Characterizing the Dynamic Properties of HIFU Lesions
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Abstract: High intensity focused ultrasound (HIFU) is a non-invasive method by which ultrasound can be used to thermally ablate tissue (tumors, for example). However, real-time imaging and lesion formation and heating of tissue is a major barrier. Our research involves employing a multi-modal approach, based on ultrasound imaging, by which the presence of a lesion can be determined and it’s formation observed. Three different types of properties will be mapped in the tissue: acoustical (through ultrasound backscattering and tomography), mechanical (through acoustic force elastography), and optical (through acousto-optic imaging). By probing these three lesion properties we anticipate developing a robust approach to tracking HIFU lesion formation in real time. The work has achieved the first lesion detection by AOI, as well as successful detection of acoustically-forced tissue motion, and the development of computer models for strain and temperature fields in tissue. The understanding and new methods anticipated from this work are intended for direct application to the emerging field of ultrasound tumor ablation.

Motivation and State of the Art
Clinical applications of HIFU therapy employ MRI to image the ultrasound-induced lesions as they are being produced. However, it’s expense and space requirements inhibit the adoption of HIFU as a viable therapy for cancer. Imaging lesion formation using ultrasound would be preferable, and techniques investigated for this purpose include acoustic force elastography (1), and thermal strain imaging (2.3). However, since no single approach has seen clinical success, our goal to combine thermal and mechanical strain imaging with acousto-optic imaging to obtain a robust multi-property imaging system.

Challenges
Traditional ultrasonic imaging has been unsuccessful at imaging HIFU lesions because its contrast is provided by differences in acoustic reflection strength (backscatter coefficient) in tissue. Lesions unfortunately have backscatter coefficients close to untreated tissue.

Technical Approach
Our planned research involves improving ultrasound image resolution of lesions using the following methods:

1. Acoustic Radiation Force Elastography

Using the HIFU transducer to simultaneously create the lesion and apply an oscillatory radiation force to the lesion area, monitor local tissue motion in the lesion region. Tissue necrosis causes a marked change in stiffness, which results in a change in this tissue motion. Motion is monitored using a pulsed diagnostic transducer and “spokele tracking” correlation software. See refs. 1, 2.

2. Acousto-optic imaging

Using the significant advances made in our department in the area of Acousto-Optic Imaging (AOI) to image HIFU lesions, which exhibit optical contrast. Local tissue motion, which changes during lesion formation, may also be detectable with AOI. See ref. 3.

3. Acoustic Backscatter

Using a detailed model for backscattering to include the diffraction and acoustic coupling function of the transducer, develop new processing algorithms to apply to raw data from our Analogic ultrasound imaging machine to achieve the necessary contrast to resolve lesions in formation. Analyze A-line time series to investigate the onset of “shadows” during lesion formation, indicating increased attenuation. Also apply temporal speckle correlation to map temperature and acoustic velocity.

Results to date
Motion is induced in tissue via acoustic forcing. An intense sound field exerts a pushing force at the focus. In our case, the beam is amplitude modulated at 3kHz, causing the tissue to jiggie. Measuring the magnitude of this motion yields the local tissue stiffness (Hooke’s law). Tissue motion is measured by “spokele tracking”. Ultrasound imaging A-lines like the one shown at right consist of echoes from the scattering particles in the tissue. If there are local movements in the tissue, the echoes will shift over successive time frames. Cross-correlation between segments of successive A-lines indicate how much each segment has moved.

Below right is a plot of tissue motion (vertical axis) vs. time, for a 1.1MPa, 3.3 MHz forcing beam, focused 1.5 cm into liver tissue. Tissue oscillation amplitude is 37µm p-p.

Technical Approach

First Acousto-Optical Imaging Results

The first known AOI scan of a lesion in tissue was made in chicken breast. The figure at right shows a photo of a post-lesion tissue cross section. The figure below shows an AOI scan of another lesion in this same orientation. The lesion is seen as the blue central area, occurring at the frequency of acoustic modulation (30Hz). The dashed oval shows the -6dB pressure contour of the HIFU focal region. At right is a standard ultrasound B-mode image of the same tissue, showing no evidence of the lesion.

References:
4. This work was supported in part by Gordon-CenSSIS, the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems, under the Engineering Research Centers Program of the National Science Foundation (Award Number EEC- 998621).

Acoustic Force Elastography

Schematic of forcing transducer and tissue

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Experimental Setup

Optical Setup. Figure courtesy of Lei Sui.

Acousto-Optical Imaging

Acoustic density fluctuations cause changes in optical index of refraction, absorption, and scattering. Diffuse photons that pass through the acoustic focus will thus have their velocities changed, causing small changes in the output optical wavefront. These photons are detected by mixing the light with a reference beam within a photo-refractive crystal (PRC). The crystal turns the interference pattern into a grating, which diffracts the beam into a photodetector. Acoustically-induced changes in the wavefront from the sample don’t match the original interference pattern, and won’t be detected by the PRC. The optical detector thus decreases.

A higher optical absorption in the focal region will weaken the above acousto-optic effect. The acoustic focus can be scanned throughout the tissue volume, and the magnitude of the AOI effect recorded, thus making a volume plot of the optical opacity in the tissue.

Results to date

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