Validation of deformable registration of prostate MRI with and without endorectal coil for IMRT planning

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Introduction

Intensity Modulated Radiation Therapy (IMRT) allows highly conformal 'sculpting' of the shape and intensity of a radiation dose distribution. One of the major challenges in further improving IMRT lies in adequately defining target volumes and quantifying tumour heterogeneity. Anatomical MRI as well as physiologic and metabolic MR techniques such as diffusion-weighted imaging (DWI), dynamic contrast enhanced (DCE) and MR spectroscopic imaging (MRSI) are increasingly being used to achieve this goal in a wide variety of organs. In prostate imaging, the quality of all these techniques can be greatly improved using an endorectal receiving coil (ERC). However, the organ displacements and deformations caused by such a coil cause systematic errors in the definitions of target volumes and surrounding organs compared to the treatment geometry [1]. To account for these errors, we have implemented a method for the deformable registration of endorectal MR images to MR images acquired without the ERC. These latter images allow registration of the MR images to the planning CT. The primary aim this work was to validate our registration method; the secondary aim was to investigate the effect of a global smoothness constraint on the deformable registration.

Materials and methods

Twelve patients underwent dual-coil T2-weighted MR imaging (TR 5100–8800 ms, TE 120–150 ms; in-plane resolution 0.46 × 0.60 mm, slice thickness 3 mm) with an endorectal coil and a pelvic phased-array coil (T2-ERC) on a Philips 3T MR unit (Achieva, Philips Medical Systems, Best, The Netherlands). The endorectal coil was subsequently removed, and T2-weighted MR imaging (TR 4700–8800 ms, TE 120–150 ms; in-plane resolution 0.46 × 60 [n=10] or 0.60 × 0.95 mm [n=2], slice thickness 3 mm) was repeated with the pelvic phased-array coil only (T2-NoERC).

Markers were placed on anatomical landmarks found in both images of each pair by a radiation oncologist (minimum number of markers 4; maximum 8; median 7; total 82). After registration, the residual distance between each of the corresponding markers on the T2-NoERC and the deformed T2-ERC was calculated.

A mutual information rigid image registration was performed for each patient as a starting point for deformable registration. Deformable registration of each T2-ERC/T2-NoERC image pair was performed using two methods: A) B-spline deformable registration with mutual information as similarity measure, using a gradient-based optimization with a 6-step multi-resolution approach (final control point resolution 3.0 mm), without constraints; B) the same deformable registration method with a global smoothness constraint. The error vector lengths of the two deformable registration methods were compared in a nonparametric pairwise test (Wilcoxon signed ranks).

Results and discussion

Figure 1 shows two deformable registrations of T2-ERC to T2-NoERC images of the same patient: A) unconstrained deformable registration; B) deformable registration with a global smoothness constraint. Grid lines are shown as a visual aid to inspecting the deformations. For comparison, the rigid registration of the same patient is shown in C), clearly illustrating the necessity of deformable registration in this situation.

Table 1 lists the mean and SD across all patients and all markers of residual distances after registration between corresponding markers in the T2-ERC and the T2-NoERC scans in left-right (LR), craniocaudal (CC) and anterioposterior (AP) directions, as well as the mean error vector lengths.

The mean error vector length was 0.63 cm after rigid registration, reducing to 0.20 cm and 0.18 cm after deformable registration without and with a global smoothness constraint, respectively. Deformable registration yields an SD of marker errors below 2 mm in all directions for both methods. In regard of the 3 mm slice thickness of the images, this suggests that the proposed image-based registration method yields clinically acceptable results. It is noted that these results include the intra-observer variation of marker placement.

The smoothness constraint penalizes deformations based on image noise features rather than anatomical features. It is therefore expected that imposing a (slight) smoothness constraint may yield more realistic results than unconstrained registration. This is also supported by visual inspection of the registrations, see Fig. 1. The mean error vector length of the deformable registration with smoothness constraint was indeed slightly smaller than that of the unconstrained deformable registration. This difference was not significant, however (P=0.113), possibly due to a lack of statistical power.

Conclusion

Deformable registration of endorectal prostate MR images to non-endorectal images with the proposed method is feasible. Our results suggest that sufficient accuracy for use in radiotherapy is attainable with this method; however, further studies involving larger patient groups are needed to validate these results. With sufficient validation this method will allow us to take full advantage of the high image quality of endorectal MR imaging in IMRT planning.

Table 1: Marker errors after deformable registration with two methods: A) unconstrained deformable; B) deformable with global smoothness constraint.

Method	LR (cm)		CC (cm)		AP (cm)		Vector length (cm)
	mean	SD	mean	SD	mean	SD	mean
A	0.00	0.10	-0.02	0.18	0.03	0.13	0.20
B	0.01	0.09	0.00	0.16	0.04	0.12	0.18

References

[1]: Y. Kim *et al., Med. Phys.* 32:3569–3578, 2005.

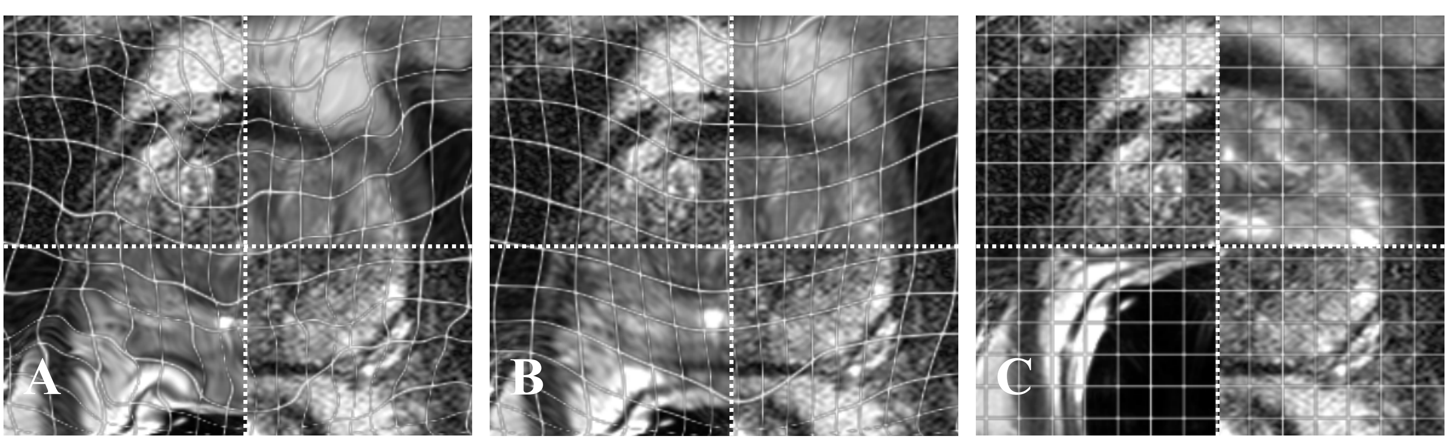

Figure 1: Cut-view examples of the three registration methods in the same patient. In all images the top left and lower right quadrants show the T2-NoERC image, and the top right and lower left quadrants show the T2-ERC image after registration.