In Vivo Measurement of Changes in Ultrasonic Backscattered Energy for Homogeneous (Water Bath) and Heterogeneous (SAHUS) Heating

William L. Straube[2], R. Martin Arthur[1], Jason W. Trobaugh[1], Jesse Parry[2], Yuzheng Guo[1], and Eduardo G. Moros[3]

[1]Electrical & Systems Engineering
[2]Radiation Oncology
Washington University in St. Louis.
St. Louis, MO, 63130, USA
[3]Radiation Oncology, University of Arkansas

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Objective of Ultrasonic Thermometry

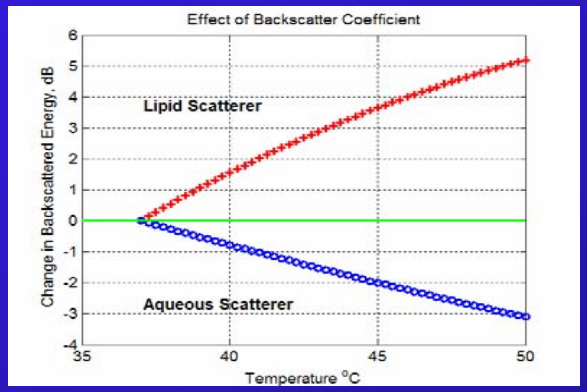
To develop a method to produce 3D temperature maps in soft tissue during hyperthermia cancer treatment

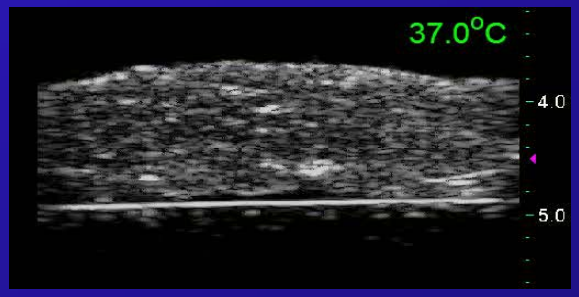
non-invasively, conveniently at low cost with a single view from standard equipment

with at least 0.5°C accuracy & 1 cm^3 resolution

Our Approach to Ultrasonic Thermometry

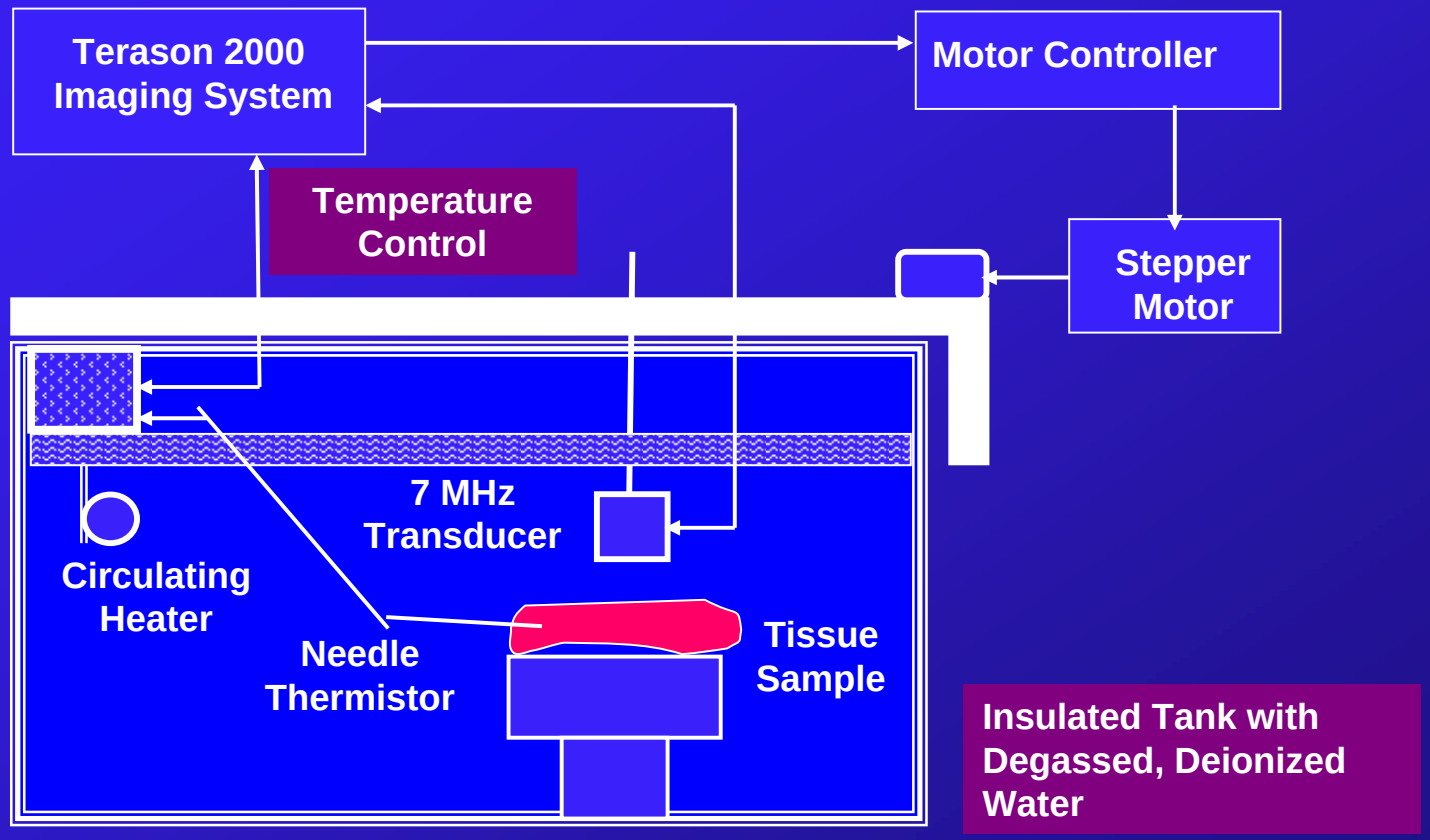
- Take a single backscatter view with standard imaging equipment
- Use the change in back-scattered energy (CBE) as a temperature-dependent parameter
- Track and correct for motion to minimize its effect on CBE





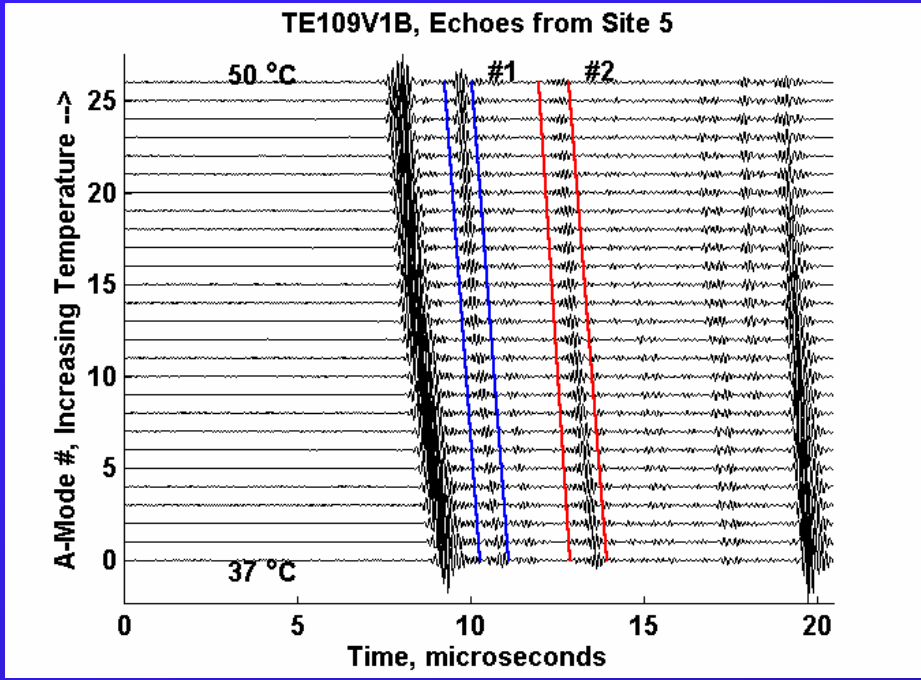
Straube & Arthur, *Ultrasound in Med. & Bio.*, 20:915-922, 1994

