Registration accuracy of high-speed single breath-hold kV-CBCT lung cancer imaging

Anna Ams, Jens Fleckenstein, Frank Schneider, Jüdi Bod-Heggemann, Yasser Abo-Madyan, Volker Stell, Frederic Wenk, Hansjoerg Wertz
Department of Radiation Oncology, Universitätsmedizin Mannheim, Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany

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Introduction and objectives:

Single breath-hold imaging reduces motion artifacts to a minimum and thus accelerates and improves hypo-fractionated deep-inspiration breath-hold SABR of lung tumors. To enable single breath-hold kV-CBCT imaging within 10-15s, linac gantry speed was accelerated to 18°/s (3 rpm) for patient positioning.

To evaluate clinical applicability of high-speed kV-CBCT, registration accuracy was determined and compared to conventional, clinical kV-CBCT with slow gantry speed of 3°/s (0.5 rpm).

Material/Methods:

Lung tumor SABR case simulation
- Inhomogeneous thorax phantom
- 4 tumor-mimicking inlays
- High precision phantom positioning with optical tracking (Clarity, Elekta AB)
- 10 different pre-defined scan positions

Conventional clinical (3°/s) vs. High-speed (18°/s) kV-CBCT
- Research linac Versa HD with XVI (Elekta AB)
- Imaging preset setup: 200° rotation, 120kV, 0.4mA/s/frame

Registration methods on planning CT
(1) Manual (2 experienced clinicians)
(2) Clinical automatic software (XVI)
(3) Self-developed fully-automatic registration framework (Matlab)

Evaluation
- Comparison of offsets between registration results and known isocenter shifts
- Registration of all inlays in RL, AP, CC direction for different imaging speeds and registration methods

Results:

- Optical tracking: systematic error of 0.05mm for 10 random pre-selected isocenter shifts in max. 19mm
- Stochastic mean displacement error for all tumor-mimicking inlays, shifts and translational directions (RL, CC, AP) with different registration methods:

<table>
<thead>
<tr>
<th>Registration method</th>
<th>3°/s CBCT</th>
<th>18°/s CBCT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean±std</td>
<td>min/max</td>
</tr>
<tr>
<td>Manual</td>
<td>-0.02±0.2</td>
<td>-0.6/0.6</td>
</tr>
<tr>
<td>Automatic (XVI)</td>
<td>-0.02±0.2</td>
<td>-1.2/0.7</td>
</tr>
<tr>
<td>Objective automatic (in-house)</td>
<td>-0.02±0.2</td>
<td>-0.4/0.5</td>
</tr>
</tbody>
</table>

- Registration results with (3) objective self-developed (in-house) automatic method:

Conclusions:

The detailed comparison study of registration accuracy for pre-treatment patient positioning between high-speed kV-CBCT (18°/s) and conventional, clinical kV-CBCT (3°/s) with different registration methods showed no degradation with higher gantry speeds for lesions in high contrast areas such as the lung.

- Proof-of-principle for high-speed single breath-hold kV-CBCT lung tumor imaging within 10-15s provided.
- Increase of patient compliance and treatment precision, since faster gantry speed facilitates avoidance of defective fluctuations between multiple breath-hold phases.
- Faster gantry rotation speed paves the way for future intra-fractional combined imaging and treatment within one breath-hold phase.

References: