

Recent Advances in Non-Invasive Thermometry Using Changes in Backscattered Ultrasound

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Objective of Ultrasonic Thermometry

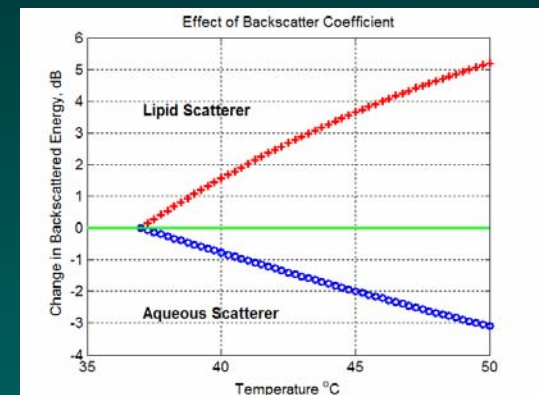
To develop a method to produce 3D temperature maps in soft tissue

- non-invasively, conveniently at low cost with a single view from standard equipment
- with at least 0.5°C accuracy & 1 cm^3 resolution



Our Approach to Ultrasonic Thermometry

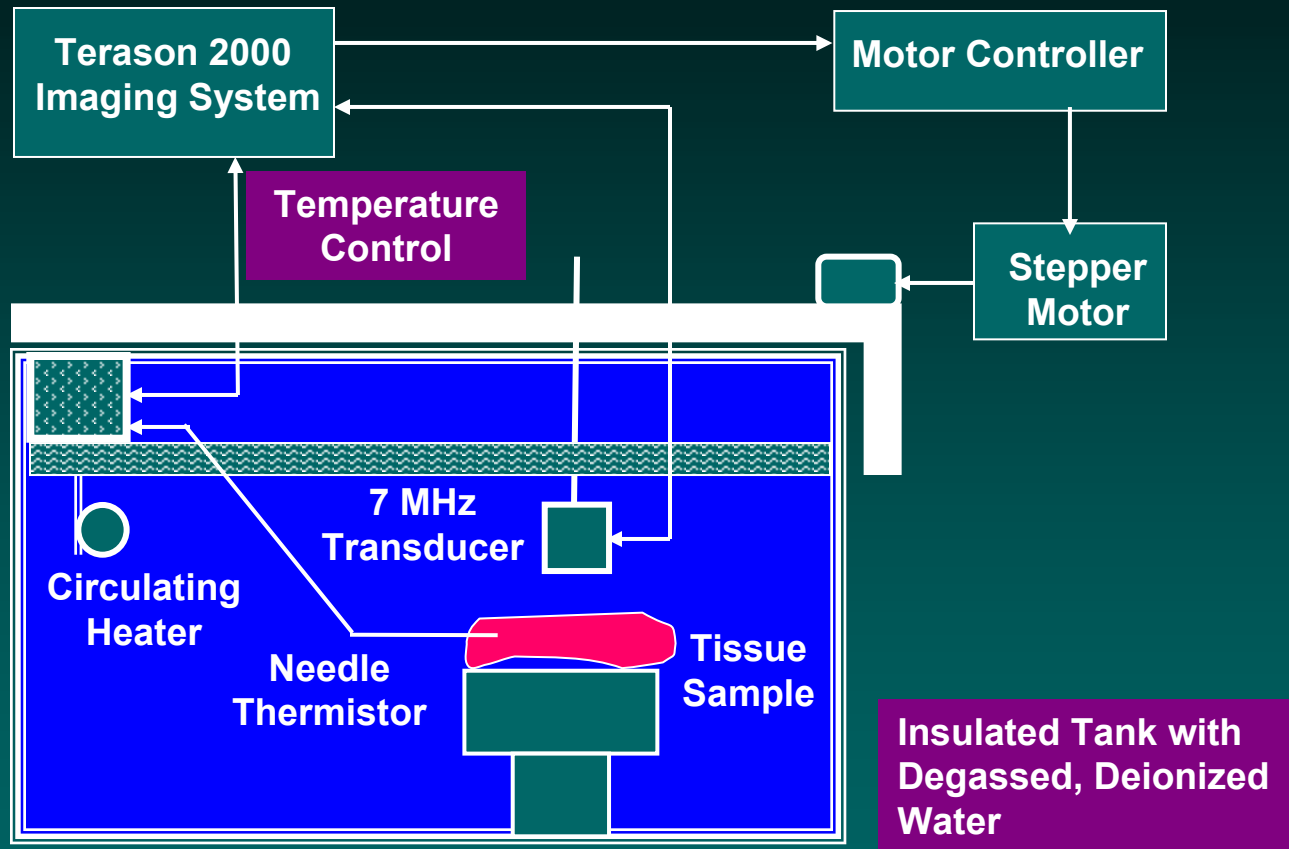
- Take a single backscatter view with standard imaging equipment
- Use the change in back-scattered energy (CBE) as a temperature-dependent parameter
- Track and correct for motion in 2D and 3D to eliminate its effect on CBE



Straube & Arthur, *Ultrasound in Med. & Bio.*, 20:915-922, 1994
Arthur, Trobaugh, et al., *IEEE Trans. on UFFC*, in press



