In Vivo Change in Ultrasonic Backscattered Energy with Temperature in Motion-Compensated Images

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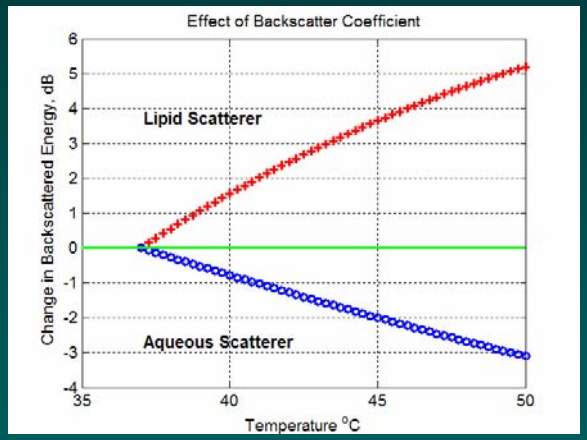
Objective of Ultrasonic Thermometry

To develop a method to produce 3D temperature maps in soft tissue during hyperthermia cancer treatment

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

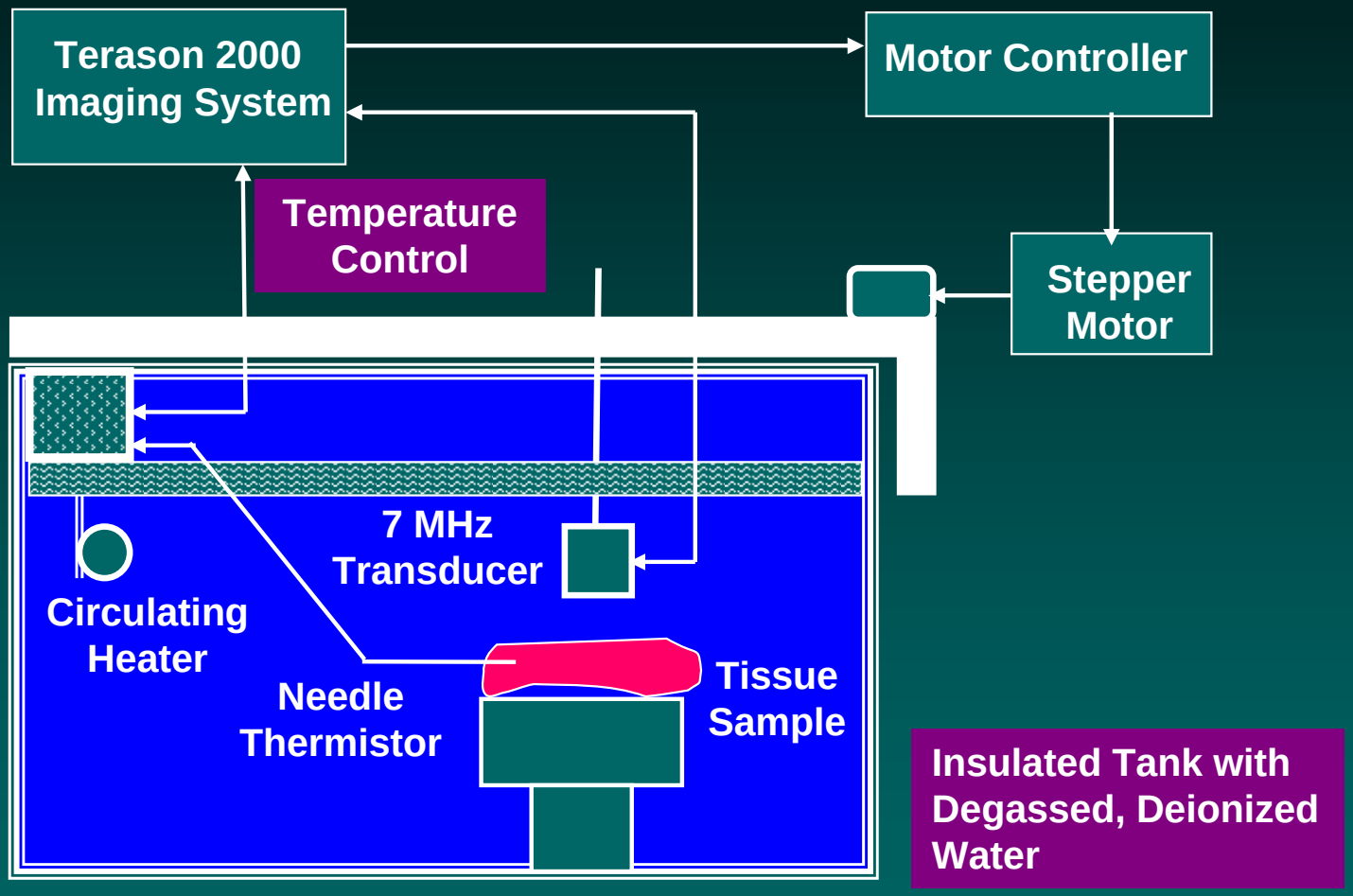
Our Approach to Ultrasonic Thermometry

- 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 to minimize its effect on CBE



