MRI-guided prostate biopsy using surgical navigation software: device validation and preliminary experience

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Abstract
Magnetic Resonance (MR) Image-guided prostate biopsy in a 0.5-T open scanner is described, validated in phantom studies, and employed in two patients. The needles are guided by fast gradient recall and T2-weighted fast spin echo images. Surgical navigation software provided T2-weighted images that were critical in targeting the peripheral zone and the tumor. MR imaging can be used to guide prostate biopsy.

Index terms:

Magnetic resonance (MR), guidance
Magnetic resonance (MR), technology
Magnetic resonance (MR), image processing
Prostate, MR
Prostate, biopsy
Introduction

Prostate cancer is diagnosed currently by transrectal ultrasound- (TRUS-) guided needle biopsy prompted by either an elevated prostate-specific serum antigen (PSA) level or a palpable nodule. Guidance is limited by low sensitivity of 60% with only 25% positive predictive value (1, 2). These studies have shown that more than 20% of cancers required more than one biopsy session to diagnose. A randomized study of the efficacy of 6 versus 12 biopsy samples showed no difference in cancer detection (3); this suggests that the sensitivity of prostate biopsy is affected more by targets rather than number of samples. As it is a transrectal procedure, there is a risk of infection which ranges from 4-11%, depending on the antibiotic regime used. It is higher in patients with indwelling catheters, diabetes, and prior histories of urinary or prostatic infections. In this group it maybe a high as 17% (4).

Magnetic resonance imaging (MRI) can clearly depict not only the prostate itself but also its substructure including the peripheral zone (PZ) and on T2 weighted images identify nodules in PZ, though the specificity for diagnosis of cancer is limited. Since PZ is the most common site of origin of prostate cancer, among the three prostate zones (PZ, central zone (CZ) and transitional zone), localizing and targeting PZ and tumor foci in prostate biopsy may increase the cancer detection rate. For these reasons and those related to the problems of TRUS, Perotti et al. have used the endorectal MRI findings of suspected tumor foci to guiding the placement of needles during TRUS-guided biopsy (5). They localized suspicious tumor lesions/targets (based only on signal and not size) on the endorectal MRI and visually correlated the locations to ultrasound images, during TRUS-
guided biopsy. They found in a study of 33 patients that the accuracy of the TRUS guided biopsies aided by MRI was 67%.

In this paper, we propose a method to use MRI for prostate biopsy, not only to localize tumors and PZ, but also to guide the needles into focal lesions. This MRI-guided prostate biopsy is possible by advancing the technical capabilities of the MR-guided prostate brachytherapy in an open-configuration MRI scanner (6) and implementing surgical navigation software originally developed for neurosurgeries (7, 8). The MRI-guided prostate brachytherapy system, in the open-configuration MRI scanner, has demonstrated the ability to place needles through the perineum into specific targets under the guidance of real-time fast gradient recalled (FGR) images. Since we can insert the needles through perineum as opposed to transrectal approach, the newly proposed biopsy method can be applicable to the patient with prior abdominoperineal resection (APR) of the rectum. It will also allow direct sampling of the peripheral zone in a cranio-caudal direction, as opposed to transaxial, as in the TRUS approach.

The surgical navigation software, referred as the 3D Slicer hereafter, is in-house software originally developed to navigate neurosurgeries by generating simulated real-time images from pre-loaded MRI. In our MR-guided biopsy, it simulates real-time T2-weighted images that are impractical due to the long scanning time (18 seconds/scan) and poor delineation of PZ and tumor.

**Materials and Methods**

Two patients were selected based on the following selection criteria: Abnormal serum PSA levels; TRUS-guided biopsies are not possible due to prior APR of the rectum;
MRI screening shows suspicious tumor in the prostate. Both patients had prior histories of protocolectomies for ulcerative colitis. Case #1 was a 59-year-old man with a rising PSA of 6.1 on 8/6/98 and 8.8 on 3/11/99. The second patient (case#2) had rising PSA from 4.1 in 1989 to 43.5 on 8/19/99. The nature of biopsy procedure was discussed with the patients and informed consent was obtained.