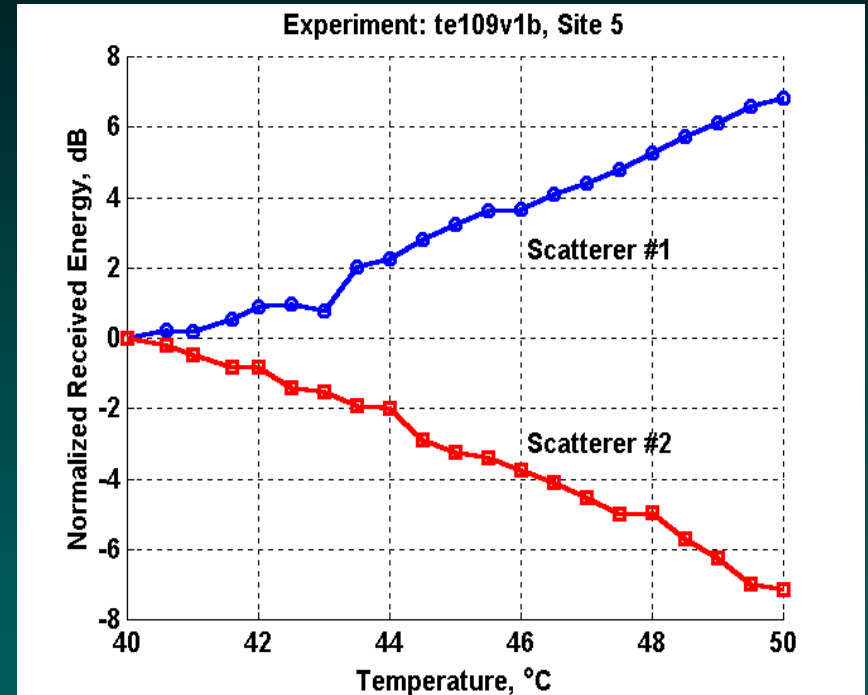
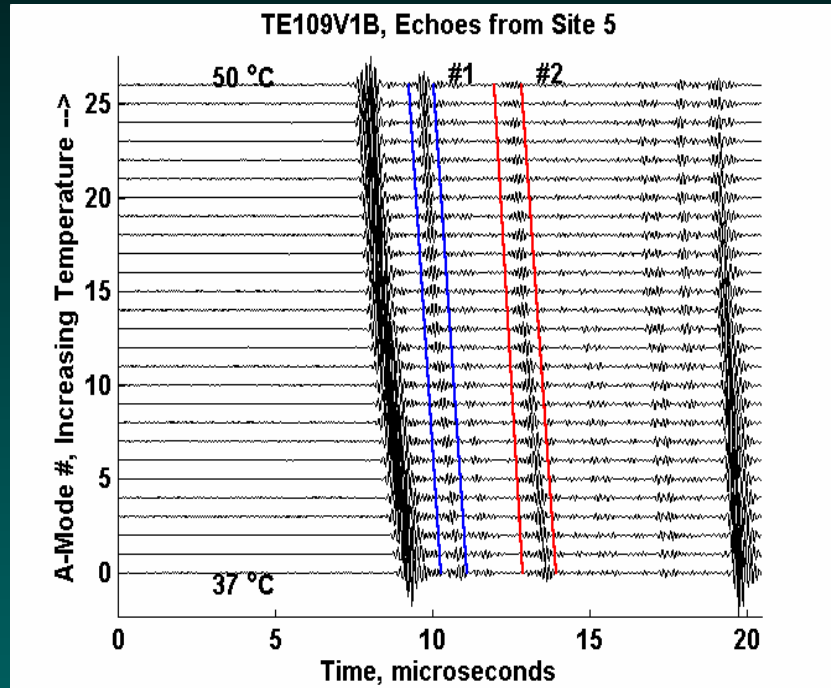
Configuration for *In Vitro* Experiments



For 3D studies images were taken at 0.6 mm intervals in elevation at each temperature



Previous Hand Segmentation of 1D Signals



A-Mode Echo Analysis

CBE of Single Scatterers

Arthur, Straube, et al., *Medical Physics*, 30:1021-1029, 2003



Measurement of Backscattered Images

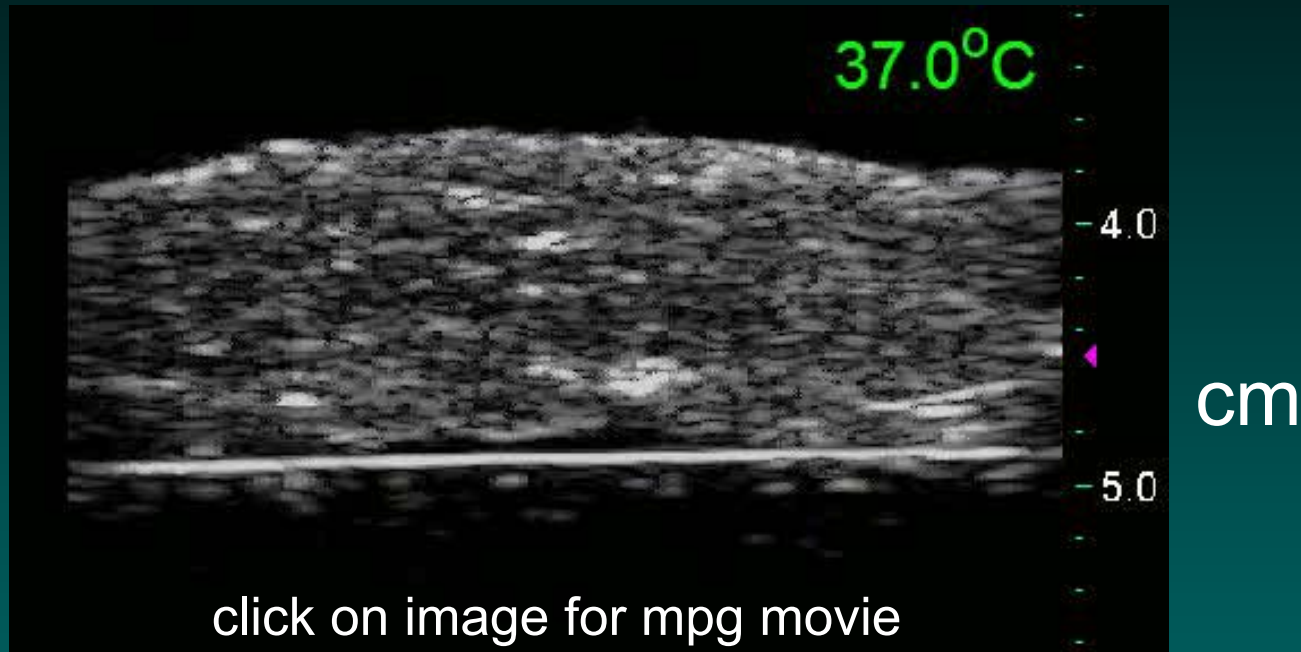


Terason 2000 (Teratech,
Corp., Burlington, MA)
laptop phased-array
imaging system

- 128 Element 7 MHz Linear Array
- Laptop control of temperature and image acquisition with AutoIt®
- Access to RF signals



