Seed Localization in MRI-guided Prostate Brachytherapy using Inversion-Recovery With ON-Resonant Water Suppression (IRON)

N. Kuo[1], J. Lee[1], C. Tempany[2], M. Stuber[1], and J. Prince[1]
[1]Johns Hopkins University, Baltimore, Maryland, United States, [2]Brigham and Women's Hospital, Boston, Massachusetts, United States

Introduction: Prostate brachytherapy is a common treatment for low-risk prostate cancer involving the insertion of needles in precise locations of the prostate to implant rice-like radioactive sources known as seeds. Seed localization in relation to the prostate is one of the major current limitations of intraoperative treatment planning for prostate brachytherapy [1]. This issue limits the effectiveness of real-time dosimetry and therefore leads to suboptimal prostate cancer treatment. While transrectal ultrasound and X-ray have been the traditional means of image guidance, MRI is a promising modality for guiding brachytherapy, having been validated in over 500 patients using the GE Signa SP 0.5T open-bore scanner [2] and now progressing toward closed-bore scanners through the aid of robotics [3,4]. Previous studies assessing MR pulse sequences in imaging brachytherapy seeds [5,6] have shown that localization is problematic because the seeds generally appear as diffuse, dark voids. Nonetheless, recent developments in pulse sequences that image local changes in susceptibility provide a new opportunity to revisit this topic. We therefore provide an initial demonstration of the potential to image and localize brachytherapy seeds using Inversion-Recovery with ON-resonant water suppression (IRON) [7].

Methods: IRON is a versatile MRI methodology that enables positive contrast visualization in regions of magnetic field susceptibility. It selects off-resonant protons near a susceptibility-generating particle by deliberately applying a spectrally selective on-resonant RF saturation pulse with a limited bandwidth prior to the imaging part of the sequence. This suppresses the on-resonant water protons of the background tissue but leaves the off-resonant protons near the particle unaffected. The area around the susceptibility-generating particle can thus be seen with positive contrast.

Once IRON images have been acquired, the brachytherapy seeds must also be localized for dosimetry calculation. We developed a localization algorithm based on the blob detection technique of the Laplacian of a Gaussian [8] to determine seed coordinates from the IRON volume.

We built two phantoms to assess the potential of using IRON for prostate brachytherapy seed visualization and localization. The first phantom is made of gelatin (Knox; Kraft Foods, Tarrytown, NY, USA) embedded with five layers of three "seeds" each. Actual seeds are composed of radioactive agents of iodine-125 or palladium-103, X-ray markers of gold or silver, and shells of titanium or stainless steel; therefore, the "seeds" in each of the five layers are made of different seed-related materials, in particular, 99.95% pure nonradioactive palladium, 99.95% pure silver, titanium alloy Ti6Al, nonmagnetic stainless steel, and nonradioactive training seeds (Theraseed; Theragenics Corporation, Buford, GA, USA). The second phantom is also made of gelatin, but now in a 61 nonradioactive palladium "seed" configuration implanted using an actual treatment plan. MR imaging was carried out on a 3T MRI Achieva system (Philips Medical Systems, Netherlands).

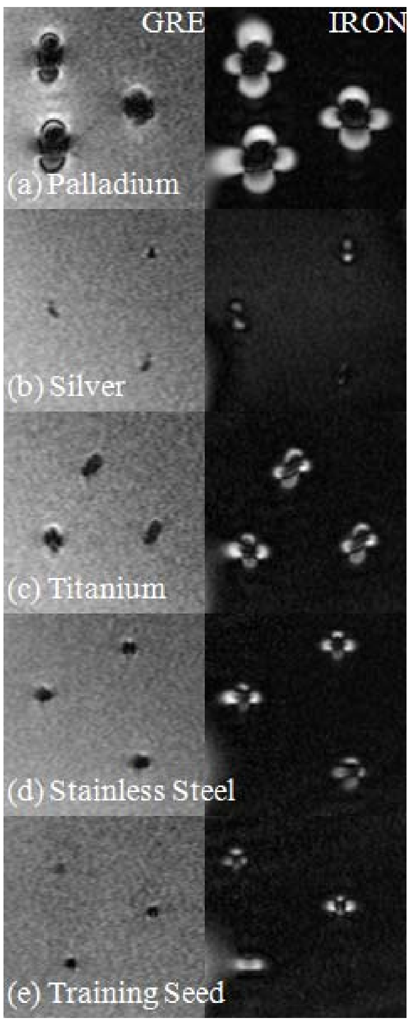

Fig. 1. GRE and IRON slice images of the five phantom materials. B_0 is oriented upward.

Results: The resulting MR images of the first phantom are shown in Fig. 1. The difference that IRON makes in the appearance of the "seeds" is clearly evident in this figure, displaying as dark unclear voids in one case and bright dipoles in the other. The background is also significantly darkened due to the suppression of on-resonant protons in the gelatin. Due to the properties of IRON, these differences would be even more striking in a more realistic study since background clutter would convolute the appearance of the seeds in GRE images but not in IRON images. Fig. 2 shows a slice through the simulated and actual IRON MRI volumes of the second phantom. We applied our localization algorithm to both cases, resulting in 61 of 61 seeds correctly localized in the simulation case with mean localization error of 1.1643 mm, and 62 seeds identified (1 false positive) in the actual IRON case with a mean localization difference of 2.5660 mm when compared to manual segmentation (see Fig. 3).

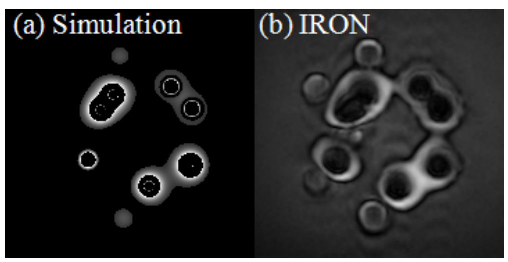

Fig. 2. Simulation and IRON slice images of the 61 seed phantom. B_0 is oriented into the page.

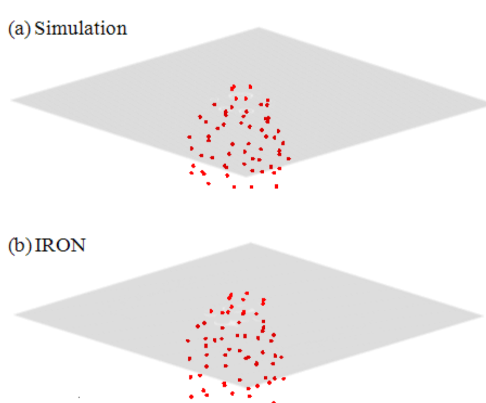

Fig. 3. Simulation and IRON reconstruction of localized seeds in the 61 seed phantom. B_0 is oriented downward.

Discussion: In all, this study shows the feasibility of using the IRON pulse sequence for seed localization in MRI. With palladium depicted very well in the phantom images, we expect actual palladium-103 seeds to be similarly well visualized through IRON imaging. Even iodine-125 seeds should be visible with IRON MRI as their titanium or stainless steel shells should produce reasonably large signals. The initial localization algorithm also shows that seeds imaged by IRON can be easily detected. IRON therefore equips MRI-guided brachytherapy with an effective seed localization technique to improve intraoperative treatment planning and optimize prostate cancer treatment.

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