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Developing equations to predict surface dose and therapeutic interval in bolused electron fields: A Monte Carlo Study

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ABSTRACT

In this research, we aim to investigate the influence of different materials, as a bolus, on the low-energy electron beam dose distributions and to develop equations for predicting surface dose based on bolus thickness, as well as the therapeutic interval based on surface dose.

All the Monte Carlo (MC) calculations and measurements were conducted on a Siemens PRIMUS linac. Based on EGSnrc MC code, BEAMnrc system was used to model a Siemens linac and generate phase-space files for three electron beams (6, 8, and 10 MeV). The particles were transported from the phase-space files to the bolus materials and the simulated water phantom using DOSXYZnrc. Various materials with different thicknesses were examined as a bolus, and appropriate equations were determined for each material and electron beam.

The comparison of percent depth dose (PDD) curves and beam profiles, using MC, with the measured data demonstrated that the calculated values properly matched with the measurements. The results indicated that the use of bolus materials with the density of higher than soft tissue can increase both surface dose and therapeutic interval simultaneously. This finding arises from the fact that the required bolus thickness for achieving the therapeutic surface dose decreases in the case of high-density materials.

Two series of prediction equations were proposed for predicting the surface dose based on bolus thickness and the therapeutic interval based on surface dose. These equations are able to calculate properly the bolus thickness required for producing a therapeutic surface dose (above 90%) for any therapeutic interval.

1. Introduction

Electron therapy is a frequently applied modality for treating superficial lesions. The electron beams, mostly available in radiotherapy departments, have energies ranging from 4 MeV to 25 MeV and are produced by Linac, a standard clinical linear accelerator (Khan, 2010; Hogstrom and Almond, 2006). Electron beams have some advantages in different clinical situations, which is due to the characteristics of their depth-dose curves. They can deliver uniform doses, in an acceptable manner, to a relatively well-defined region that extends from the surface dose to therapeutic range. In selection of the appropriate energy of electron beam for a specified clinical case, matching between the central axis depth-dose curve parameters and the clinical situation is necessary (Thwaites and McKenzie, 2007; Hogstrom and Almond, 2006).

Central axis depth-dose curve parameters are usually used for evaluating the effect of bolus materials on the electron beam dose distributions. These parameters are: a) relative surface dose (%D_s), i.e. the ratio of dose determined on the surface to the dose determined at the depth of maximum dose, b) therapeutic range (R_T), which means the calculation of the clinically useful portion of the depth dose taken to be the depth of the distal 90%, c) therapeutic interval (T_I) that is the distance between the proximal (R_{90p}) and the distal 90% depth dose (R_{90d}) (Healy et al., 2005), d) the depth of the maximum dose (R_m), e) the depths of 85% (R_{85}) and 50% (R_{50}) dose levels.

The surface dose and the therapeutic range of electron beams are the most important parameters in radiotherapy. Depth-dose curves of electron beams are dependent on the size and the shape of the treatment field and can modify with electron beam energy (Gunhan et al., 2003). The most effective treatment depth, so called therapeutic range, of electrons is the depth of 90% dose level (Khan, 2010; Eldib et al., 2010); which can be altered to fit the clinical situation by varying the energy of beam.

Unlike photon beams, the percentage of electron surface dose raises with energy (Khan, 2010). In general, the surface dose of electron beams is virtually 80% of the maximum dose; however, it changes with

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energy of beams. It means that with the increase of electron energy, the surface dose is also elevated (Gunhan et al., 2003; Khan et al., 1991). For low-energy electron beams, the surface dose can be increased to the required level using a tissue compensator (bolus) in contact with the patient surface (Gunhan et al., 2003). In addition, the bolus thickness can be selected by inspecting the relevant depth-dose data. Tissue-equivalent bolus can always be caused to decrease the therapeutic range equable to the bolus thickness (Nygaard et al., 2005; Lambert et al., 1999). So, there is an association between bolus thickness and electron beam energy. In this sense, the higher the thickness of bolus is beyond the minimum required for achieving a therapeutic surface dose, the T_I would be less (Lambert et al., 1999).

Some investigations have been conducted on the problem of increasing surface dose while minimally influencing therapeutic range (Alasti et al., 1995; Galbraith and Rawlinson, 1984). Partial bolusing technique has also been applied for a fraction of each treatment using the tissue-equivalent material. One of the disadvantages of this method is interrupting each fraction (Galbraith and Rawlinson, 1984). In a study, it has been indicated that the application of the tin mesh grid positioned far from the patient can help to evaluate the surface dose (Alasti et al., 1995). In another work, lead was used as a bolus material for the treatments of photon as well as electron beams. In addition, only one thickness of lead was used for both nominal electron beams (6 and 9 MeV). Surface dose was also increased to 100% in each case, which significantly reduced the therapeutic range as well as therapeutic interval (Moyer et al., 1986). Metal foils with high density, such as tin and lead, have been introduced as a replacement for conventional boluses because of having higher therapeutic interval. However, in the case of irregular patient contours, tissue-equivalent boluses can easily cover patients' skin in an acceptable way (Gunhan etal, 2003; Lambert et al., 1999).