**Pre-operative 1.5-T MRI study**

Each patient had an MR exam with the pelvic phased-array coil at 1.5-T MRI (Signa LX, GE Medical Systems, Milwaukee, WI). The images were analyzed to determine if there were any MRI suspicious lesions and to evaluate the size and location of the gland and its substructure. The 1.5-T T2-weighted images were fast spin echo (FSE) images (4050/135, field of view of 14cm, section thickness of 4mm, section gap of 0 mm, matrix of 256 X 224, 3 signal averages). These images provided planning information for the biopsy both for target definition and depiction of the prostatic zonal anatomy.

**Intra-operative imaging equipments**

The biopsy procedures were performed in the open-configuration 0.5-T MR scanner (Signa SP, General Electric Medical Systems, Milwaukee, WI), referred to an Intraoperative MRI (IMRI) scanner (9). The scanner realizes real-time MR imaging while allowing the physicians' access to the interventional field from a gap between two vertical superconducting coils (9).

The 3D Slicer (Figure 1) is surgical simulation and navigation software to display multi-modality images three- and two- dimensionally. The major contribution of the 3D Slicer in the MR-guided prostate biopsy is to simulate real-time T2-weighted images
otherwise not practical using the IMRI scanner. The simulation was possible by resampling the pre-loaded 0.5-T T2-weighted (FSE) images taken a few minutes before the needle placements. The resampling plane of the simulated real-time T2-weighted image should be at the same scanning location and direction of the single slice real-time FGR images, so that the physician can intuitively understand the correspondence between the two images. The location and direction of the FGR images can be retrieved by the 3D Slicer from the IMRI scanner through on-line real-time network communication; thus the simulated real-time T2-weighted images and the real-time FGR images are updated simultaneously and displayed side by side in the two in-bore displays. In this paper, we will refer the simulated real-time T2-weighted images as “real-time T2-weighted image” for the simplicity.

An imaging workstation (Ultra 30, Sun Microsystems, Mountain View, CA) for the 3D Slicer has been set up next to the scanner console in our interventional MRI suite (10). The workstation is connected to two monitors driven by separate graphics accelerator cards (Creator 3D, Sun Microsystems, CA), which are both installed inside the bore of the magnet or in-bore. One video output is intended for the computer operator’s display, and the other is for the physician performing the procedure; this display signal is converted to an NTSC video signal and passed to an in-bore monitor placed next to the other in-bore monitor displaying images from the MR scanner.

The scanner and the imaging workstation have a transmission control protocol/internet protocol (TCP/IP) interface for on-line and real-time image transfer. The speed is 10 mega bit per second (Mbps) for each machine on the switched Ethernet, and
155 Mbps through the ATM equipment, thus each workstation communicates maximally at 10 Mbps to another workstation.

**Validation studies**

We performed phantom validation studies to assess the accuracy of the surgical navigation by the 3D Slicer. The phantom (GEMS Quality assurance phantom, General Electric Medical Systems, Milwaukee, WI) was a cylindrical plastic container filled with a solution of doped water with characteristic sub container markers (lines, shapes, letters) inside.

The first part of the validation studies involved five real-time FGR images (axial, 24.5/12.1, field of view of 24 cm, section sickness of 5.0 mm, matrix size of 256 x 128, 1 signal averages) at randomly selected locations of the phantom and their corresponding real-time T2-weighted FSE image processed by the 3D Slicer from volumetric T2-weighted FSE images (4050/135, field of view of 24 cm, section thickness of 4 mm, section gap of 0 mm, 256 X 224 matrix, 3 signal averages). Intensity profiles of two randomly selected lines cutting through the markers were generated from both FGR and T2-weighted images to compare the location of intensity drops/rise at boundaries of the markers.

In the second part of the study, we created a check-board composite of real-time FGR and T2-weighted images to investigate the discrepancy of the two images due to the reconstruction inaccuracy and chemical shift. The degree of image matching was measured by five readers as a group by classifying the continuity of the marker boundary on consecutive cell borders. The classifications into no gap, half pixel gap, and one pixel
gap were performed at all the crossing points of the cell borders and the marker boundaries.