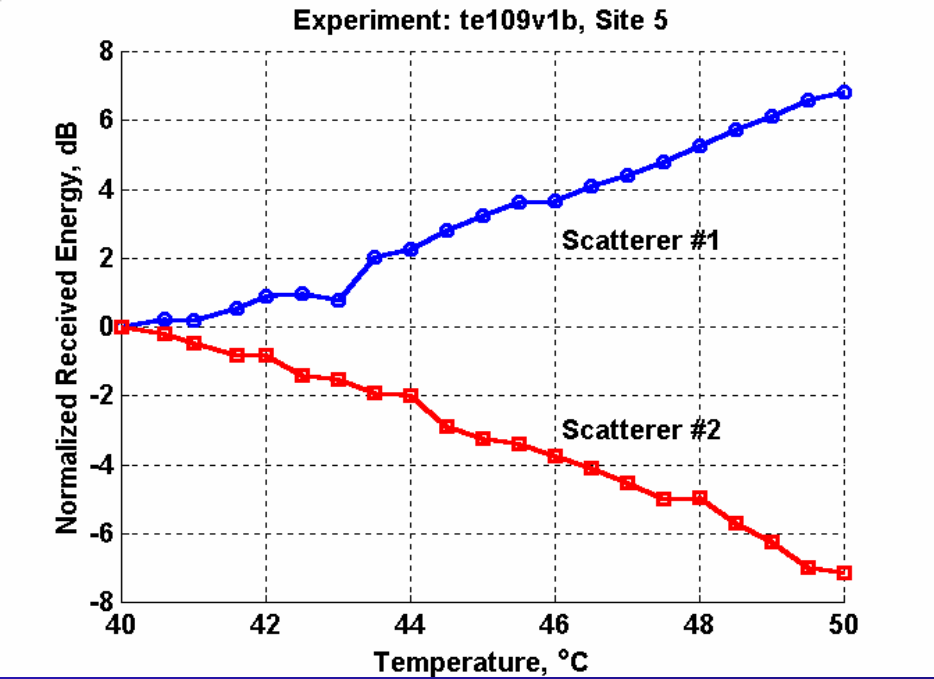
Configuration for *In Vitro* Experiments



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

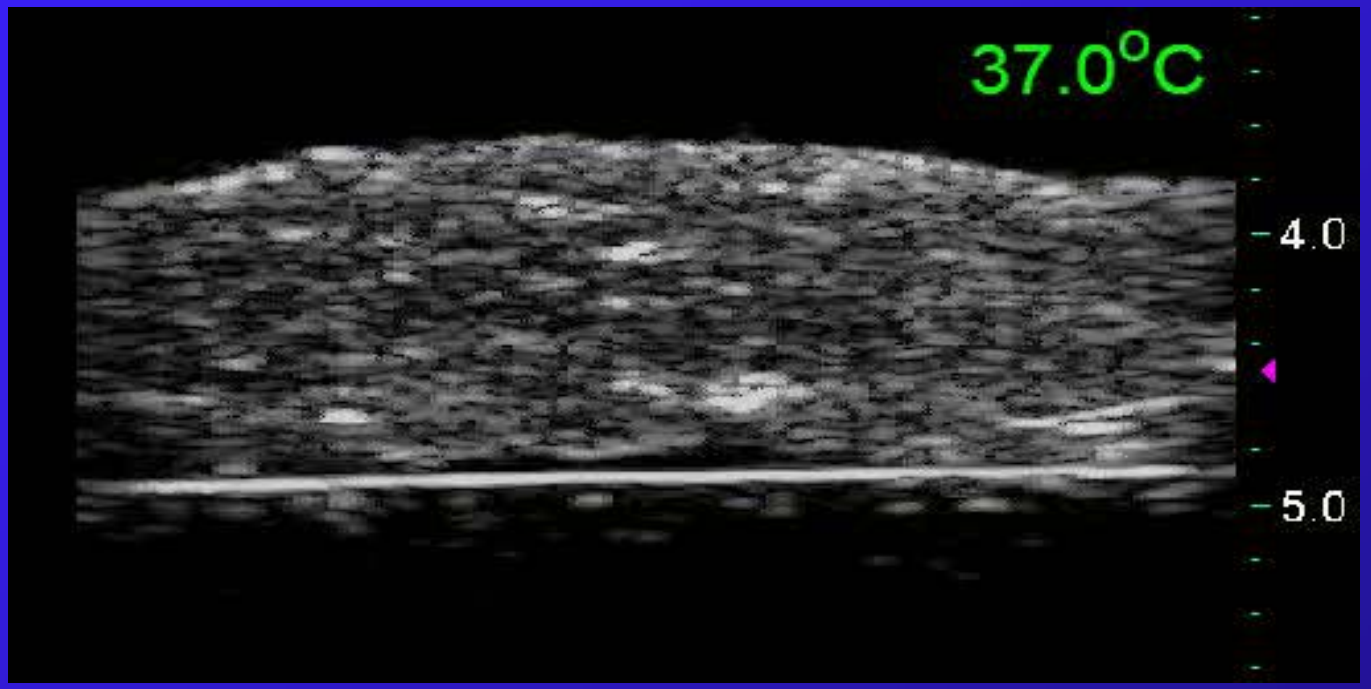
Arthur, Straube, et al., *Medical Physics*, 30:1021-1029, 2003

