Design of an Endorectal Coil for MR-guided HIFU Therapy of the Prostate

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Purpose: Prostate cancer is a significant health risk to men of all ages. MRI is utilized to localize and identify prostate cancer lesions using either external pelvic receive coil arrays or endorectal coils for signal reception. Currently, MR-guided high intensity focused ultrasound (HIFU) is increasingly being investigated as a treatment option for prostate cancer. Due to space restrictions in the rectum, current prostate HIFU systems use external coils only. In this work, an endorectal HIFU transducer is combined with an endorectal receive coil in a simulation study to assess the coil performance.

Methods: Simulations were carried out at 63.7 MHz (i.e., 1.5T) using the finite element method (HFSS, ANSYS, Inc.) to investigate the influence of HIFU transducers on signal characteristics. Two coils were modeled: (1) a simple coil modeled after the MedRad endorectal coil and (2) an in-house design of an endorectal coil. The coils were modeled inside a rectum 3.5cm in diameter with the prostate and surrounding tissues. Both coils were placed close to the prostate (0.6 cm) and are large enough to provide a full view of the prostate. The simple coil measures 4x9cm with rounded corners, and utilizes a co-axial wire. The coil's co-axial ground is split at the top, and a single capacitor is used for tuning (Fig. 1). The in-house design is a square loop 4x8x0.32cm with matching and tuning capacitors at the coil.

Since transducer and coil will be immersed in cooling water during the ablation procedure, B_1 fields and S_{11} parameters were compared for the coil in air and in water. Additionally, simulations were carried out with and without the presence of an ultrasound transducer (3.5x5.5 cm, Image Guided Therapy, Pessac, France, cf. Fig. 1).

Results: For the two sets of experiments a change in the coil profile is observed. With water present around the coil, a significant change of load occurs. This causes the Q of the coil to change and a resonance shift (Fig. 2). The resonance of the simple coil shifts ~13MHz, while the in-house coil shifts more than 14MHz. The shift of frequency causes an 80% or more loss of signal intensity within the region of interest. There is also an observable change in the shape of the field profile, shown in Fig. 3. After the transducer is placed within the vicinity of the coil, a less significant change is observed in the ROI. When a metal backing was placed in close proximity to a surface coil, a change of coil properties was observed [1]. While a flat backing should produce a uniform disturbance, the curved surface of the transducer creates a varied disturbance. In air, a decrease of signal strength is seen but also a more uniform profile in the ROI (Fig. 3).

The in-house coil was tuned to work in water and has a much more uniform field profile, shown in Fig. 4. When the transducer was placed in the model, no noteworthy change was observed. The in-house coil was able to increase the B_1 field by eight-fold with respect to the simple coil.

Discussion and Conclusion: The observed change in the response of the coil suggests further research is warranted to design a coil that can be utilized in close proximity to a HIFU transducer. Additionally, the unfavorable effects of water loading on the coil must be taken into consideration. While it appears at the outset that the transducer is detrimental, with proper positioning and design the transducer's effect may actually prove to be an advantage. As shown, through proper tuning and matching the effects of water can be mitigated. Despite the challenges presented by the use of an MR-HIFU endorectal coil, a suitable design can be obtained.

References: [1] Ong K.C., et.al. 1995, JMRI, 5:773-777

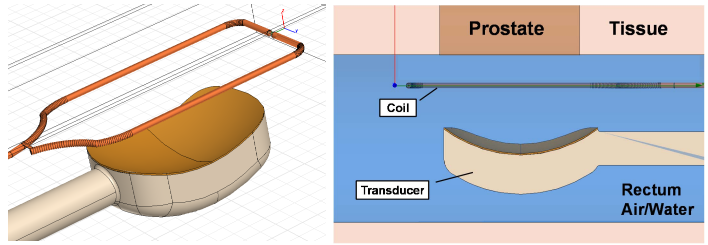

Fig. 1: Simple endorectal coil with HIFU transducer (left) and a cross plane cut of the simulation environment (right).

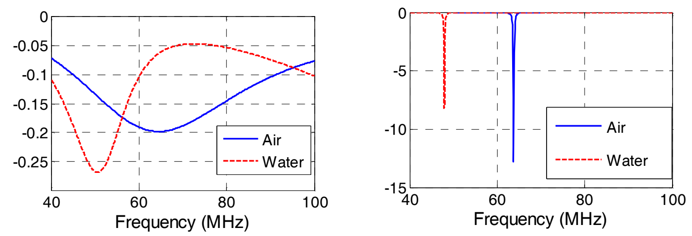

Fig. 2: S11 response from the simple coil (left) and in-house coil (right) in the different scenarios.

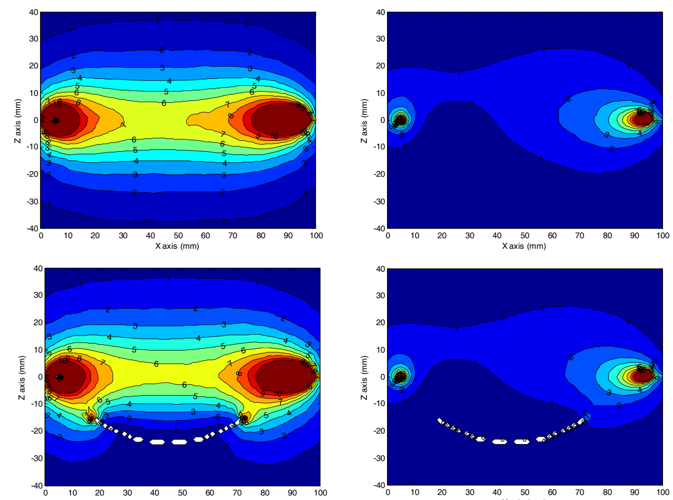

Fig. 3: Magnetic field map through the center of the simple coil for air (top left) and water (top right) when the transducer is not present, and in air (bottom left) and water (bottom right) when it is.

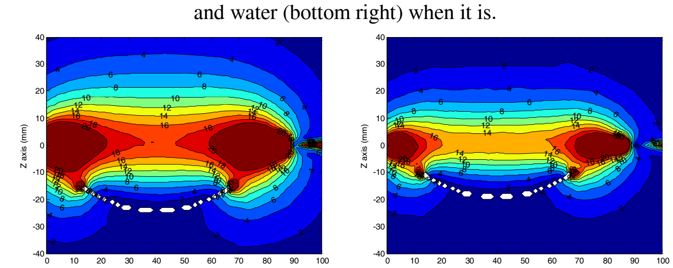

Fig. 4: Magnetic field map of the in-house coil in air (left), and after tuning for use in water (right). The scale has been altered to adapt the increased signal intensity