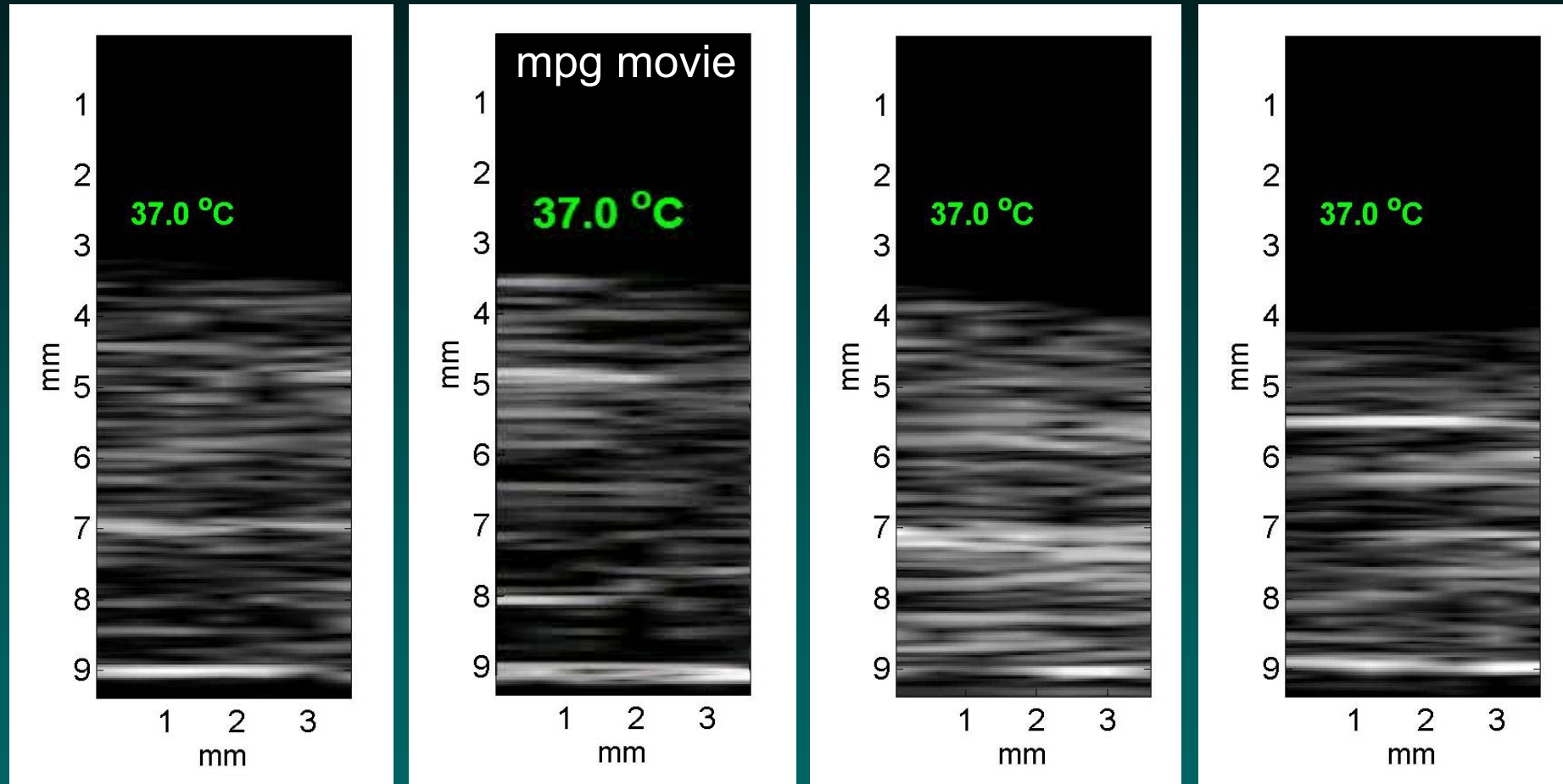
Ultrasonic Image of Bovine Liver



- Focal zone at arrow
- 128-element, 7 MHz linear array (10L5)
- Temperatures from 37 to 50 in 0.5°C steps



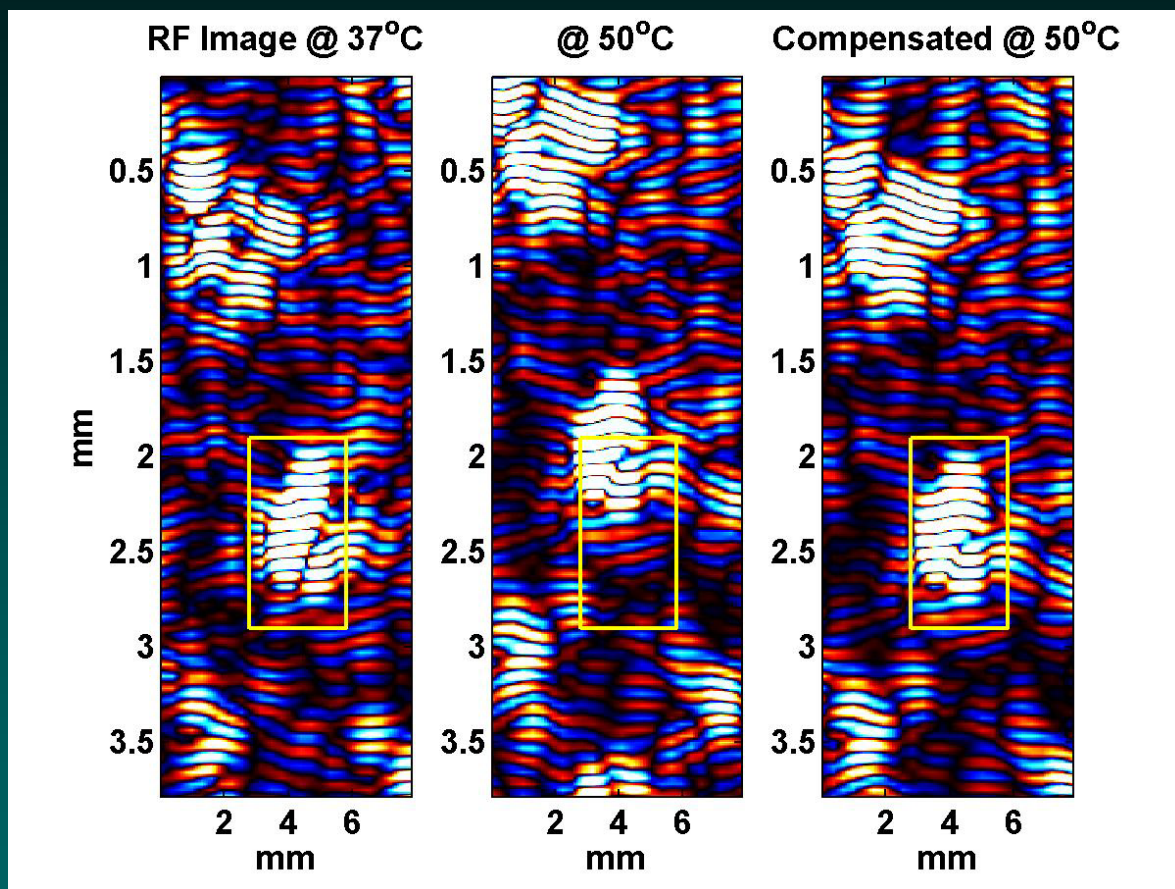
Images in Elevation



Elevation images in turkey breast separated by 7.5 mm laterally



Apparent Motion in RF Images



- Radio-frequency images of bovine liver at 37 (left) and 50°C (center & right)
- Features in the fixed, highlighted region appear to have moved both axially and laterally at 50 compared to positions at 37°C
- Motion compensation to correct for apparent motion of features was applied to the image at 50°C (right)



