EVALUATION OF A CT TO CONE-BEAM CT DEFORMABLE REGISTRATION ALGORITHM

J.W. Piper[1,2]

[1]MIMvista Corp., Cleveland, OH • [2]Dept of Computer Science, Wake Forest University, Winston-Salem, NC

Purpose and Objectives

The advent of on-board cone-beam CT (CBCT) imagers for radiation therapy delivery devices offers the potential for daily dosimetry and adaptive therapy. Heretofore this potential has been limited by several artifacts in the CBCT volumes which may require surrogates with reliable density values to be used for recalculation of dosimetry, such as a CT volume deformed to the treatment space of the CBCT. Additionally, automatically accumulating dose to critical structures and target volumes requires structures defined on the original planning CT to be deformed into the treatment space identified by the CBCT. We propose a high degree of freedom free-form deformation with maximization of local information theoretic metrics algorithm for CT to CBCT to meet these challenges.

Materials and Methods

For a single patient with Stage III base of tongue cancer undergoing IMRT, a second planning CT and CBCT were acquired four weeks into treatment. The CBCT was acquired a day before the planning CT with a Varian Trilogy™ kV CBCT imager. The original planning CT was deformed to the CBCT using our free-form deformable registration algorithm which has previously been used successfully for intensity-based CT to CT registration.[1] We utilize the correlation between pairs of volumes to evaluate registration accuracies. We also calculate the correlation between a volume and itself with a mis-registration applied as a reference to indicate what correlations can be expected.

Results and Discussion

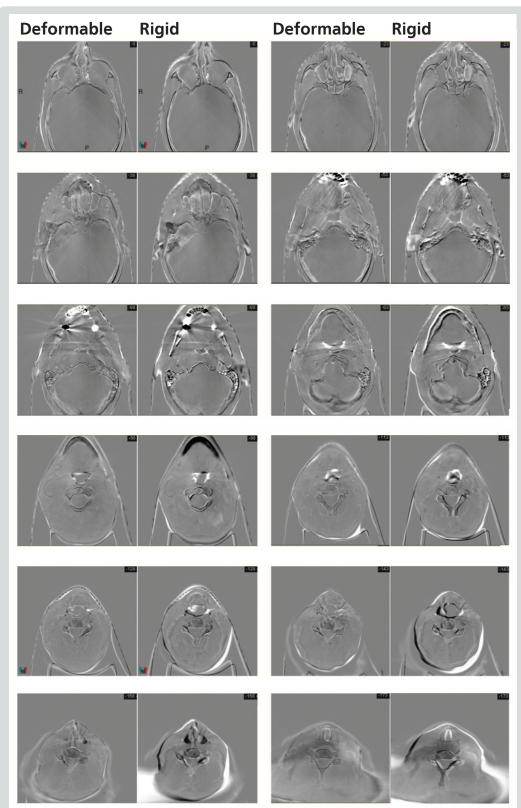
Deformable registration of the original planning CT to the CBCT resulted in a correlation of 0.9698. This compares favorably to the 0.9523 self-correlation of the CBCT with a 1mm mis-registration in each direction and represents a considerable increase over the 0.8969 correlation between the same two volumes after rigid registration only (Table 1, Figure 1). The correlation between the CBCT and new planning CT was 0.9503. Some of this error is due to CBCT artifacts while other differences arise from the fact that the patient had to be repositioned between acquisitions. The original planning CT after deformation to the CBCT demonstrated a closer correlation with the new planning CT at 0.9548. This also compares favorably to the 0.9511 self-correlation of the new planning CT with itself with a 2mm mis-registration in each direction (Table 2). Again, some of the residual error is due to positioning differences between the CBCT and new planning CT.

Table 1
Correlation of Original Planning CT with CBCT

	Primary	Secondary	Correlation
Deformable	CBCT	CT_{od}	0.9698
Rigid	CBCT	CT_{o}	0.8969
1mm Error	CBCT	CBCT	0.9523

Correlation coefficients between the mid-treatment CBCT and the original planning CT deformably registered to it (CT_{od}) and between the mid-treatment CBCT and the original planning CT rigidly registered to it (CT_{o}). The correlation after deformable registration is considerably better than rigid registration. These results are also graphically depicted in Figure 1. The self-correlation of the CBCT with 1mm translational mis-registration in each direction is shown for reference.

