Abstract

The temperature dependence of the power received by an ultrasound transducer from the backscatter of an interrogating pulse is dependent on how certain ultrasonic tissue characteristics (speed of sound, attenuation and backscatter coefficient) change with temperature. A theoretical parametric analysis showed that the temperature dependence of the backscatter coefficient dominates the variation of the received power with temperature. According to this analysis the power received by the transducer could either increase or decrease depending on the type of tissue and the inhomogeneities within the tissue. We have confirmed this experimentally in vitro. By capturing the RF signal from a single A-mode scan we have been able to identify individual scatterers and follow these scatterers as signals were obtained at temperatures from 37°C to 50°C. The change in energy of these scatterers can increase or decrease with temperature and is for the most part monotonic. Typically we have seen a change of between 5 and 15 dB in backscatter energy over the temperature range of 37°C to 50°C. The envelope of a collection of scatterers can be used to infer the temperature of the tissue by analyzing the statistics of the collection. We found that the standard deviation of backscattered power increased monotonically with temperature and was accurately approximated by a second-order polynomial. Thus far we have segmented the individual scatterers by hand. We are also working on utilizing automatic techniques such as matched filters and arbitrary segment intervals. Supported in part by R21 CA90531.

Goals

1. Measure the effect of temperature change on ultrasound tissue characteristics using the simplest measurement possible: backscatter.
2. Evaluate the prospects of using this measurement as a method for noninvasive thermometry during hyperthermia.

Theory

In order to explore the potential of using pulse-echo measurements from a single transducer for thermometry, we parametrically analyzed a theoretical model for the backscattered energy received from a small tissue volume in response to an insonifying burst. Backscattered energy was determined relative to the energy received from the same volume at a reference temperature (37°C). Temperature dependence of attenuation and velocity was taken from the literature together with literature values of the speed of sound and density. The energy received from each scatterer was assumed to be proportional to the scattering cross section of a small scatterer, which depends on the square of the scattering potential (Starr and Brandt 1989; Starr et al. 1983). By using a known tissue absorption and speed in sound (50°C) data along with estimated backscatter coefficients, we predicted what changes in backscatter energy could be expected with temperature from certain medium and scatterer combinations.

Results: Theoretical

The effect of temperature change on the received backscatter energy at 5.9 MHz is shown. Calculations were made using an insonification signal at 5 MHz. The temperature dependence was modeled with a quadratic fit.

Results: Experimental

Graphs showing the experimental results of backscatter energy changes and comparison with theoretical predictions.

Procedures

Experimental Setup

Measurements were made with the experimental configuration depicted in Figure 1. 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 piezoelectric 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 Mettler 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°C 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 scatterers were then tracked as they pulse shifted with temperature. We have segmented the scatterers by hand and with a simple matched filter technique.

Summary and Conclusions:

- Measured changes in backscattered energy were consistent with our model of the energy reflected from sub-wavelength scatterers.
- Statistical analysis of the distribution of change in scatterer energy over the temperature range of 37 ± 0°C was monotonic.
- Signal processing algorithms should provide the capability of identifying and following scatterers at different temperatures.

Future Directions:

The matched-filter technique used here is primarily 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.