Managing Cardiac Motion in Ventricular Tachycardia: Use of Deformable Registration to Determine Shifts Magnitude.

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Problem

SBRT has been proposed to treat refractory ventricular tachycardia. Current clinical planning follows a typical SBRT planning workflow where uniform margins are added to the electrocardiographic signal to create a PTV. We track heart motion in clinical imaging and estimate its effect on the delivered dose.

Purpose

This study assesses the accuracy of the current planning paradigm compared to an improved workflow where the cardiac motion is tracked through deformable registration.

Method

Datasets

- ✓ 13 patients treated with SBRT for tachycardia
- ✓ Simulated using 4D CT
- ✓ Setup based on CBCT

Margins

- ✓ Scar motion tracked in the 4DCT
- ✓ Motion magnitude compared against the uniform margin approach

Setup accuracy

- ✓ Rigid registration of 4DCT → CBCT used for setup
- ✓ Retrospectively using B-Spline deformable registration to track residual deformations at treatment

Conclusions

Margins: Heart motion is patient dependent, maximum magnitude may exceed isotropic scar expansion

Setup accuracy: Local scar displacements due to motion can be quantified with deformable registration

This is a clinical investigation into how we can improve ventricular tachycardia treatment planning by considering heart motion.

Results

How is motion tracked ?

Heart motion is tracked by using a B-Spline deformable registration method as implemented in Velocity between the respiratory phases of a 4D CT. The displacements found by the registrations are applied on the contours to track motion in each point of the electrocardiographic signal, that represents the treatment target. Setup accuracy is estimated with a similar workflow where heart displacement relative to surrounding anatomy is encoded with a deformable registration between the planning CT and setup CBCT. This is then compared with the online rigid setup that was used clinically. BSpline algorithm is ideally suited for this problem to alleviate the poor soft tissue contrast around the scar in the CBCT, as it interpolates the motion from displacements of surrounding anatomy that is better visualized in these images.

Does motion affect dose ?

To estimate motion effect on the delivered dose, we overlay the original dose distribution on the motion-corrected contours and plot the corresponding DVHs. This analysis was done independently for motion-corrected contours as determined from the 4D CT scan and for contours corrected with deformations not taken into account by the online rigid setup.

What do we see in the 4D CT ?

Cardiac displacements were patient-specific with means ranging from 0.91 to 2.84 mm and maximums from 4.8 to 18 mm. Although scar points moved smoothly as denoted by the standard deviation (average 1.6 mm across all patients) displacements depended on the scar location within the heart, largest observed for a patient with an exterior left ventricle scar while smallest being recorded for an interior left ventricular lesion.

What do we see in the CBCT ?

While the average displacements were 2 mm across al patients, maximum displacements larger than 7 mm have been an observed for 7 out of 13 patients, leading to a consistent degradation of the PTV coverage for each case analyzed

Can we change our workflow ?

A review of the imaging from the online setup and deformable match confirmed that the current online setup is sub-optimal for patient positioning and suggests a clinical strategy is needed to compensate for cardiac motion based on deformable registration.

