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Liver Ultrasound as a predictor for online proton 4D dose distributions in lung tumours

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Introduction: Motion management is crucial when applying scanned proton therapy to lung tumours. In order to mitigate
the detrimental motion effects, it is important to know the deformable motion of the patient's lungs during treatment. To date, no real-time 3D imaging modality is available, which is why a surrogate for the motion is needed. This study investigates the predictive power of liver ultrasound (US) images combined with a statistical motion model for the proton dose distributions in the lung.

Materials & Methods: Liver ultrasound and lung 4DMR images of two volunteers were acquired simultaneously during 10 minutes of
free breathing, resulting in ˜700 variable 3DMRI volumes per volunteer. The breathing motion was extracted using deformable image registration. The deformation vector fields (DVFs) were used to warp full-exhale CTs of two lung cancer patients, resulting in four sets of synthetic 4DCTs. After combining the geometry of both patients with the motion of both volunteers, each synthetic dataset contained ˜700 motion states, which were considered as "ground truth".
For each patient/volunteer combination, a statistical motion model based on Gaussian process regression was trained on the first ˜600 motion states, correlating the US images with the corresponding MRI DVFs. This model was used to predict MRI DVFs from the remaining ˜100 US images. These DVFs are referred to as the "predicted motion".
Two-field PBS proton treatment plans were optimised on the geometrical ITV, including all CTV positions of one respiratory cycle. The planning CT was defined in the following way: the HU value per voxel outside of the ITV was the average of all phases of this respiratory cycle, whereas within the ITV, maximum intensity projection was applied.
For these plans, 4D dose distributions with varying starting phases were calculated for the ground truth as well as for the predicted motion. The results were analysed in terms of absolute dose differences and dosedifference-

histograms in the CTV.

Results: Figure a) shows the dose-difference histograms for all four datasets, including 4DDCs depending on all starting
phases in the shaded areas, with median values shown by the solid line. The dose differences due to model prediction errors are mostly within 10% of the prescribed dose (median Vdiff>10% = 0.4%, 5.5%, 2.8%, 2.6%), with most of the voxels showing a difference of less than 5% (median Vdiff>5% = 11.5%, 30.6%, 14.3%, 13.4%). An example comparison of dose distributions based on ground truth and predicted motion is shown in Figure b).

Conclusion: Our study suggests that liver US in combination with a statistical motion model can accurately predict lung 4D
dose distributions. Such a framework is thus useful for providing online image guidance for real-time proton beam adaptation. A further study will investigate the effectiveness of proton tracking for the lung based on this model.

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