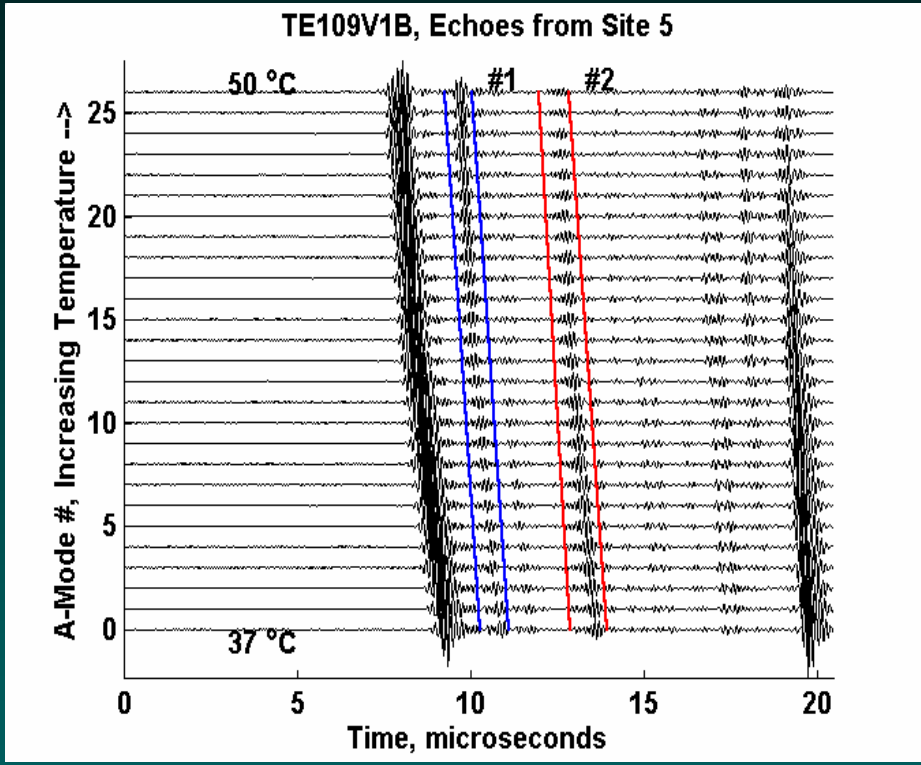
Straube & Arthur, *Ultrasound in Med. & Bio.*, 20:915-922, 1994

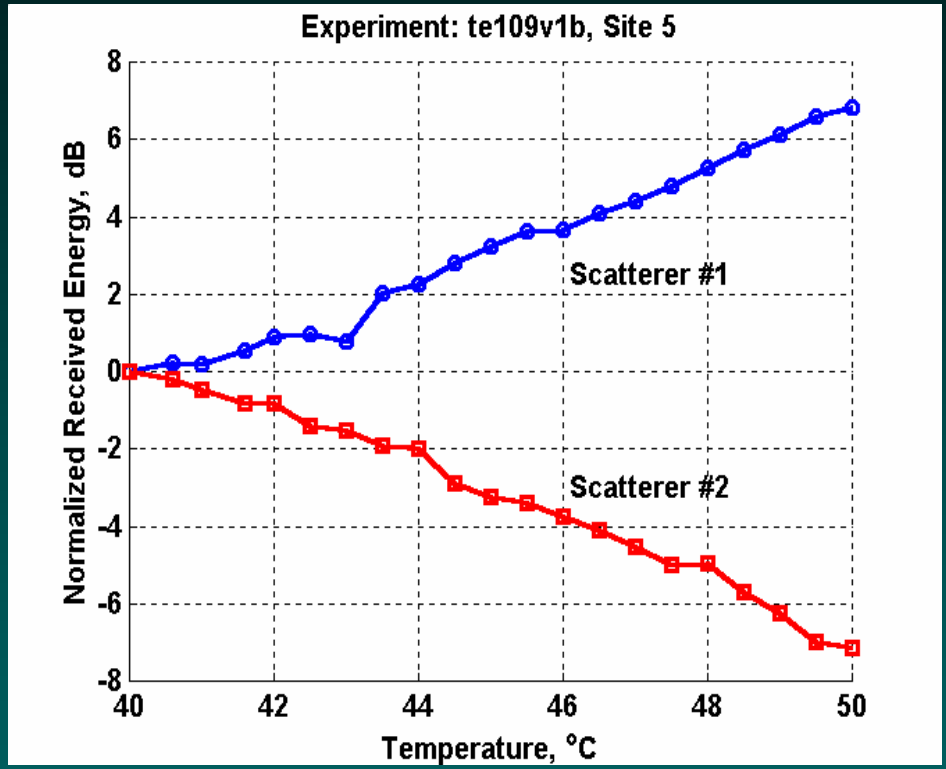
Configuration for *In Vitro* Experiments



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

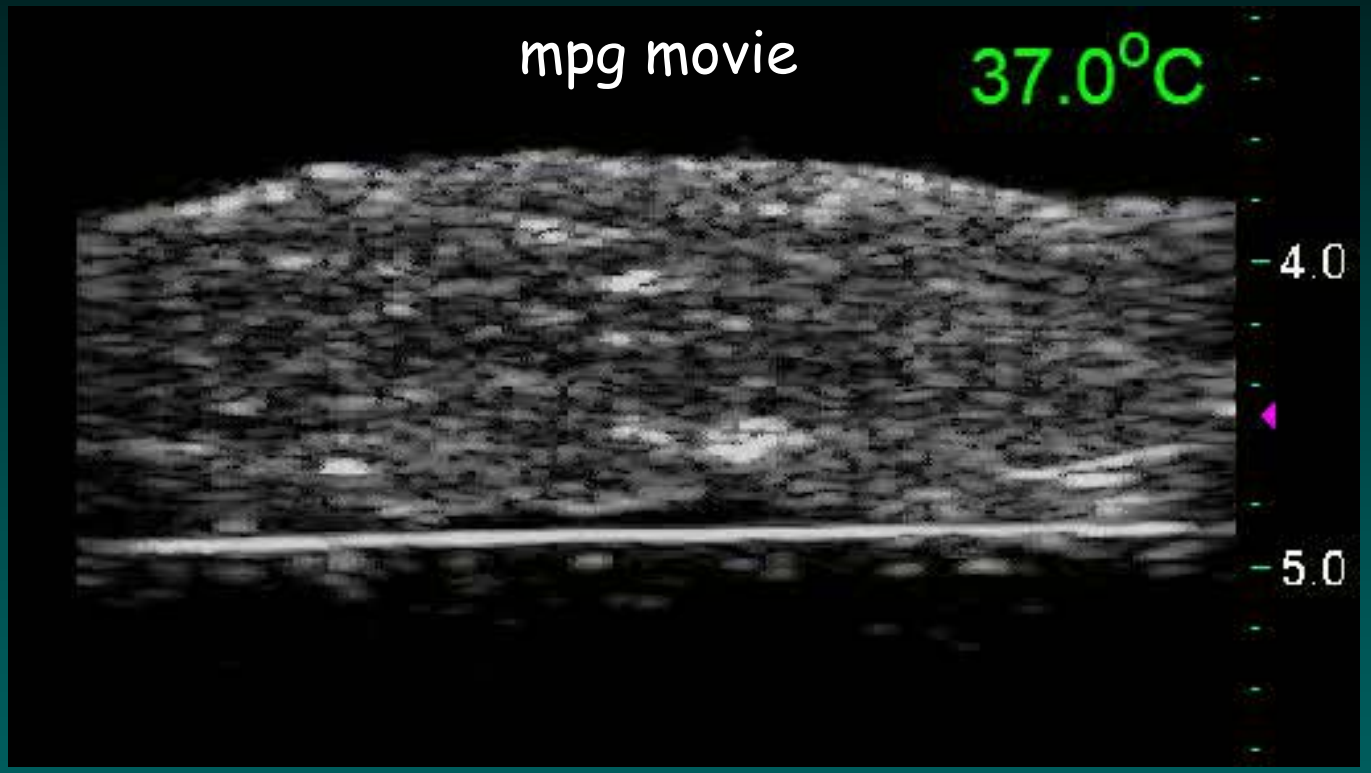
Arthur, Straube, et al., *Medical Physics*, 30:1021-1029, 2003

