Available online at www.sciencedirect.com
ScienceDirect
Applied Radiation and Isotopes 66 (2008) 1438–1442
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Surface and build-up region dose analysis for clinical radiotherapy photon beams

E. Ishmael Parsai*, Diana Shvydka, David Pearson, M. Gopalakrishnan, John J. Feldmeier

Department of Radiation Oncology, University of Toledo Health Science Campus, 3000 Arlington Avenue, Toledo, OH 43614, USA

Received 8 June 2007; received in revised form 15 February 2008; accepted 20 February 2008

Abstract

The standard clinical approach of dose measurement using a Farmer type fixed plane parallel cylindrical ionization chamber produces erroneous results in the build-up region. We studied dose distribution in this region using a Monte Carlo simulation technique and compared our results with data measured using extrapolation, parallel plate, and cylindrical farmer type ionization chambers for 6 and 10 MV photon beams from two different accelerators. The extrapolation chamber data agreed favorably with the Monte Carlo results, suggesting that dose at the skin surface and a few mm beneath is significantly lower than conventionally accepted values.

keywords: Build-up region; Surface dose; Extrapolation chamber; Monte Carlo simulations

1. Introduction

As the energy of the ionizing radiation increases, the penetrating power of the secondary charged particle as well as of primary particle increases, leading to a deeper position of the maximum dose point. Even though the dose maximum is achieved at a larger depth, the dose near the patient skin surface is not negligible and needs to be accounted for. The primary dose contribution of contaminant electrons to the build region originates mostly from the primary photon interaction with components of accelerator head, such as the secondary jaws and beam modifiers, as well as the air column between the treatment head and patient surface. The secondary contribution arises from the back scattering of the photons inside the patient body.

In clinical settings, the percentage depth dose values are typically measured using computerized scanning systems in a water phantom. This method, however, is susceptible to erroneous results as the dose registered in the first few mm below water surface is prone to high degree of uncertainty. This could be attributed to the rapid change of dose gradient, the lack of charge particle equilibrium and also the nature and sensitivity of the ionization chamber being used. It was established that the instrument of choice for measurements made in this region of high-dose gradient is the extrapolation chamber (Nilsson and Montelius, 1986). As this particular chamber is cumbersome to use and is not widely available, a common method of measuring the percentage depth dose (PDD) in the region above the dose maximum of high-energy photon beams is to employ fixed plane parallel plate ionization chambers (Lawrence, 1973). A comparison of the extrapolation and fixed plane parallel plate chamber shows an increase of charge collection for parallel plate chamber, which is attributed to increased in-scattering of the electrons from the sidewalls into the active volume of the chamber (Manson et al., 1975; Velkley et al., 1975). It was found that the parallel plate chamber overestimated the PDD values by 10–40% depending upon the energy of the photons. A method for correcting for the over-response of the parallel plate chamber was proposed by Velkley et al. (1975) and further modified by Gerbi and Khan (1987, 1990) to account for the effect of separation of the guard ring width with respect to the central electrode.

The Monte Carlo (MC) simulation technique has been demonstrated to be an accurate method for dose calculations in radiotherapy. Rogers et al. (1985, 1995) have shown that OMEGA BEAM, a general purpose MC

*Corresponding author. Tel.: +1 419 383 5113; fax: +1 419 383 6313.
E-mail address: e.parsai@utoledo.edu (E. Ishmael Parsai).

0969-8043/$ - see front matter
doi:10.1016/j.apradiso.2008.02.089

modeling code, can be used to study the beam characteristics of a linear accelerator. The MC calculations have been bench-marked by various investigators (Ding et al., 1996; Van der Zee and Welleweerd, 1999; Libby et al., 1999a, b; Deng et al., 2000; Sheikh-Bagheri, 2000), validating the accuracy of the simulations with respect to the various variance reduction techniques and coding geometry. Even though MC has become a standard tool for the verification of radiation dosimetry measurements, there is still a disagreement between measurements and simulation results in the build-up region, where MC shows significantly lower dose (Rogers and Bielajew, 1985; Ding, 2002; Abdel-Rahman et al., 2005).

