Evaluating the Feasibility of Multi-Slice Endorectal Magnetic Resonance Elastography for Prostate Cancer Localization

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Introduction: The stiffness of malignant prostate tissue is elevated as compared to normal or benign tissue, which suggests that the biomechanical properties of prostate tissue may be an independent marker for prostate cancer. Using dynamic MR elastography, micrometer amplitude shear waves are propagated into tissue, and the resulting tissue displacements are measured to calculate the underlying stiffness distribution of tissue. Unfortunately, these waves experience significant attenuation as they propagate through soft tissue. As a result, there have been few successful attempts at measuring prostate stiffness in patients using external mechanical actuators[1]. Recently, the feasibility of using an intracavitary transurethral actuator for magnetic resonance elastography (MRE) has been proven to be technically feasible *in vivo*[2] and a previous study, conducted in *ex vivo* human prostates, has reported this technique to have a high sensitivity (89.1%) and specificity (89.5%) for identifying malignant prostate tumours[3]. The advantage of using an intracavitary actuator over an external actuator is that the necessary penetration depths of these shear waves is reduced from 10-15 cm to 3-5 cm. A shorter penetration depth allows for higher frequency shear waves to be sent into the organ of interest giving an estimated 3 fold increase in the spatial resolution of the technique. With experiments conducted in both an *in vivo* canine model and in tissue mimicking prostate phantoms embedded with tumour mimicking inclusions it has been demonstrated that an intracavitary MRE approach has the potential to identify tumours as small as 0.05cc in volume[4]. These results suggest that intracavitary MRE has the sensitivity to detect tumours that are well below 0.5cc, which is considered to be the lower size limit of clinically significant tumours[5]. Although the results of transurethral MRE are encouraging, there are challenges to routine diagnostic use of this technique. A more practical implementation of intracavitary MRE for prostate cancer detection is to use an endorectal coil to generate shear waves in direct proximity to the gland while simultaneously imaging with the coil. *Therefore, the objective of this study was to evaluate the feasibility of using an endorectal coil for intracavitary prostate MRE and to evaluate the feasibility of obtaining stiffness measurements across a volume equivalent to the prostate gland in a single imaging acquisition.*

Methods: Experiments were conducted using a custom-made prostate phantom from CIRS Inc. (Norfolk, VA., USA) that mimicked the size, geometry, and stiffness of the gland. The prostate region of the phantom was embedded with four spherical inclusions (two 1cm diameter, two 6mm diameter) with stiffness values that were twice that of the prostate (Fig.1). All MR imaging in this study was conducted on a 1.5T closed bore MR imager (Signa; GE Healthcare, Milwaukee, WI, USA) using a rigid prototype endorectal coil (Sentinelle Medical Inc., ON, Canada) for simultaneous imaging and shear wave generation. The rigid endorectal coil was mechanically coupled to a custom made piezoceramic actuator that was designed and manufactured in house (Fig.2). To test the effects of vibration on the imaging performance of the endorectal coil, MR images were acquired using the endorectal coil with and without vibration, using oscillation frequencies ranging between 100-400Hz, and measuring the signal to noise ratio of these images. To evaluate the ability of endorectal MRE to resolve local regions of stiffness within an equivalent prostate volume MR elastography was conducted using a modified fast gradient echo sequence with sinusoidal gradients encoding longitudinal motion. Imaging was conducted in both axial and sagittal planes using an oscillation frequency of 400Hz, a matrix size of 128x128, a field of view of 16 cm, flip angle = 30 degrees, 3 sinusoidal gradients (4 G/cm, in S/I direction), number of excitations = 4, 4 phase offsets, and a 2 mm slice thickness. Multi-slice MRE covering the entire prostate volume (27 slices, 2mm slice thickness) was performed in the axial plane using a TE = 10ms and acquiring all slices in a single TR of 375ms. MRE in the sagittal plane was acquired using a TE = 10ms and a TR = 15ms. A magnitude multi-slice data set was acquired using a fast spin echo sequence (FRFSE-XL/90) in order to prescribe a region of interest (ROI) around each of the four inclusions throughout the entire prostate volume. These ROIs were then mapped onto their corresponding elastogram images and the mean stiffness of each inclusion volume was measured for both the endorectal and the transurethral MRE data sets.