Recently, an article has provided a compact review of various bolus materials and their practicality for convenient and informative use in clinics (Vyas et al., 2013). Patient-specific bolus is usually designed for providing the therapeutic range for conforming and containing the planning target volume while delivering a minimal dose to organs at risk and normal tissues (Zeidan et al., 2011).

Paraffin wax, polystyrene, Poly (methyl methacrylate) (PMMA) or acrylic, Lucite, Super stuff, Super-flex, and Superflab are commonly available materials used as bolus materials (Khan, 2010; Gerbi et al., 2009). However, there are some other bolus materials, such as lead and tin foils, that have higher Z than tissue-equivalent materials (Lambert et al., 1999; Arancini and Brackenridge, 2008).

The custom fabrication of some tissue-equivalent bolus materials such as paraffin wax is a time-consuming and difficult process (Humphries et al., 1996). Although gelatin-based or 'flab' materials has been indicated to be effective, some practical problems, such as dosimetric distortion, may occurs when air gaps exist between the bolus and the surface (Bedford et al., 2005).

High-Z materials, such as tin, lead foil, etc., have some advantages, including a large therapeutic interval, easily available, relatively inexpensive, and easy to use (Lambert et al., 1999; Arancini and Brackenridge, 2008). Unlike the commonly used tissue-equivalent boluses, the air gaps (up to 5 mm) exist between the high-Z material foils and phantom surface have minor impact on the surface dose or therapeutic range (Healy et al., 2005).

In the current study, we investigated the characteristics of three clinical electron beams (6, 8, and 10 MeV) used for different thicknesses of various bolus materials. Among the materials studied in this work, there are some bolus materials, such as low-Z and high-Z materials, commonly used in radiotherapy.

Since treatment machines lack sufficiently fine energy spacing for providing the optimal surface dose and therapeutic range, it seems that this problem can be solved using appropriate materials as a bolus in electron therapy. Thus, the purpose of this study is to investigate the influence of different materials, as a bolus material, on the low-energy

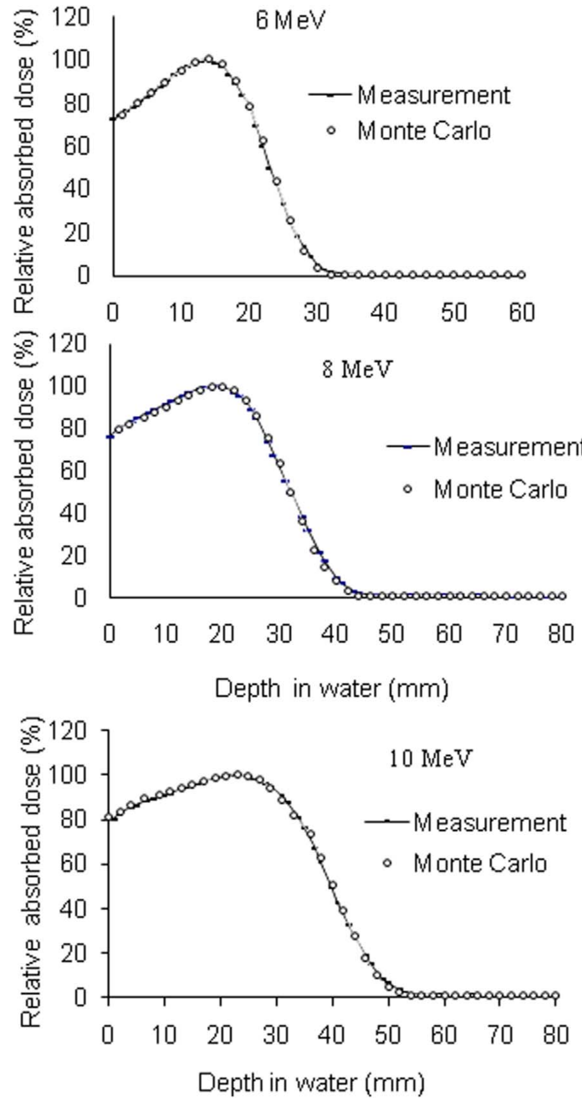

Fig. 1. Percentage of depth dose curves of three electron beams of the Siemens PRIMUS linac at the reference field size (10×10 cm^2).

electron beam dose distributions using Monte Carlo (MC) method. In addition, the present study was undertaken to develop some prediction equations for estimation of the surface dose based on bolus thickness, as well as of the therapeutic interval based on surface dose.

2. Materials and methods

2.1. Medical linear accelerator

All the MC calculations and experimental measurements were conducted on a medical linear accelerator (Siemens PRIMUS, Germany), which is a dual photon standing-wave linac. This accelerator can be used in radiation therapy in photon and electron modes. In addition, two dual-channel, segmented ionization chambers are used for dosimetry monitoring, one for electrons and one for photons beams. In the current study, three electron beams of linac (6, 8, and 10 MeV) were investigated.

2.2. Experimental measurements

Dose measurements were performed using an automatic water phantom (Sun Nuclear Corporation, USA) and a waterproof EDGE diode detector made by the same manufacturer. The central axis depth-