REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 17 (2012) 38–43

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Original article

Effect of the bone heterogeneity on the dose prescription in orthovoltage radiotherapy: A Monte Carlo study

James C.L. Chow [a,b,*], *Grigor N. Grigorov* [c]

[a] *Radiation Medicine Program, Princess Margaret Hospital and Department of Radiation Oncology, University of Toronto, Toronto, ON M5G 2M9, Canada*

[b] *Department of Physics, Ryerson University, Toronto, ON M5B 2K3, Canada*

[c] *Department of Medical Physics, Grand River Regional Cancer Center, Kitchener, ON N2G 1G3, Canada*

ARTICLE INFO

Article history:
Received 3 June 2011
Received in revised form
5 August 2011
Accepted 25 September 2011

Keywords:
Orthovoltage photon beam
Orthovoltage radiation therapy
Monte Carlo simulation
Bone backscatter and surface dose

ABSTRACT

Background: In orthovoltage radiotherapy, since the dose prescription at the patient's surface is based on the absolute dose calibration using water phantom, deviation of delivered dose is found as the heterogeneity such as bone present under the patient's surface.

Aim: This study investigated the dosimetric impact due to the bone heterogeneity on the surface dose in orthovoltage radiotherapy.

Materials and methods: A 220 kVp photon beam with field size of 5 cm diameter, produced by a Gulmay D3225 orthovoltage X-ray machine was modeled by the BEAMnrc. Phantom containing water (thickness = 1–5 mm) on top of a bone (thickness = 1 cm) was irradiated by the 220 kVp photon beam. Percentage depth dose (PDD), surface dose and photon energy spectrum were determined using Monte Carlo simulations (the BEAMnrc code).

Results: PDD results showed that the maximum bone dose was about 210% higher than the surface dose in the phantoms with different thicknesses of water. Surface dose was found to be increased in the range of 2.5–3.7%, when the distance between the phantom surface and bone was increased in the range of 1–5 mm. The increase of surface dose was found not to follow the increase of water thickness, and the maximum increase of surface dose was found at the thickness of water equal to 3 mm.

Conclusions: For the accepted total orthovoltage radiation treatment uncertainty of 5%, a neglected consideration of the bone heterogeneity during the dose prescription in the sites of forehead, chest wall and kneecap with soft tissue thickness = 1–5 mm would cause more than two times of the bone dose, and contribute an uncertainty of about 2.5–3.7% to the total uncertainty in the dose delivery.

* Corresponding author at: Radiation Medicine Program, Princess Margaret Hospital and Department of Radiation Oncology, University of Toronto, Toronto, ON M5G 2M9, Canada. Tel.: +1 416 946 4501x5089; fax: +1 416 946 6566.
E-mail address: james.chow@rmp.uhn.on.ca (J.C.L. Chow).

1507-1367/$ – see front matter
doi:10.1016/j.rpor.2011.09.001

1. Background

Orthovoltage radiotherapy has a long history of over 60 years of treatment of superficial tumors such as basal cell carcinoma, squamous cell carcinoma and melanoma.[1–3] In some skin treatment sites, such as the forehead, chest wall, skin over the cheekbone and kneecap, soft tissue of thickness equal to about 1–5 mm is over the bone of skull, rib or patella, respectively. When skin tumor in the above sites is irradiated by orthovoltage photon beams, the presence of bone heterogeneity affects the surface dose in the treatment due to the changed backscatter contribution, as water is replaced by the bone. Since bone heterogeneity is not considered in dose calculation based on dose calibration using a water phantom, an underestimation of dose might occur when it is prescribed. This effect of surface dose enhancement due to bone backscatter is more significant in the high orthovoltage photon energy of 220 kVp than the lower superficial photon energies such as that of 100 kVp.[4]

2. Aim

To investigate the impact of the surface dose variation due to the presence of bone heterogeneity, a photon energy spectral study was carried out using a heterogeneous phantom and Monte Carlo simulation. The photon energy spectra at the phantom surface were determined with different thicknesses of water. These energy spectra of photons and backscattered photons helped us to understand in detail the relationship between the surface dose variation and thickness of the overlaying tissue. A Gulmay D3225 orthovoltage X-ray machine (Gulmay Medical Ltd., UK) which produces a photon beam with energy of 220 kVp was modeled for Monte Carlo simulations using the BEAMnrc code to study this problem. The aim of this study was to investigate the impact of dosimetric uncertainty when bone heterogeneity is present and underneath the patient's surface of soft tissue (millimeter scale), as prescribed dose calculation is based on absolute dose calibration using a homogeneous (water) phantom.

