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SCIENTIFIC NOTE

Skin and build up dose determination for a 2.5 MV medical linear accelerator imaging beam

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Abstract
The 2.5 MV Imaging beam produced by a Varian TrueBeam linear accelerator produces a dose build up effect at the beam entrance similar to other high energy photon beams. The surface dose values were found to range from 39% of maximum dose at a 5 cm × 5 cm field size up to 69% of maximum at a 40 cm × 40 cm field. The depth of maximum dose deposition was found to range from 5 mm at smaller field sizes to 4 mm at larger field sizes. Whilst large absorbed doses will not be delivered utilizing these beams, the data provided will allow the medical physics community to assess and estimate doses to patient's skin and subcutaneous tissue from low energy MV imaging beams.

Keywords Radiotherapy · Skin dose · Build up · Dosimetry · Radiation · Surface dose · Radiochromicfilm

Introduction

Low energy megavoltage photon beams have been utilised for imaging capabilities within clinical medical linear accelerators in recent years [1]. The Varian TrueBeam linear accelerator machine (Varian Medical Systems, Palo Alto, California, USA) is capable of producing a 2.5 MV photon beam along the same beam path as its high energy 6 MV to 18 MV clinical photon treatment beams. This functionality allows a portal image to be taken where an increased contrast and resolution compared to traditional MV images is achieved [2, 3]. This provides a substantial improvement for targeting and delineation [1]. By decreasing the nominal incident beam energy and using materials with lower atomic numbers in the target, the 2.5 MV beam produces a lower average photon energy and thus better soft tissue contrast.

The 2.5 MV imaging beam is controlled using a dose integrating mode in the same way as patient dose delivery, comprising the use of the ionisation monitor chambers. As such the beam must be calibrated for use in the same way as treatment beams [4–6]. Thus, when imaging is performed, an estimation of maximum delivered dose from the image can be calculated. Grafe et al. 2016 [1], have provided beam characteristics for standard field size and depth dose configuration of these beams and thus estimates of delivered dose can be ascertained at other depths in tissue. However, only single values of "surface dose" have been quoted for these beams in their work [1].

The surface dose is an important factor in radiotherapy as the skin has dose limits which should be met [7–11]. There are a variety of tools that can be used to determine the surface dose using experimental measurements as well as Monte Carlo calculations [12–14]. They have also shown that the effective depth of the measurement or the Monte Carlo calculation has a major impact on the quote surface dose [15, 16].

It is well known that high energy X-ray beams produce significantly different surface, skin and build up dose not only for energy changes [17], for field sizes variations as well [18]. Surface dose values alone can range from the order of a 5% for a small field of 5 cm × 5 cm for an 18 MV X-ray beam up to 42% for a 40 cm × 40 cm 6 MV X-ray

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beam. The aim of this work is to quantify the surface, skin and build up characteristics of a 2.5 MV photon beam and provide data available for the medical community to assess and estimate doses to patient's skin and subcutaneous tissue from low energy MV imaging beams.

Materials and methods

Build up dose characteristics were evaluated for a 2.5 MV beam produced by a Varian TrueBeam linear accelerator. All irradiations were performed at 100 cm source to surface distance (SSD) in standard conditions. Irradiations were performed in a RMI 457 Solid Water (Gammex Inc, Middleton, Wisconsin, USA) stack phantom which was 30 cm × 30 cm × 30 cm in size. Measurements were made with an Attix parallel plate ionisation chamber (Gammex, Middleton, WI, USA). placed in a dedicated solid water holder which allowed accurate placement of the chamber at specified depths. The Attix chamber has previously been described as an accurate detector for surface and build up dose due to its solid water construction, very thin front window thickness and large guard ring design [19]. Reynolds et al. [20] showed a less than 1% variation in measured surface dose was found between the Attix chamber and an extrapolation chamber at 6 MV energy. As such, no corrections were made to surface dose and build up dose measured for effective depth. These measurements depths ranged from 0 to 10 mm in 1 mm intervals until the depth of maximum dose was measured and at specified depths after wards. Field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm were evaluated.

Surface dose profiles were also evaluated at various field sizes to ascertain the variation in percentage dose across the beams profile. These values were also compared to the beam profile and build up characteristics of a standard 6 MV photon beam produced by the same True Beam accelerator for comparison. This was performed using an extrapolation method from a three-film stack of Gafchromic EBT3 radiochromic film positioned at the top of the solid water stack phantom. Gafchromic EBT3 film has been shown to effectively measure skin dose before [21–23], and have an effective depth of measurement of 0.125 mm. The extrapolation technique consists of irradiating the three-film stack to effectively measure sub millimetre depths. Each EBT3 film has a radiological effective thickness of 0.25 mm with the film centre chosen as the relative point of measurement. Each film was separately read out and an extrapolation to zero thickness was performed via linear extrapolation to estimate surface dose, similar to the method used by Reynolds et al. [20]. The films were scanned using an Epson 10000xl scanner in transmission mode at a scanning resolution of 50 dots per inch using the red channel for evaluation. The change in coloration of the film was used to evaluate the measured dose at each point of the film by comparison with a calibration curve where known doses were given to films and a calibration equation produced.