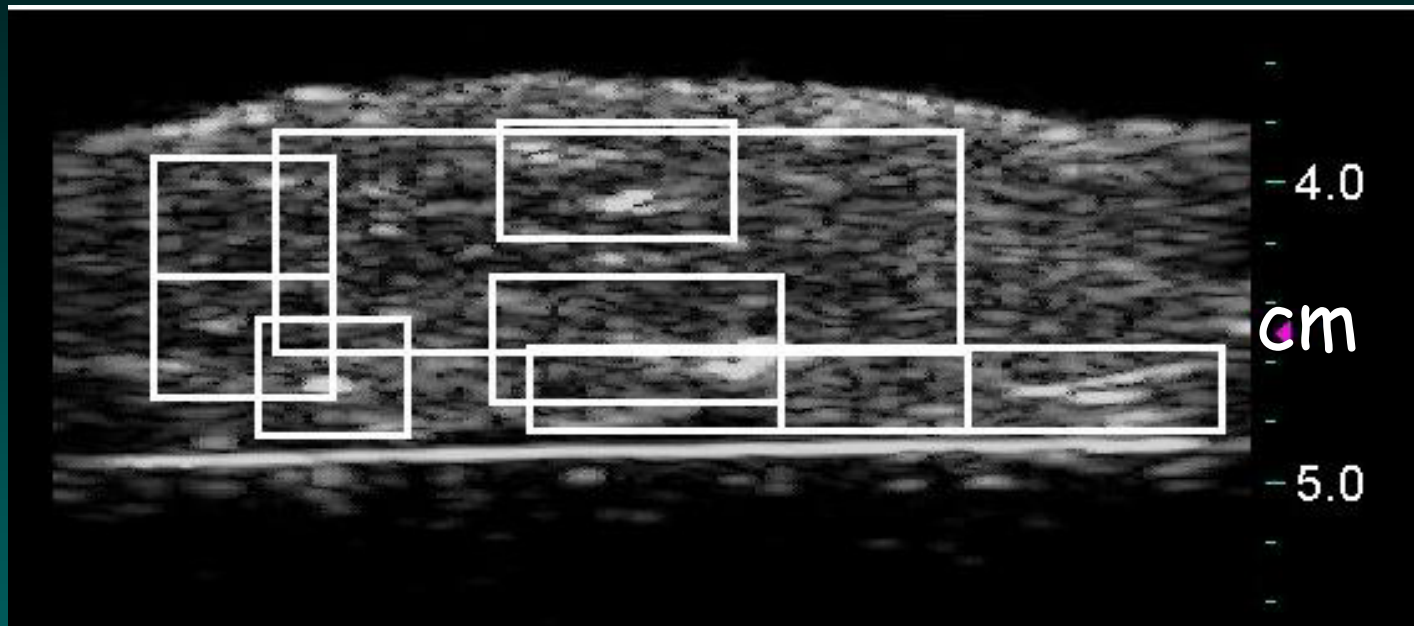
Motion Tracking

- RF signals analyzed
- Cross-correlation maximized for images at adjacent temperatures
- Motion estimation implemented using optimization and image resampling to reduce dependence on spatial sampling
- Method applied to multiple regions within each tissue sample



Arthur, Trobaugh, et al., *I J Hyperthermia*, in press

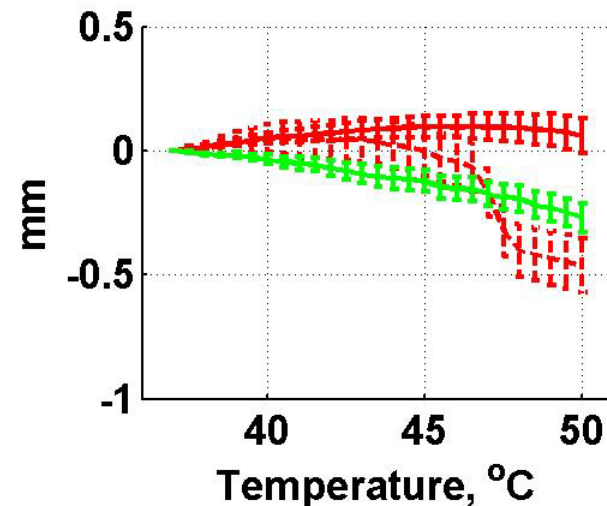
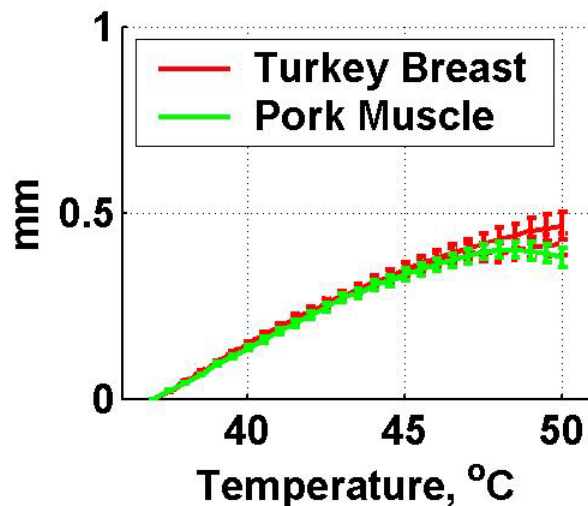
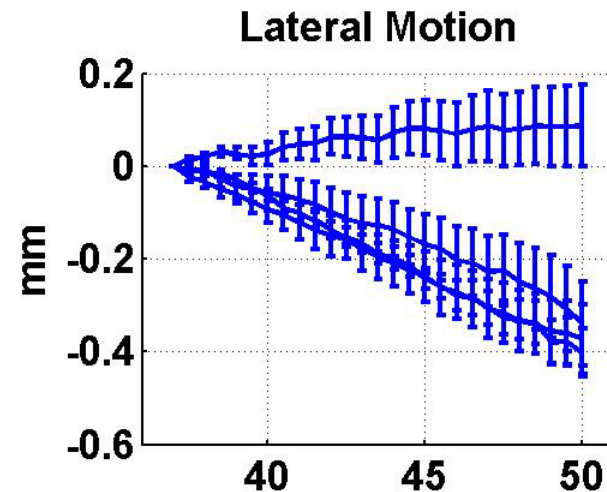
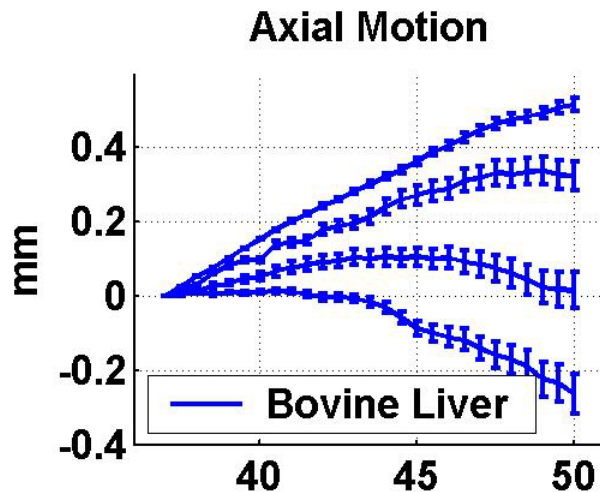
Analysis of Bovine Liver Images