Measurement of Backscattered Images

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

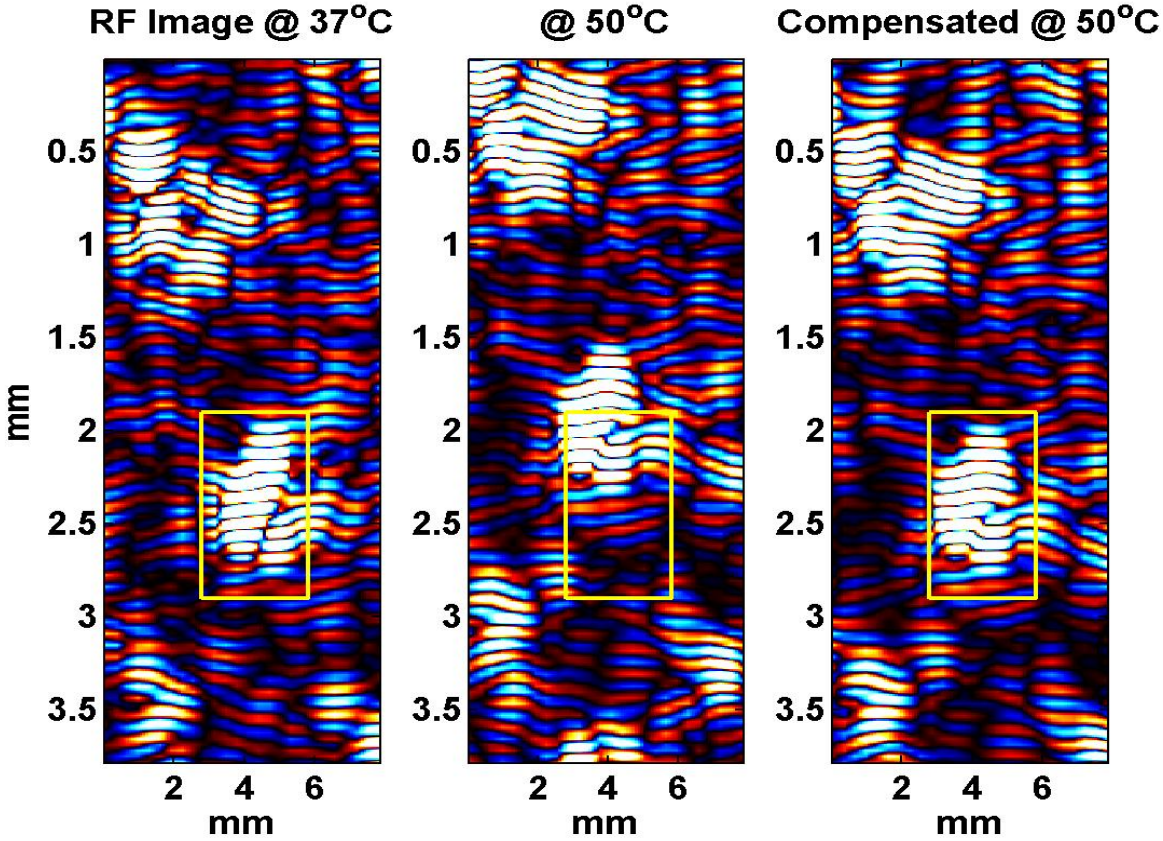
- 128 Element 7 MHz Linear Array
- Laptop control of temperature and image acquisition with AutoIt®
- Access to RF signals

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

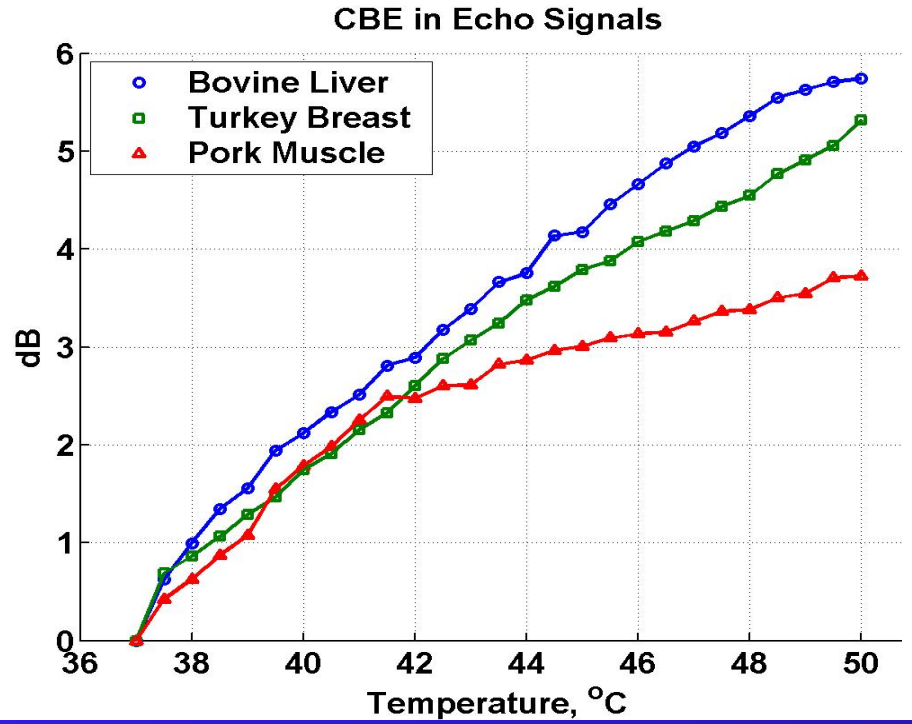


- Radio-frequency images of bovine liver at 37 (left) and 50°C (center & right)
- Features in the fixed, highlighted region appear to have moved both axially and laterally at 50 compared to positions at 37°C
- 2D cross-correlation maximized at adjacent temperatures used to correct for apparent motion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

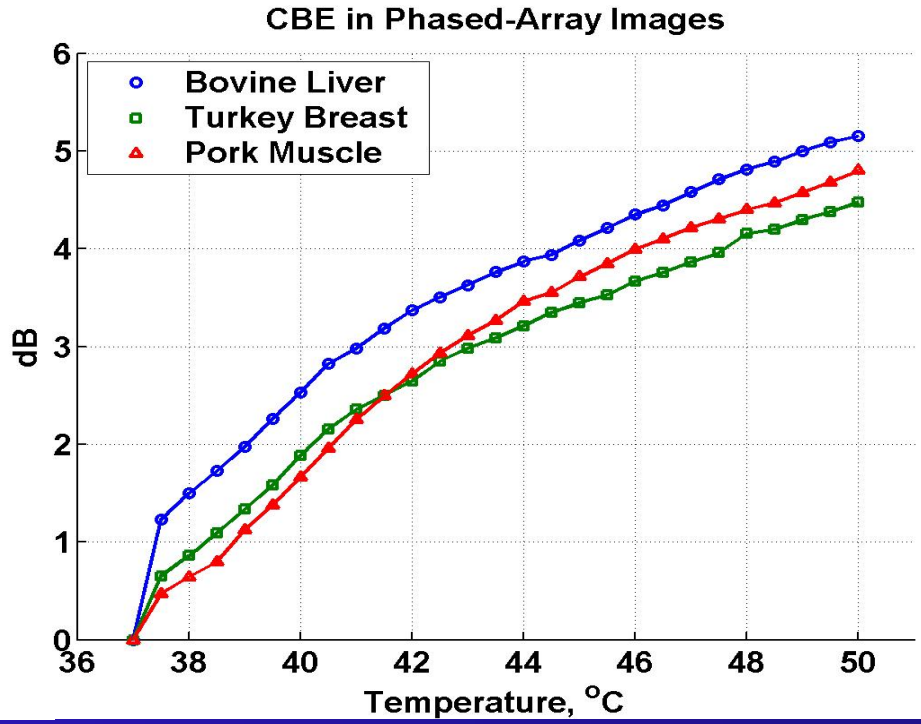
Arthur, Trobaugh, et al., *I J Hyperthermia*, 21:589-600, 2005