Measurements for build-up dose assessment with the Attix chamber were performed multiple times for analysis of errors and uncertainties. Sources of error included both type A and type B which accounted for errors in measurement accuracy as well as set up uncertainty. The errors are expressed as 2SD of the mean using the square root of the sum of the squares of each error component, shown in Eq. 1.

$$\delta R = \sqrt{\left\{(\delta x)^2 + (\delta y)^2 + (\delta z)^2\right\}} \quad (1)$$

where δR is the total error and δx, δy and δz are representative components of measured uncertainty. These include (but not limited to) components such as repeat measurements, scanner optical density variations and chamber polarity variations. It was found that less than 2% variation (2SD of the mean) in measured dose was observed at all measurement's positions for the Attix chamber. Measurements for profile doses with EBT3 Gafchromic film were performed three times. The results shown are one set of results with variations up to ± 3% seen in measured dose. Error bars have not been included to assist with the clarity of the figure.

Results

Figure 1a shows the build-up characteristics of the 2.5 MV beam for field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm as measured by the Attix parallel plate ionisation chamber. Results show that the measured surface dose range from 39% for a 5 cm × 5 cm field up to 69% for a 40 cm × 40 cm field.

Figure 1b shows the build-up characteristics of the 6 MV beam for field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm as measured by the Attix parallel plate ionisation chamber. Results show that the measured surface dose range from 10% for a 5 cm × 5 cm field up to 42% for a 40 cm × 40 cm field.

Figure 2 shows extrapolated surface dose profile measurements for the 2.5 MV beam in the cross-plane direction for square field sizes of 10 cm, 20 cm and 30 cm as representative data. Results show the rounded nature of the surface dose profiles which are similar in shape to the dose profiles at the Dmax position. The rounded nature of the profiles is due to the fact that the beam does not use a flattening filter.

Figure 3 shows extrapolated surface dose profile measurements for the 6 MV beam in the cross plane direction for square field sizes of 10, 20 and 30 cm as representative data. Results show the relatively flat nature of the surface dose profiles which are similar in shape to the dose profiles

