

## Deformable Registration for Recovering Image Distortions in DWI MRI of the Prostate at 3T

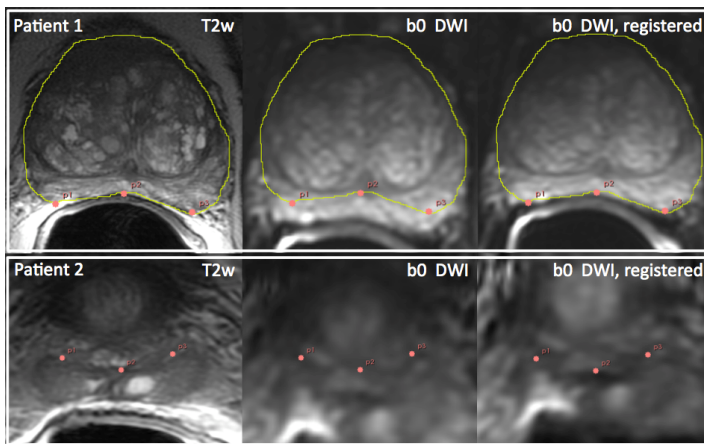
Andriy Fedorov<sup>1</sup>, Luis Ibanez<sup>2</sup>, Kemal Tuncali<sup>1</sup>, Robert V Mulkern<sup>1,3</sup>, William M Wells<sup>1</sup>, Clare Tempany<sup>4</sup>, and Fiona Fennessy<sup>1</sup>

<sup>1</sup>Department of Radiology, Brigham and Women's Hospital, Boston, MA, United States, <sup>2</sup>Kitware Inc, Clifton Park, NY, United States, <sup>3</sup>Department of Radiology, Children's Hospital, Boston, MA, United States, <sup>4</sup>Brigham and Women's Hospital, Boston, MA, United States

**Introduction** Prostate cancer (PCa) is one of the most common cancers in men. Currently, clinical management of PCa is complicated by the fact that no reliable biomarker of the disease exists, and histopathological analysis of the core biopsy sample is the only acceptable approach for accurate diagnosis of PCa. Unfortunately, this approach is invasive, inaccurate for estimating tumor volume and cannot be applied for the quantitative assessment of PCa treatment. With the recent advances in multiparametric MRI (mpMRI) [1], there is a hope that the various MR imaging markers, such as Apparent Diffusion Coefficient (ADC) derived from Diffusion Weighted (DWI) MRI can be applied for PCa localization and grading [2], and in the evaluation of the response to treatment [1]. A practical issue in quantitative pixel-wise analysis of mpMRI is in the large slice spacing, differences in resolution, misalignment and distortions that complicate joint analysis of the individual MR parameters. These challenges are particularly prominent in imaging of the prostate with endorectal coil (ERC) at 3T, where the strong differences in the magnetic susceptibility of the air-filled coil balloon and tissue cause severe distortions in, for example, ADC maps. Herein we propose a non-rigid registration approach fine-tuned to compensate for such artifacts by incorporating the prior knowledge about the nature of the distortion into the method.

**Materials and Methods** MRI studies were obtained as part of the mpMRI exam of biopsy proven PCa patients (N=17) with the research aspects of the study approved by the institutional review board. Imaging was done with a 3T MR scanner (GE, Milwaukee, WI) using a combination of an ERC located within an air-filled balloon (MEDRAD, Inc., Warrendale, PA) and 4 pelvic phased array receiver elements. The series analyzed were axial FRFSE T2w MRI (voxel size 0.3x0.3x3 mm) and axial EPI GEMS DWI MRI (0.7x0.7x3 mm) with trace diffusion sensitization and b-factors of 0 and 500 s/mm<sup>2</sup> (AP phase encoding) covering the whole gland.