Measurement of Backscattered Images

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

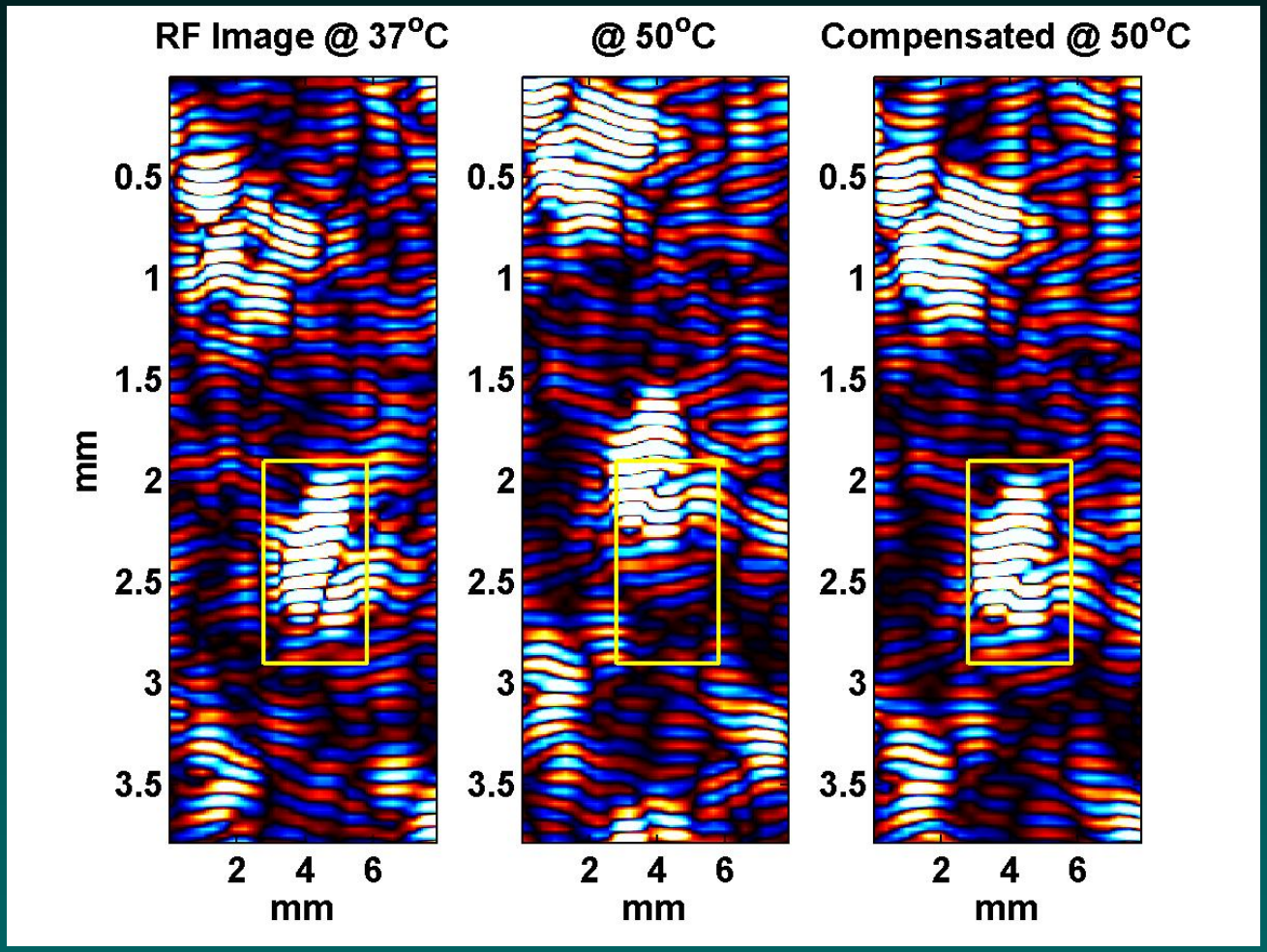
- 128 Element 7 MHz Linear Array
- Laptop control of temperature and image acquisition with AutoIt®
- Access to RF signals

