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Comparison of BAT System and a New 3D Transabdominal Ultrasound-Based Image-Guided System for Prostate Daily Localization During External Beam Radiotherapy

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Figure 1
Resonant Medical Inc, RESTITU system [RES] shown in the (a) CT-Sim room and (b) treatment room.

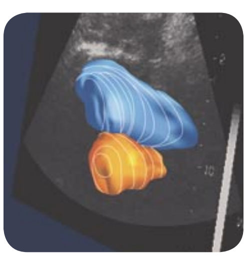

Figure 2
Prostate (gold) and bladder (blue) structures contoured manually from the 3D ultrasound reconstruction of the pelvic region. An original ultrasound slice is also shown.

Figure 3
Probe with attached sensor array.

Figure 4
Calibration phantom with probe positioning slots used to calibrate RES to both CT-Sim and treatment room laser coordinate systems.

Introduction

Combined with modern radiation treatment techniques, such as 3D-CRT or IMRT, reduction of PTV margins in prostate cancer external beam radiotherapy [EBRT] reduces dose to nearby normal tissues and could potentially allow an increased radiation dose to the prostate. However, tight margins could lead to geographical misses due to daily prostate displacement. The purpose of this study was to compare two distinctly different ultrasound-based image-guided verification methods for prostate alignment during daily radiotherapy. To this end, a 39 patient phase I/II study (CTC#02-017) was performed to compare two different ultrasound-based, image-guided patient positioning systems for daily prostate alignment.

Prostate alignment with the BAT (North American Scientific Corp., California, previously NOMOS Corp. Pennsylvania) system [BAT] was compared to that obtained with the RESTITU system (Resonant Medical Inc., Montreal) [RES]. The RES system resides in both the CT-Sim and treatment rooms and calculates prostate misalignment by comparing 3D ultrasound images of the prostate acquired at both planning and treatment times (intramodality comparison). This is unlike the BAT system which calculates prostate misalignment by comparing cross-modality images (i.e. two-orthogonal 2D ultrasound versus CT images).

References

[1] Molloy et. al., *"A method to compare supra-pubic ultrasound and CT images of the prostate: Technique and early clinical results," Med. Phys. 31, pp. 433-442, 2004.*

[2] Langen et. al., *"Evaluation of ultrasound-based prostate localization for image-guided radiotherapy," Int. J. Radiat. Oncol. Biol. Phys., 57, pp. 635-44, 2003.*

Material and Methods

A prospective clinical trial was conducted wherein prostate displacements were measured in 39 patients undergoing daily EBRT for prostate cancer. Comparison was made between the two-dimensional transabdominal ultrasound-based BAT system and the three-dimensional trans-abdominal ultrasound-based RES system. A total of 217 BAT and 217 RES prostate displacement measurements were collected within a minute of each other with all patients in the supine position. For prostate alignment with the BAT, two nearly orthogonal 2D ultrasound images obtained immediately prior to treatment were compared to the position of the CT-designed treatment planning volumes (i.e. *cross-modality* calculation method – comparing ultrasound to CT data). The RES system compared 3D ultrasound images acquired immediately prior to the planning CT scan to those acquired immediately prior to the treatment (i.e. *intramodality* calculation method – comparing ultrasound to ultrasound data).

For each patient, the RES system acquires a 3D ultrasound pelvic data set within a minute of the CT-Sim scan, as well as a 3D ultrasound pelvic data set just prior to each daily treatment with the patient in the treatment planned position (see Fig. 1). The prostates from each pelvic data set are then manually contoured and the prostate position just prior to treatment delivery is compared to the planned position. Fig. 2 shows a contoured 3D ultrasound prostate data set. The daily displacements between the treatment and planned positions are recorded. The RES system acquires the 3D ultrasound pelvic data with a modified 2D abdominal ultrasound probe, outfitted with positional sensors, which is swept across the region of interest of the patient. An optical camera scanner system tracks these sensors and calculates the position and orientation of the multiple 2D images obtained with the probe to reconstruct the 3D data set.

Accurate reconstruction relies on accurate RES system calibration relative to the CT room or treatment room laser coordinate system. RES system calibration can be performed quickly and easily (less than a minute is required) using the RES calibration phantom (See Figs. 3 and 4 for sketches of probe and calibration phantom, respectively).

Since the RES system resides in the CT-simulation room as well, prostate displacements were also compared to those measured by CT scan, which is the gold standard since it is used for treatment planning.[1] This comparison was done in 10 patients, who were rescanned 3 additional times, at biweekly intervals, during their treatment course (resulting in 30 data points). The prostate displacement between the planning CT and the subsequent CT scans was calculated with the AcQSim CT-Sim Software (Phillips Medical Systems, Massachusetts) and compared to the 3D-US data obtained just prior to each of the 30 additional CT scans.

