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Personalized Contrast-Enhanced Four-Dimensional Computed Tomography Imaging for Target Volume Definition in Pancreatic and Liver Stereotactic Body Radiotherapy

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Abstract
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Abstract

Objectives:

Four-dimensional computed tomography (4D-CT) does not frequently depict abdominal lesions clearly due to the poor difference in CT numbers (Hounsfield Unit, HU) between tumors and surrounding normal tissues. The aim of this study is to report our institutional implementation of 4D-CT simulation combined with individually synchronized intravenous contrast injection for better target volume delineation and breathing motion management in pancreatic and liver Stereotactic Body Radiotherapy (SBRT) treatment planning.

Methods:

Since March 2022, twelve patients with pancreatic (n=6) and liver (n=6) tumors were treated with SBRT regimen of 33-35 Gy in 5 fractions and 50-60 Gy in 5 fractions, respectively. Each underwent two sequential CT scans: a baseline non-contrast 4D-CT and, after evaluating the personalized delay time required to achieve the desired contrast-enhanced phase in the tumor region, a second 4D-CT with synchronized intravenous injection. Previous diagnostic triple-phase CT scan was mandatory to identify the optimal contrast-enhanced phase for tumor visibility. Uniform protocol parameters included a flow rate of 2.5 ml/s, a contrast agent volume equal to 1.8-2.0 times the patient's weight, and 2 mm slice thickness. A delay time of 40-50 seconds for the arterial phase and 60-70 seconds for the venous phase was considered. The clinical target volume (CTV) was delineated on the ten phases after rigid registration of the contrast and non-contrast scans and merged to obtain internal target volume (ITV). A planning target volume (PTV) was created by an isotropic 5 mm expansion around the ITV, and treatment plans were generated on the baseline average 4D-CT. HU values of the aorta on the contrast-enhanced 4D-CT were acquired as a function of time, allowing for the calculation of actual peak and washout contrast times.

Results:

All contrast-enhanced 4D-CT scans provided clear delineation of anatomical structures and vessels. The use of contrast significantly improved tumor visibility over all phases of the breathing cycle in 83% of cases. The mean duration of non-contrast 4D-CT acquisition ranged from 0.57 to 1.45 minutes and the time delay programmed within the contrast 4D-CT acquisition protocol with respect to the contrast injection varied from 0 to 35 seconds according to the scan length, pitch, and breathing cycle. Most liver lesions were imaged in the arterial phase, while pancreatic tumors were most visible in the venous phase. In four cases, a personalized early-intermediate phase was also considered. The mean differences in HU relative to the adjacent vessels and liver parenchyma obtained for pancreatic and liver tumors were -92 HU and +43 HU, respectively. The aortic HU analysis revealed that the peak contrast time ranged from 53.4 to 56.7 seconds and the washout plateau was observed between 66.5 and 72.5 seconds. The mean ± SD aortic peak value was 307 ± 85 HU, while the mean ± SD aortic plateau value was 165 ± 16 HU.

Conclusion(s):

An individually synchronized contrast 4D-CT simulation proved to be feasible and resulted in optimal tumor enhancement and vessels definition over the whole patient's breathing cycle. The main limitation is that the optimal tumor contrast is highly dependent on the correct calculation of the delay time from contrast

injection to CT scan. Nonetheless, our approach improves the accuracy of target volume definition and mitigates uncertainties in radiotherapy planning, by addressing the challenges associated with poor target visibility and respiratory motion. As a result, it allows for the administration of more aggressive doses within SBRT regimens, at the cost of a small investment of resources.