due to contamination electrons and low-energy scattered photons. The relative contribution from both to the build-up dose has been controversial. Marbach and Almond (1977) stated that, for a 25 MV X-ray beam from a Sagittaire linear accelerator, Compton scattered photons were responsible for the additional dose in the build-up region, and not electrons. Biggs and Ling (1979), Ling et al. (1982), and Padikal and Deye (1978), however, found that electrons were the major source of contamination in beam electrons. Hounsell and Wilkinson (1999) explained that, the build-up region dose was depended upon the primary photon beam, backscattered radiation from the patient and contamination radiation from outside the patient.

The influence of electron contamination on the dose distribution in phantoms has been investigated by a number of authors. Many of them (Biggs and Ling, 1979; Biggs and Russel, 1983; Sixel and Podgorsak, 1994; Rogers and Bielajew, 1985; Attix et al., 1983; Jursinic and Mackie, 1996; Zhu and Palta, 1998) have performed experiments to measure the increased surface dose and the shift of the depth of the maximum dose (d_{max}) to shallower depths by increasing the field size or decreasing the source-to-surface distance (SSD). In experimental studies (Biggs and Russel, 1983; Jursinic and Mackie, 1996; Sjogren and Karlsson, 1996) a magnet placed just below the treatment head was used to sweep the electrons coming from the head and thus to determine their contribution to the surface dose and the build-up region. Others (Attix et al., 1983; LaRiviere, 1983; Sjogren and Karlsson, 1996) measured the contribution of electrons coming from the head by using a thin helium-filled plastic bag just below the accelerator head, which minimizes the electron production in air. Calculation models have been used to derive the contribution of the contamination electrons, generated in air (Nilson and Brahme, 1979) and the accelerator head (Hounsell and Wilkinson, 1999), to the dose in the build-up region. Also Monte Carlo simulations have been applied to investigate the electron contamination in therapeutic beams (Sixel and Podgorsak, 1994; Petti et al., 1983a,b; Daryoush et al., 2000). Malataras et al. (2001) concluded that the Monte Carlo method was an elegant way to separate the electron contamination component from the photon beam.

Radiochromic film is an established and valuable dosimeter for surface and superficial dosimetry (Quach et al., 2000; Paelinck et al., 2004). Bilge et al. (2009) specifically studied surface dose using GafChromic EBT film and compared the results to plane-parallel chamber. They found agreement between EBT film and Parallel Plate (PP) ionization chamber within 3% for 18 MV. Devic et al. (2006) introduced correction factors to directly obtain skin entrance dose from three types of radiochromic film if the clinically relevant skin depth was assumed to be at 70 μm, by taking into account the effective depth of measurement.

Application of radiographic film to surface and superficial dose measurement has been reported in a few publications. Dogan and Glasgow (2003) investigated the surface and build-up dose of both perpendicular and oblique IMRT beam incidence. Therefore they compared EDR2 film to plane-parallel ionization chamber. However, they judged EDR2 film not reliable enough for depths shallower than 5 mm. EDR2 film was also used by Higgins et al. (2007) to study the surface and superficial dose for head-and-neck conventional and IMRT treatments. To that end, EDR2 film was compared to TLD and treatment planning. Due to the thickness of the TLDs and the coarse voxel size used in planning, the authors could not really judge the value of EDR2 for this application. More recently, Hsu et al. (2010) used radiographic XV film to assess dose accuracy in the build-up region for segmental IMRT planning and delivery.

It is hard to compare the published results obtained from various machines since the energy spectrum, collimating and filtering systems, and accessory devices may differ to a substantial degree. Kim et al. (1998) measured skin doses for 8 MV and 18 MV photon beams for various clinical setups including dynamic wedge, blocked and multileaf collimator (MLC) fields. They found that skin dose increases with field size and the use of blocks, block tray, and dynamic wedge. Later, Paelinck et al. (2004) compared the measured skin doses from a typical head-and-neck IMRT delivery between two different linear accelerators. They found differences in skin dose at the beam level, but in the composite dose IMRT distribution the differences faded out.

In this work we tested the hypothesis that radiographic EDR2 film is a suitable dosimeter to assess whether comparable unmodulated and intensity-modulated beams affect surface and superficial dose differently. Therefore, we intended to sweep the contaminating electrons with a magnetic dipole field that was positioned perpendicular to the beam axis. We studied the dose at the surface and in the shallow build-up region for unmodulated, step-and-shoot and dynamic IMRT beams. Radiographic and radiochromic films were used to measure the surface dose with and without magnet. We measured at nominal depths of 1 and 4 mm and focused on 6 and 18 MV. Higher beam qualities may be clinically preferred because they produce lower skin dose. Butson et al. (1997), for instance, achieved a 10–15% decrease in dose at 1-mm depth with 18 MV compared to 6 MV.

2. Materials and methods

2.1. Experimental conditions

The experiments were carried out on the Elekta SLiplus linear accelerator (Elekta, Crawley, UK), which was equipped with a standard MLC. In this study, the X- and Y-direction are defined according to IEC 601-2-1. Hence, the Y-direction is the travelling direction of the leaves of the MLC. The radiographic film, radiochromic film measurements and PP measurements were performed at isocentre using 6 and 18 MV X-ray beams. Polystyrene (Polystyrol 495F, BASF, Germany) $30 \times 30 \times 20$ cm^3 slab phantoms were used. In order to convert the obtained data from TPR context to depth dose context, we applied the conversion formula proposed by Khan (1994).

2.2. Magnet to assess electron contamination

A magnetic dipole was created by mounting two permanent cylindrical magnets (Supermagnet, Gafarlicher, Germany) with poles of 4.5-cm diameter in an attracting alignment. The magnets were placed in a special polystyrene holder to keep the poles with their centres at 3.5 cm above the phantom surface and at an interdistance of 2.5 cm and allowing radiation fields up to 2×24 cm^2 as shown in Fig. 1. Using a calibrated Hall sensor (IC SS94A2D from Honeywell) and a universal digital voltmeter, the magnetic field strength was measured along the axes X, Y, and Z as indicated in Fig. 1. For symmetry reasons, along these axes the magnetic field is oriented along the Z-axis allowing a fixed sensor orientation. The sensor position was controlled by a water phantom scanning device (MP3, PTW, Germany). A measurement was performed and registered manually every 1 mm.

2.3. Beam geometries and intensity modulation

For 6- and 18-MV photon beams, one unmodulated and two intensity-modulated beams were investigated. The gantry and collimator rotation angles were set at 0°. Modulated beam means