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Comparison of surrogate matching methods for target localization with free-breathing in stereotactic body radiation treatment for liver tumors

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Objectives: The use of fiducials implanted around liver tumors or lipiodol present in transarterial chemoembolization cavities allow for accurate target positioning during stereotactic body radiation therapy (SBRT) for liver tumors. Other markers such as calcifications, stents, and surgical clips that are in close proximity to the target volume aid in daily patient setup. A majority of patients, however, have no such, or unusable markers. The present study investigates the 3D image matching accuracy between the planning computed tomography (CT) and daily pretreatment 3D cone beam computed tomography (CBCT) based on the anatomical surrogates bone (spine), liver, and diaphragm in freebreathing SBRT. Methods: We identified patients treated with free breathing liver SBRT at our institution having markers including fiducials, lipiodol, stents, clips or calcifications, with none of them further than 3 cm away from the target volume. Patients were immobilized with Elekta bluebagTM with vacuum coversheet. Those with respiratory motion in excess of 15 mm in any direction on acquired 4D-CTs were excluded. The planning CTs were retrospectively registered to the pretreatment CBCTs based on markers, liver, bony anatomy, and diaphragm using rigid registration. The coordinates for marker registration were used as reference coordinates. Differences of registration coordinates between the marker and liver/diaphragm/bone registrations were used to quantify target positioning error. Statistical significance between all the registrations was assessed using t-tests in craniocaudal (C-C), mediolateral (M-L), anteroposterior (A-P) direction. Planning target volume (PTV) margin estimates were calculated using Van Herk formula. Results: Thirty-four CBCTs from seven patients who met the eligibility criteria treated during 2015-2018 were used for the analysis. Six patients had hepatocellular carcinoma and one had metastatic sigmoid adenocarcinoma. Three patients were treated to segment 7, two to segment 8 and one each to segments 2 and 5. Lipiodol was the marker in 15, calcifications in 10, and clips in 9 out of 34 CBCTs. The 3D positioning error compared to markers was the smallest when using liver matching (3.0 ± 0.3 mm), followed by diaphragm (3.6 ± 0.3 mm) and bone (4.5 ± 0.4 mm) matching, with all $p < 0.05$. Absolute positioning errors were significantly lower in C-C direction with liver and diaphragm matching compared to bone matching ($p < 0.05$). In M-L direction the positioning errors were significantly lower with liver matching compared to bone matching ($p < 0.05$) and there was a trend to lower error in A-P direction with liver compared to bone as well as in M-L direction with diaphragm

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matching compared to bone. Liver matching had the lowest interfraction error with a magnitude of 2.0 ± 0.3 mm compared to 2.5 ± 0.3 mm and 2.7 ± 0.3 mm for diaphragm and bone matching, respectively. We estimate image registration-based target positioning error contribution to PTV margins for liver, bone, and diaphragm matching in mm to be 6.3, 7.8, 6.3 in M-L, 4.2, 5.8, 6.1 in A-P, and 2.5, 6.0, 3.7 in C-C directions, respectively. Conclusions: Matching pretreatment 3D-CBCT with planning CT using the patient's liver is a feasible option showing significantly lower deviations compared to bone and the commonly used diaphragm matching. A larger PTV margin is needed when using bone and diaphragm alignment to ensure adequate target coverage in free-breathing liver SBRT.