Superimposed boxes indicate regions studied

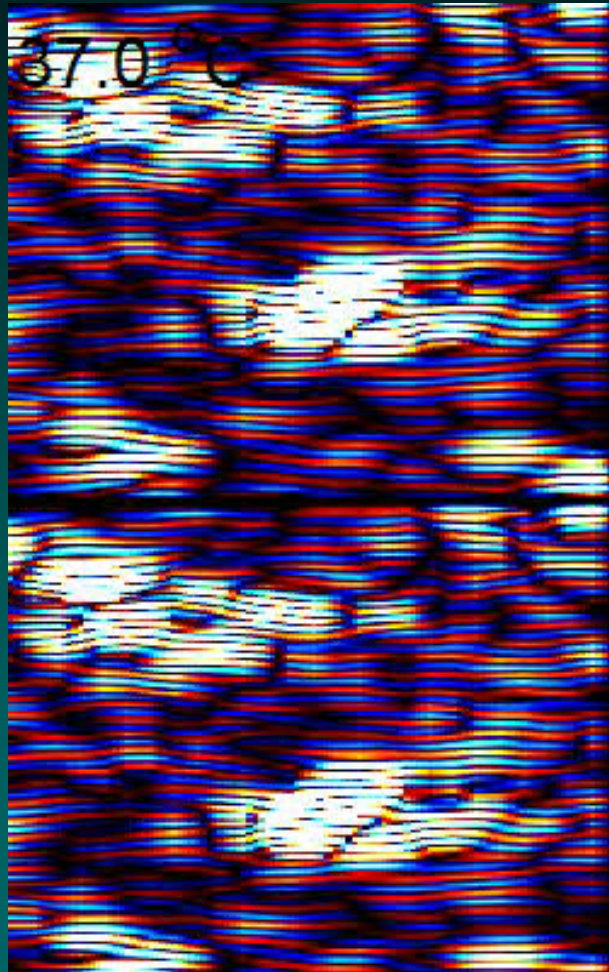


Apparent Motion in Liver, Turkey & Pork

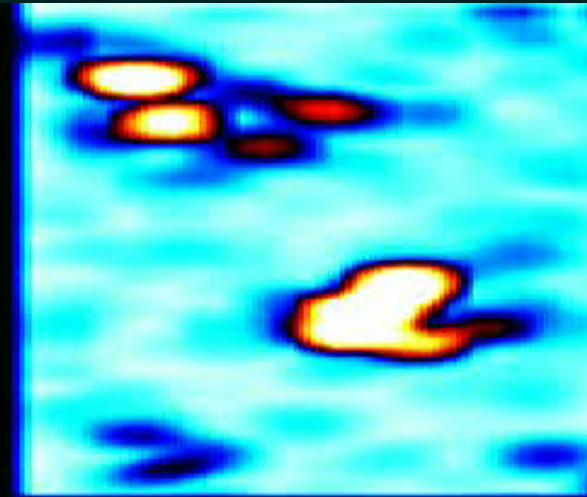


Motion-Compensated Change in Backscattered Energy

RF
Image



Motion
Corrected
RF Image



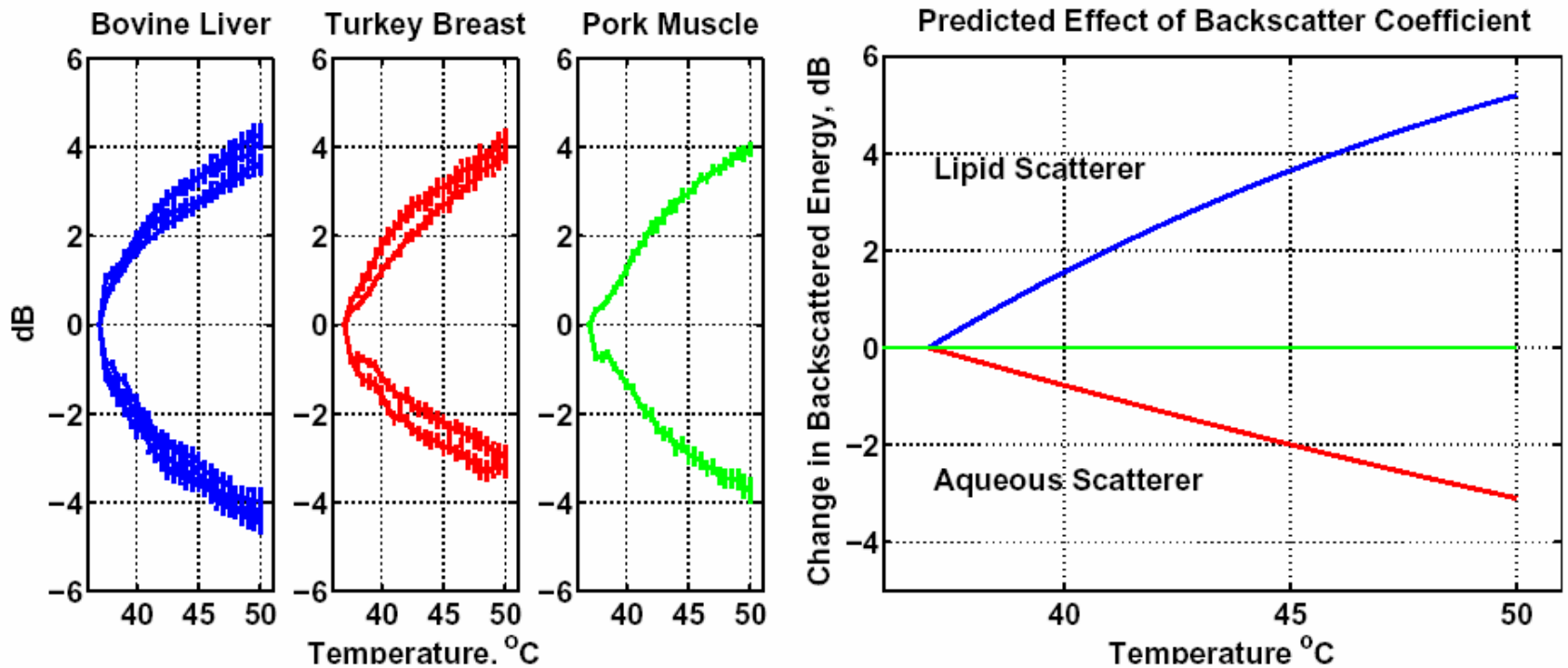
Motion
Corrected
BE

CBE
relative
to 37°C

mpg movie



2D Motion Compensated CBE Compared To Predicted CBE



Means of CBE

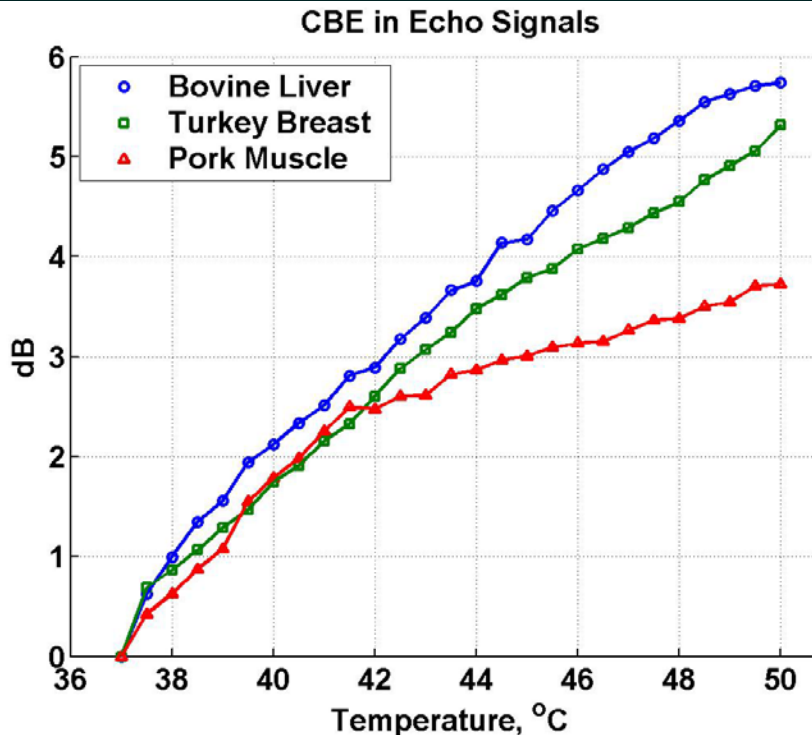