**Patient preparation**

These biopsies are currently performed under general anesthesia, as targeting specific foci requires minimum motion of the pelvis. Several days prior to the biopsy, the patients were evaluated by the anesthesia service, as they do of all men undergoing anesthesia in an MR environment. Cardiac ischemia is a contra-indication for general anesthesia in the MR environment. On the day of the procedure the patient came to the IMRI suite and was prepared for the biopsy. The patient was positioned in the lithotomy position, with the table placed in the vertical gap of the scanner.

A needle guidance template was set against the perineum and attached to the table. The template, originally developed for prostate cancer brachytherapy, has a grid of 0.0059” holes spaced 5 mm apart. The template was registered to the IMRI scanner using the optical tracking system (Flashpoint 5000, Image Guided Technology, Boulder, CO) integrated to the scanner (11). This registration achieves geometric correlation between the template and patient anatomy, enabling the selection of a hole that will guide a biopsy needle towards the target determined from the scans. The usage of the template including the detail of the registration is presented in (12).

We performed T2-weighted FSE imaging (axial and coronal, 6400/100, field of view of 24cm, section thickness of 3.5mm, section gap of 0 mm, matrix of 256 x 128, 2 signal averages) in the IMRI scanner using a flexible external pelvic wrap around coil. These 0.5-T T2-weighted images were correlated with the 1.5-T T2-weighted images to
define the PZ; then any suspicious lesion were identified and localized in 0.5-T T2-weighted images. We measured the coordinates of the targets so that we can stereotactically approach the target using the template. The 0.5-T T2-weighted images (axial and coronal) were loaded into the 3D Slicer to provide guidance into the PZ and suspicious tumor lesions during needle insertion.

**Biopsy method**

We placed the needles using the two guidance methods; first using the real-time FGR imaging (24.5/12.1, field of view of 24cm, section sickness of 3.5mm, matrix size of 256 x 128, 1 signal averages), and then real-time T2-weighted processed by the 3D Slicer.

The real-time FGR images were single slice scan updated every 8 seconds, and were used to guide the needle by confirming that the target was in the path of the needle. The real-time T2-weighted images were also updated every 8 seconds, and were used to find the T2-weighted information elucidating the position of the PZ and the suspicious lesion(s).

The sextant and targeted biopsies of suspicious lesion were performed with a MR-compatible single action biopsy needle (Single Action Biopsy Device; U.S. Biopsy, Franklin, IN). The needle is 18-gauge with 20 mm throw and trocar tip. For each needle placement, a hole that will guide a biopsy needle towards the target was selected and target depth was notified to the physician. Each specimen was carefully labeled based on the location it came from, prior to submission to Pathology.
The pathological results for all biopsy specimens were recorded and full analysis included documentation of the pathology—presence or absence of tumor. If a cancer was diagnosed, each specimen’s Gleason score was recorded.

Results

Validation studies

Figure 2 shows a real-time FGR and its corresponding real-time T2-weighted image prepared by the 3D Slicer. The images include the two lines along which intensity profiles were created; the vertical line cut the large marker in the center and two subsequent smaller markers, and the horizontal line cut two circle markers in the PZ in addition to the large central markers and its two subsequent rectangular markers. The intensity profiles along the vertical and horizontal lines are also illustrated (Figure 2). At each boundary of the markers, the intensity drop and rise occurred at the same location in FGR and T2-weighted images. In horizontal profile, we observed similar signal drop due to an inhomogeneous signal sensitivity caused by the use of a surface coil.

This visual finding is objectively re-confirmed by the second part of the validation study. We measured the discrepancy of the boundary of the markers at 289 points in five images of the checkboard composite images (37 – 96 points/slice, total). Figure 3 is a representative composite image chosen from the five slices. The result in Table 1 indicates that the average boundary mismatch is 0.112 mm (standard deviation 0.255 mm). At any point in all of these measured points, the mismatch was not more than 2 pixels or 1.88 mm.
Clinical studies

In both cases, 1.5-T T2-weighted images allowed a clear depiction of prostate PZ (Figure 4). Also in both cases, suspicious tumor lesions were found at the apex and mid gland levels. In case #1 the images revealed a large gland with a moderate amount of Benign Prostatic Hyperplasia (BPH). The BPH caused considerable compression of the PZ, causing it to appear thin and difficult to identify at some transaxial levels.