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

Compensation for Apparent Motion

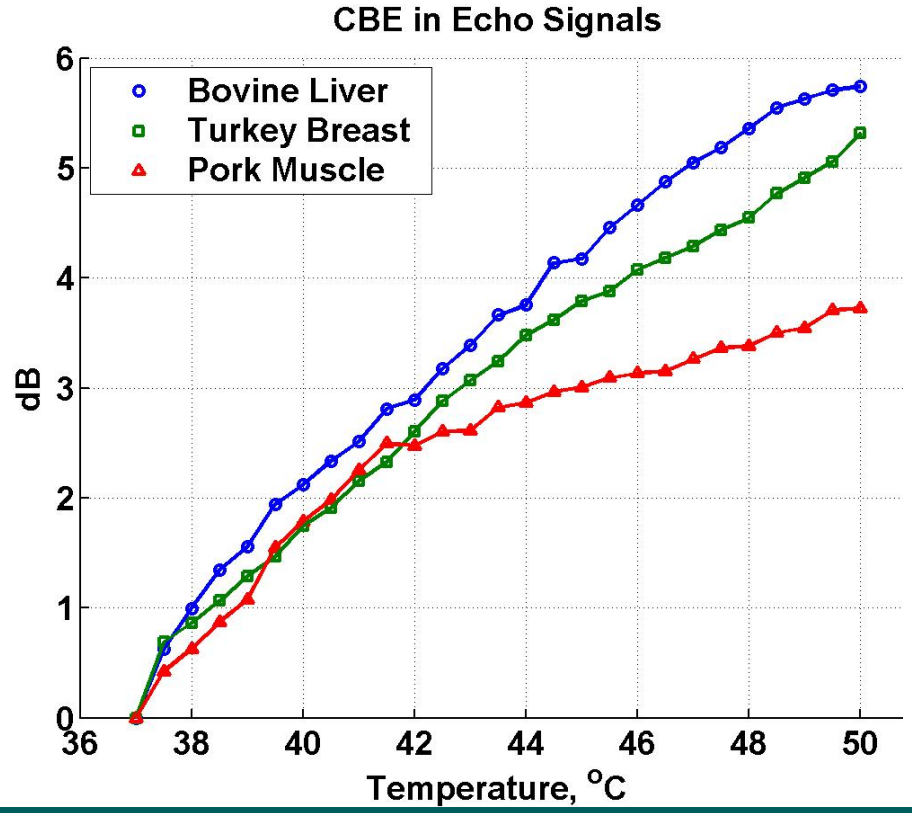


- Radio-frequency images of bovine liver at 37 (left) and 50°C (center & right)
- Features in the fixed, highlighted region appear to have moved both axially and laterally at 50 compared to positions at 37°C
- 2D cross-correlation maximized at adjacent temperatures used to correct for apparent motion of features in the image at 50°C (right)

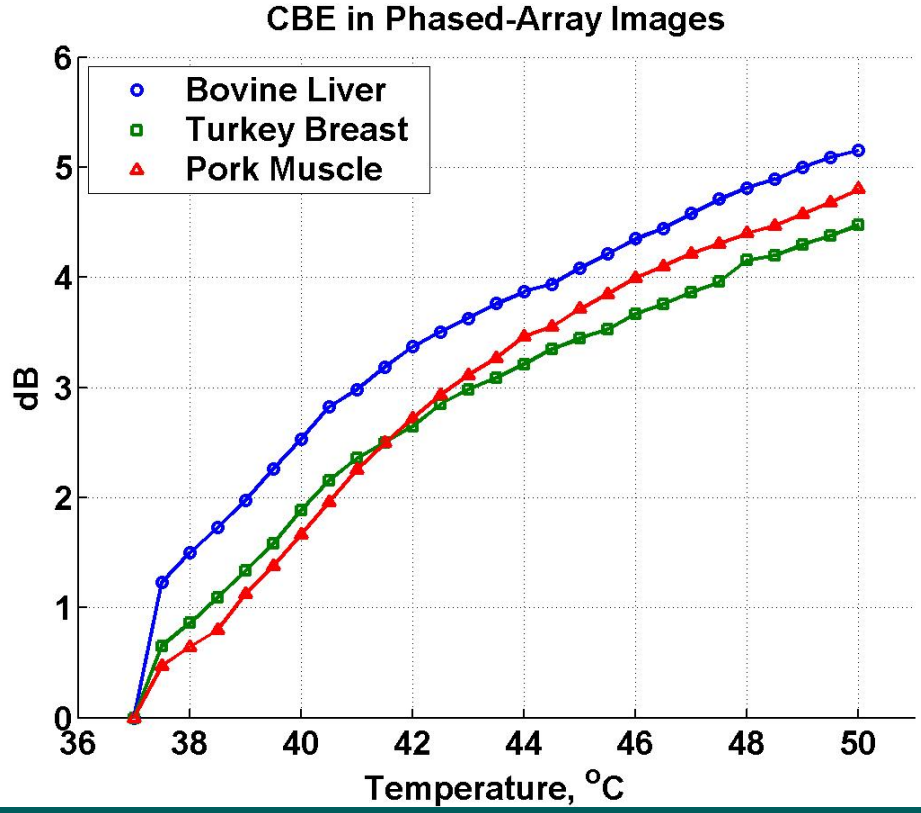
Arthur, Trobaugh, et al., *I J Hyperthermia*, 21:589-600, 2005

