Original Investigation

# 3D Registration of mpMRI for Assessment of Prostate Cancer Focal Therapy

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**Rationale and Objectives:** This study aimed to assess a novel method of three-dimensional (3D) co-registration of prostate magnetic resonance imaging (MRI) examinations performed before and after prostate cancer focal therapy.

**Materials and Methods:** We developed a software platform for automatic 3D deformable co-registration of prostate MRI at different time points and applied this method to 10 patients who underwent focal ablative therapy. MRI examinations were performed preoperatively, as well as 1 week and 6 months post treatment. Rigid registration served as reference for assessing co-registration accuracy and precision.

**Results:** Segmentation of preoperative and postoperative prostate revealed a significant postoperative volume decrease of the gland that averaged 6.49 cc ($P = .017$). Applying deformable transformation based on mutual information from 120 pairs of MRI slices, we refined by 2.9 mm (max. 6.25 mm) the alignment of the ablation zone, segmented from contrast-enhanced images on the 1-week post-operative examination, to the 6-month postoperative T2-weighted images. This represented a 500% improvement over the rigid approach ($P = .001$), corrected by volume. The dissimilarity by Dice index of the mapped ablation zone using deformable transformation vs rigid control was significantly ($P = .04$) higher at the ablation site than in the whole gland.

**Conclusions:** Our findings illustrate our method's ability to correct for deformation at the ablation site. The preliminary analysis suggests that deformable transformation computed from mutual information of preoperative and follow-up MRI is accurate in co-registration of MRI examinations performed before and after focal therapy. The ability to localize the previously ablated tissue in 3D space may improve targeting for image-guided follow-up biopsy within focal therapy protocols.

**Key Words:** Prostate cancer; focal therapy; longitudinal follow-up; MRI; image processing; three dimensional; biopsy; deformable registration.



## INTRODUCTION

Contemporary methods of multiparametric magnetic resonance imaging (mpMRI) of the prostate have greatly improved the ability of radiologists and urologists to detect prostate cancer (1). mpMRI allows physicians to diagnose clinically significant cancer in its early stage, to plan prostatectomy and radiation therapy, and to detect local recurrence.

Combined with the trend of earlier detection, noninvasive prostate cancer therapies are gaining interest. Focal therapies (FT) aim to combine oncologic benefit with preserved continence and erectile function. The use of this tissue-preservation approach is evolving, and FT are being applied to more aggressive disease than when initially proposed (2,3). Clinical FT trials depend on mpMRI for tumor localization, treatment planning, and posttreatment follow-up (4–7).

There is no consensus regarding optimal assessment of oncologic success of FT (3,5,8). Current criteria of successful FT involve negative histology at the treatment site. Different methods have been proposed to detect cancer recurrence after FT. Although invasive transrectal prostate biopsy or transperineal mapping biopsy are often performed, mpMRI-targeted biopsy has shown promising results (9,10). Such assessment by MRI requires an ability to delineate on imaging the ablation zone (AZ) that is characterized histologically by homogeneous coagulation necrosis (11,12). In addition, it has been suggested (7,13) that mpMRI underestimates the total tumor volume, requiring inclusion of some surrounding margin

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within the AZ for a complete focal ablation. After treatment, dynamic contrast-enhanced (DCE) MRI delineates AZ as a devascularized, nonenhancing area (4). Within several weeks after treatment, the AZ shrinks, often leading to a changed configuration of the gland (8,14).

These novel therapeutic developments require a reliable and accurate software system for assessment of the changes in the prostate gland, including tissue necrosis, because of ablation. To be effective, such a system must depict how the viable tissue is reorganized around the AZ, thereby requiring a comparison of pretreatment and posttreatment images of the prostate. Development of image registration methods for this application is challenging. First, one must register longitudinal MRI, including different sequences, across different time points. Second, inherent in focal therapy, the tissue changes are inhomogeneous. Third, the variations in shape between the preoperative and the postoperative examinations are highly dependent on treatment delivery, location of the tumor, energy choice, and surrounding tissues. These factors make it difficult to use a normative atlas to facilitate registration.