Predicted

Straube & Arthur, *Ultrasound in Med. & Bio.*, 20:915-922, 1994
Arthur, Trobaugh, et al., *IEEE Trans. on UFFC*, in press

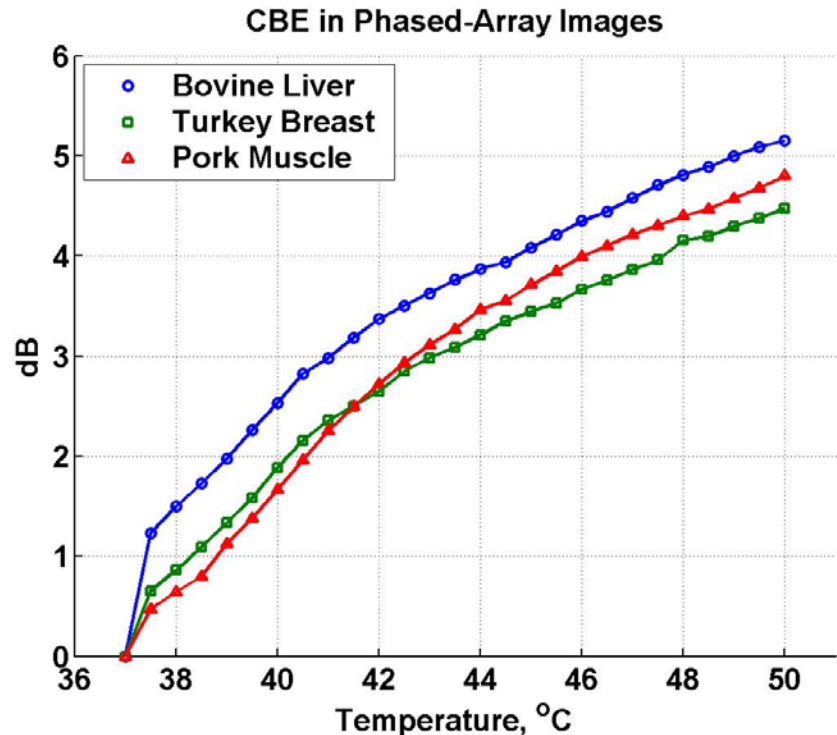


Standard Deviation of CBE

1D



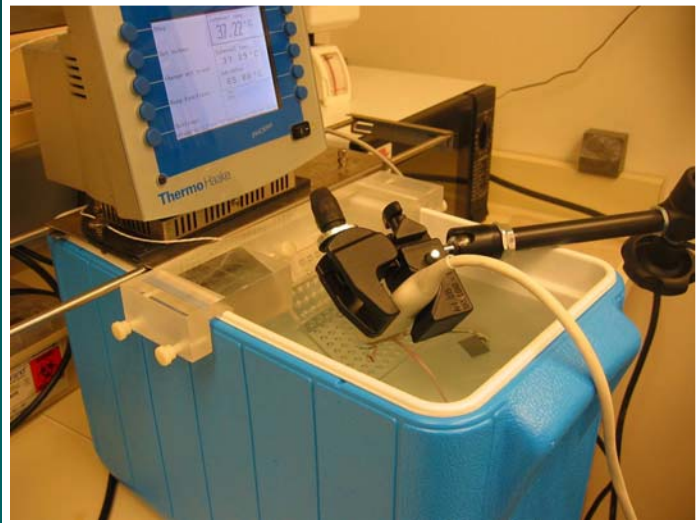
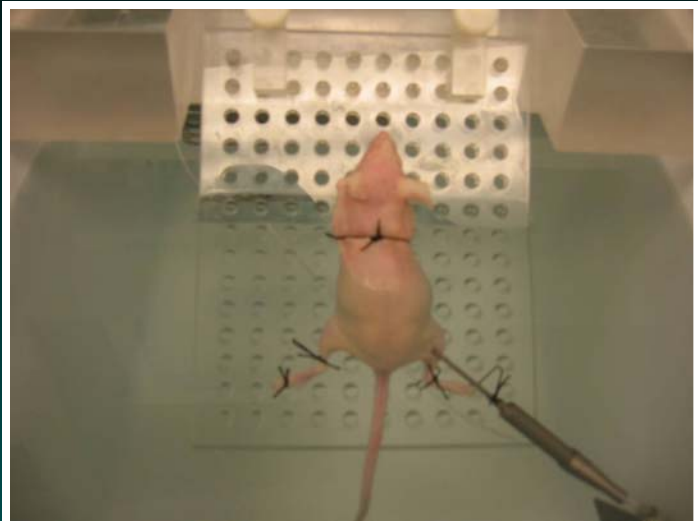
2D



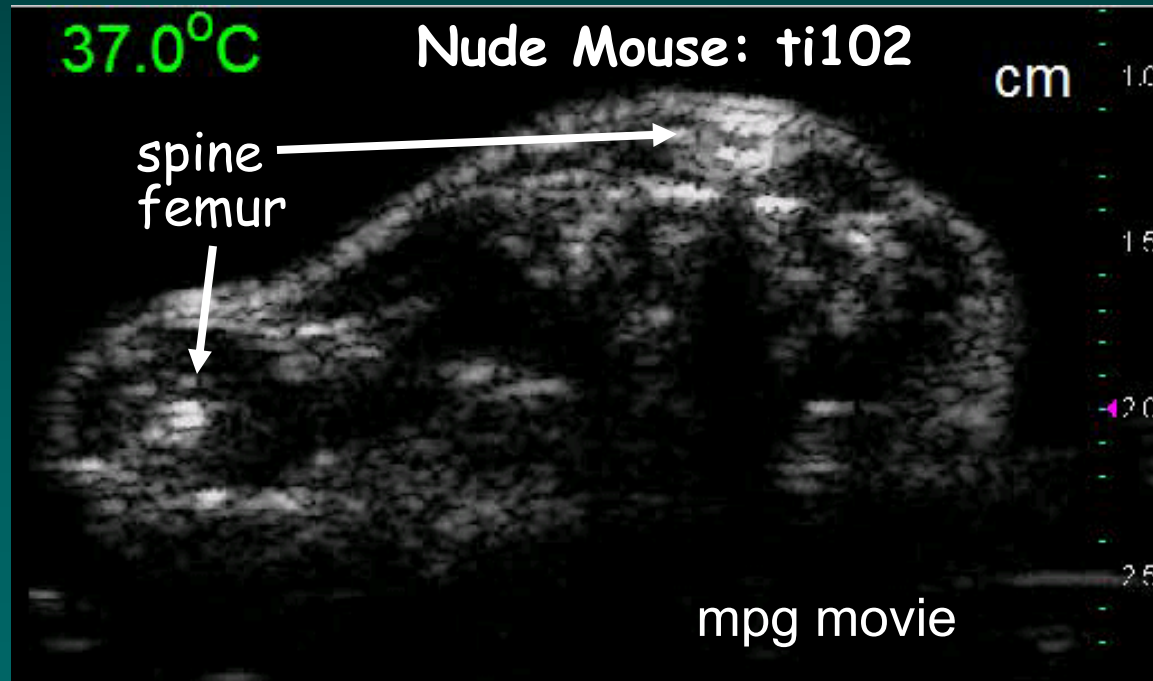
- CBE is nearly monotonic with temperature
- By calibrating CBE we believe we can use it to image temperature