CBE with Temperature *In Vitro*

1D



2D



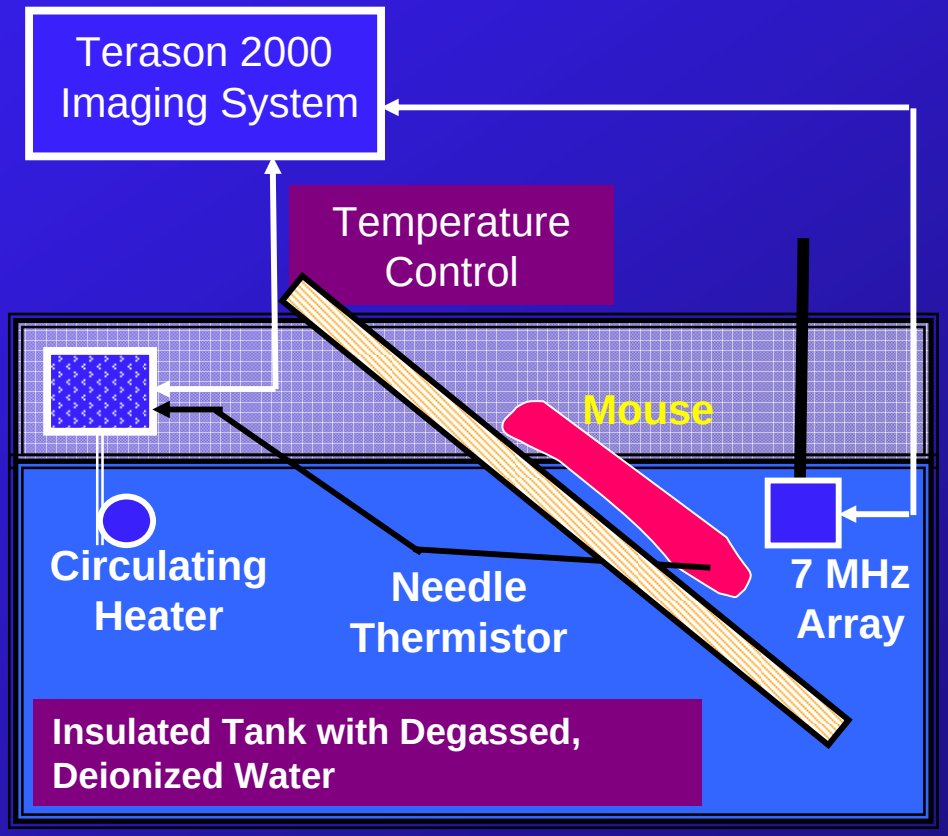
- CBE is nearly monotonic with temperature
- Calibration of CBE may enable temperature imaging

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

CBE *In Vivo*

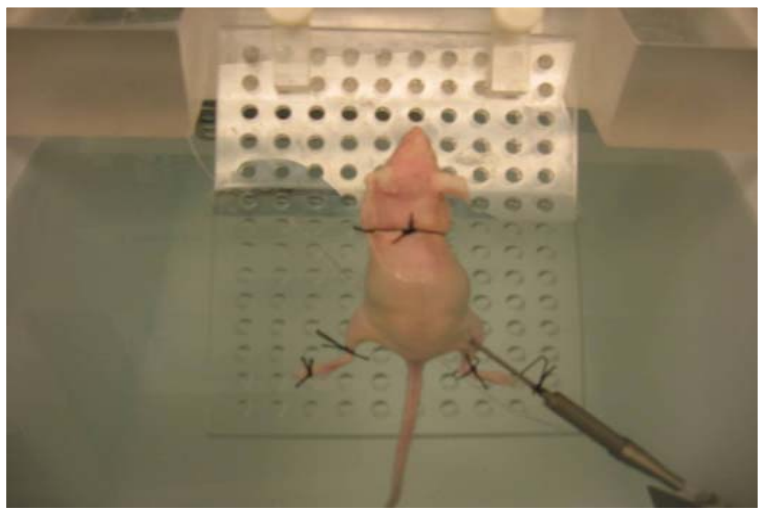
Added Problems for *in vivo* application of CBE temperature estimation include

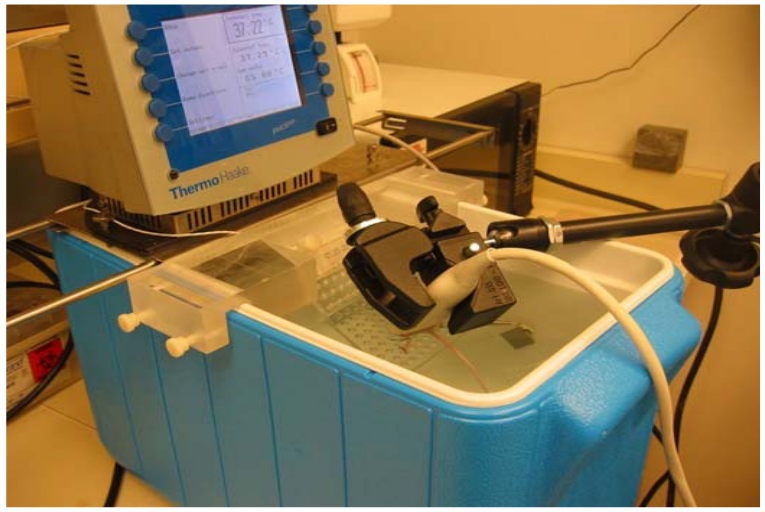
- **CBE in living tissue**
- **Perfusion effects**
- **Added motion**



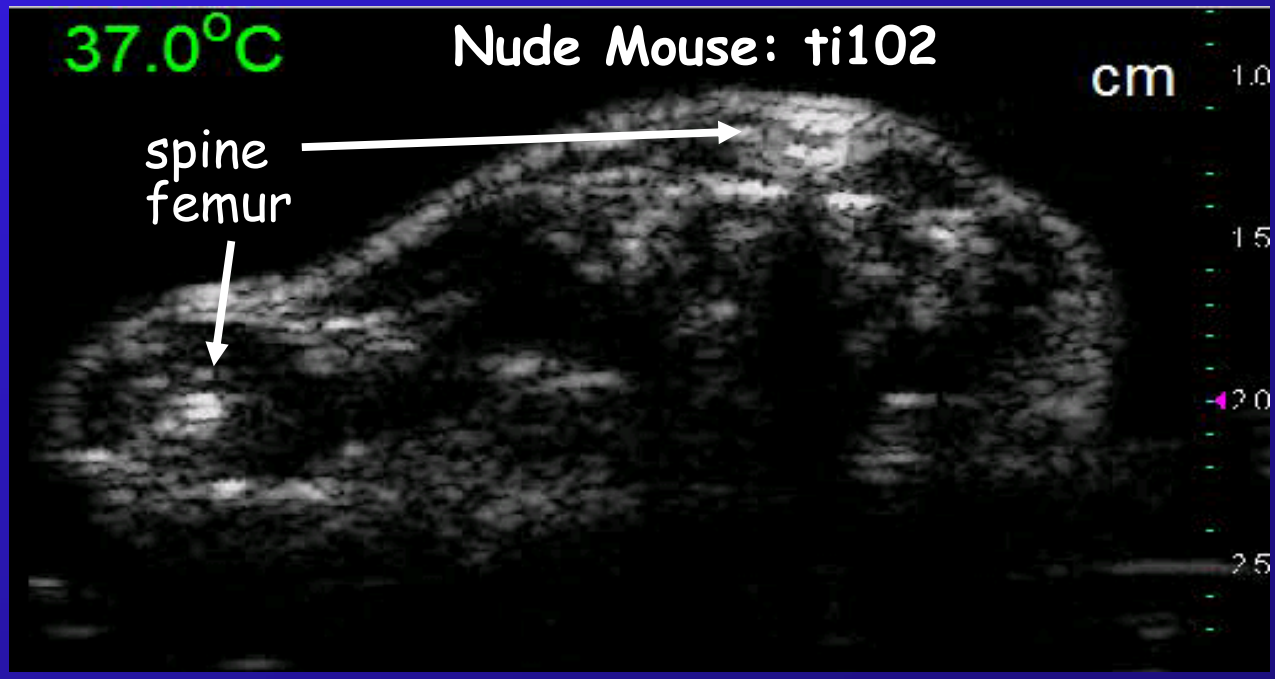
***In vivo* Experimental Configuration**

