**Ruprecht-Karls-Universität Heidelberg**
**Medizinische Fakultät Mannheim**
**Dissertations-Kurzfassung**

# Real-Time Ultrasound Image-Guidance and Tracking in External Beam Radiotherapy


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Background and Purpose

To evaluate the accuracy of Clarity (clinical version) system by using ultrasound phantom and some probe position.

To evaluate the intrafraction motion of prostate by collecting and analyzing ultrasound monitoring data from some patients.

To evaluate the accuracy of Clarity (Anticosti) system by using 3D phantom programmed with sinusoidal and breathing movement patterns to simulate computer-controlled based breath-hold phases interspersed with spontaneous breathing.

To evaluate the clinical applicability of Clarity (Anticosti) system for liver cases in healthy volunteers. The tracking results of healthy volunteers were compared to surface marker.

To evaluate the intrafraction motion during breath-hold in liver case by collecting and analyzing US monitoring data from some patients.

Material and Methods

The accuracy of Clarity (clinical version) system was evaluated using ultrasound phantom and some probe position. Two different probes were used: transabdominal ultrasound (TAUS) and transperineal ultrasound (TPUS) probe. Two positions of the phantom were used for TPUS, the vertical and the horizontal position. Intrafraction motion assessment of the prostate was based on continuous position monitoring with a 4D US system along the three directions; left(+)-right (LR), anterior(+)-posterior (AP), and inferior(+)-superior (SI). 770 US monitoring sessions in 38 prostate cancer patients' normo-fractionated VMAT treatment series were retrospectively evaluated. The overall mean values and standard deviations (SD) along with random and systematic SDs were computed. The tracking accuracy of the research 4D US system was evaluated using two motion phantoms programmed with sinusoidal and breathing patterns to simulate free breathing and DIBH. The clinical performance was evaluated with 5 healthy volunteers. US datasets were acquired in computer-controlled DIBH with varying angular scanning angles. Tracked structures were renal pelvis (spherical structure) and portal/liver vein branches (non-spherical structure). An external marker was attached to the surface of both phantoms and volunteers as a secondary tracked object by an infrared camera for comparison. Residual intrafractional motion of DIBH tracking target relative to beginning position in each breath-hold plateau region was analysed along three directions; superior-inferior (SI), left-right (LR) and anterior-posterior (AP). 12 PTVs of 11 patients with primary/secondary liver tumours or adrenal gland/spleen metastases of diverse primaries were irradiated with SBRT in DIBH. Real time tracking of target or neighbouring surrogate structures was performed additionally using 4D US system during CBCT acquisition after permission of local IRB.

Results

The geometric positioning tolerance for Clarity-Sim and Clarity-Guide is 1 mm according to the manufacturer's specifications. The results showed that all phantom and probe combinations met this criterion. The mean duration of each prostate monitoring session was 254s. The mean (μ), the systematic error (Σ) and the random error (σ) of intrafraction prostate motion were μ=(0.01, -0.08, 0.15)mm, Σ=(0.30, 0.34, 0.23)mm and σ=(0.59, 0.73, 0.64)mm in LR, AP and SI direction, respectively. The percentage of treatments for which prostate motion was $\leq$2mm was 97.01%, 92.24%, and 95.77% in the LR, AP, and SI directions, respectively. At 60s, a vector length of prostate motion >2mm was present in about 0.67% of the data. The percentage increased to 2.42%, 6.14%, and 9.35% at 120s, 180s and 240s, respectively. The phantom measurements using Clarity (Anticosti) system showed increasing accuracy of US tracking with decreasing scanning range. The probability of lost tracking was higher for small scanning ranges (43.09% (10°) and 13.54% (20°)).The tracking success rates in healthy volunteers during DIBH were 93.24% and 89.86% for renal pelvis and portal vein branches, respectively. There was a strong correlation between the motion of the marker and the US tracking for the majority of analyzed breath-holds. 84.06% and 88.41% of renal pelvis target results and 82.26% and 91.94% of liver vein target results in AP and SI direction, the Pearson correlation coefficient was between 0.71 and 0.99. For evaluation of the intrafraction motion during breath-hold, 680 individual BHs during 93 treatment fractions were analysed. On visual control of tracking movies, target was lost in 27.9% of tracking, leaving a total of 490 BHs with optimal tracking. During these BHs, mean(±SD) target displacement were 1.7(±0.8)mm, 0.9(±0.4)mm, 2.2(±1.0)mm and 3.2(±1.0)mm for SI, LR, AP and 3D vector, respectively. Most of target displacement was below 2mm with percentage of 64.6%, 88.1% and 60.5% for SI, LR and AP, respectively. Data percentage of large target displacement increased with added BH time. At 5s, 3D vector of target displacement >10mm could be observed in 0.1% of data. Percentage values increased to 0.2%, 0.6%, and 1.1% at 10s, 15s and 20s, respectively.

Conclusions

The 4D US system offers a non-invasive method for online organ motion monitoring without additional ionizing radiation dose to the patient. The magnitudes of intrafraction prostate motion along the SI and AP directions were comparable. On average, the smallest motion was in the LR direction and the largest in AP direction. Most of the prostate displacements were within a few millimeters. However, with increased treatment time, larger 3D vector prostate displacements up to 18.30 mm could be observed. Shortening the treatment time can reduce the intrafractional motion and its effects and US monitoring can help to maximize treatment precision particularly in hypofractionated treatment regimens. For organ monitoring during BH application, the 4D US system showed a good performance and tracking accuracy in a 4D motion phantom when tracking a target that moves in accordance to a simulating breathing pattern. A 30°scanning range turned out to be an optimal parameter to track along with respiratory motion considering the accuracy of tracking and the possible loss of the tracked structure. The ultrasound tracking system is also applicable to a clinical setup with the tested hardware solution. The tracking capability of surrogate structures for upper abdominal lesions in DIBH is promising but needs further investigation in a larger cohort of patients. Ultrasound motion data show a strong correlation with surface motion data for most of individual breath-holds. Further improvement of the tracking algorithm is suggested to improve accuracy along with respiratory motion if using larger scanning angles for detection of high-amplitude motion and non-linear transformations of the tracking target. The exact quantification of residual motion impact requires an in-depth analysis of time spent at every position, nevertheless mean residual motion during DIBH is low and predominant direction is SI and AP. Only infrequently larger displacements of 3D vector >1 cm were observed, for short periods. Beam interruption at predefined thresholds could take DIBH treatments close to perfection.

Key words: Medical Physics, 4D ultrasound, IGRT (image-guided radiotherapy), prostate motion, stereotactic body radiotherapy (SBRT), deep inspiratory breath-hold (DIBH).