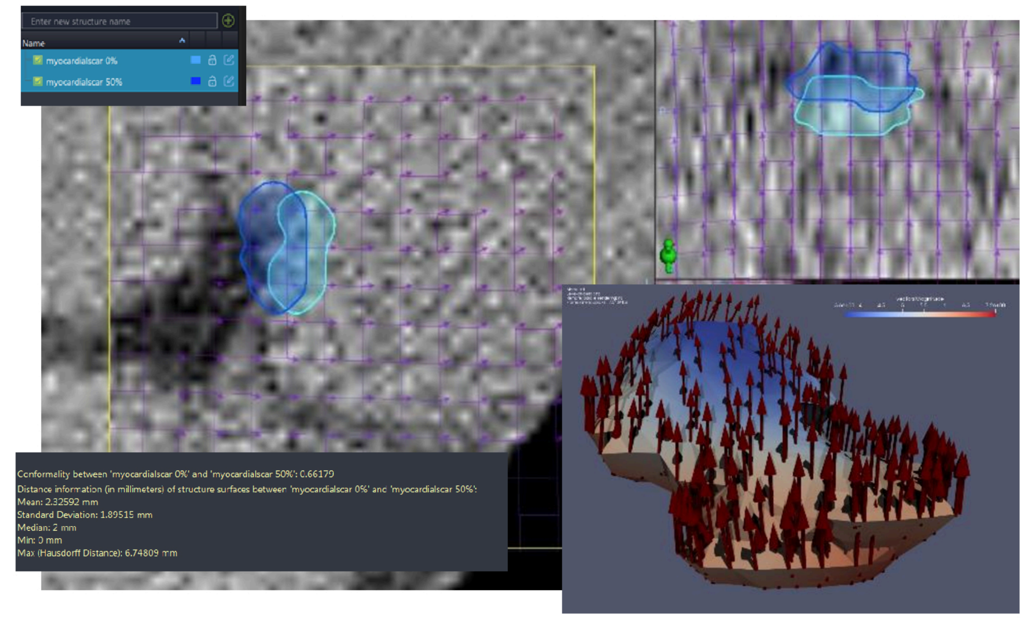

Figure 1. Cardiac scar motion is determined by registering the 0 and 50% phases of a 4D CT dataset with a deformable registration in Velocity. On the left, the scar in at 0% is shown in light blue while it's displacement at 50% is shown in dark blue. Tools within Velocity are used to calculate the Dice coefficients and distances between the two segmentations, as well as to evaluate the accuracy of the deformable registration (left insert). The shifts for each point defining the scar are detected by this procedure and included in the statistics, as shown in the insert where arrows represent each point's displacement direction and magnitude.

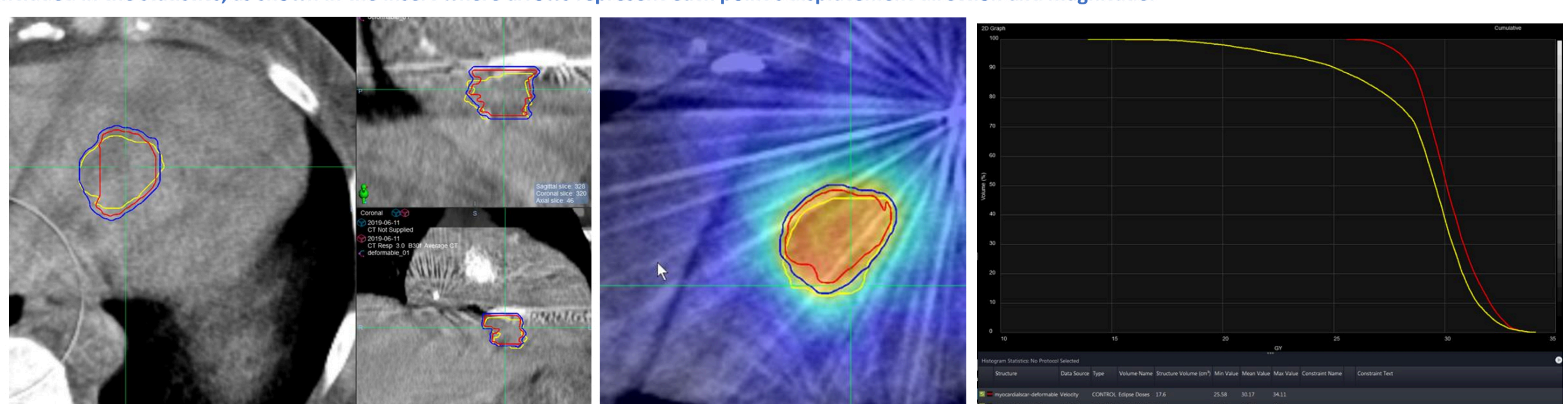

Figure 2. Example of local scar displacement between plan (blue segment) rigid setup (red segment) and deformable setup (yellow segment). While online registration accounted only for translations, there was a pitch created by the local cardiac motion that created the dose degradation seen in the DVH plot. For this particular case, the PTV's smooth and round shape allowed for a tight dose conformity to the target, that in turn created one of the worst dose degradation when the true PTV location was taken into account.