CBE with Temperature *In Vitro*

1D



2D



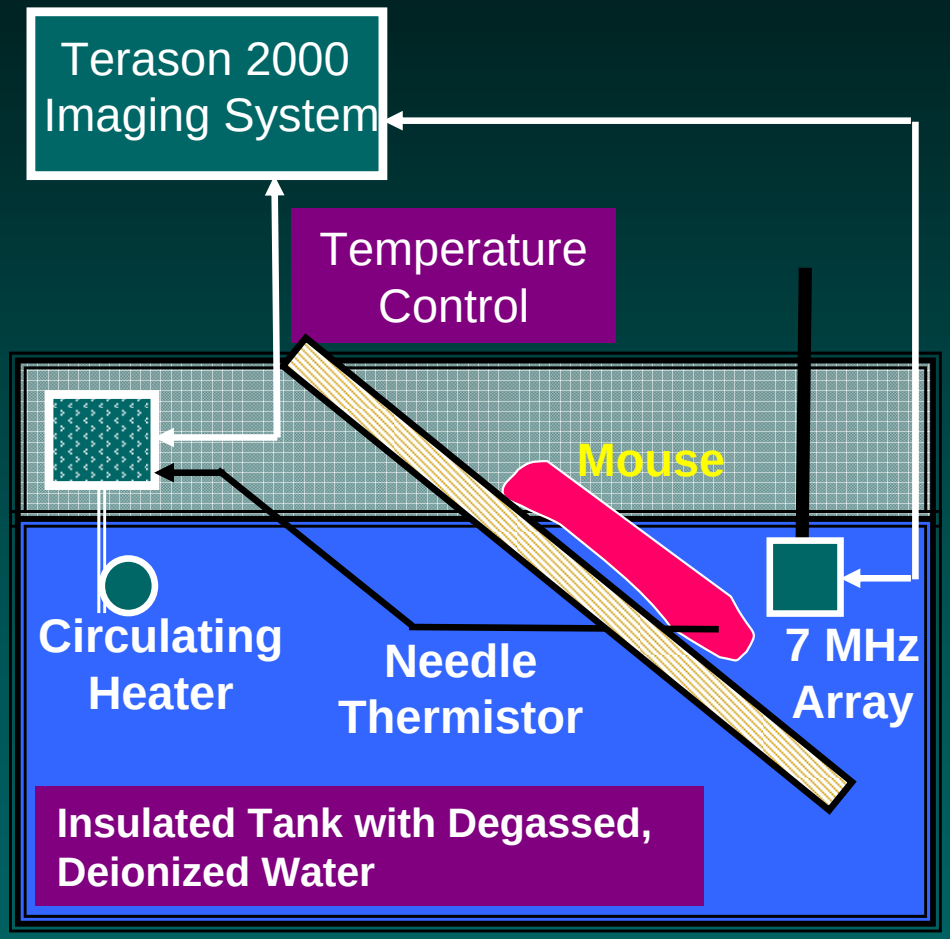
- CBE is nearly monotonic with temperature
- Calibration of CBE may enable temperature imaging

Arthur, Trobaugh, et al., *IEEE Trans. on UFFC*, 52, pp. 1644-1652, 2005.

CBE *In Vivo*

Added Problems for *in vivo* application of CBE temperature estimation include

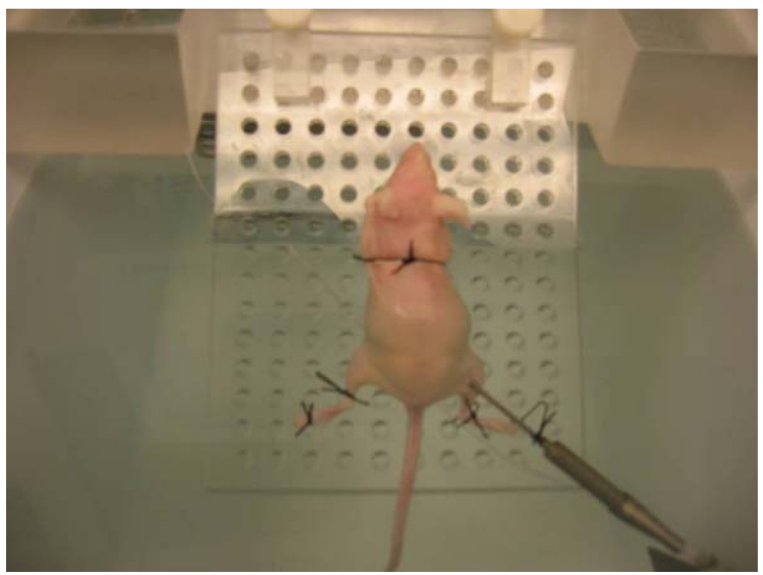
- CBE in living tissue
- Perfusion effects
- Added motion

