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学 位 論 文 の 内 容 の 要 旨

Dissertation Abstract

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（学位論文のタイトル） Title

Dose distribution estimation toward CT-less adaptive carbon ion radiotherapy for liver tumors using the divided-volume matching technique

（分割体積マッチング法を用いた肝腫瘍に対するCTレス適応炭素線治療に向けた線量分布評価）

（学位論文の要旨）2,000字程度、A4判 （approx. 800 Words in English /A4 size）

Dose distribution estimation during the treatment course is essential for carbon ion radiotherapy because beam ranges are highly sensitive to density changes along beam paths, triggering the adaptive re-planning at an appropriate time. There are currently three main approaches for evaluating daily dose distributions during the treatment course in particle therapy: dose recalculations based on cone-beam computerized tomography (CBCT), periodically offline CT, and in-room CT. However, CBCT may encounter inferior image quality and Hounsfield unit (HU) inaccuracy issues, which precludes its availability for direct dose recalculation. Moreover, not all particle therapy centers are routinely equipped with CBCTs. The periodically offline CT approach utilizes a CT simulator for dose evaluation. However, the patient positioning between two separate setups is not completely reproducible to realistically reflect the daily dose on the treatment position. In-room CT offers diagnostic-level image qualities and is currently optimal for dose recalculations to determine plan adaptation; however, additional exposure doses to the patients are inevitable. The longer treatment room occupation time decreases the efficiency and flexibility of the treatment workflow. This study aims to investigate the feasibility of evaluating daily dose distributions using the divided-volume matching (DVM) technique without additional daily computed tomography (CT) scans for adaptive carbon ion radiotherapy for liver tumors.

The DVM technique is an in-house 2D-3D matching software initially developed to visualize and estimate the 3D displacements of internal and bony structures to enable more accurate patient positioning for radiation therapy. The accuracy of the DVM technique for patient positioning was shown to be comparable to the conventional 2D-3D matching techniques. The planning CT (PlanCT) was divided into two volumes: the volume of interest (VOI) and the base volume (BV). The VOI could be delineated arbitrarily and was supposed to cover the internal structure, such as the entire internal structure or just one organ with the target in it; the rest of the CT volume was the BV. The 3D positions and rotations of each volume could be adjusted independently and simultaneously. The divided-volume matching was achieved by matching the

orthogonal DRs routinely taken at the patient positioning with the iteratively generated DRRs of the PlanCT by changing the 3D positions and angles of VOI and BV. Upon matching, a virtual CT (DVM CT) reflecting the final DRRs was obtained, and this DVM CT was expected to reflect patients' anatomical structures at the positioning. Bone matching (BM) and tumor matching (TM) are the two common ways of patient positioning correction to determine the isocenter for the irradiation of the day. We compared the dose distributions between DVM and in-room CTs with different isocenters based on BM or TM to verify whether the DVM CTs sufficiently represent the in-room CTs for daily dose distribution evaluations.

Two types of phantoms and ten HCC patient data were included in this study. The performance of the DVM technique with large inter-fractional motions in patient data was tested as well. The CTV/PTV coverage differences were <2% in the phantom study and <3% in the clinical data for nine out of ten patients and in all large inter-fractional motion data. The dose coverage of DVM CT changed with the dose coverage of in-room CT at different isocenters. This showed that the daily dose distributions between DVM CT and in-room CT had high similarities and supported the concept that DVM CTs sufficiently represent in-room CTs to evaluate daily dose distributions. Unlike the conventional 2D-3D matching techniques used in most particle facilities for patient positioning, the matching regions of interest can be the bony structures or fiducial markers, leading to different isocenters for treatment, and thus, different dose distributions. The proposed DVM method allows choosing different isocenters (setups). The DVM technique simultaneously considers the internal (VOI) and bony structures (BV) while providing their corresponding isocenters, which helps efficiently determine the optimum isocenter for patient positioning.

It is important to know the unsuitable conditions for the clinical use of the DVM method. The DVM CT is obtained by adjusting the VOI and BV of the PlanCT to match the DRRs of the adjusted PlanCT with the 2D setup images. Therefore, gastrointestinal tract motility in the beam paths during the treatment course cannot be estimated by the current DVM technique. Although the DVM technique is currently limited in the types of deformation it can handle, the technique is efficient and reliable in finding changes in particle beam range and target coverage in clinical practice. This technology provides a promising solution to CT-less evaluation of daily dose distribution and requires further development.

Evaluating daily dose distributions without additional CT scans by the DVM technique was shown to be feasible in carbon ion radiotherapy for liver tumors. The proposed method can potentially prevent HU inaccuracy problems of CBCT, lower cost, improve treatment room usage efficiency, smooth workflows, trigger the adaptive re-plan procedure at an appropriate time without increasing the patient dose by repeat imaging, and integrate with the future development of online adaptive radiotherapy—from patient positioning to daily dose distribution evaluation to online adaptation.