In Vivo Studies

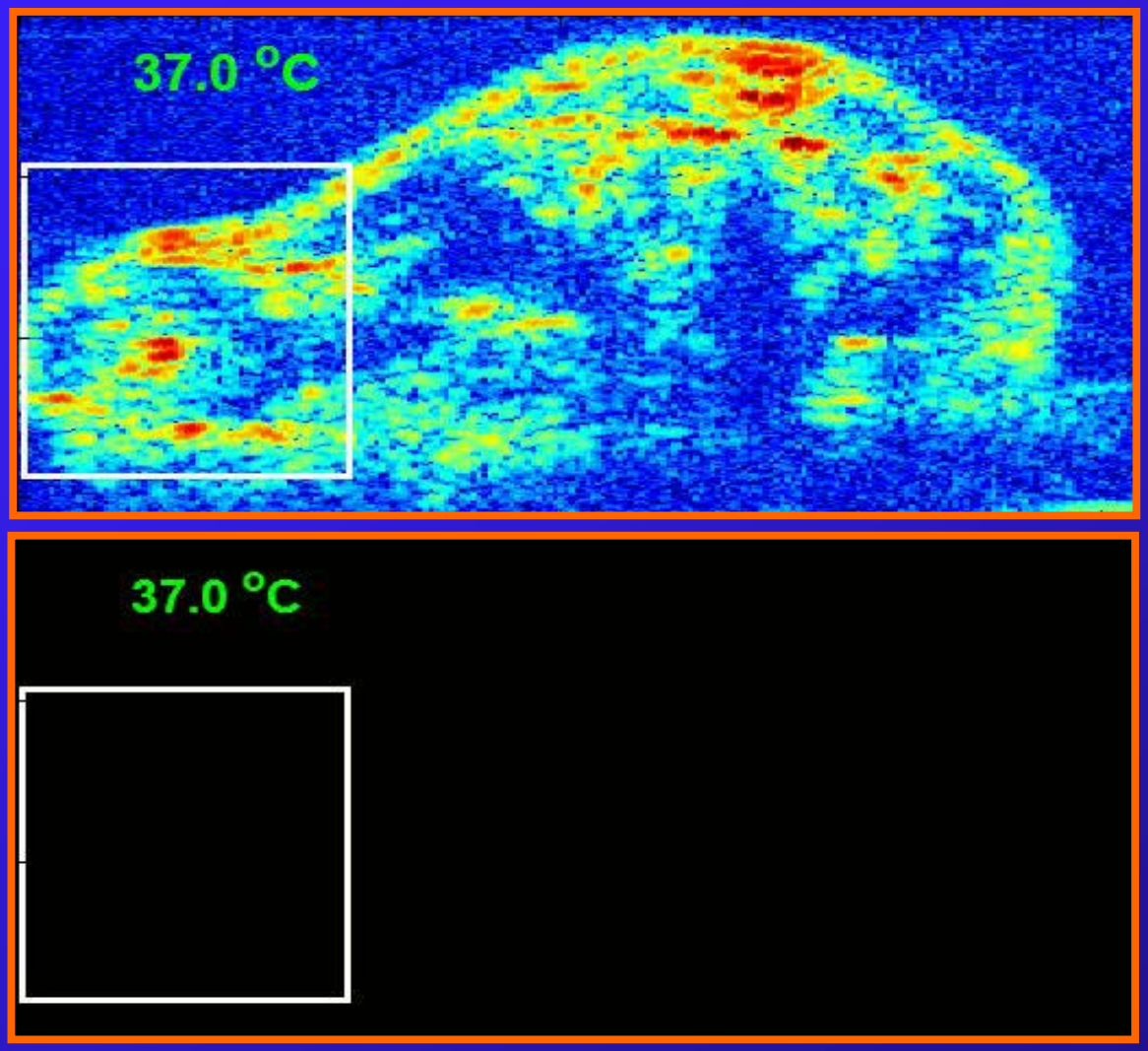




- Performed on nude mice
  - attached to submerged angled tray
  - bilaterally implanted HT29 tumors
  - RTD thermistor in contralateral tumor
- *In vitro* procedure followed
  - from 37.0 to 45.0°C in 0.5°C steps
  - for an experiment of 0.5 hours
- Mice euthanized without recovery
- Images analyzed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



Change in Backscattered Energy in Motion-Compensated Images



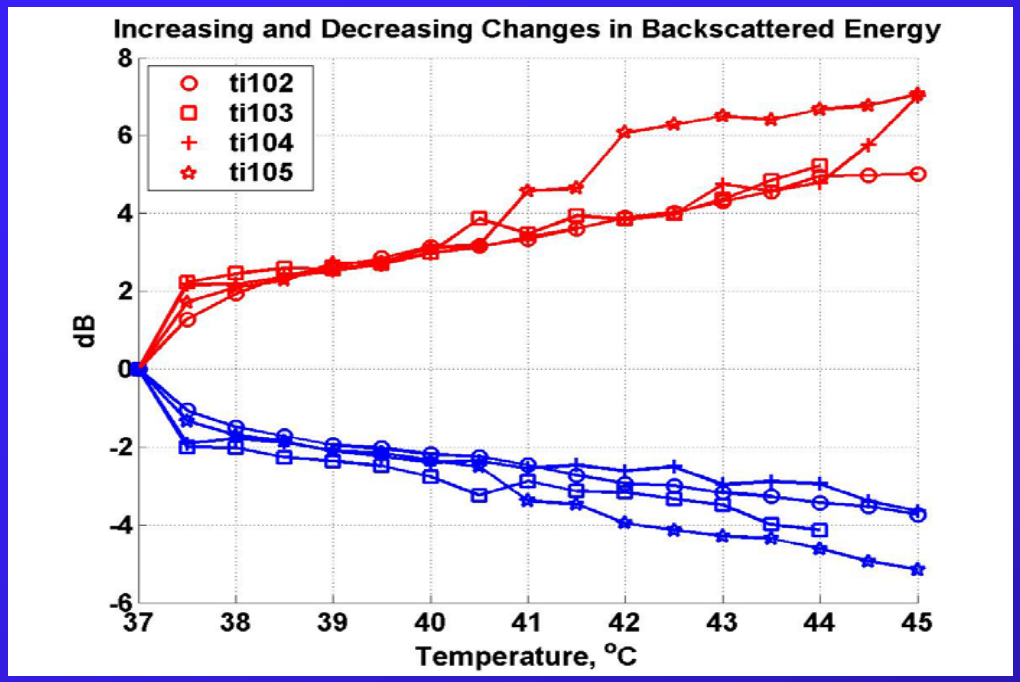
Images after Non-Rigid Motion Compensation