**Image Registration and Evaluation** We separated the baseline (b0) image from the DWI series and registered it to the T2w structural image. As part of preprocessing, the approximate contours (ROIs) of the prostate gland in the T2w and DWI b0 baseline image were prepared [3] to constrain the evaluation of similarity metric to the region of prostate, followed by correction of intensity signal inhomogeneities [4]. Sparse B-spline grid (3 control points in each dimension) that covered just the bounding box of the contoured prostate gland was used to represent the transformation, parameters of which were optimized to maximize the mutual information similarity metric using regular step gradient descent optimizer [5]. Optimizer scales were initialized such that the deformation in the left-right direction is penalized, since the major component of distortion in the images was in the anteroposterior direction. The parameters of the optimizer were fine-tuned by experimentation on one pair of images, and were next applied without changes to the rest of the images. Registration results were first examined visually to identify cases that did not lead to meaningful results. Successful registration results were included in the quantitative evaluation that was focused on the posterior portion of the prostate capsule, since this is the area of the image most affected by the distortions. Residual registration errors were quantified by calculating the distance between the posterior wall of the capsule in the T2w image and the registered b0 DWI image. The error was measured at 9 points that were distributed over 3 levels of the gland in the craniocaudal direction (apex, mid-gland and base). At each of these levels three marker points were located at left, midline and right portion of the gland. In addition to the residual registration error, magnitude of the displacement recovered by non-rigid registration was calculated at each of these points.



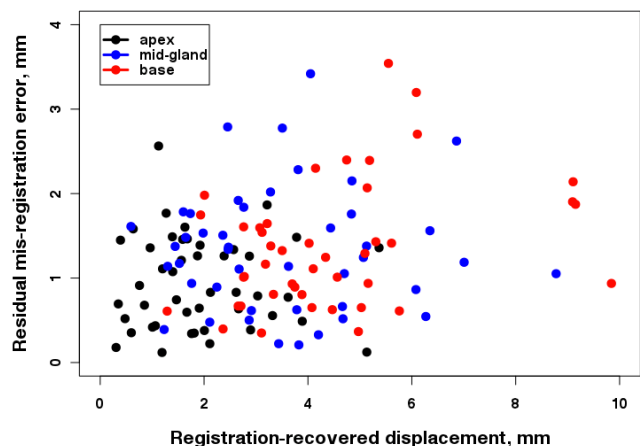
**Figure 1:** Illustration of the registration results in 2 patients. Patient 1: registration at the mid-gland level. Patient 2: more challenging registration at the base level. Yellow contour overlays in Patient 1 correspond to the outer capsule of the prostate contoured in the T2w image. Red marker dots correspond to the approximate location of the posterior wall of the outer capsule on T2w images, where errors were quantified. Note the difficulty in identifying the capsule reliably at the base level, primarily due to the partial volume effect.

**Results** Registration results were inspected visually and were deemed successful in 15 out of 17 cases. In all of these cases registration led to improved alignment of the image features based on qualitative inspection (e.g., see Fig.1). Out of the total of 135 points used for error quantification in the 15 successfully registered cases, residual error was less than 1.6 mm in 75% of the cases, with the largest residual error 4.7 mm. The mean residual error at apex, mid-gland and base were 0.9, 1.4 and 1.4 mm (3<sup>rd</sup> quartiles 1.4, 1.8 and 1.9 mm), respectively. The mean displacement recovered by the registration at the points used in the evaluation was 3.4 mm, with the 75% of the displacements being less than 4.6 mm (see Fig.2). The largest displacements were observed at the base level (mean 4.6 mm).

**Discussion and Conclusions** In this study we presented preliminary evaluation of a registration approach that can be used to reduce, if not recover, the distortions in the EPI DWI MRI. When applied to the imaging data used in this evaluation, the approach appears to be reliable and capable of handling large deformations that are common when the gland is imaged using ERC secured in place with air-filled balloons at 3T MRI. To the best of our knowledge, this is the first study to focus on registration for recovering susceptibility-induced artifacts in the ERC prostate imaging. The described method can be applied to improve the accuracy of pixel-wise quantitative analysis of mpMRI and correlation of the individual parameters, facilitating more reliable imaging-based characterization of the prostate tissue. The accuracy of the registration might be further improved by fine-tuning registration parameters and introducing hierarchical B-spline transformations.

**Acknowledgments** This work was supported by NIH grants R01 CA111288, P41 RR019703, P01 CA067165 and U01 CA151261.

**References** [1] Padhani A. *Radiology*, 2010, 256(2):348-64. [2] Hambrock T. *Radiology*, 2011, 259(2):453-61. [3] 3D Slicer, <http://slicer.org>, 2011 [4] Tustison N. *IEEE TMI*, 2010, 29(6):1310-20. [5] Insight Toolkit, <http://itk.org>, 2011.



**Figure 2:** Scatterplot summarizing the distribution of the recovered displacements and the residual mis-registration errors at the different levels of the gland. The distortions at the mid-gland and base appear to be slightly stronger and lead to larger residual mis-registration compared to apex. The mis-registration error for the majority of the points is less than 2 mm.