3. Materials and methods

3.1. *Phantom and calculated geometry*

A heterogeneous phantom containing water (thickness = 1–5 mm) over the bone (thickness = 1 cm) was used as shown in Fig. 1. The phantom was irradiated by an orthovoltage photon beam perpendicular to the phantom surface. The energy of the beam and source-to-surface distance (SSD) were equal to 220 kVp and 20 cm, respectively. A treatment cone with diameter equal to 5 cm was used to conform the beam field. This treatment cone was examined in this study because it was typical and generally used as a reference cone for the backscatter and relative exposure factor. Percentage depth dose (PDD) was calculated along the central beam axis (vertical broken line) in the phantom. The photon energy spectra were determined based on the particle scoring planes at the phantom surface. For the purpose of dosimetry comparison and determining the relative results, all Monte Carlo simulations were repeated in a water phantom using the same calculated geometry with the bone layer replaced by water.

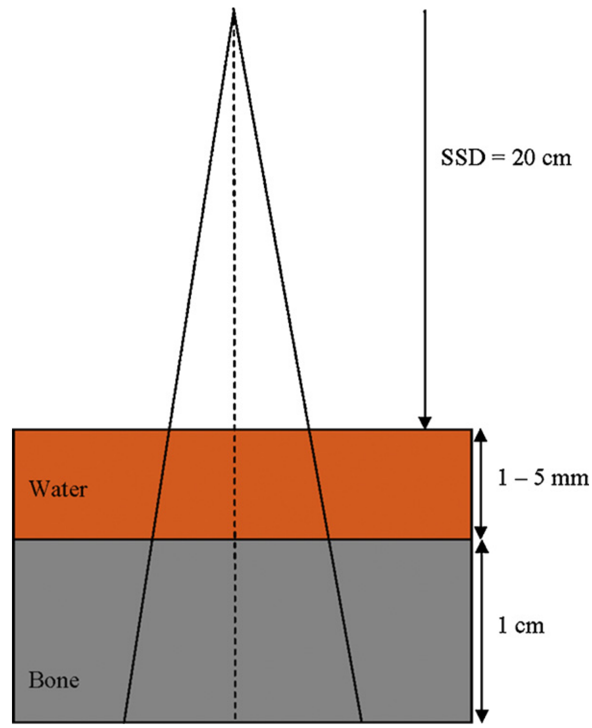

Fig. 1 – Schematic diagram (not to scale) showing the calculation geometry of the surface dose and PDD for different thicknesses (1–5 mm) of water on top of the bone. The thickness of bone is 1 cm.

3.2. *Monte Carlo simulation*

The Electron Gamma Shower (EGSnrc) code (version 4-r2-2-4) developed by the National Research Council of Canada was used.[5] In this code, the shape of the X-ray energy spectra is improved by implementing the electron impact ionization model.[6] Moreover, the efficiency of energy transition from the electron current to photons is increased by including a directional bremsstrahlung splitting.[7]

3.2.1. *Monte Carlo modeling and verification of the orthovoltage photon beam*

A 220 kVp photon beam produced by a Gulmay D3225 orthovoltage X-ray machine was used in this study. An open circular end fixed applicator with diameter of 5 cm and SSD = 20 cm was used. The BEAMnrc[8] was used to generate a phase-space file based on the treatment head data of geometries and materials of different components such as the X-ray tube, primary collimator, filter, ionization chamber and applicator, provided by the manufacturer and Knoos et al.[9] In our 220 kVp photon beam, 1.2 mm of Cu and 1 mm of Al were used as a filter to define the beam quality. The energy cut off for electron and photon transport was set at 521 keV and 1 keV, respectively. A phase-space file including information of the energy,