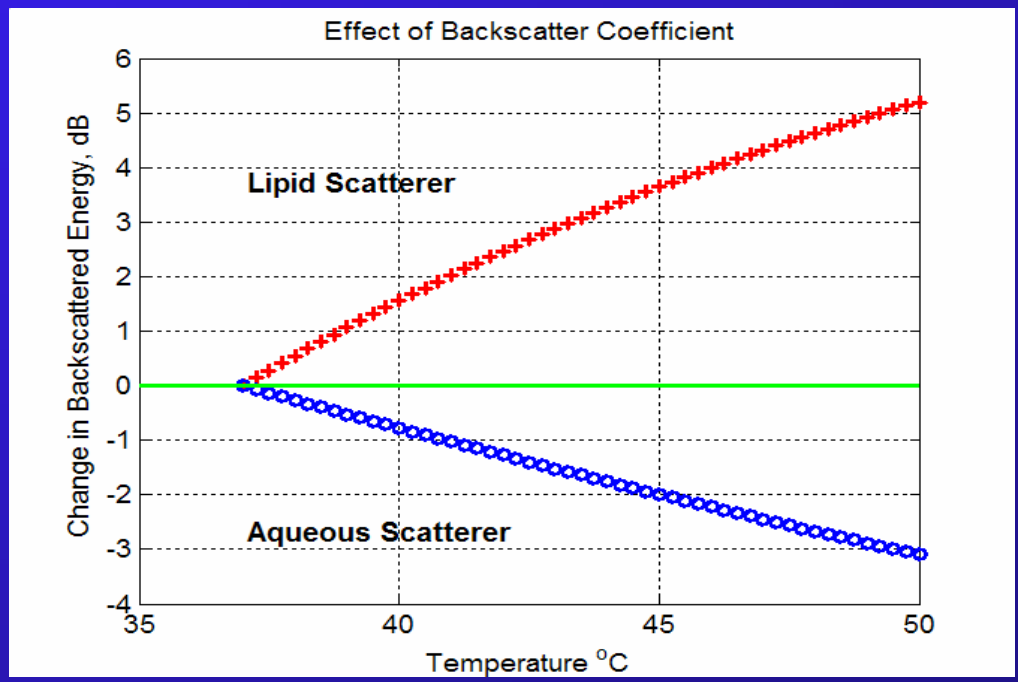
CBE

Increasing – Red

Decreasing - Blue

CBE with Temperature *In Vivo*

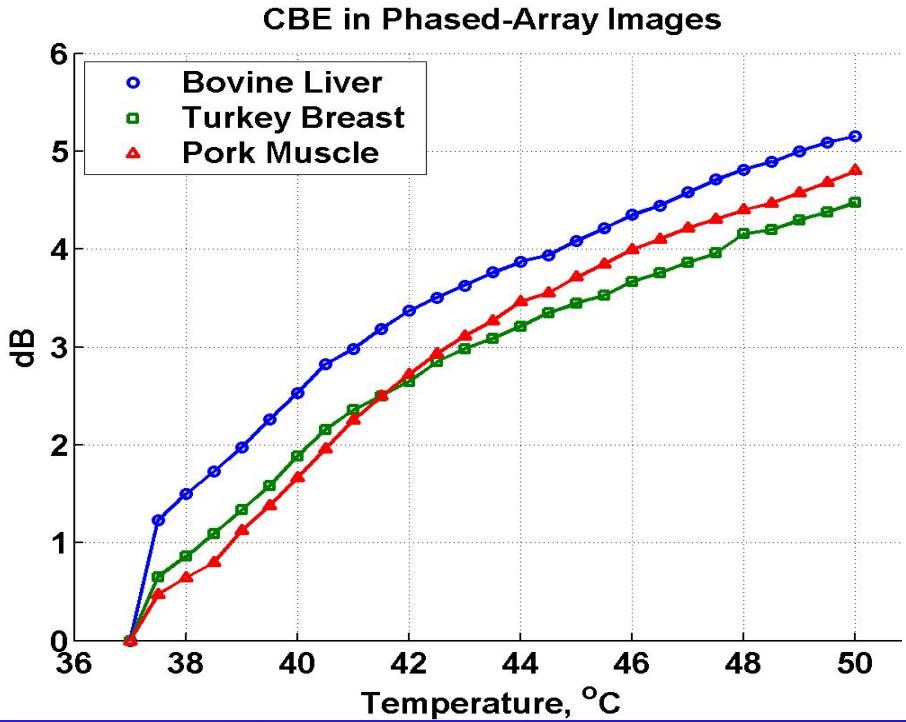




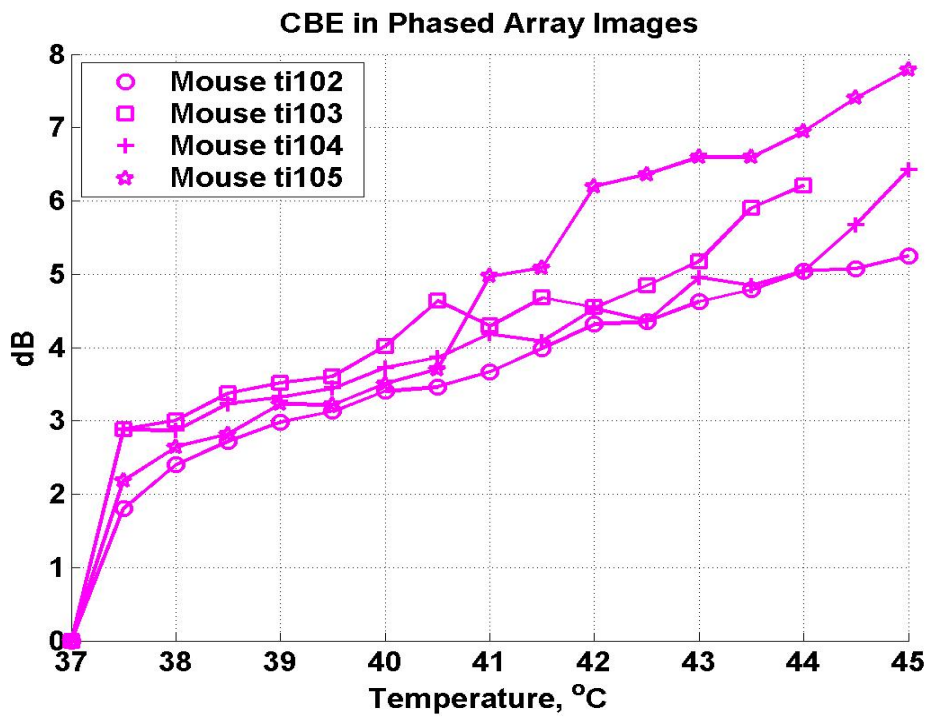
***M*easured CBE in mice**

Predicted CBE in sub-wavelength scatterers

CBE with Temperature



In Vitro



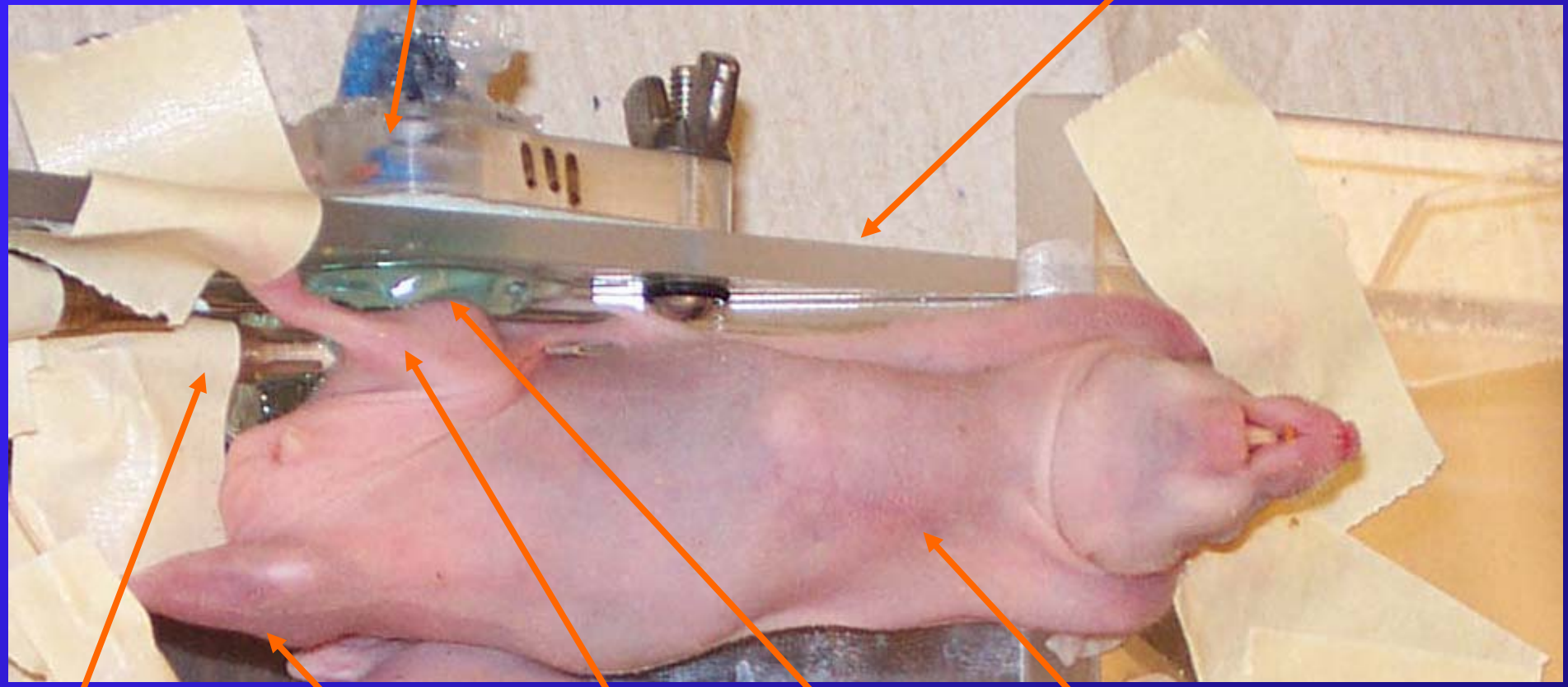
In Vivo

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

Small Animal Hyperthermia Ultrasound System