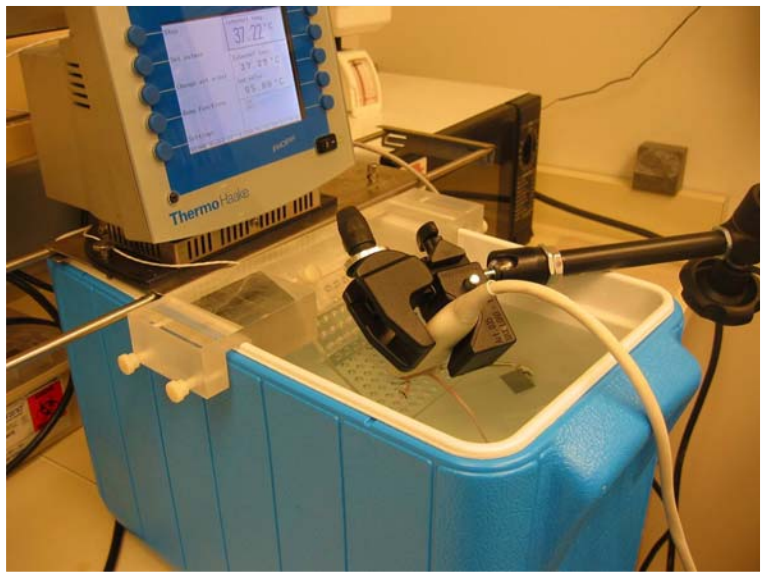


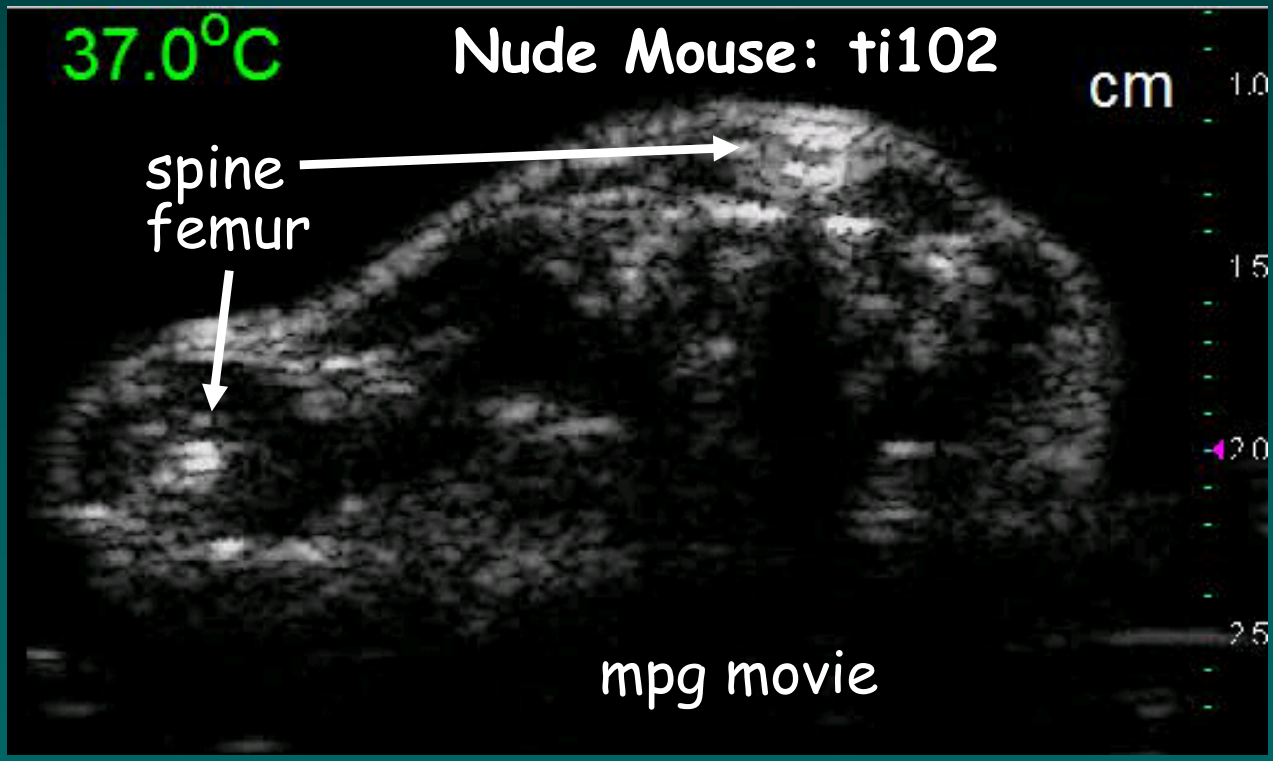
In vivo Experimental Configuration

In Vivo Studies

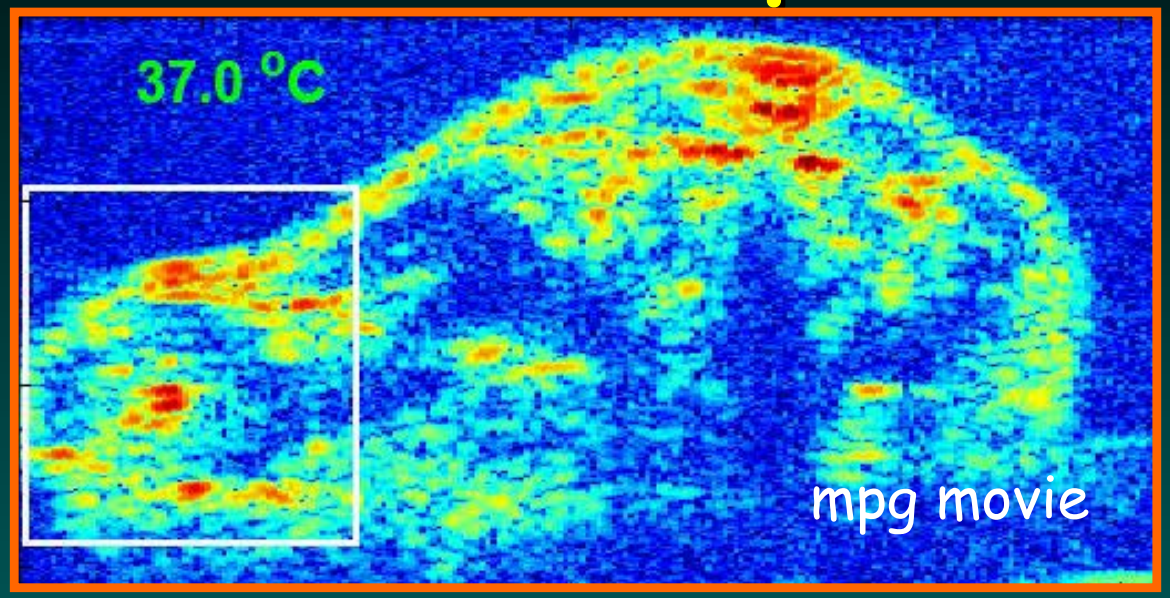
- Performed on nude mice
  - attached to submerged angled tray
  - bilaterally implanted HT29 tumors
  - RTD thermistor in contralateral tumor
- *In vitro* procedure followed
  - from 37.0 to 45.0°C in 0.5°C steps
  - for an experiment of 0.5 hours
- Mice euthanized without recovery
- Images analyzed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

