Dose calculation on dual energy CT images for carbon ion therapy using TOPAS: a Monte Carlo Study

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1. Introduction

Carbon ion radiotherapy (CIRT) is applied in several countries, mainly in Japan and Germany, and related research is ongoing worldwide. Since accurate dose calculation is required for CIRT, many studies using Monte Carlo (MC) simulation are being conducted. Meanwhile, compared with single energy Computed Tomography (SECT), dual-energy Computed Tomography (DECT) has been studied for more accurate tissue segmentation and MC dose calculation [1]. Recently, MC dose calculation based on DECT is applied for proton radiotherapy [2].

In this study, we aim to calculate doses utilizing DECT images for CIRT using the MC code, TOPAS [3]. To achieve the goal, we modeled a 3D-active beam scanning system and we are creating effective atomic number (Z_{eff}) to material converter file to import DECT images to TOPAS.

2. Methods

2.1 3D-Active Beam Scanning System Modeling

The 3D-active beam scanning system in the Heavy-Ion Medical Accelerator in Chiba (HIMAC) treatment facility [4] was modeled using the TOPAS MC code.

Three dimensional active beam scanning method is largely divided into lateral field scanning and depth scanning. Lateral field scanning is carried out using raster scanning method. The movement between beam spots was achieved by changing the direction and intensity of the magnetic field applied to the ion pencil beam. The magnet used at this time is called wobbling magnet, and this was modeled by applying the time feature to the magnetic field in the TOPAS. Depth scanning is performed through energy modulation of the initial carbon ion beam. The modeled active scanning system is shown in Fig. 1. In the figure, the left box represents a water phantom, and the two right boxes represent wobbling magnets in X and Y directions, respectively.

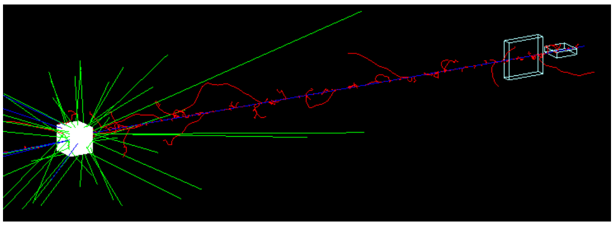


Fig. 1. Graphical representation of TOPAS model of active beam scanning system. Green lines mean gammas, red lines mean electrons, blue lines mean carbon ions.

2.2. Import of DECT images in TOPAS

2.2.1 Import of SECT images in TOPAS

Basically, TOPAS has a built-in function to retrieve Hounsfield Unit (HU) information from SECT Digital Imaging and Communications in Medicine (DICOM) files. HU value read from DICOM file was converted into density value and material information, respectively, through a file containing a converting algorithm [5]. MC dose calculation could be performed using this information, but since each material was assigned one mean excitation energy, materials with the same HU value but different compositions could not be distinguished.

2.2.2 Z_{eff} to material converter file for DECT

There is no converter file that imports DECT image in TOPAS. Therefore, it is necessary to create a converter file suitable for TOPAS, following the existing research on how to import DECT image into MC code [1, 2]. A schematic diagram of the MC code import process of the DECT image is shown in Fig. 2.

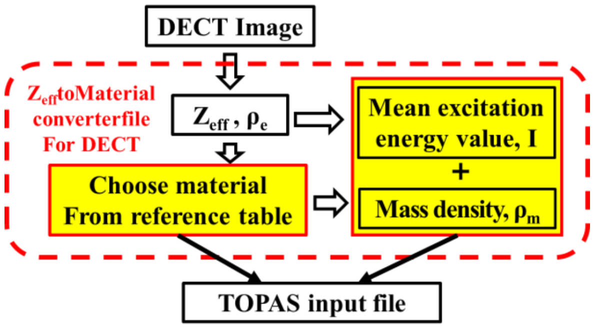


Fig. 2. Schematic diagram of the process of extracting the information necessary for dose calculation from the DECT image and making it an input file of TOPAS

ρ_e means the electron density. In DECT, all physical values are given per voxel of the image. The difference from SECT is that each voxel of the CT image can have a different mean excitation energy value, which means that more accurate dose calculations are possible.

3. Preliminary Result

To confirm the basic performance of the beam scanning system model, a simulation was performed to obtain a uniform dose distribution. Monoenergetic carbon ion beam was irradiated on a water phantom of 20 × 20 × 30 cm^3 with a field size 10 × 10 cm^2. The voxel size for scoring was 2 × 2 × 5 mm^3, referring to the reference paper [4]. Fig. 3 shows the integral depth dose (IDD) in the beam-scanned water phantom. The dose uniformity was found to be within ± 4% of the planned dose. Fig. 4 shows that SECT image of CIRS Phantom 062M was imported into TOPAS and that the IDD curve of the SECT image was obtained using the modeled active beam scanning system.

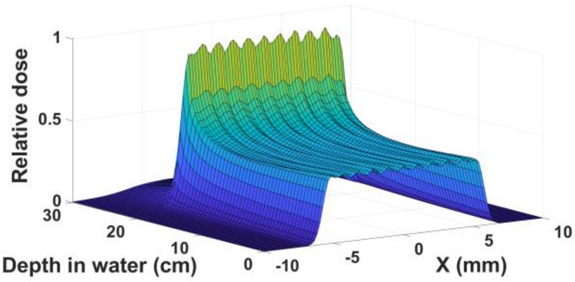
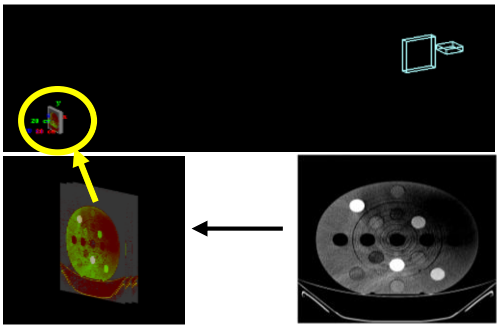


Fig. 3. IDD curve of 350 MeV/u monoenergetic carbon ion beam in water phantom.

(a)



(b)

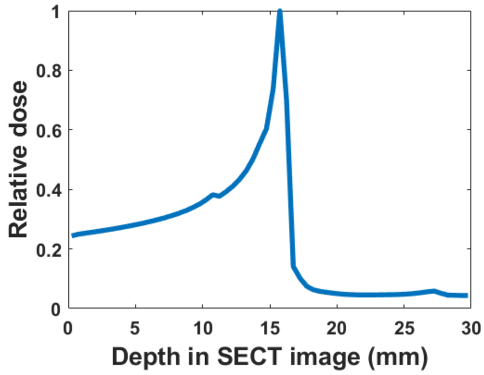


Fig. 4. (a) Raw SECT image (down, right) and SECT image imported to TOPAS (down, left). (b) IDD curve of 80 MeV/u monoenergetic carbon ion beam after beam is scanned on SECT images.

4. Ongoing and Further studies

From preliminary result, it was confirmed that the MC dose of the SECT image can be calculated in TOPAS. Following the method described in 2.2.2, we are currently creating C++ based in-house Z_{eff} to material converter files. Using this, we will calculate the MC dose of the DECT image and check what difference is there with the MC dose value of the SECT image.

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