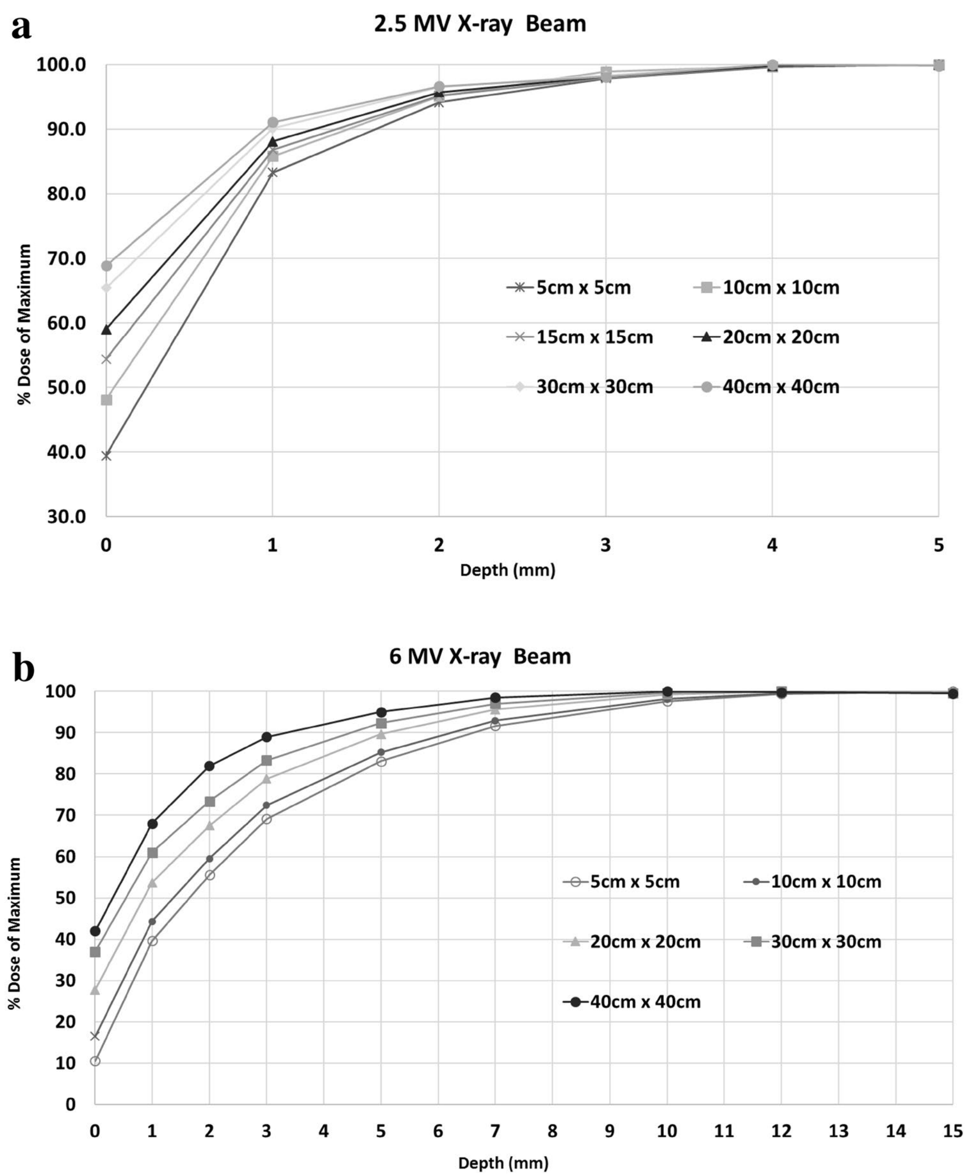

Fig. 1 Build up dose measured for a 2.5 MV (**a**) and a 6 MV (**b**) photon beam for various fields sizes ranging from 5 cm × 5 cm to 40 cm × 40 cm

at the Dmax position. Larger peripheral doses are seen for all field sizes.

Discussion

As can be seen in Fig. 1a the surface dose values range from 39% for a 5 cm × 5 cm up to 69% for a 40 cm × 40 cm field. This is compared to Fig. 1b where surface doses of 10% and 42% are seen for a 6 MV photon beam with the same field sizes and irradiation conditions. The depth of Dmax dose for the 2.5 MV beam varies slightly with field size with the smaller fields from 5 up to 20 cm^2 having Dmax at 5 mm depth and larger fields have the Dmax positions at 4 mm. In comparison the 6 MV beam has values of 15 mm and 12 mm for these field sizes respectively. Grafe et al. [1] quote the relative entrance dose for a 10 cm × 10 cm field size at 100 cm SSD as 63 ± 5% and 23 ± 5% for the 2.5 MV and 6 MV beams respectively. These values were measured with a single layer EBT3 film measurement technique and at a quoted effective depth of 0.163 mm. Estimated relative entrance doses from our results, by empirical modelling, shows that at 0.163 mm depth, the relative entrance dose would be 59% and 22% for the 2.5 MV and 6 MV beams respectively. As such, our results are in agreement with Grafe.

Figure 2 shows that the highest extrapolated surface dose was measured at the central axis for the 2.5 MV beam. Results were normalized to 100% at the Dmax positon dose on the central axis. As can be seen the surface dose profiles vary across the beam with smaller doses being delivered off axis relative to the central axis dose. This profile shape is

