Imaging HIFU Lesions Using Ultrasound

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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. One important application is the treatment of tumors. However, real-time imaging of the heating of tissue and lesion formation is a major barrier for HIFU. Our research involves employing a multi-modal approach, based on ultrasound imaging, by which the temperature distribution and presence of a lesion can be determined. Three different types of properties will be mapped in the tissue: acoustic (through ultrasound backscatter and tomography), mechanical (through elastography) and optical (through acousto-optic imaging). By combining acoustical, optical and mechanical properties of the lesion we anticipate developing a robust approach to tracking HIFU lesion formation in real time. The first phases of the work have involved the development and validation of computer models for temperature prediction in phantoms and liver tissue, the detection and control of acoustic cavitation during lesion formation, and the spatial measurement of acoustic and mechanical properties of lesions produced by heating and cavitation. 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 utilize MRI machines to image the ultrasound-induced lesions as they are being produced. This is the only means at present to obtain accurate information on the placement and completeness of the cell necrosis. 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.

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 ultrasonic image resolution of lesions using the following methods:

1. **Signal processing.**
   - 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 and Terrason ultrasound imaging machines 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.

2. **Ultrasound Tomography.**
   - Develop Born-based frequency-domain inversion method for variations in density, soundspeed and attenuation.

3. **Acousto-optic imaging.**
   - Utilize the significant advances made in our department in the area of acousto-optic imaging (AOI) to image HIFU lesions, which exhibit optical contrast. Temperature may be another critical piece of information for the radiologist to determine adequate therapeutic exposure. Examine the possibility of using AOI to measure the temperature at the lesion site. This is possible because one of the main mechanisms by which photons are “tagged” in this technique depends on the piezo-optic coefficient (“drivip”), where n is index of refraction and p is pressure) of the material at the focus spot, and this is known to have a significant temperature dependence for many materials.

Results to date

Cavitation is produced by acoustic waves. When the pressure gets low enough, liquid molecules are pulled apart, forming spherical voids. These voids then oscillate in the acoustic pressure field in a complex, often chaotic manner. Because they are nearly perfectly spherical, their collapsing can be violent, producing tissue destruction and increased heat production.

After lesions are made in tissue, flat cross-sections are examined with the scanning acoustic microscope (SAM). Acoustic properties like velocity, backscatter, and attenuation (the things that can make for contrast in an ultrasound image) are mapped with high spatial precision.

The figure below is a contour plot of attenuation in the region of a liver tissue lesion. Cavitation was present in the forming of the lesion, and thus it’s size is much larger than the acoustic beam width (1.5mm). Without cavitation, it is possible to determine the borders between “cooked” regions with high attention, and healthy regions with low attenuation.

**Experimental Setup**

Cavitation detector

HIFU transducer

sample

3-Level Diagram

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**Technology Transfer**

The application of new data processing algorithms will be implemented on existing ultrasound machines. The extra processing power will be offset by the smaller imaging area around the lesion site.

*If lesions can be imaged with AOI, commercialization is possible.*