In Vivo Studies

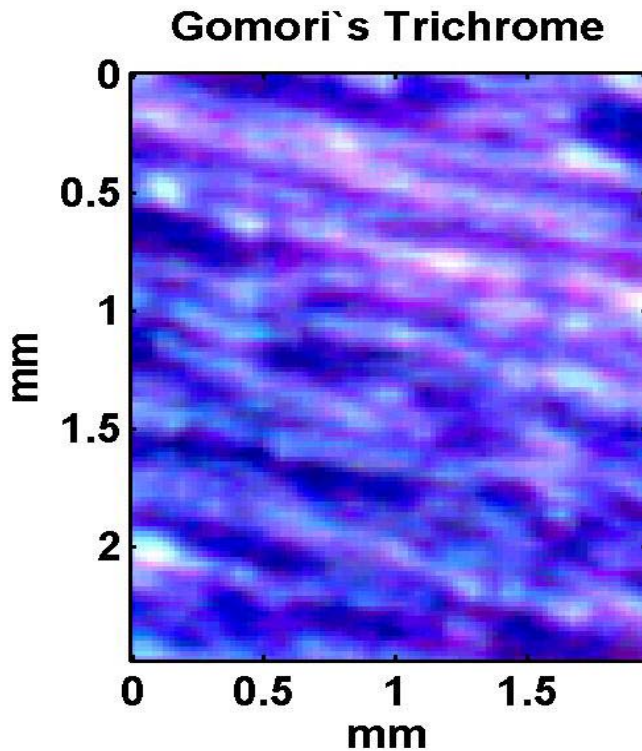


- Performed on nude mice
 - ✦ attached to submerged angled tray
 - ✦ bilaterally implanted HT29 tumors
 - ✦ RTD thermistor in contralateral tumor
- *In vitro* procedure followed
 - ✦ from 37.0 to 45.0°C in 0.5°C steps
 - ✦ for an experiment of 0.5 hours
- Mice euthanized without recovery
- Images to be analyzed in a manner similar to that for *in vitro* experiments



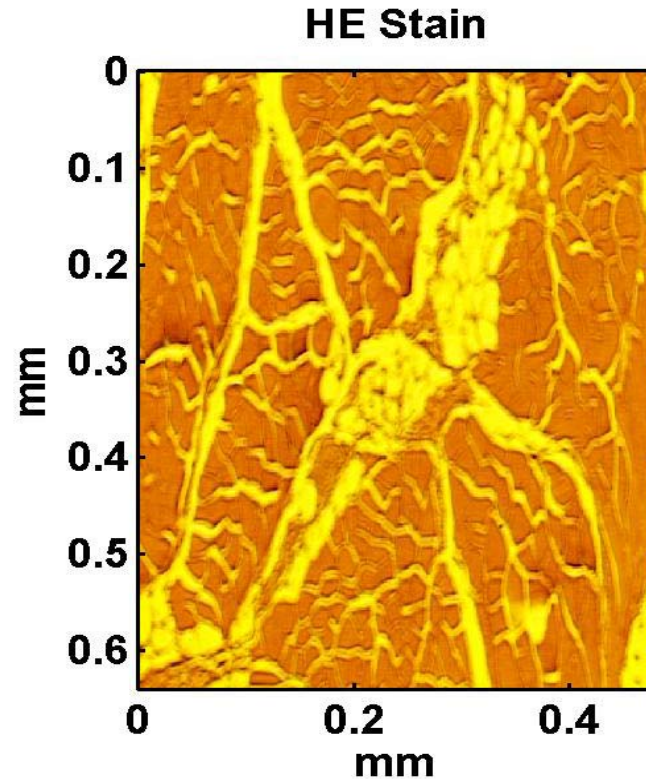
Histological Studies to Determine Distributions of Scatterer Types

Turkey
breast
tissue



Pixel size is about $20\ \mu\text{m}$, the scatterer size assumed in our model of CBE. Muscle is red; fat, white; connective tissue, blue.