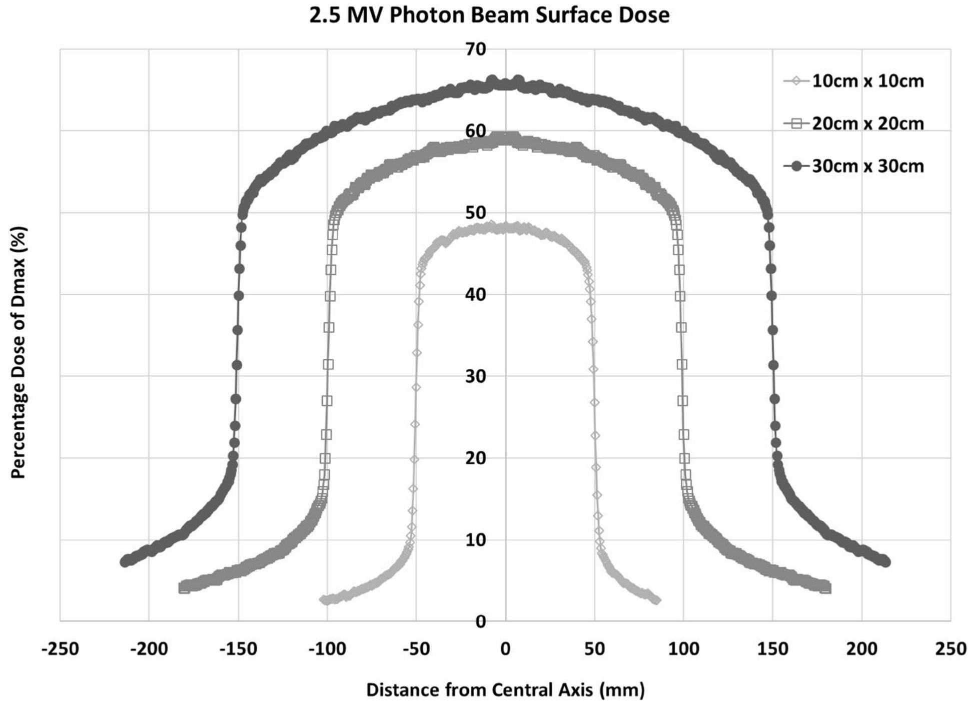

Fig. 2 Measured extrapolated surface dose profiles for a 2.5 MV photon imaging beam produced by a medical linear accelerator

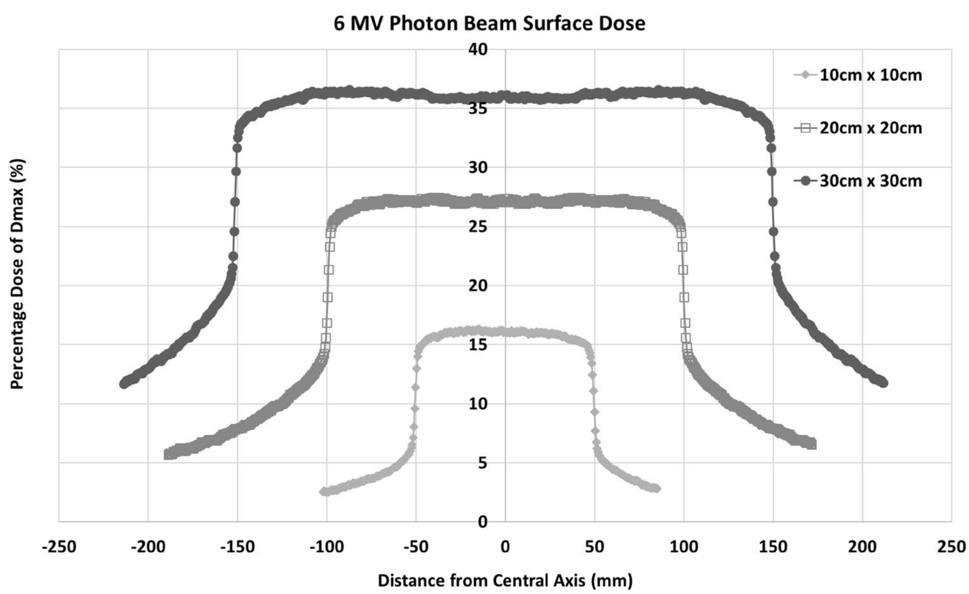

Fig. 3 Measured extrapolated surface dose profiles for a 6 MV flattened photon beam produced by a Varian TrueBeam linear accelerator

similar to the dose profile at depth as the 2.5 MV beam is not a flat field at Dmax either. In comparison, a 6 MV photon beams measured at the surface dose position provides a relatively flat dose across the entire profile as shown in Fig. 3.

Of interest, by comparison the dose delivered in the peripheral regions for the 2.5 MV photon beam is smaller than the 6 MV photon beam at larger field sizes. For example, at 5 cm peripheral to the geometric beam edge for a 30 cm × 30 cm field, the surface dose for the 2.5 MV and 6 MV beams are approximately 8% of Dmax and 13% of Dmax respectively. A similar feature holds for all large ($\geq$20 cm) field sizes. Whereas at smaller fields, the 6 MV profile peripheral dose is smaller at the surface. It is expected that the extra peripheral contribution is caused by enhanced electron contamination with the 6 MV photon beam which spreads surface dose over a wider region than the 2.5 MV beam. This is due to the larger contribution to surface dose at larger field sizes and the increased production of electron contamination with increased beam energy.

Whilst large doses will not be delivered by 2.5 MV imaging beams, the measurement of build-up characteristics will allow us to determine skin and subcutaneous tissue dose exposure when these types of image beams are used during therapy. Doses at Dmax are known and calibrated through the use of monitor unit to dose calculations and with the knowledge of percentage surface and build up doses, estimates of applied skin and subcutaneous tissue dose can be calculated.

Conclusion

The 2.5 MV imaging beam produced by the Varian TrueBeam machine produces a noticeable build up effect in dose delivery. The position of Dmax is found at approximately 4 to 5 mm depending on the field size and the measured surface dose can range from 39 to 69% for field sizes of 5 to 40 cm^2. This information provides useful data for analysis of skin and subcutaneous dose delivered in association with beam imaging using this 2.5 MV photon beam.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval No procedures involving human participants were performed in this study. No procedures involving animals was performed in this study.

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