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Energy spectrum and dose enhancement due to the depth of the Lipiodol position using flattened and unflattened beams

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ABSTRACT

Aim: Lipiodol was used for stereotactic body radiotherapy combining trans arterial chemoembolization. Lipiodol used for tumour seeking in trans arterial chemoembolization remains in stereotactic body radiation therapy. In our previous study, we reported the dose enhancement effect in Lipiodol with 10× flattening-filter-free (FFF). The objective of our study was to evaluate the dose enhancement and energy spectrum of photons and electrons due to the Lipiodol depth with flattened (FF) and FFF beams.

Methods: FF and FFF for 6 MV beams from TrueBeam were used in this study. The Lipiodol ($3 \times 3 \times 3\,cm^3$) was located at depths of 1, 3, 5, 10, 20, and 30 cm in water. The dose enhancement factor (DEF) and the energy fluence were obtained by Monte Carlo calculations of the particle and heavy ion transport code system (PHITS).

Results: The DEFs at the centre of Lipiodol with the FF beam were 6.8, 7.3, 7.6, 7.2, 6.1, and 5.7% and those with the FFF beam were 20.6, 22.0, 21.9, 20.0, 12.3, and 12.1% at depths of 1, 3, 5, 10, 20, and 30 cm, respectively, where Lipiodol was located in water. Moreover, spectrum results showed that more low-energy photons and electrons were present at shallow depth where Lipiodol was located in water. The variation in the low-energy spectrum due to the depth of the Lipiodol position was more explicit with the FFF beam than that with the FF beam.

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Conclusions: The current study revealed variations in the DEF and energy spectrum due to the depth of the Lipiodol position with the FF and FFF beams. Although the FF beam could reduce the effect of energy dependence due to the depth of the Lipiodol position, the dose enhancement was overall small. To cause a large dose enhancement, the FFF beam with the distance of the patient surface to Lipiodol within 10 cm should be used.

1. Introduction

Stereotactic body radiation therapy (SBRT) delivers high-dose radiation to hepatocellular carcinoma (HCC). Although the SBRT procedure and treatment evaluation varies in different facilities, the ability and safety of this technique for intrahepatic HCC has been reported.[1] In the liver, when Lipiodol is used as an embolic agent, SBRT can be used for tumour seeking in trans arterial chemoembolization (TACE).[2] Recently, promising responses in patients with unrespectable hepatocellular carcinoma treated with TACE followed by radiation therapy have been reported.[2,3] In our previous study, we reported the dose enhancement in Lipiodol,[4] where only the absorbed dose at the depth of 5.0 cm was considered using Lipiodol located in a water-equivalent phantom ($3 \times 3 \times 3\,cm^3$). The dose enhancement was 6.0% with a 10 MV FFF beam for the clinical case. However, the difference in the dose enhancement with the FF and FFF beams, variations in dose enhancement due to the depth of the Lipiodol position, and difference in the energy spectra were not investigated.

The Varian TrueBeam linear accelerator can produce flattened (FF) and flattening-filter-free (FFF) beams. While it is advantageous to use an FFF beam in radiation dose delivery, the removal of the flattening filter significantly decreases the beam attenuation and increases the photon fluence. Thus, it also affects the photon energy distribution or beam quality.[5,6] For the FFF beam, these low-energy photons contribute to dose deposition in the photon-beam build-up region close to the patient surface. Compared to the FF beam, although the FFF beam has smaller head scattering and leakage, measurements and Monte Carlo (MC) simulations found that irradiation of the FFF beam results in a higher surface dose than the FF beam.[7] This indicates that low-energy photons may play an important role in the surface dose enhancement of the FFF beam. Therefore, it is worthwhile to evaluate the difference in dose enhancement due to the depth, where Lipiodol was located, using FF and FFF beams.

The purpose of this study is twofold: (i) to evaluate the dose enhancement and (ii) to investigate the energy spectrum variations of photons and electrons at various depths due to the depth of the Lipiodol position with FF and FFF beams.

2. Methods and materials

2.1. Linac and Monte Carlo calculation

A TrueBeam linear accelerator (linac) (Varian Medical Systems, Palo Alto, USA) provides FFF and FF beams of 6 MV was used. BEAMnrc and PHITS-based MC scripts were used to model the linac. Geant4 and EGSnrc are the most widely used tools in medical physics.[8,9] An important special-purpose code built on the EGSnrc platform is the user code BEAMnrc.[10] This code is optimized to model the treatment head of radiotherapy linacs and includes a number of geometry and source subroutines, together with variance reduction techniques to enhance the efficiency of simulations.[11] Phase space files were created in two stages because the components of the TrueBeam accelerator head are proprietary and not available to the public for direct simulations. The first stage of the phase space files located just above the secondary X/Y collimator was simulated using the GEANT4 MC code and provided IAEA-compliant phase-space files by Varian. Using the first stage of the phase space files, the second stage of the phase space files located below the secondary collimator was modelled using the Beamnrc MC code. The second phase-space data scored at a source-to-surface distance (SSD) of 70 cm were used as input data for an inhomogeneity virtual phantom. Although BEAMnrc can easily create the linac model, BEAMnrc cannot analyze the energy spectrum in the phantom. PHITS can deal with the transport of nearly all particles, including neutrons, protons, heavy ions, photons, and electrons, over wide energy ranges using several nuclear reaction models and nuclear data libraries. There were some studies about the energy spectrum for linacs with the PHITS code.[12] Thus, the dose calculation and photon and electron energy spectrum acquisitions were performed for water and the Lipiodol phantom using the PHITS code. The dose calculation grid size was 2.0 mm. The number of photon histories in Beamnrc and PHITS were 2.0×10^8 and 2.0×10^9, respectively.

2.2. Evaluation of the dose enhancement factor

A virtual inhomogeneity phantom, with Lipiodol ($3 \times 3 \times 3\,cm^3$) located on the central axis at depths of 1, 3, 5, 10, 20, and 30 cm in a water-equivalent phantom ($40 \times 40 \times 40\,cm^3$) was made (Fig. 1). Lipiodol contains 480 mg/mL of Iodine organically combined with ethyl esters of fatty acids of poppy seed oil. The mass density of Lipiodol was overridden by $1.28\,g/cm^3$. A field size of $5 \times 5\,cm^2$ was used for irradiation. In this field size, losses in longitudinal and lateral charged particle equilibrium could be small. The factors include the following, the electron range could be small in a high-Z and high-density material, and the effect of scattering in the lateral direction was within 0.5 cm in our previous study.[4] The percent depth dose (PDD) curves were measured and normalized to the calculated dose at d_{max}. The DEF was estimated according to the following definition: the