Ultrasonic Transducer Holder Mounted On The Body Of The Applicator

SAHUS Acrylic Body applicator



Temperature probes

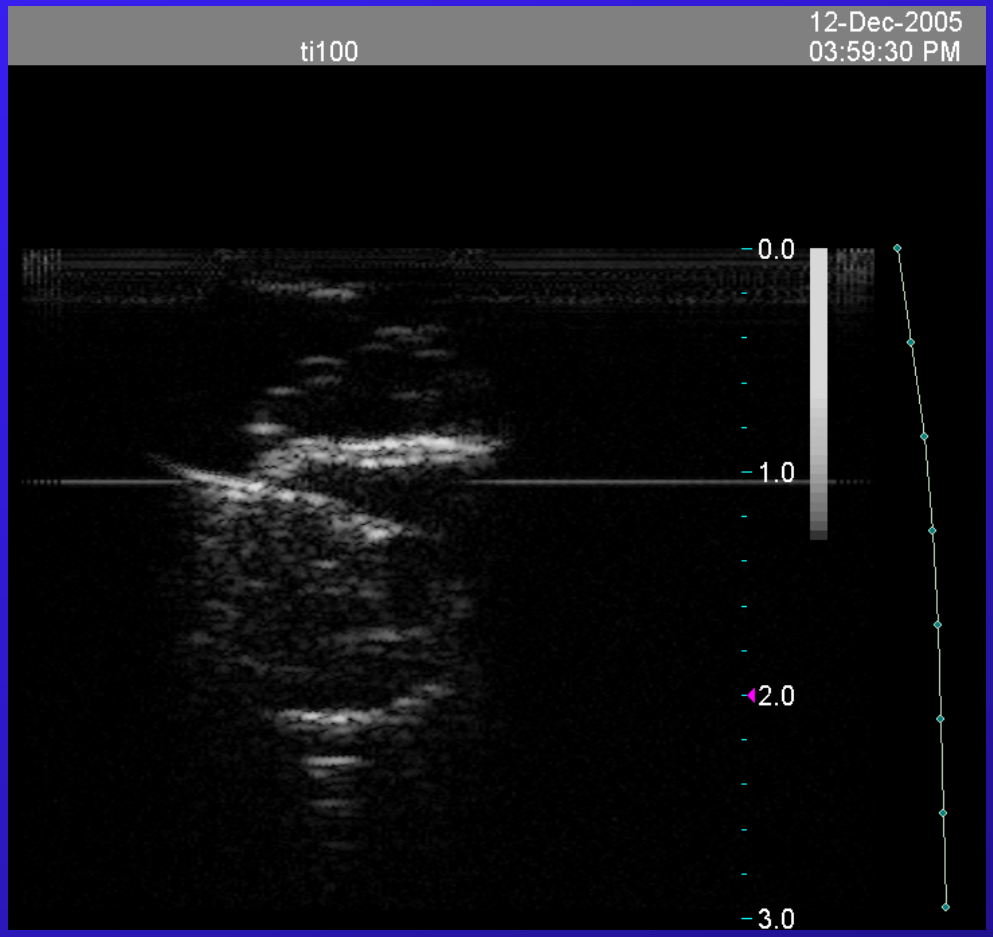
Non -heated tumor

Heated tumor

Coupling gel

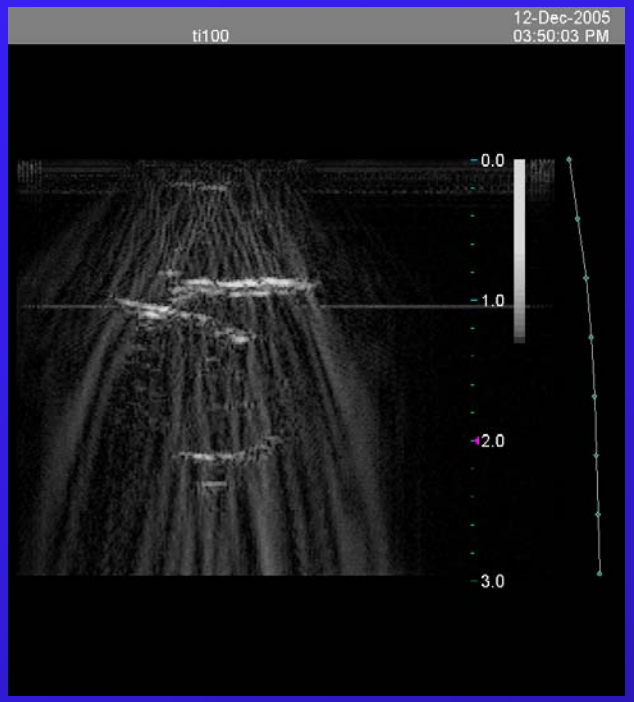
Animal

Ultrasound Images Generated by the Terason <u>Before</u> Ultrasound Heating with the SAHUS

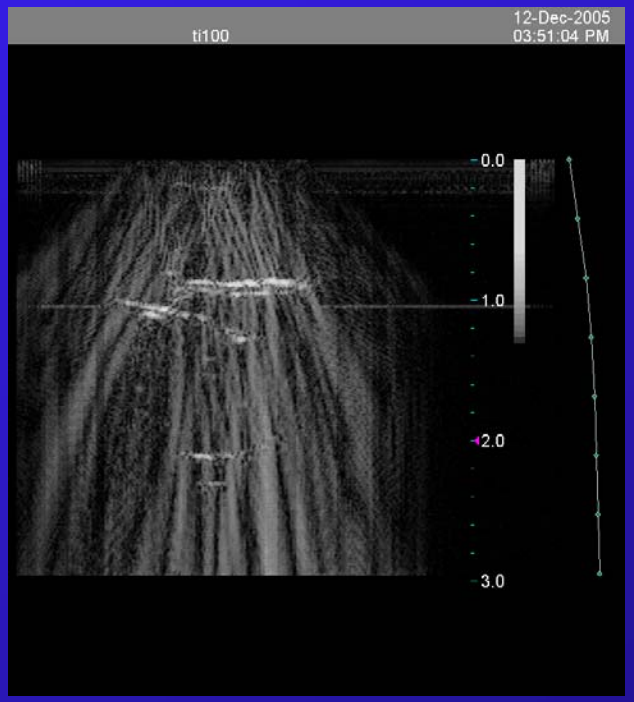


Ultrasound Images Generated by the Terason During Ultrasound Heating with the SAHUS

