Liver SBRT Planning and Delivery at the Mean Respiratory Position

**Methods:** To create the mid-position CT, a percentage of the deformation between exhale and inhale 4DCT was applied to deformation vector field. This percentage was calculated as the time-averaged superior-inferior liver displacement normalized from exhale, determined across each patient's 6 4D cone-beam CTs. To calculate the 4D predicted breathing dose distribution, each element's dose was summed as follows:

\[
D(x,y,z) = D_e(x_e,y_e,z_e)[T_e] + D_m(x_m,y_m,z_m)[T_m] + D_i(x_i,y_i,z_i)[T_i]
\]

where respectively \(x,y,z\) are the element coordinates at the exhale, mid and inhale position, \(D_e, D_m\) and \(D_i\) are dose contributions from the matrices on the exhale, mid and inhale CT, and \(T_e, T_m\) and \(T_i\) are the time percentage weighting factors for the time spent nearest each dose grid, determined from the average 4D cone-beam CT breathing motion curve. For planning on the mid-position CT, we applied the following margin to account for errors specific to liver SBRT:

\[
M = 2.5\sqrt{\Sigma_{\text{DIR}}^2 + \Sigma_{\text{INTER}}^2 + \Sigma_{\text{INTRA}}^2} + 0.7\sqrt{\sigma_{\text{DIR}}^2 + \sigma_{\text{INTER}}^2 + \sigma_{\text{INTRA}}^2 + (0.36A)^2}
\]

which includes the systematic (\(\Sigma\)) and random (\(\sigma\)) errors in the deformable registration algorithm (DIR) and the interfraction (INTER) and intrafraction (INTRA) liver SBRT errors. The patient-specific GTV amplitude (\(A\)) is modeled from DIR of exhale to inhale 4DCT.

**Results:** Compared to liver SBRT plans on exhale CT, dose escalation was possible in the majority of patients. The mean GTV dose increased by an average of 6.7 Gy on 4D dose distribution, and the minimum 0.5 cm\(^3\) GTV dose similarly increased despite the PTV on the mid-position plans not encompassing the full amplitude of breathing motion (right figure). Dose distribution differences (4D breathing dose – static dose) were larger for plans based on exhale 4DCT (below left) compared to plans created at the mean respiratory position (i.e. on mid-position CT) (below right).

**Innovation/Impact:** To our knowledge this is the first application of DIR to reconstruct a mid-position CT for liver SBRT, thus enabling the use of a probability-based PTV margin. The potential for dose-escalation to improve clinical outcomes was demonstrated.