A Dedicated 3 Tesla Prostate Coil for Magnetic Resonance Elastography, Imaging, and Tracking

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Introduction: Prostate cancer is the most common type of cancer in men. Early detection holds the promise for improved treatment and outcomes. Although biopsy is considered the gold standard for detecting cancer, it is invasive and can miss malignant tissue. MR elastography (MRE) is used clinically for diagnosing fibrosis and cirrhosis in the liver[1], and holds great potential for objective quantification of tissue stiffness in the prostate, which is important, since many tumors possess approximately 10 times higher stiffness than normal prostate glands, as demonstrated by ultrasound and MRI elastography[2,3]. We present a novel platform for MR imaging and elastography in the prostate, consisting of an endo-rectal probe incorporating an MR imaging coil providing improved SNR over surface imaging coils MR tracking coils in a tetrahedral configuration, allowing for correcting rotation and translation resulting from respiratory and peristaltic motion artifacts[4] and thereby performing lengthy scans, and a balloon compression mechanism, which generates large compressional and sheer displacements, which can serve to obtain higher spatial resolution MRE strain measurements.

Materials and Methods: The coil former was designed in two half shells: one contained the imaging coil, and the other contained five MR tracking coils (Figure 1a). The imaging coil was made with solid silver wire and tuned to 123.183MHz. The tuning capacitor was 44 pF and the loading capacitors were 102 pF and 151pF respectively. Network measurements were performed with an Agilent HP8751A Network Analyzer. At 123.183MHz a resistance of 51.6Ω and a phase of 13.7° was measured when the coil was loaded with both hands. Transmit detuning was implemented with a UM9415 pin diode. A semi-rigid coax cable connected the matching circuit of the coil with a can balun.

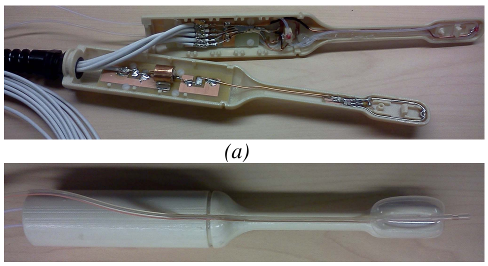

Figure 1: *Prostate coil (a) electronics overview (b) shell (c) tip (balloon on).*

Five tracking coils were placed in the upper shell around a polyethylene tube. Four coils formed a tetrahedron in the handle of the probe. The fifth tracking coil was placed above the tip of the imaging coil. Each tracking coil was connected to a 0.47” semi-rigid coaxial cable. At the end of the shell the semi-rigid coaxial cable was connected to small low loss flexible coax cable to interface with the system. The shell (Figure 1b) was built out of ULTEM™ using 3D printing technology (Stratasys). The outside features of the shell include a channel for a 12 French catheter, a channel around the shell handle to keep a condom in place (Figure 1b), and an indentation at the tip for a balloon. The balloon generates mechanical waves in tissue for MRE. The balloon compression system consists of a medical grade balloon (Vention Medical, MA, USA) at the tip of the probe, a TTL trigger signal unit for timing control and MR scanner synchronization, and a control unit for prostate compression and de-compression (Figure 2a). The trigger signal unit is located in the MR control room, receives a TTL trigger from the MR scanner or other source, converts the TTL using an electrical-optical converter, and sends optical signals to the control unit inside the scanner room. The control unit is an RF shielded aluminum Faraday-cage enclosure (Figure 2b) containing a pair of piezoelectric valves, valve drivers, an Optical-Electrical converter (OE converter) (CK1500, Carl’s Electronics, CA, USA) and a DC power supply. OP-AMPs manipulate the control signal and drive the piezoelectric valves (PS11111-B, HOERBIGER, Altenstadt, Germany) which generate pulsatile air flow to the balloon. One valve for inflation (positive pressure) and the other for balloon deflation (zero pressure). The balloon is operated at around 20psi and the air source is an industrial-grade 150psi pneumatic pump located in the control room. The system also allows 1-80 Hz frequencies to be created at depths of 7-8 cm, balancing penetration depth with resolution in MRE. Imaging experiments were performed on a 3T (Verio, Siemens Healthcare, Erlangen Germany). A dedicated 8-channel receiver was used for the prostate tracking and imaging coils. Imaging was performed with the prostate assembly combined in an array with a 32-channel Invivo cardiac array.

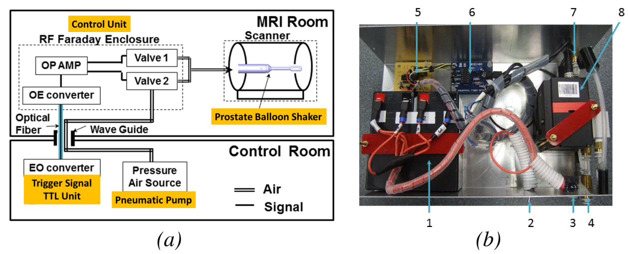

Figure 2: *(a) Prostate shaker platform (b) Control unit and components (1: battery, 2: power switch, 3: battery charge plug, 4: air inlet, 5: valve drivers, 6: optical-electric signal converter, 7: air outlet, 8: piezoelectric-valves).*

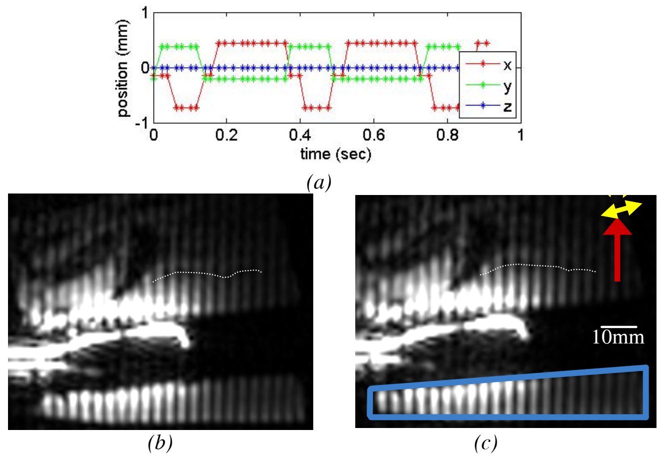

Figure 3: *Sequence used in a gel phantom contains inclusions (a) tracked coil positions during balloon cyclical expansion/compression (b) and (c) two sample tagged image frames during (blue: stationary, red: direction of wave propagation from coil/balloon surface, white dashed line: wavefronts, yellow: direction of particle motion).*

Results and Outlook: The platform provided high SNR for MR tracking as well as imaging (Figure 3). Figure 3a shows tracking coil positions along x (right-left), y (top-bottom), and z (in-out of scanner) for one tracking coil located at the tip of the probe during periodic inflation and deflation of the balloon. Measurements were very stable for displacements as small as 0.6mm. Figure 3b shows sample tagged images showing propagation of waves away from the balloon surface with particle motion direction depicted by the yellow arrow, wave front propagation direction away from the balloon surface depicted by the red arrow, and the stationary area behind the balloon highlighted in blue. The control system and balloon motion did not result in significant imaging radio-frequency interference or artifacts while maintaining excellent SNR. The ability to provide large displacements, on the order of a few mm, while preserving the ability to consistently track and correct for undesirable motions ales than a mm, is very encouraging for higher resolution and accuracy in MRE strain measurements. This system will now be used to image sheer and compressional straining in a dog model of prostate cancer.

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