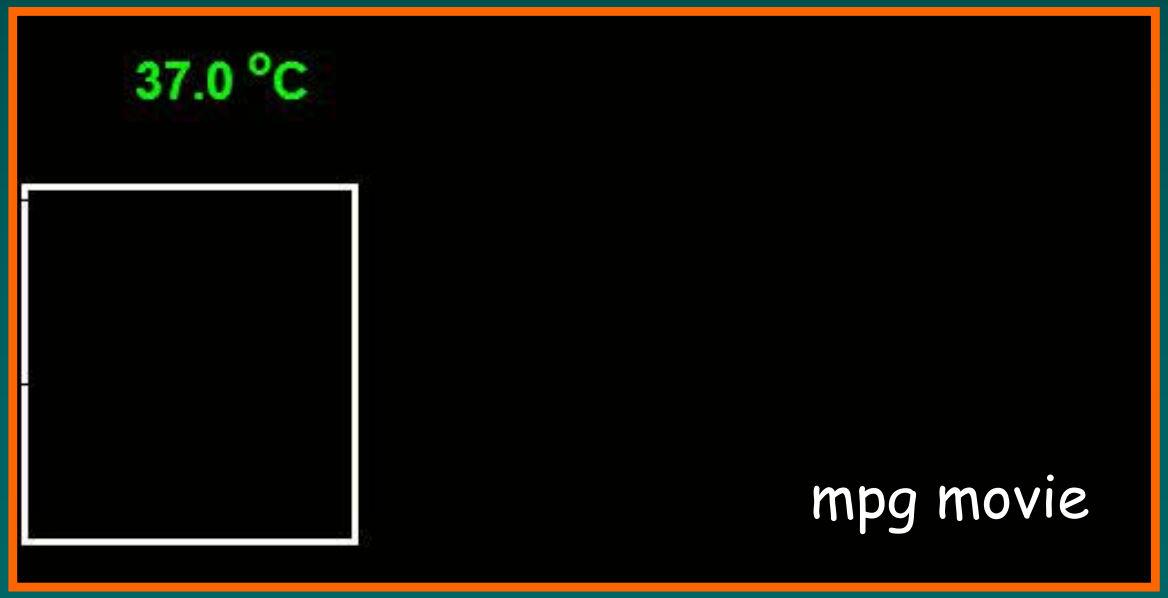






Change in Backscattered Energy in Motion-Compensated Images





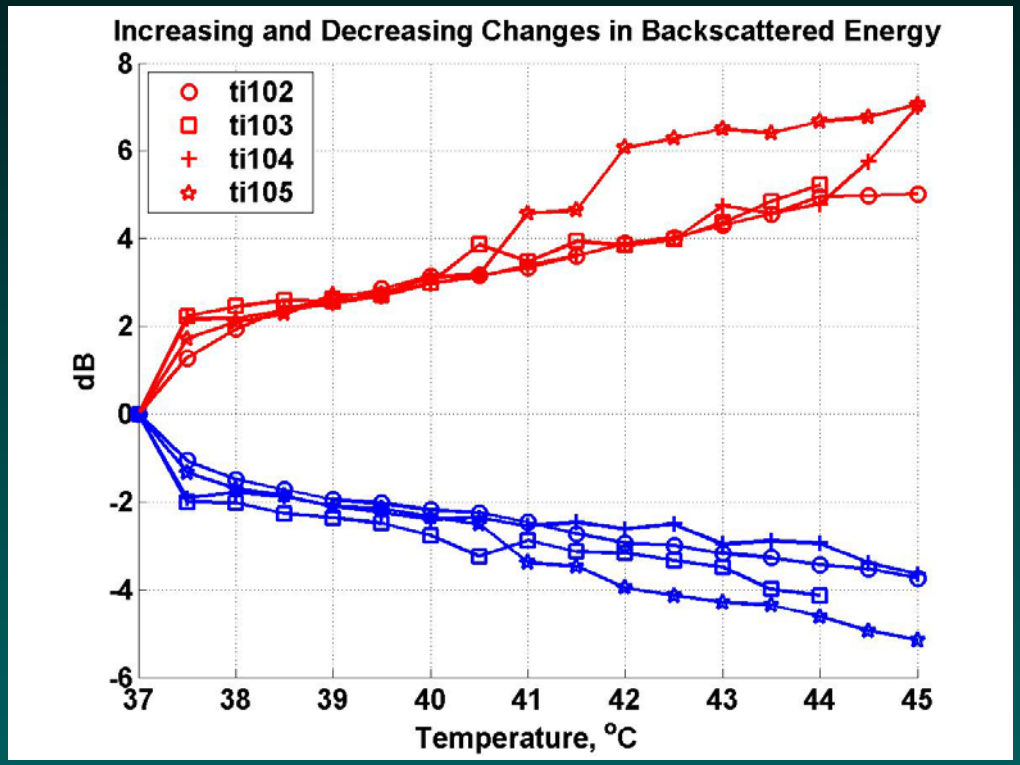
Images after Non-Rigid Motion Compensation

