In Vitro Measurement and Analysis of Backscattered Ultrasound and Its Change With Temperature.

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Supported by NIH Grant #R21 CA90531

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Abstract

The use of an interrogating ultrasound beam for noninvasive measurement of temperature has been investigated from several perspectives. Our group is looking at how the backscattered energy from individual scatterers changes with temperature. By measuring the backscattered energy from a single ultrasound beam (A-mode) in a tissue sample while changing the tissue temperature we have gathered data from a minimum of 5 sites in several different tissue samples. We have performed experiments on bovine liver and turkey breast. Changes in backscattered energy appear to be consistent between the different types of tissue. Typically we have seen a change of between 5 and 15 dB in backscattered energy over the temperature range of 37 to 50 °C. The energy may either increase or decrease with temperature depending on the type of scatterer that is being followed. To follow the behavior of the signal from individual scatterers we have segmented signals by hand. To automate the process we have segmented with matched filters and with arbitrary segment intervals. The performance of both methods was appears to be comparable to hand segmentation. The success of these automatic methods suggests that changes in backscattered signals with temperature can be tracked in real time over a variety of tissue types.

Goals

ï Compare different methods of tracking what appear to be individual scatterers in ultrasonic echo signals as the temperature of a tissue sample is increased from 37 to 50 °C.

ï Evaluate the possibility of automatically identifying and tracking these signals.

Procedures

Experimental Setup

Tissue samples were heated in an insulated tank that was filled with deionized water, which had been degassed by vacuum pumping in an appropriate vessel. Tissue was placed in the focal zone (2 mm in diameter) of a focused, circular piston transducer. Center frequency of the transducer was 7.5 MHz. Temperature in the tank was set by a heater that circulated the water in the tank. The temperature in the tissue was monitored by a thermometer, which used an indwelling needle thermocouple. After temperature in the tank reached equilibrium, the transducer was pulsed with a MetroTek pulser and echoes recorded. The transducer was moved to the next site of interest and a new echo signal recorded. After all sites of interest had been insonified, the transducer was returned to its original position, so that the process could be repeated at the next temperature. The temperature range covered was 37 to 50 °C in 0.5 °C increments.

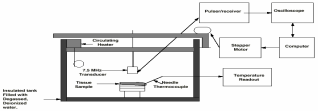
Data Analysis

Data were analyzed by identifying what appeared to be individual scatterers in the echo signal. These ìscatterersî were then tracked as there position shifted with temperature. We have segmented the scatterers using four methods:

by hand,
with arbitrary zero order segments,
with arbitrary first order (linear) segments,
and with a simple matched filter technique.

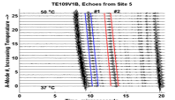
The matched-filter method used the hand segmented scatterers at the baseline temperature (37 °C) then automatically identified these scatterers at subsequent temperatures.

Experimental Setup

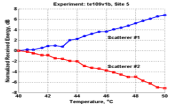


Configuration for the measurement of backscattered ultrasound from tissue samples. Deionized and degassed water in the tank was heated to equilibrium, as monitored by an invasive thermocouple probe in the tissue. The transducer was scanned over different sites and the backscattered signal recorded for subsequent analysis.

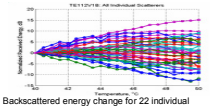
Hand Segmentation



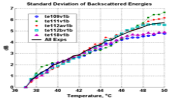
Echoes measured from a single site in a 1 cm thick sample of bovine liver at temperatures from 37 to 50 °C. The two delineated echoes that appear to track with temperature have energies that changed with temperature in opposite directions.



Backscattered energy change from 40 to 50 °C for two scatterers in a bovine liver sample indicated in Figure 3. The nearly monotonic temperature change for both suggests the possibility of accurate temperature estimation.



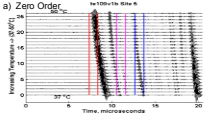
Backscattered energy change for 22 individual scatterers in a sample of bovine liver over the 40 to 50 °C temperature. Tissue volume was about 0.5 cc.



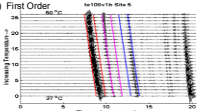
Standard deviation of backscattered energies at 0.5 °C intervals over the 37 to 50 °C temperature range of 120 scatterers. Five scatterers from each of 5 sites in 4 experiments and from 4 sites in 1 experiment were used.

Automatic Segmentation

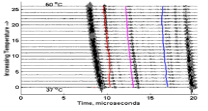
a) Zero Order



b) First Order



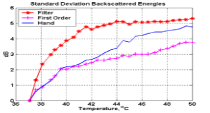
c) Matched Filter



Automatic segmentation of scatterers using:

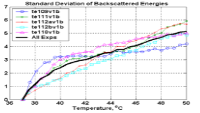
a) An arbitrary vertical segmentation with regular spacing. This approach does not track individual scatterers and is therefore not analyzed further.
b) An Arbitrary first order segmentation with regular spacing. This approach uses the echoes at the beginning and end of the signals to follow the shift due to increasing temperatures.
c) A simple matched filter technique that uses the hand segmented scatterers from above (hand segmentation) and correlates that signal in the subsequent higher temperatures.

Results

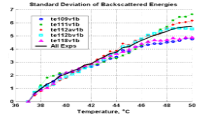


Comparison of the first-order and matched-filter segmentation methods with the hand segmentation method. This result is from a single experiment (single sample of liver).

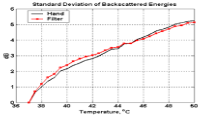
a) Matched Filter



b) Hand Segmentation



c) Both



Comparison of the matched-filter technique with the hand segmentation method for all experiments on bovine liver. Part c) includes the lAll Expsl curves from a) and b).

Discussion and Conclusions:

The zero-order automatic segmentation method did not track individual scatterers and was therefore not considered in further analysis. The first-order method and the matched-filter method were nearly able to follow what appear to be echo signals from individual scatterers. The first-order method relies on a fixed change in the speed of sound with temperature, which is not necessarily true in tissues with inhomogeneities. The matched filter was not always able to follow the scatterers especially at higher temperatures. This failure could be due to the fact that the filter was taken from the baseline temperature (37 °C) and could be improved by redefining the filter as the temperature is increased.

Future Directions:

The matched-filter technique used here is preliminary and can be improved by redefining the filter at each temperature step. Defining a stylized filter to eliminate noise may also contribute to better tracking of the signals.

Eventually in order to accurately track these signals it will be necessary to image the tissue samples in three dimensions.