Case #1 indicated the usefulness of MRI in sextant biopsy, due to the compression of the BPH. When it the PZ is so thin the T2W images are critical to guide the needle directly into the PZ. As is shown in Figure 5, the real-time FGR images delineated the gland, the rectum the catheter and bladder, but not the internal zones of the prostate. The real-time FGR images also showed needle artifact indicating the location of the needles. On the other hand, real-time T2-weighted images from the 3D Slicer distinguished PZ that is critical for the sextant biopsy approach. The combined information from the needle position in FGR image and T2-weighted images was helpful in placing needles in the PZ. With coronal imaging, we could control the needle insertion depth to precisely collect the sample tissue in the PZ (Figure 6). The pathology results for the sextant and targeted biopsy from the case #1 were all negative for tumor.

The availability of real-time T2-weighted images by 3D Slicer was also very valuable in Case #2 (Figure 7) where the real-time T2-weighted images clearly identified the same suspicious foci as the 1.5T images, which is not visible on real-time T1-weighted images. Pathology in this patient showed prostatic adenocarcinoma (Gleason score 3+3) in the samples from the targets in the left apex and left mid-gland. The pathological finding from the sextant biopsies showed no tumor.
Discussion

The initial experience we have gained from the two feasibility studies and the phantom validation studies lead us to believe that MRI can be used to target the PZ and prostate nodules in prostate biopsy. By adapting this approach, we can perform MRI-guided percutaneous prostate biopsies with unobstructed access to the prostate through the perineum. We have previously performed transgluteal percutaneous MR and CT-guided biopsies of the prostate gland (13). While this approach is feasible, it is limited by the long trajectory and distance from the skin the gland. This long distance precludes accurate navigation and control of the needle. Based upon our brachytherapy and biopsy experience we believe it is desirable to direct the biopsies through the perineum. The access route is direct and the sampling of the peripheral zone can be maximized. The volume of PZ in each sextant biopsies will likely be increased, using this approach, if compared to transrectal samples. While we have not evaluated this feature at this time we believe that this will be an added benefit to MR’s ability to target specific lesions in the gland.

With regard to the accuracy of the image guidance method, the validation studies showed that it is possible to be as accurate as 0.112 mm. Considering that the thickness of the PZ can be as thin as 2~3 mm, this accuracy of 0.112 mm (standard deviation 0.255mm) is in our opinion, clinically acceptable, to target both PZ and any suspicious tumor targets. The tumor targets will not usually be less than 5mm in size in any one dimension.

Although our preliminary experience shows the promising aspects of MR-guided biopsy, the success of the procedure relies on the ability to localize suspicious lesions and the PZ using the 0.5-T IMRI. A previous study (14) discussed the issue by comparing the image quality in a subset of 20 patients, evaluating each of the studies for ease of
identification of the gland, its substructure, and abnormal foci from the endorectal coil 1.5-T images and the pelvic wrap 0.5-T images. In almost all aspects the 0.5-T images compared very favorably with the 1.5-T images. The only area where a difference was found was in the identification of focal lesions, in 12 of 20 men, suspicious foci were identified at 1.5-T and not at 0.5-T alone. This is the reason why we need to refer to the pre-operative 1.5-T MRI to identify and localize suspicious tumor foci in 0.5-T MRI.

A more objective approach to correlate 1.5-T and 0.5-T MRI to overcome insufficient imaging capability of 0.5-T MRI is by using deformable registration of 1.5-T MRI to 0.5-T MRI. By warping the 1.5-T MRI to match real-time FGR images, a physician can have an access to more detailed information about the tumor location while keeping the real-time imaging capability of IMRI. This deformable registration can be later generalized for TRUS-guided biopsy to fuse diagnostic MR onto the TRUS images.