(cont'd)

Results

Analysis performed on the difference in the paired 217 BAT and RES prostate displacements shows a mean difference of 0.9 (C.I. 0.5, 1.3) mm in the lateral [LAT] direction (p<0.0001), of 0.1 (C.I. -0.5, 0.7) mm in the anteroposterior [A/P] direction (p=0.604), and 6.0 (C.I. 5.4, 6.6) mm in the superoinferior [S/I] direction (p<0.0001). These trends in the difference results are similar to those determined by Langen et. al., [2] who compared the BAT system and implanted radio-opaque markers. Figure 5 (a-c) shows results as histograms for the difference between BAT and RES daily prostate displacements.

Analysis of the 30 CT-scan and RES measured prostate displacements shows mean values of 0.2 (C.I. -0.4, 0.8) mm in the LAT direction (p=0.314), -0.3 (C.I. -0.9, 0.3) mm in the A/P direction (p=0.405), and 0.1 (C.I. -0.5, 0.7) mm in the S/I directions (p=0.727). In Fig. 6, a multivariate scatter plot matrix is shown which graphically illustrates the high correlation (thin clustered groupings) between the CT and RES prostate displacement measurements for the same directions and little correlation (rounder spread out groupings) for comparisons of CT to CT, RES to RES and CT to RES measurements in different directions. This validates the good correlation between RES with CT for accurately measuring prostate displacement.

Conclusions

The 217 BAT/RES paired statistical analysis shows a p-value (Wilcoxon signed-rank test) of <0.0001, 0.604 and < 0.0001, for the LAT, A/P and S/I directions, respectively, which indicates that the nul hypothesis (zero difference) is rejected for the LAT and S/I directions. The 30 RES/CT paired statistical analysis shows that there is no clinically significant difference between their measured prostate displacements with p-values 0.314, 0.405 and 0.727 for the LAT, A/P and S/I directions, respectively. Therefore, the study indicates that a clinically significant systematic difference exists between cross-modality (BAT) and intramodality (RES) methods when assessing prostate alignment during daily EBRT. Since RES displacements are consistent with the CT displacements, a more accurate prostate alignment is obtained when the RES method is used, compared to the BAT method.

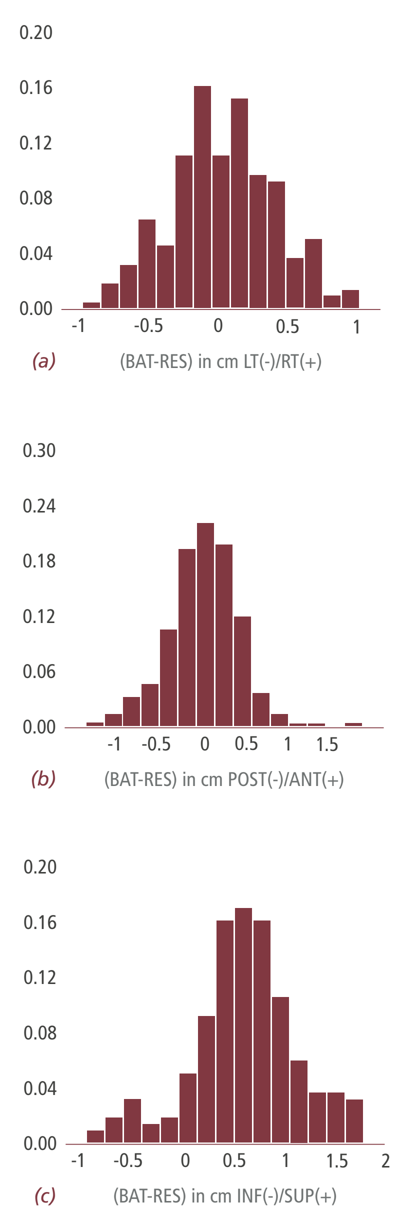

Figure 5

Histograms showing prostate shift differences between BAT and RES for the (a) LAT, (b) A/P and (c) SI/ directions.

Figure 6

Multivariate scatter plot matrix showing the correlation between the CT and RES measured prostate displacements.

Multivariate

Correlations

	res Lt-Rt+	res Post-Ant+	res inf-sup+	ct Lt-Rt+	ct Post-Ant+	ct inf-sup+
res Lt-Rt+	1.0000	-0.1756	-0.0479	0.8674	-0.2948	-0.1182
res Post-Ant+	-0.1756	1.0000	0.7666	0.0213	0.9797	0.8092
res inf-sup+	-0.0479	0.7666	1.0000	0.0537	0.7808	0.9671
ct Lt-Rt+	0.8674	0.0213	0.0537	1.0000	-0.1046	0.0613
ct Post-Ant+	-0.2948	0.9797	0.7808	-0.1046	1.0000	0.8324
ct inf-sup+	-0.1182	0.8092	0.9671	0.0613	0.8324	1.0000

Scatterplot Matrix