Evaluation of intracavitary pneumatic actuators for prostate MR elastography

R. Chopra[1,2], A. Punjani[1], A. Arani[1,2], A. Chau[1], and D. Plewes[1,2]

[1]Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada, [2]Medical Biophysics, University of Toronto, Toronto, Ontario, Canada

Introduction

MR elastography (MRE) is a method for tissue stiffness imaging in which dynamic shear waves are propagated into tissue and measured using motion-sensitive MRI sequences. The production of shear waves is usually achieved using external mechanical actuators placed on the surface of the body [1]. Unfortunately, the attenuation of shear waves can be very large in tissue, so achieving shear wave propagation in deep-seated organs such as the prostate gland has been largely unsuccessful except at low frequencies [2]. One solution to this limitation is to place the source of vibration in body cavities close to the tissue region of interest in order to achieve adequate propagation of shear waves [3]. In the case of the prostate gland, the rectum and urethra offer natural pathways. The purpose of this study was to evaluate the feasibility of producing shear waves from transrectal and transurethral mechanical actuators using pneumatic energy sources. Previous work has used either piezoelectric or electromagnetic drivers.

Methods

Transurethral and transrectal pneumatic actuators were constructed from rigid plastic tubing with portions of the wall removed and replaced with a thin membrane. Vibration of the membrane was achieved using sound energy transmitted to the actuator from a remote loudspeaker (Delta Pro 12A, Eminence Speaker, USA) mounted in a custom enclosure. Sound was transmitted down a 1" diameter flexible hose. A photograph of a transrectal actuator is shown in Figure 1. The vibration of the membrane was first characterized using a scanning laser vibrometer (PSV400, Polytec, USA) to evaluate the frequency and amplitude response of the actuator. The surface displacement was also characterized in air and water to determine the influence of the mechanical load on the performance of the actuator. Actuators were subsequently embedded in a gel phantom comprised of 1.5% agar (Bacto Bacto Agar, Voigt Global Distribution, USA) and placed in a standard head coil in a 1.5T MR imager (Signa, GE Healthcare, USA) for MRE experiments. An axial gradient echo sequence (FGRE, TE/TR=25/30ms, 128x128, FOV=20cm, ST=5mm, 10NEX) with 8 bipolar sinusoidal gradients along the slice select direction was used to image shear waves propagating in the gel. The actuator was vibrated at 390 Hz (its natural resonance), and the bipolar gradients were at either 390Hz or 780Hz to evaluate the fundamental and first harmonic shear wave propagation from the actuator.

Results

Figure 2 shows the frequency response of a prototype transrectal actuator as measured with the scanning laser vibrometer. Actuators exhibited a different behavior in air and water, with a mechanical resonance at approximately 400 Hz. Overall, a maximum displacement of approximately 90µm was observed at the resonant frequency of 390Hz. Figure 3 shows the wave images and elastogram acquired using the tranrectal actuator shown in Figure 1. Vibrometer measurements (not shown) indicated that the membrane vibrated non-linearly at high sound intensities, so wave images were acquired at both 390 and 780Hz to evaluate whether the actuator produced shear waves at both these frequencies. Figure 3 b) and c) confirm the presence of shear waves at both frequencies. The elastogram calculated with MRE/Wave using the 390Hz wave images is shown in d), and depicts uniform stiffness estimates in the region adjacent to the actuator where the prostate gland would be expected. The calculated shear stiffness (18.9±1.5 KPa) agrees with the published value for this gel formulation (17.6+1.1) [4].

Conclusions

The generation of shear waves using intracavitary pneumatic actuators is feasible. Actuators designed for insertion into the rectum have been developed and produced shear waves at frequencies of 390 and 780 Hz in agar phantoms. These frequencies are potentially suitable for prostate elastography where detection of small inclusions is necessary. The vibrometer measurements enabled a thorough understanding of the performance of the actuators, and can be a valuable tool for the design of novel actuators for MRE.

References

[1] Rouviere et al,Radiology. 240 (2006) 440-448.
[2] Kemper et al, Rofo. 176 (2004) 1094-1099.
[3] Dresner et al, Proc. ISMRM (1999).
[4] Ringleb et al, MRM. 53 (2005) 1197–1201.

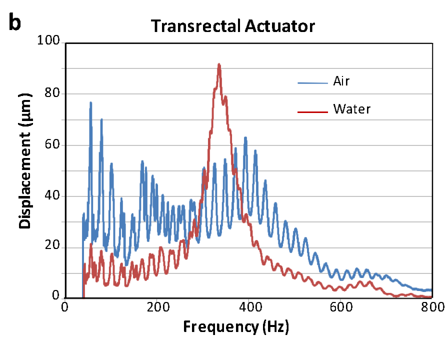

Figure 2: Laser vibrometer measurements of the vibration of a pneumatic transrectal actuator in air and water over a frequency range of 50 to 800Hz.

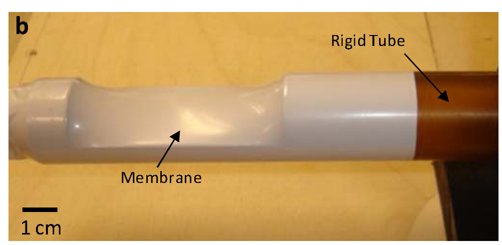

Figure 1: Photograph of a prototype pneumatic transrectal actuator for MRE

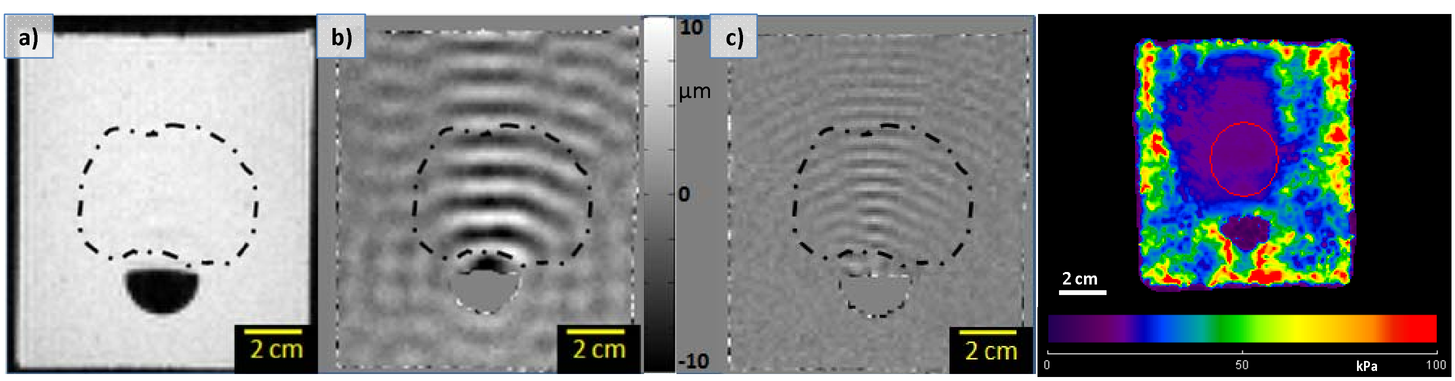

Figure 3: a) Magnitude MR image acquired transverse to a transrectal actuator embedded in an agar gel phantom. Wave images acquired at b) 390 Hz and c) 780 Hz depict propagation of shear waves in the adjacent gel. d) The resulting elastogram depicts uniform stiffness estimates in the region where the prostate gland would be. The calculated shear stiffness agrees well with the published value for this gel.