A Model-Based Method for Registration of Ex Vivo to In Vivo Prostate MRI Using Elastography

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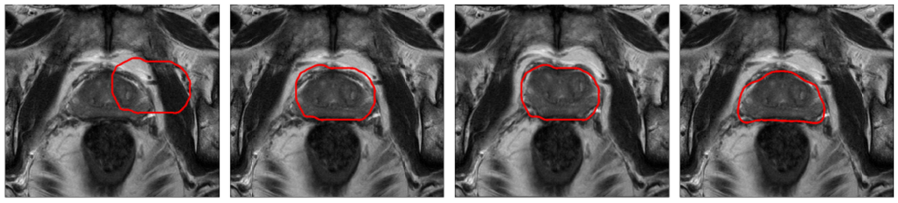
Introduction

The most accurate image-based characterization of prostate cancer to date is generated from multi-parametric magnetic resonance imaging (MRI) [1]. In order to obtain cancer probability maps that correlate histopathology with *in vivo* MRI, one can use *ex vivo* MRI scans of the fixed prostate specimen after radical prostatectomy. While *ex vivo* images can be easily registered to histology using mechanical constraints [2], it remains a challenge to register *ex vivo* to *in vivo* MRI due to unknown misalignment, change in volume and deformation of the prostate between the scans. It is the goal of this work to develop a method for accurate registration between *ex vivo* and *in vivo* MRI. Biomechanical models which are deformed in a physical manner have been used extensively for registration of medical imaging data [3]. However, these models are assigned arbitrary and typically constant elasticity properties that are optimized to produce a low target registration error. This is not always realistic and may result in inaccurate deformation maps. We propose the novel use of magnetic resonance elastography (MRE) [4] that assigns actual *in vivo* measurements of elasticity parameters to the prostate and periprostatic tissue. The incorporation of such elastography data into the registration framework ensures a realistic regularization of the deformation maps and, to the best of our knowledge, has not been reported before.

Methods

The study was approved by the institutional ethics board and a signed consent was obtained prior to experiments. A patient scheduled for radical prostatectomy underwent an *in vivo* pre-op T2-weighted (T2w) MRI scan followed by MRE in a 3.0-Tesla system (Philips, The Netherlands). We used a dynamic harmonic MRE technique based on transperineal application of vibrations to the prostate. We obtained the elasticity image using local frequency estimation (LFE) of the displacement images. The *ex vivo* post-op prostate specimen was fixed in 10% buffered formalin and scanned in a 7.0-Tesla system (Bruker, Germany). High quality *ex vivo* images allow a 3D model of the prostate to be constructed easily. In contrast, the *in vivo* images contain surrounding anatomy and tissue, with which the prostate blends. Thus, we employ a model-based registration scheme, in which the *ex vivo* model is matched to the *in vivo* volumetric image. As a pre-processing step, we interpolate the *ex vivo* model onto the field of view of the *in vivo* volume. Next, we align the 3D model to fit the image with respect to translations, scaling and rotations. We use a rigid registration algorithm [5] that translates, scales and rotates the model over the volume in order to minimize the intensity variations on the regions inside and outside the surface of the model. Finally, we employ a novel iterative elastic registration algorithm to compute the residual non-rigid mapping between the aligned model and the image. Rather than deforming the *ex vivo* model, the *in vivo* volumetric image is warped in order to match the model, by minimizing global intensity variations inside and outside its surface. In this approach, each voxel of the image is associated with an elasticity value (Young's modulus) that was determined by the MRE scan. In addition, this approach allows the forces that drive the deformations to be computed on the entire volume, not only around the model. Therefore, displacements of the voxels are propagated through the image in a physical fashion. As a post-processing step, we compute the inverse mapping and warp the model onto the volume. We implement our method using a numerical scheme based on [6]. Figure 1 illustrates the registration process on a transverse slice of the volume.

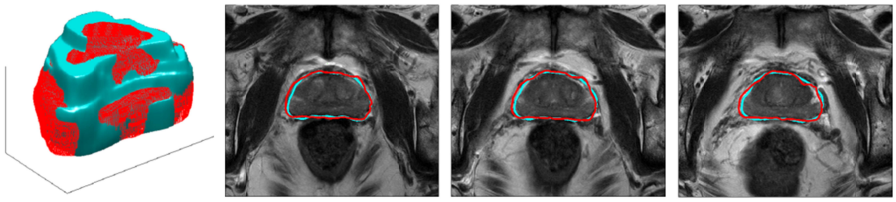


(a) Initial (b) Rigidly aligned (c) Warped image (d) Warped model

Figure 1. Registration process. Cross-section of the *ex vivo* 3D model (red) overlaid on an *in vivo* T2w slice. Notice that in (c) the image is warped to fit the prostate inside the model. The inverse map, applied to the model, produces (d).

Results

To evaluate registration performance, we compared the final registered *ex vivo* model to a model constructed from manual segmentation of the prostate in the *in vivo* T2w slices. The results are illustrated in Figure 2. Quantitatively, we found the relative 3D volume overlap between the two models (Dice's similarity coefficient) to be 46.7% initially, 78.4% after rigid alignment, and 86.8% after non-rigid registration. On mid-gland slices, the relative 2D area overlap after non-rigid registration is 93.3±0.54%.



(a) 3D (b) Slice 16 (c) Slice 18 (d) Slice 20

Figure 2. Registration results. (a) Registered *ex vivo* model (red) and manually segmented *in vivo* model (cyan) in 3D. (b-d) Selected cross-sections of the registered model overlaid on corresponding T2w slices and manual segmentations.

Discussion

We outlined a method for a model-based registration of an *ex vivo* model to an *in vivo* T2w MRI volume with a corresponding MRE data. The method utilizes both intensity information and the measured elasticity to warp the volumetric image. To the best of our knowledge, this is the first model-based registration method that uses MRE. Early experiments on both synthetic and clinical data show promising results. An ongoing study will provide further evaluation of the method on clinical data, which is needed in order to build cancer distribution probability maps.

References

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