Target displacement evaluation for fluoroscopic and four-dimensional cone-beam computed tomography

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Purpose or Objective: Four-dimensional cone-beam computed tomography (4D-CBCT) has great capability to provide volumetric and respiratory motion information with one gantry rotation. It is necessary to quantitatively assess, how difference of tumor displacement between actual and 4D-CBCT image exists. In this study, we evaluated the displacement of implanted fiducial markers assumed as tumor on fluoroscopic projection images and reconstructed 4D-CBCT images with different sorting methods.

Material and Methods: We have developed 4D-CBCT utilizing dual source kV X-ray imaging subsystems. Five lung cancer patients with two to four implanted fiducial markers were enrolled in the institutional review board-approved trial. Each patient underwent three consecutive 4D-CBCT imaging. For at least two scans out of three, the imaging parameters were 110 kV, 160 mA and 5 ms, the rotational speed of the gantry was 1.5°/s, rotation time was 70 s, the image acquisition interval was 0.3°, and the rotational angle of 105°. A marker that located the most nearest to the lung tumor was used for surrogate respiratory signal. The marker motion in superior-inferior (SI) direction was used as surrogate respiratory signal for 4D-CBCT image reconstruction. Surrogate respiratory signal were converted eight phase bins with retrospective amplitude- or phase-based sorting. On reconstructed 4D-CBCT images, the marker positions on two fluoroscopic images were co nverted to 3D position. Depending on the sorting methods, the positional difference was up to 2 mm on 4D-CBCT images, the mean underestimation of 5 mm on average was observed in SI direction.

Results: Depending on the sorting methods, the positional difference was up to 2 mm on 4D-CBCT images. Overall mean ± standard deviation of Da-f and Dp-f in LR, AP, and SI direction were -1.5±1.2, -2.9±1.2, -5.1±1.6 mm and -1.4±1.1, -2.3±0.9, -5.2±1.2 mm, respectively (Table 1). 4D-CBCT underestimated displacement of marker by 5 mm on average in SI direction.

Conclusion: We performed displacement evaluation of fiducial markers on 4D-CBCT with two sorting methods. Since 4D-CBCT requires convolution of marker motion in eight bins, underestimation of 5 mm on average was observed in SI direction.
Results: Table 1 summarizes the localization results for each patient and imaging angle. All TEs remain below 2.5 mm and results between DRR-HE and DRR-DE are similar. However, a significant difference in TE is present for 1 imaging angle. From a qualitative analysis, see Figure 1, it can be observed that for those imaging angles where the tumor is mainly obscured by bony anatomy, tumor localization through intensity based registration is more accurate when dual-energy images are applied.

Figure 1: High-energy (left) and dual-energy (right) images from patient 1. Note that the tumor, indicated by the implanted marker, is obscured by soft tissue only for image 1 (above), while for imaging angle 2 the tumor is mostly obscured by the ribs.

<table>
<thead>
<tr>
<th>RMS tracking error</th>
<th>DRR - DE</th>
<th>DRR - HE</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>patient 1 Im. 1 - 10°</td>
<td>1.7 ± 0.8</td>
<td>2.2 ± 0.8</td>
<td>p = 0.08</td>
</tr>
<tr>
<td>patient 1 Im. 2 - 100°</td>
<td>1.2 ± 0.6</td>
<td>1.3 ± 0.5</td>
<td>p = 0.83</td>
</tr>
<tr>
<td>patient 2 Im. 1 - 70°</td>
<td>1.8 ± 0.7</td>
<td>3.1 ± 1.1</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>patient 2 Im. 2 - 340°</td>
<td>1.4 ± 0.5</td>
<td>1.6 ± 0.8</td>
<td>p = 0.78</td>
</tr>
<tr>
<td>patient 3 Im. 1 - 250°</td>
<td>1.3 ± 0.4</td>
<td>1.2 ± 0.4</td>
<td>p = 0.85</td>
</tr>
<tr>
<td>patient 3 Im. 2 - 160°</td>
<td>1.3 ± 0.4</td>
<td>2.1 ± 0.5</td>
<td>p = 0.06</td>
</tr>
</tbody>
</table>

Conclusion: The results of this prospective evaluation indicate that for markerless localization of lung tumors through 4D/3D intensity-based registration, using DE images is more accurate than using regular kV images for certain imaging angles. Removing overlying bony anatomy and enhancing tumor visualization prior to registration makes the workflow more robust.

PV-0324
Intra-fraction motion characterisation of head-and-neck tumors using cine-MRI
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Purpose or Objective: Intensity modulated radiotherapy and the recent introduction of the MR-linac emphasize the need for detailed tumor motion characterization for adequate motion management in radiotherapy planning and online MRI-guidance. Hitherto, intra-fraction head-and-neck (H&N) tumor motion has been assessed as the displacement of local landmarks in cone beam CT or X-ray. The superior soft-tissue contrast of MRI enables characterization of the actual tumor displacement. Here, we investigate the intra-fraction tumor displacement on a sub-second and 10-minute time scale, using cine-MRI.

Material and Methods: Thirteen patients with H&N squamous cell carcinoma underwent pretreatment clinical MR imaging in a radiotherapy immobilization mask. Two 2D sagittal cine-MR scans (balanced steady state free precession; TE/TR = 1.2/2.5 ms; 1.42x1.42mm², slice thickness 10 mm, 500 dynamics), positioned through the tumor were acquired with 8 frames per second and an interval of 10-15 min on a 3.0T MR scanner. Tumor GTVs were delineated by a radiation oncologist.

Image analysis: Tumor motion was estimated by non-rigid image registration over the 1 minute dynamic MRI data using an optical flow algorithm (Fig. 1a). The displacement vectors on the GTV border were combined into a 95th percentile distance (dist95%) for every image. 95% of the range of dist95% over time was used as a measure of tumor displacement. The standard deviation of the GTV border displacement vectors was calculated and averaged over the time series as a measure of tumor deformation. Tumor displacement over 10 minutes was estimated by computing the difference in the average tumor position between the two dynamic series with an equivalent non-rigid registration.

Results: Results of the image registration (Fig. 1c) showed respiratory-induced tumor motion, which was confirmed by a peak at the principle respiratory frequency in a power spectrum analysis. Displacements were relatively small in both directions with a median displacement of 0.60 ± 0.13 mm (range: 0.18-1.44 mm) (AP) and 0.59 ± 0.11 mm (range: 0.32-2.69 mm) (CC) (Fig. 1b), which agreed with visual inspection. For two patients standard deviations within the border pixels were > 0.20 mm, which might imply a deformation of the tumor. The average tumor position differences over 10 minutes were smaller than the tumor displacement in the 1-minute data for both directions, with means of 0.28 mm (range: 0.08-0.99 mm) (AP) and 0.34 mm (range: 0.07-0.99 mm) (CC).

Conclusion: Tumor displacements on both time scales were relatively small, but varied considerably between patients.

PV-0325
Retrospective self-sorted 4D-MRI for the liver
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Purpose or Objective: There is an increasing interest in 4D-MRI for MR-guided radiotherapy. 4D-MRI methods are typically based on either an external respiratory surrogate with possible deviations from internal motion or an internal navigator channel which can disturb the image acquisition.