Figure 1
Residual Intensity Differences



Shown are (1) difference image between original planning CT and mid-treatment CBCT after deformably registering the CT to the CBCT and (2) difference image between original planning CT and mid-treatment CBCT after rigid registration only. The residual intensity differences which appear brighter or darker than neutral gray are considerably reduced after deformable registration compared with rigid registration. Much of the residual differences seen after deformable registration are due to CBCT artifacts which are not present in the planning CT.

Table 2
Correlation of Replanning CT with CBCT

	Primary	Secondary	Correlation
Deformable	CT_{r}	CT_{od}	0.9548
Rigid	CT_{r}	CBCT	0.9503
2mm Error	CT_{r}	CT_{r}	0.9511

Correlation coefficients between the mid-treatment replanning CT (CT_r) and the original planning CT deformably registered to the CBCT (CT_{od}) and between the mid-treatment replanning (CT_r) and the mid-treatment CBCT that was rigidly registered to it. The correlation between the replanning CT and the surrogate CT_{od} is better than the between the replanning CT and CBCT, suggesting that whatever errors there are in the deformable registration are less significant than the artifacts from the CBCT imaging and that the deformable registration is fairly robust to these artifacts. The self-correlation of the replanning CT with 2mm translational mis-registration in each direction is shown for reference.

Figure 2
Integration Into Adaptive Therapy Workflow

In a dose-guided adaptive therapy treatment protocol, the deformable registration of CT to CBCT can be used both to automatically or semi-automatically contour the CBCT for replanning and to deformably co-register the dose volume for dose accumulation on the planning CT. On any day a CBCT is acquired either it or the surrogate deformably registered original planning CT is used to compute dose with the current plan. If the dose is not as desired, the Deformable Adaptive Re-contouring method would be used to propagate the contours from the original planning CT to the CBCT or a new planning CT and used for replanning. The dose is then deformably co-registered to the planning CT and accumulated for the next day's treatment decision.

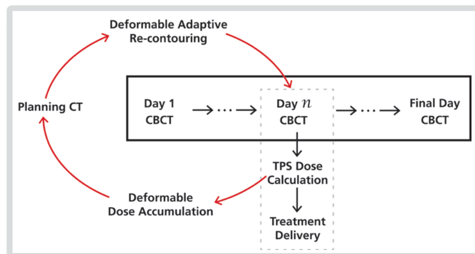
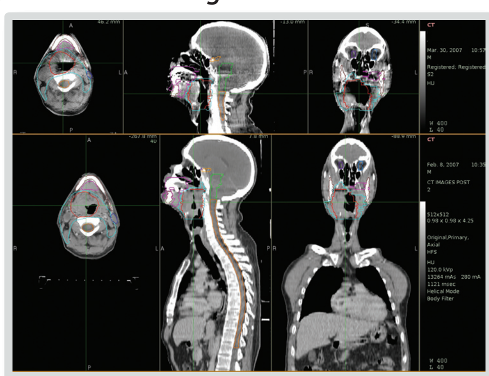


Figure 3
Adaptive Re-contouring



Contours from the original planning CT are automatically deformed to match the anatomy in the mid-treatment CBCT. These can then be used in a treatment planning system to re-optimize the plan for Adaptive Therapy.

Conclusions

The results indicate that our registration algorithm is suitable for correcting for deformations due to patient positioning error and anatomical changes between the original planning CT and CBCT acquired several weeks into treatment. The algorithm thus shows the potential for use in contour deformation and creation of surrogate CT volumes for dosimetry and adaptive therapy (Figures 2 and 3).

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References

[1]Piper JW. Evaluation of An Intensity-Based Free-Form Deformable Registration Algorithm. Medical Physics. June 2007;34(6):2353-2354.

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