In conclusion, we found MR-guided biopsy in the open-configuration MR scanner navigated by real-time FGR and T2-weighted images is feasible to perform sextant and targeted prostate biopsies through the perineum. The availability of real-time T2-weighted images provided by the 3D Slicer was critical in targeting the PZ and tumor. The phantom validation studies showed the discrepancy between real-time T2-weighted image and FGR image is clinically feasible 0.112 mm. While both cases indicated that the guidance with real-time T2-weighted images is very useful to ensure sextant sampling of PZ, the other cases also indicated that the method is suitable for targeted biopsy.
References


14. McTavish J, D'Amico A, Cormack R, Jolesz F, Tempany C: Evaluation of interventional MRI images (0.5T) of the prostate gland compared to endorectal coil MRI images (1.5T) in men undergoing MR guided brachytherapy. ISMRM, 1999.
Table 1: Results of phantom validation study

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Captions for illustrations

Figure 1: The 3D Slicer. Surgical navigation software to guide biopsy approach to the target with 2D and 3D display of pre-loaded images. The software is integrated into IMRI scanner to achieve on-line transfer of the images.
Figure 2: Transverse MR images of the phantom and intensity profile plotting to assess the accuracy of the method. (Top left) Real-time FGR image with a horizontal and a vertical line for intensity profiling. (Top right) Real-time T2-weighted image generated by the 3D Slicer in the same imaging plane of the FGR image. (Bottom left) Intensity profile plotting on the horizontal sample line in the FGR and T2-weighted images. The locations of intensity drop/rise at the boundaries of substructure matches reasonable well. (Bottom right) The plotting along the vertical sampling line also matches well.
Figure 3: A composite checker-board image from a real-time FGR image and the T2-weighted image on the same scanning plane. Size of boundary gaps at cell borders in the image and the other four composite phantom images are measured and summarized in Table 1.

Figure 4: 1.5-T T2-weighted image (left), 0.5-T real-time FGR image (middle), and 0.5-T real-time T2-weighted image (right) of the prostate gland. 1.5-T weighted T2-weighted
images are used to identify PZ and tumor foci in the PZ, while 0.5-T images are mainly used for guiding the needle to the pre-identified lesion and targets.

Figure 5: Axial real-time FGR images (top row) and real-time T2-weighted images generated by the 3D Slicer (bottom row) in sextant biopsy of case #1. The T2-weighted images are generated by resampling pre-procedural T2-weighted FSE (axial, 6400/100, number of slices 19, field of view of 24cm, section thickness of 3.5mm, section gap of 0 mm, matrix of 256 x 128, 2 signal averages). Shadow artifacts (arrows) in the real-time FGR images indicate the location of needles. The real-time T2-weighted images are useful for placing the needles in PZ.
Figure 6: Coronal view of (left) real-time FGR image and (right) real-time T2-weighted image. The tip of the needle, appearing as shadow artifact in real-time FGR image, reached the PZ appearing as high intensity area in real-time T2-weighted image. The neck of the trocar tip, where sample tissue is collected, has narrowing shadow in the real-time FGR image. The insertion was guided in such a way that the narrowing is placed in the PZ.

![Figure 6: Coronal view of (left) real-time FGR image and (right) real-time T2-weighted image.](image)

Figure 7: Left: 1.5-T T2-weighted FSE for identifying the tumor foci prospectively (arrows). Middle: Real-time FGR to guiding needle appearing as shadow artifact (arrow head). Left: T2-weighted image to visualize the suspicious tumor lesion processed by the 3D Slicer. Note that the tumor foci is well visualized both in 1.5-T and 0.5-T T2-weighted images, while T1-weighted image does not show the PZ, tumor or a distinctive boundary of the gland. Pathology result of the sample taken from the lesion was prostatic adenocarcinoma (Gleason score 3+3).

![Figure 7: Left: 1.5-T T2-weighted FSE for identifying the tumor foci prospectively (arrows). Middle: Real-time FGR to guiding needle appearing as shadow artifact (arrow head). Left: T2-weighted image to visualize the suspicious tumor lesion processed by the 3D Slicer. Note that the tumor foci is well visualized both in 1.5-T and 0.5-T T2-weighted images, while T1-weighted image does not show the PZ, tumor or a distinctive boundary of the gland. Pathology result of the sample taken from the lesion was prostatic adenocarcinoma (Gleason score 3+3).](image)