The purpose of this study is to investigate the PDD variation in the build-up region for 6 and 10 MV photon beams from a Varian 1800 Clinac and an Elekta SL 25 linear accelerator using MC simulations and to compare the simulation results with the data acquired using an extrapolation chamber, parallel plate chamber and a conventional 0.125 cm^3 cylindrical chamber. We also compare a subset of our results for a 6 MV beam with the data recently reported by Abdel-Rahman 2005 for Varian 2300 Clinac.

2. Materials and methods

2.1. Extrapolation chamber measurements

An extrapolation chamber (Far West Technology) was used as a ''golden'' standard against which all the measured and simulated depth dose data were compared. The central electrode as well as the guard ring of the chamber was made of A-150 Tissue Equivalent Plastic; the chamber window was made of 6.9 mg/cm^2 polyethylene. The saturation voltage of 50 V/mm was determined by varying the voltage across the chamber for a fixed dose and plotting measured charge vs. voltage. We employed this voltage as a parameter for data collection, ensuring that it remained constant with the change of plate separation and that small fluctuations in applied voltage would not affect the electrometer readings.

The measurement of the collected charge was done in a solid water phantom for specific depths and field sizes at an SSD of 100 cm. For each depth the ionization charge was measured at the positive and negative bias voltage and the average taken. Readings were taken for each depth using 4, 3, 2 and 1 turn of the scribe, which varied plate separation from 0.65 to 4.65 mm. A linear regression equation was used to fit the measured PDD, which was extrapolated to the surface to determine the surface dose. The doses at successive depths were measured by adding thin layers of solid phantom material over the entrance foil, while maintaining 100 SSD at the top of the phantom.

2.2. Parallel plate chamber measurements

A Markus chamber of type 23343 from PTW-Freiburg was used to measure the PDD for various field sizes and depths. The chamber consists of a cylindrical body made of Perspex, a window made of polyethylene coated with a graphite layer (2.3 mg/cm^2), and a collecting electrode made of Perspex coated with a graphite layer. The chamber measuring volume has a diameter 6 mm and a height 2 mm, while the collecting electrode has an effective diameter of 5.4 mm. The separation between the electrodes is 2 mm. The chamber is provided with an add-on protective cap of ~1 mm to be used for measurements in water. The surface dose measurement at $d = 0$ was done without the protective cap by placing the chamber carefully at the water surface. The successive dose measurements inside the phantom were performed with the protective cap in place and positioning the chamber at respective depths.

Interpretation of the data acquired with a parallel plate chamber requires special consideration. As previously shown by Velkley et al. (1975), parallel plate chambers over-respond at the phantom surface down to a depth of about 20% of d_{max}. The difference is greater for the low-energy photons due to the contribution of electrons scattered from the sidewalls of the chamber and collected in the chamber active volume. As the beam energy increases the scattered electrons are more forward peaked and are less likely to add to the dose in the chamber active volume.

Velkley et al. (1975) proposed an empirical formula for correction of PDD measured with parallel plate chamber for the region above d_{max}. It has been shown by Gerbi and Khan (1990) that the above-mentioned formalism either under- or over-compensates the surface dose measurements for chambers at different depths. The Velkley method was extended to include the effects of collector edge to sidewall distance to represent the chamber response in a more accurate way. The new corrected PDD equation was given by

$$P'(d) = P(d) - \xi(E,0) l \exp\left(-\alpha\left(d/d_{max}\right)\right) \quad (1)$$

where

$$\xi(E,0) = 27.19 - 32.59IR + (-1.666 + 1.982IR)C$$

Here $P'(d)$ is the corrected PDD, $P(d)$ is the uncorrected PDD, E is the maximum energy of the photon spectrum, d and d_{max} are the depths, l is the plate separation in mm, $\xi(E,0)$ is the over response in percent per mm (%/mm) of plate separation at the surface of the phantom for energy E, IR is the ionization ratio measured at 10 and 20 cm for 10×10 field size at a constant chamber distance of 100 cm, C is the collector edge to side wall distance in mm and $\alpha = 5.5$ is an empirically determined constant of proportionality. We used Eq. (1) to obtain the corrected readings for our Markus parallel plate chamber.

2.3. Cylindrical chamber measurements

For comparison with other techniques we collected PDD data in the build-up region with a setup typically used in the clinic environment for radiation dosimetry and quality