"SONOELASTOGRAPHY" IMAGING OF VIBRATION IN SOFT TISSUE

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INTRODUCTION

Many diseases in soft non-load bearing tissues like breast, prostate and liver alter their mechanical properties. For example cirrhosis is known to increase the shear modulus of liver while digital rectal examination of the prostate and breast self-examination are standard screening processes which detect qualitative increases in shear modulus in the fight against cancer. Various imaging techniques have been proposed and developed to image the relative mechanical properties of tissue [1]. Unfortunately, conventional CT, MRI, US imaging are **not capable** of imaging the relative (or absolute) mechanical properties of tissue.

In this work a technique which we have called sonoelastography is described. In sonoelastography forced external vibration in the low audio range (50-300 Hz) is applied to a region of tissue producing shear waves which propagate below the tissue surface. Megahertz range ultrasound is the used to scan the same region and collect data on particle displacement in the tissue being vibrated. Real-time Doppler methods are applied to estimate the relative vibration amplitude at each point in the region of interest. When the shear waves enter a small region with an elevated shear modulus, such as a tumor, the vibration image will show a region of decreased vibration at this location. By mapping the measured vibration amplitude to a gray scale a relative vibration amplitude image is produced.

THEORY

In this section the theory of lesion detection and vibration estimation are described.

Lesion Detection

A finite-element study [2] was performed to verify that a lesion contained with in an otherwise homogeneous region would be detectable using relative vibration. A two dimensional (2D) homogeneous- isotropic rectangular region, 50 mm by 100 mm, with a shear modulus of 7 kPa was modeled with a 6 mm square inclusion in it.. The inclusion was located at a point 25 mm from the right and top edges. The modulus of the inclusion was varied from 0.7 to 70 kPa in a series of program runs. The 2D domain was uniformly meshed using 2500 bilinear isoparametric elements with 1 mm grid spacing using a commercial FEM package (MSC/NASTRAN). The top and edges were modeled as free of normal stresses and the bottom edge was modeled as fixed. The vibration source was modeled as a point on the center of the top surface.

To assess the impact on the vibration field of the inclusion the vibration amplitude at the inclusion was compared to the amplitude at the same location without the lesion. This allowed the determination of the relative vibration amplitude. Figure 1 shows a chart of the results for forced vibration at 400 Hz as the modulus of the inclusion was varied over the indicated range. The relative vibration amplitude, which is amplitude at the lesion with the lesion present divided its value with the lesion removed, is plotted against the relative lesion stiffness, the ratio of the shear modulus of the lesion divided by the shear modulus of the surrounding material.

The results of the study [2] found in general that lesion contrast as visualized in sonoelastography increases with increasing relative lesion stiffness and with increasing frequency. Figure 2 shows the results of increasing frequency while holding lesion size and relative lesion stiffness constant.

Vibration Estimation

Ultrasound Doppler techniques are used to determine the amplitude of vibration at each point in the region of interest. By emitting ultrasound pulses at rate more than twice the frequency of the applied vibration, the displacement of particles at each point in the region of interest can be estimated. It should be noted that only the displacements in the direction of the ultrasound beam are capable of being measured. As a particle undergoes harmonic motion, the time it takes for the ultrasound beam to hit the particle and return varies slightly. To estimate the vibration amplitude, the amount of shift or cross

correlation between successive pulses is calculated. If the particle is not moving, successive pulses will correlate exactly. If the if particle is vibrating with a high amplitude successive pulses will decorrelate. The autocorrelation of a sequence of pulses (usually 16) is calculated and is mapped to a gray scale to create a relative vibration image.

RESULTS

Figure 2 shows images of an acoustic phantom containing an elliptically shaped lesion with a shear modulus 7 times that of the background tissue. The top image is a T2 weighted MR image taken at a slice through the embedded stiff lesion. The circular dark area in the top of the phantom is the urethra. The lesion itself is on the lower right hand side of the phantom. The middle image is a conventional ultrasound B-mode image of the same image plane as the MR image above it. It shows the urethra but not the lesion. The lower image is the vibration amplitude sonoelastography image, which was also taken in the same plane as the MR image. Here vibration amplitude has been mapped to a gray scale where high vibration is bright gray and low vibration is dark gray. Note that the area of low vibration in the sonoelastography image is located in the region where the MR detected the lesion.

CONCLUSION

FEM studies performed verify that a small inclusion in otherwise uniform elastic space being forced to vibrate will cause a decrease in the vibration amplitude at the inclusion when the relative elasticity between the lesion and background is high enough. This forms the basis for detecting lesions in sonoelastography. The amplitude of vibration in a region of interest can be estimated using ultrasound correlation techniques. The resulting vibration images reflect the underlying relative elasticity of a small inclusion. An image of a hard elliptical lesion in soft acoustic phantom has been made using sonoelastography and validated by and MR image of the same object.

REFERENCES

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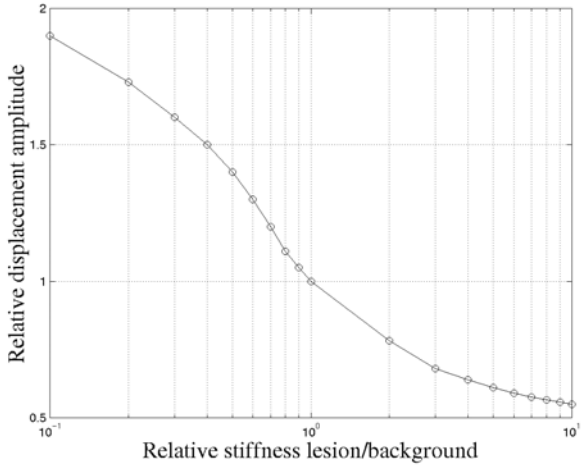

Figure 1. Relative displacement amplitude vs. relative stiffness

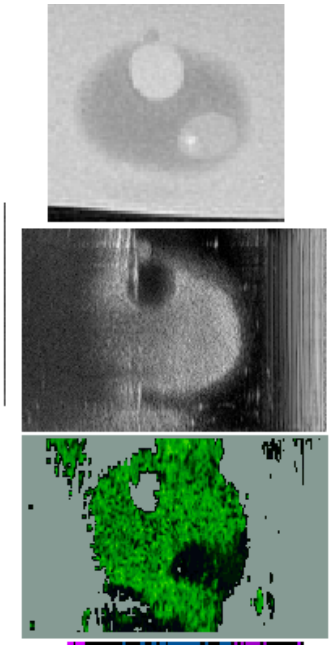

Figure 2. MRI (top), ultrasound (middle) and Sonoelastography (bottom) images.