Results: The SNR of the endorectal coil in the presence and absence of vibration was determined to be 107±8 and 110±4, respectively. Vibrating the endorectal coil did not affect the SNR, within error, over the entire range of frequencies and amplitudes investigated. To illustrate the capability of endorectal MRE to produce uniform propagation of shear waves across the entire length of the prostate a sagittal wave image has been shown in Fig.3B. Three elastograms from the multi-slice acquisition are shown in Fig. 3C. In each elastogram, the stiffness of the background, prostate, and inclusions can be visualized. The measured stiffness values for each inclusion with endorectal MRE are shown in table 1.

Discussion and Conclusions: The small micron vibrations necessary to conduct MRE do not seem to affect the SNR of the endorectal coil demonstrating the technical feasibility of endorectal MRE. The use of a ridged endorectal coil gives the capability of generating uniform shear waves across the entire length of the prostate, making multi-slice endorectal MRE possible in a single repetition time. Endorectal MRE was capable of resolving the 0.5 and 0.1 cc inclusions from background. The results of this study, in combination with the clinical availability of an endorectal coil, motivate further investigation of endorectal MRE in patients.

References: **1.** Kemper et al. ROFO, 2004 **2.** Chopra et al., MRM, 2009 **3.** Dresner et al., ISMRM, 2003 **4.** Arani et al., MRM, 2010 **5.**Wise et al. Urology, 2002

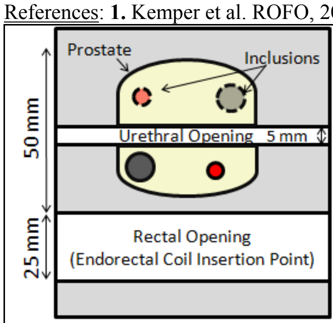

Figure 1: Schematic of prostate phantom depicting the endorectal and transurethral inserting points as well as the relative location of the 6mm (red) and 10 mm (black) diameter inclusions. The inclusions were twice as stiff as the prostate region of the phantom.

Figure 2: Picture of piezoceramic actuator mechanically coupled to the endorectal coil.

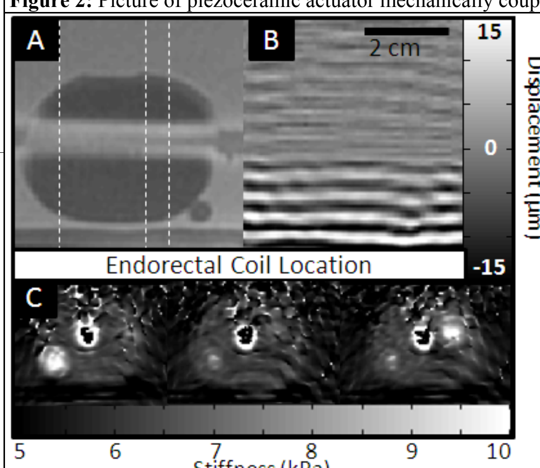

Figure 3: A) Sagittal Magnitude image of prostate phantom. B) Sagittal view of the 400Hz shear waves produced by the endorectal coil. C) Three axial elastograms of the prostate phantom, where each slice location is shown as a dotted white line in A), respectively.

Table 1: Stiffness measurements obtained using endorectal MRE for the prostate region of the phantom and all 4 inclusions. The expected prostate and inclusion stiffness values, as validated by compression testing, were 6.5±0.7 kPa 13±1 kPa, respectively.

Inclusion Diameter and Expected Stiffness	Measured Modulus by Endo-rectal MRE (kPa)
1 cm (top, 13kPa)	8±1
1 cm (bottom, 13kPa)	8±1
6 mm (top, 13 kPa)	6.8±0.7
6 mm (bottom, 13kPa)	7.2±0.5
Prostate Stiffness (6.5 kPa)	6.2±0.3