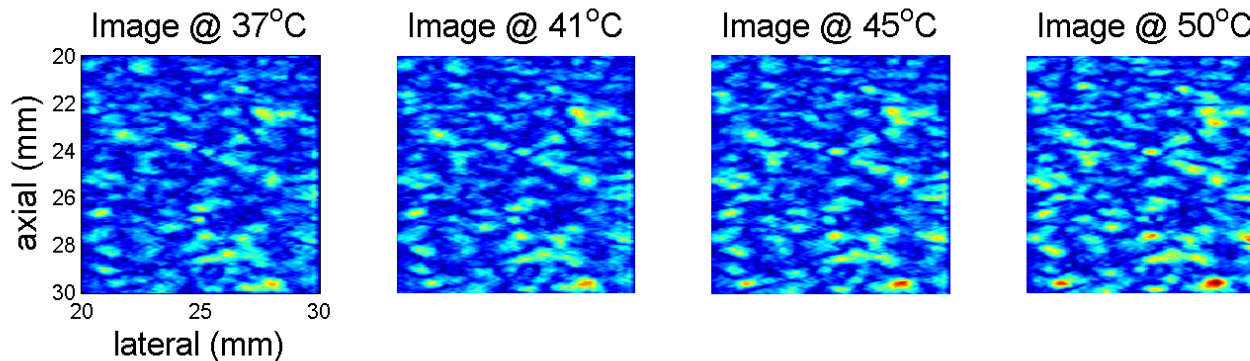
Pork
rib
muscle



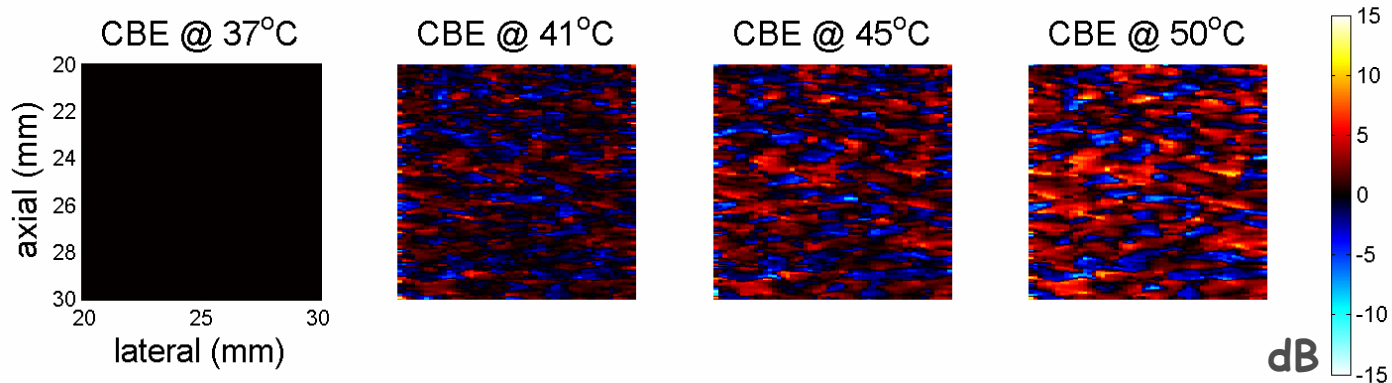
Pixel size is about $1\ \mu\text{m}$. Voids (light color) left by fat cells. Connective tissue is clearly visible along the left to right diagonal.



Simulated Images



Simulated images from 500 lipid and 1000 aqueous scatterers randomly placed in a liver-like medium. Scatterer amplitudes varied with temperature using properties from the literature.



CBE from simulated images computed in the same manner used for actual images. Increase in BE (red). Decrease in BE (blue).



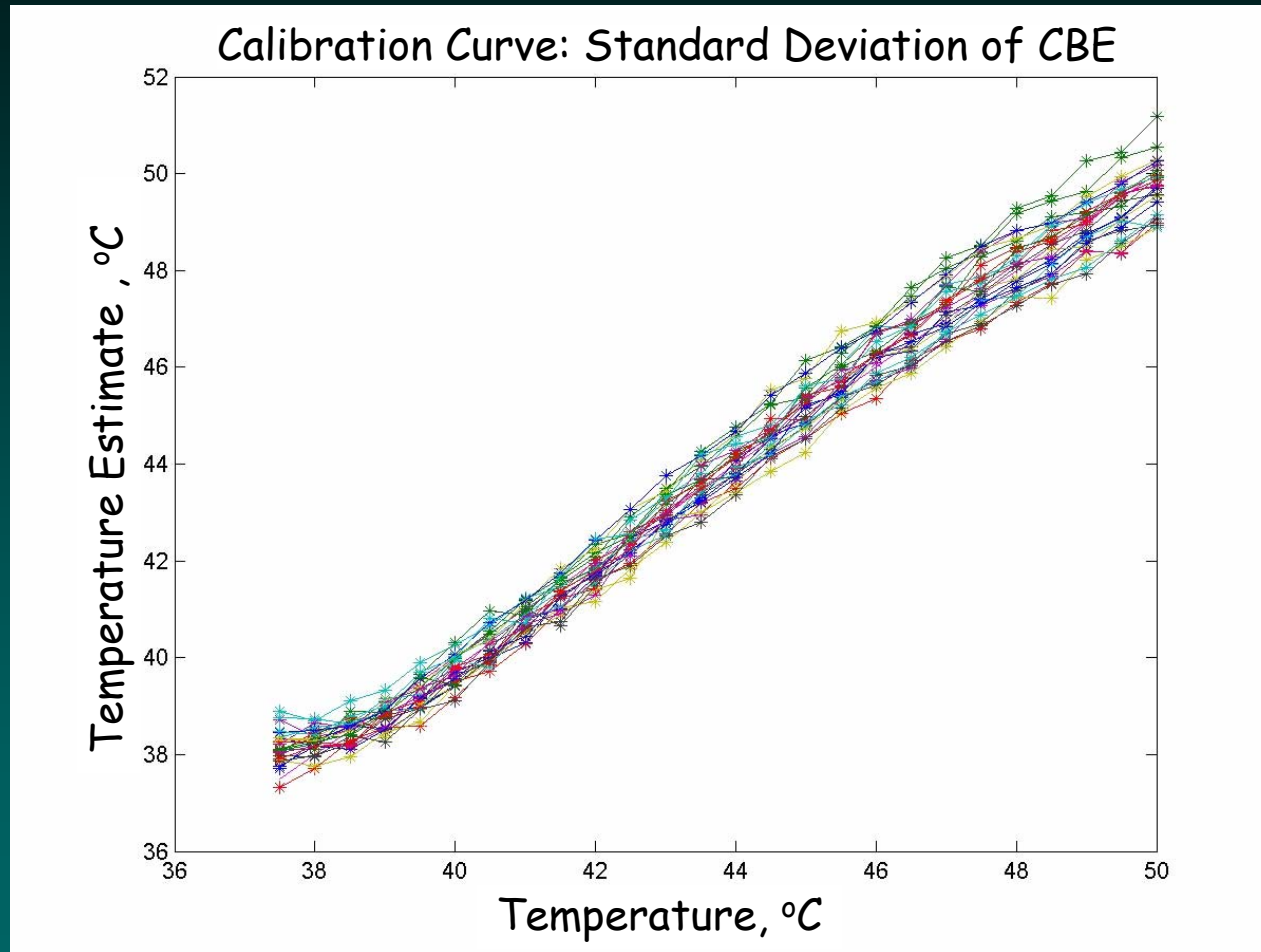
Trobaugh & Arthur, *IEEE Trans. UFFC*, 48:1594-1605, 2001

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ESHO
2005

Graz, Austria, 11 Jun 05

Temperature Estimation from Simulated Images



Estimates with added noise in a 0.3 cm^3 tissue volume



Summary & Conclusions

- Measured changes of backscattered energy (CBE) from 37 to 50°C in motion-compensated images were consistent with our model of the energy reflected from single sub-wavelength scatterers
- Means and standard deviation of CBE varied nearly monotonically with temperature in beef liver, turkey breast, pork muscle
- Because this approach exploits inhomogeneities present in tissue, *in vivo* temperature dependence is expected to be similar to our *in vitro* results
- New methods have been initiated for *in vivo* measurement, histological studies of sub-wavelength scatterers, simulation of images & estimation of temperature



Future Directions for Thermometry Based on Ultrasonic CBE

- 3D motion tracking and compensation
- Expansion of frequency range to 2-50 MHz
- Refinement of the CBE model
 - ✦ histological study of scatterer distribution
 - ✦ evaluation of images & CBE using simulation
- *In vivo* temperature dependence of CBE
- Estimation of temperature from simulations and measurements
- Development of clinically relevant heating and measurement setups