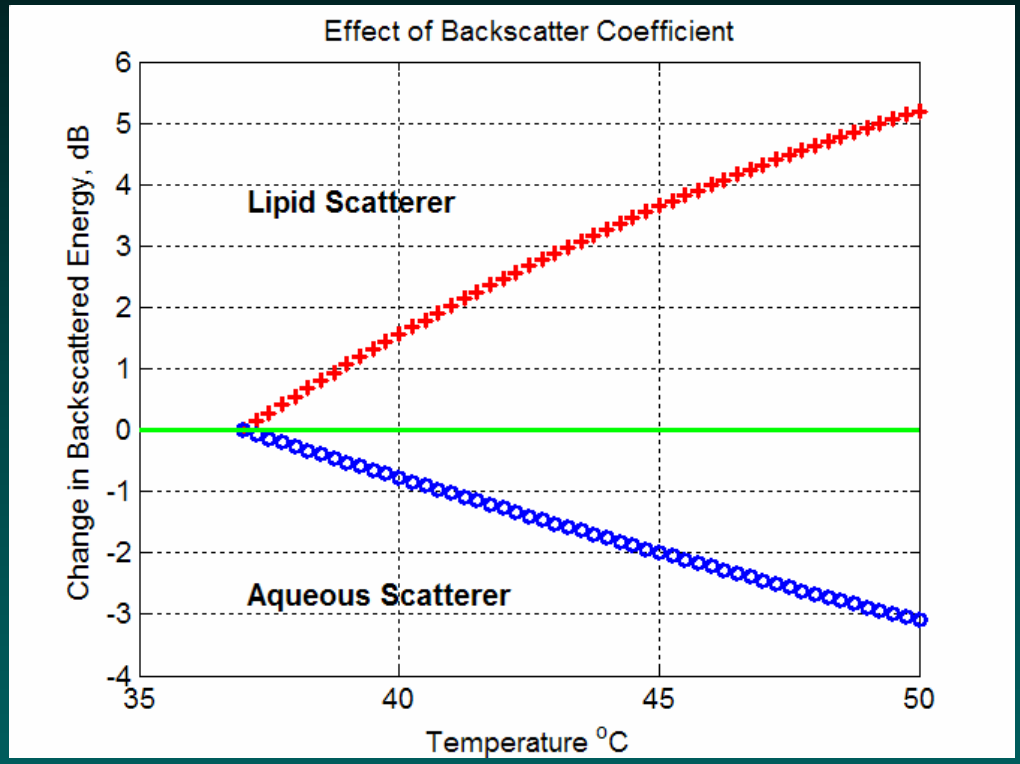
CBE

Increasing - Red

Decreasing - Blue

CBE with Temperature *In Vivo*

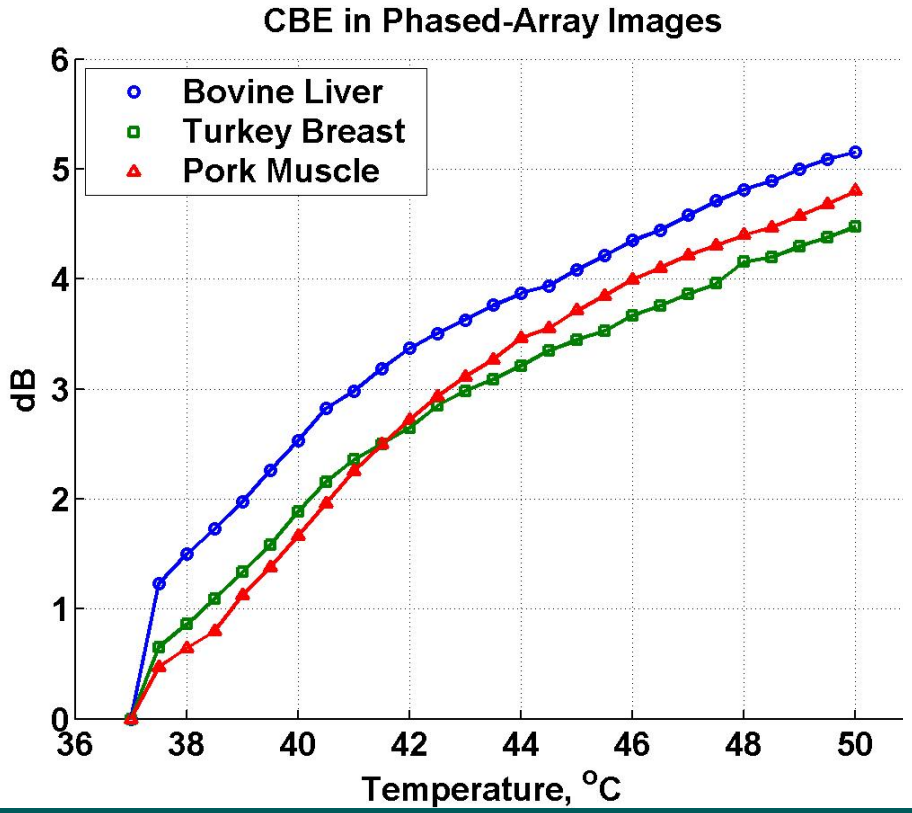


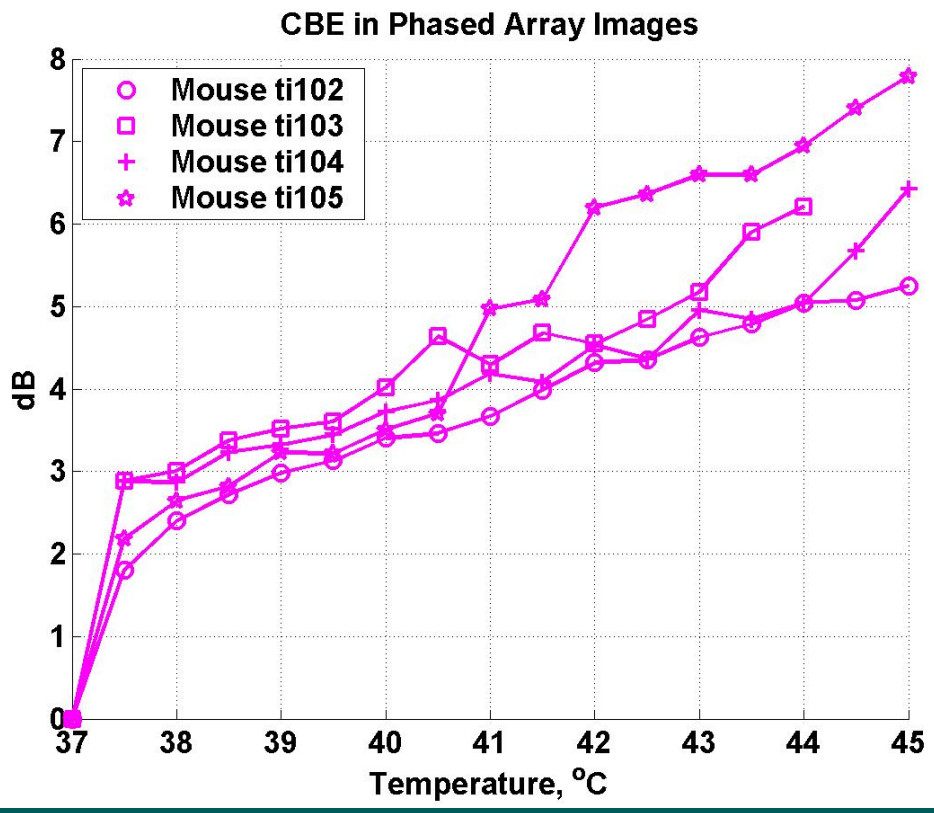


Measured CBE in mice

Predicted CBE in sub-wavelength scatterers

CBE with Temperature





In Vitro *In Vivo*

- CBE is nearly monotonic with temperature
- Calibration of CBE may enable temperature imaging

Summary & Conclusions

- Measured changes in backscattered energy (CBE) from 37 to 45°C in motion-compensated images were consistent with CBE in our model of single sub-wavelength scatterers and in simulations of collections of scatterers
- CBE varied nearly monotonically with temperature in *in vivo* mice just as it did in *in vitro* beef liver, turkey breast & pork muscle
- Because CBE is nearly monotonic with temperature, we expect calibration of CBE to enable temperature imaging

Future Directions for Thermometry Based on Ultrasonic CBE

- Refinement of the CBE model
  - Histological study of scatterer distribution
  - Evaluation of images & CBE using simulation
- Estimation of temperature from simulations and measurements
- Development of clinically relevant heating and measurement systems, such as
  - Small Animal Heating with Ultrasound
  - Scanning Ultrasound Reflector Linear Array