Fei et al. (15) described a mutual information (MI)-based rigid-transform method to align a preoperative prostate T2-weighted (T2W) imaging sequence to an intraoperative sequence. Wu et al. (16) combined MI measure with low-order polynomial transformation to register spectroscopy with the prostate deformed by inflated intrarectal balloon. Using a finite elements method (FEM), Marami et al. (17) validated a registration approach between MRI acquired with an endorectal coil and the intraoperative MRI. Toth et al. (18) also used FEM to model the changes in prostate shape after laser ablation.

It has been previously demonstrated that the deformation of the gland after surgery is well captured by the affine transformation $T$ that incorporates nonisotropic three-dimensional (3D) sheer and stretch factors (19). This technique was also found to accurately define a 3D target for focal therapy based on MRI findings (7). We have now implemented an image-based framework for accurate estimation of the affine transform from the pre-FT to the post-FT MRI. This study evaluates the method using longitudinal mpMRI acquired before and after modern interstitial laser (4) and photodynamic FT (20). This study aims to assess this novel method of 3D co-registration of prostate MRI examinations performed before and after prostate cancer focal therapy, to facilitate focal therapy follow-up.

## MATERIALS AND METHODS

### Patients

Ten male patients, aged 65 ± 6.4 years, diagnosed with localized prostate cancer at biopsy (median prostate-specific antigen 5.1 ng/mL, median Gleason Score 6) underwent FT. Five patients were treated by interstitial laser procedure within the MRI bore (4) and five by photodynamic therapy, included in an earlier publication (20). Local institutional review board approved this study.

### Image Acquisition

All patients underwent a preoperative mpMRI, and two follow-up postoperative mpMRI (1 week and 6 months after treatment, Fig 1) using 3T Magnetom Trio system equipped with a pelvic phase array (Siemens Healthcare, Erlangen, Germany). Each examination used identical mpMRI protocol that included a T2W sequence, a diffusion-weighted sequence, and a DCE-MRI examination specified in detail below.

The anatomical T2W images through the pelvis were acquired using turbo spin echo sequence with the following parameters: repetition time = 4950 ms, echo time = 122 ms, axial orientation, 256 × 256 acquisition matrix, no interslice gap, 180 × 180 mm field of view, 3 mm slice thickness, and 3 signal averages.

Diffusion-weighted sequence was based on axial fat-suppressed single-shot echo-planar imaging with repetition time = 4100 ms; echo time = 86 ms; diffusion gradient b-values of 50 and 1000 s/mm$^2$; slice thickness 3 mm; 100 × 100 matrix; 200 × 200 mm field of view, and 10 signal averages. Apparent diffusion coefficient maps were reconstructed in line.

DCE-MRI examination consisted of continuous acquisition of T1-weighted 3-mm-thick contiguous images (240 × 240 mm field of view; matrix 128 × 128) every 15 seconds after intravenous administration of 0.1 mmol/kg of gadopentetate dimeglumine (Magnevist; Bayer HealthCare Pharmaceuticals, Montville, NJ). The contrast agent was administered as an intravenous bolus via power injector (Spectris; Medrad, Warrendale, PA), followed by a 20-mL saline flush, both administered at a 3 mL/s injection rate.

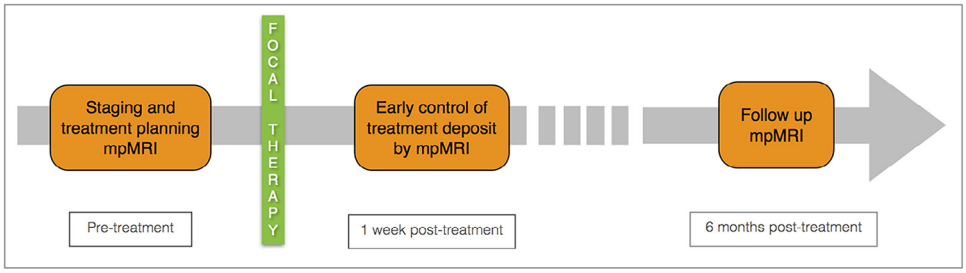


**Figure 1.** Timeline of treatment and imaging examinations.