Verification study of the dose calculation algorithm for carbon beam therapy based on dual energy CT image and LEM IV biological model

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1. Introduction

It is well-reported that the conventional computed tomographic (CT) image and Schneider model [1], typically used in radiation therapy field, are very practical to predict electron density map and calculate photon dose because of the physical characteristics of Hounsfield Unit (HU).

However, in the case of particle therapy such as proton and carbon beams, relative stopping power ratio (RSP) instead of electron density is needed for the dose calculation.

Several approaches predicting RSP map have been investigated such as HU to RSP calibration [2], proton radiography and CT [3], and using dual energy CT (DECT) [4].

The DECT approach enables to accurately decompose the tissue materials by using two different monoenergetic image, and the dose calculation based on the DECT image can more accurately predict the particle range.

The aim of this study is to develop a dose calculation algorithm based on the DECT images, and to quantitatively evaluate the influence of the DECT by comparing with conventional CT on biological dose calculation.

2. Materials & Methods

2.1. DECT and conventional CT

The DECT and conventional CT images of abdomen case, which represents the homogeneous media, are obtained by Philips IQon Spectral double-layer CT and given algorithm [5].

The conventional CT images directly converted to RSP maps using the HU-RSP calibration table. On the other hand, the DECT images are decomposed into Z_{eff} and ρ_e based on Joshi method [6] and vender-specific algorithm. After that, the RSP maps can be generated using the material decomposition results based on Bethe-Bloch formula.

We first compare the differences between RSP maps obtained by conventional CT and DECT images.

2.2. Inverse planning and dose calculation algorithm

In order to develop dose calculation algorithm for carbon beam therapy, carbon beam data including integral depth doses (IDDs) and lateral profiles is assessed by Geant4 Monte Carlo simulation.

The pencil beam dose calculation algorithm is developed in this work based on the inverse planning including LEM IV biological model [7] implemented in matRAD software [8].

For the fair comparison, the treatment plan inversely generated based on DECT image is used for the dose calculation of both DECT and conventional CT cases.

3. Results and Discussions

3.1. RSP maps obtained by DECT and conventional CT images

The RSP maps obtained by DECT and conventional CT images show differences up to 20% according to the organ as shown in Figure 1. In the liver and duodenum which is in beam path, RSP difference is relatively small within 5%. However, significant RSP decreases in kidneys and stomach are observed about 10% even in the homogeneous media.

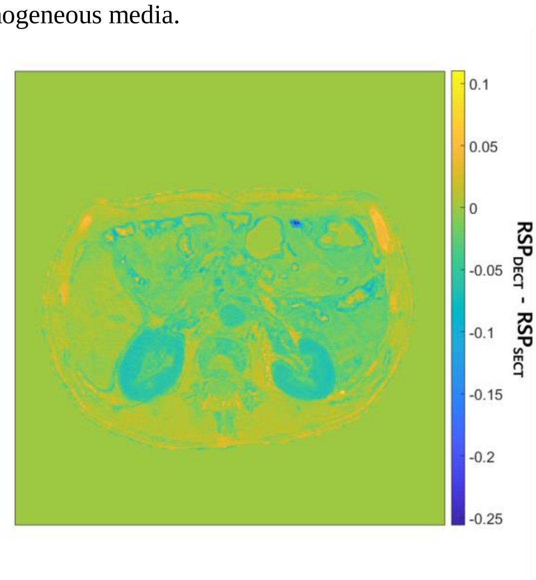

Fig. 1. RSP difference between DECT and conventional CT images (DECT as a reference).

3.2. Biologically effective dose and influence of DECT

The biologically effective dose (BED) results show very close distribution to each other, and a good target conformity for both cases of conventional CT and DECT as shown in Figure 2.

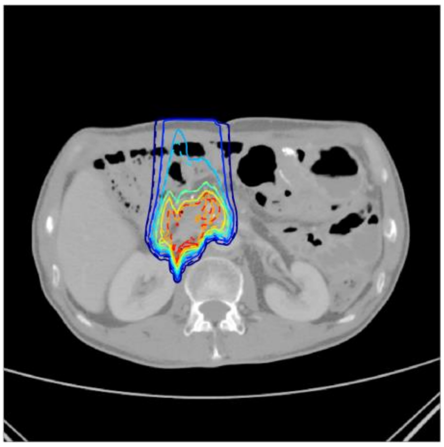

Fig. 2. BED distribution calculated with DECT (solid line) and conventional CT (dashed line).

However, in the longitudinal depth profile in Figure 3 shows the discrepancy of carbon range due to the small RSP difference. The carbon range in the target on conventional CT image is shorter than the range of DECT up to 2 mm in the same treatment plan.

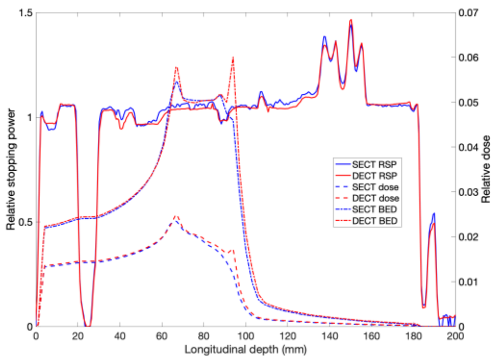

Fig. 3. RSP (solid line), dose (dashed line), BED (dotted-dashed line) profile assessed by DECT (red) and conventional CT (blue) along beam direction

4. Conclusions

In this work, the plausibility of the biological dose calculation algorithm for carbon therapeutic beam based on DECT has been verified. The results show that DECT approach could correct up to 2 mm range uncertainty due to the CT conversion method of conventional CT. These results could be used for the clinical usage of DECT for carbon ion therapy in order to accurately predict the relative stopping power ratio which is the most important in dose calculation algorithm. In further, the influence of DECT on heterogeneous region will be quantitatively evaluated with more patient cases in the other therapeutic regions.

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