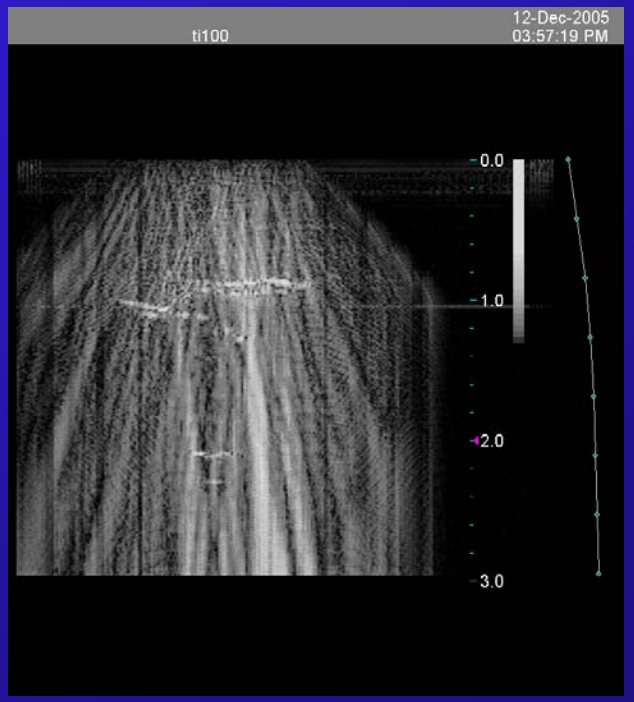
400 mW



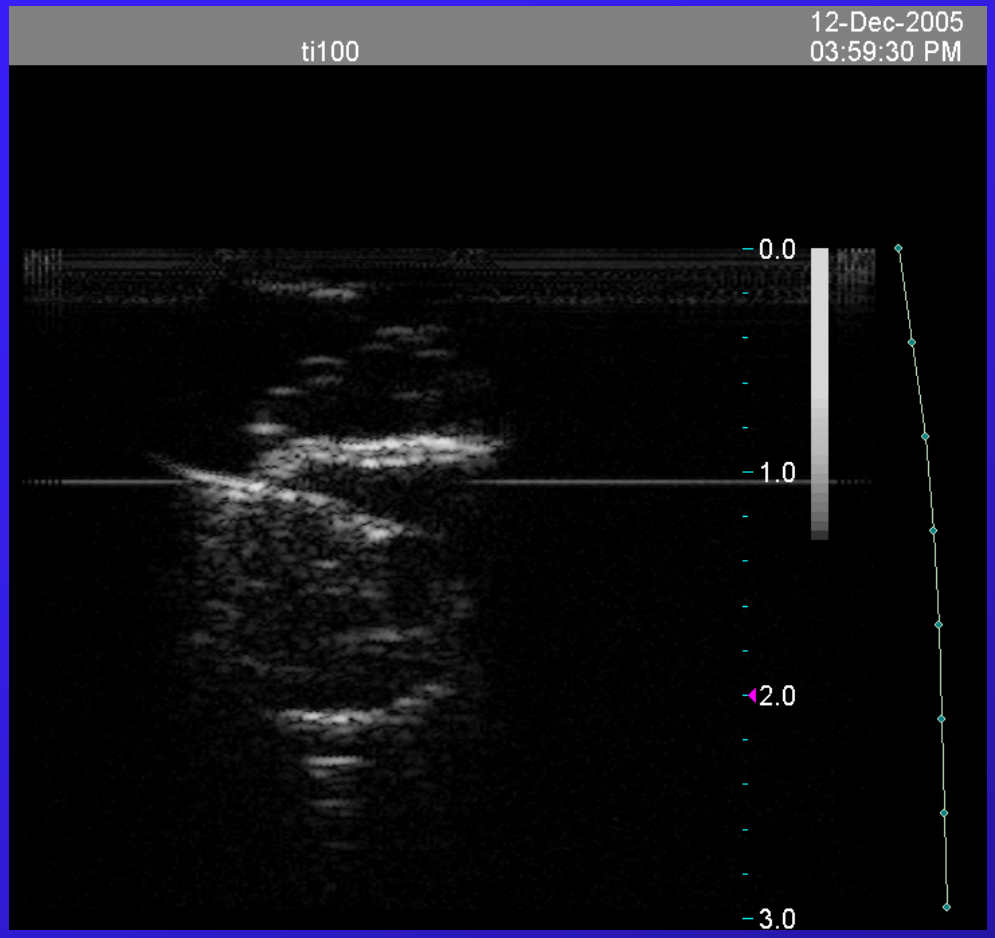
800 mW



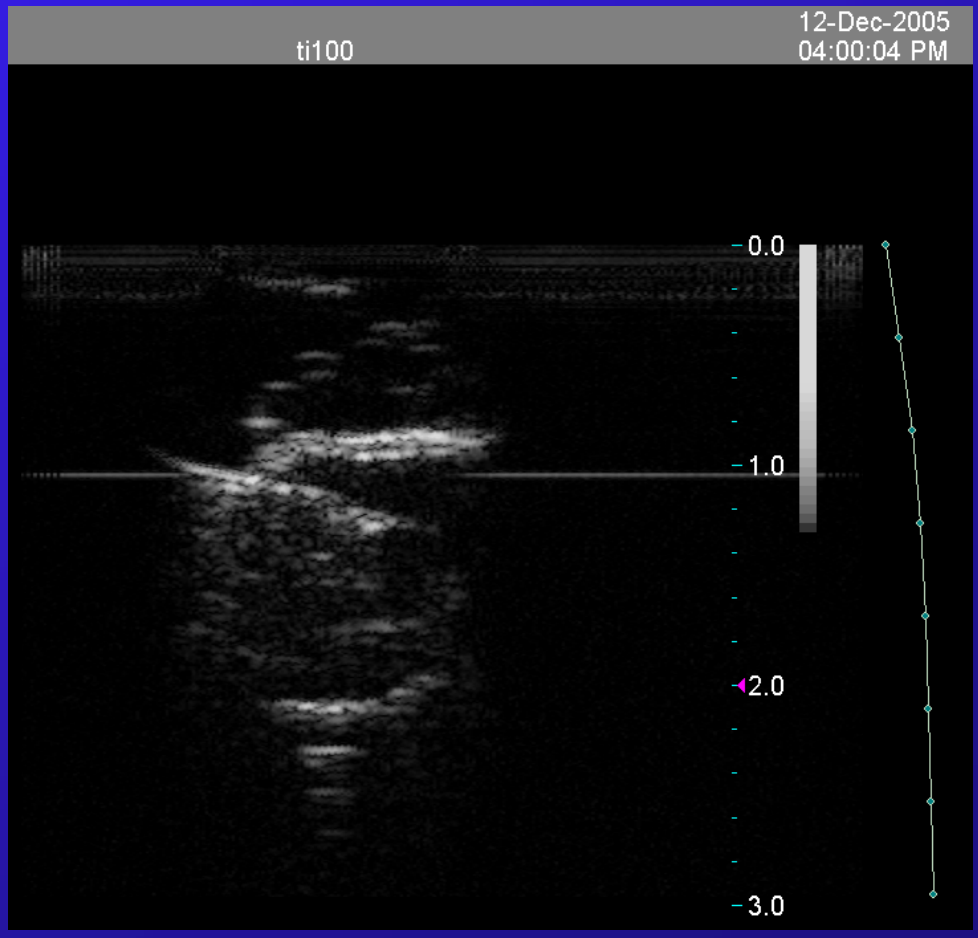
1600 mW



Ultrasound Images Generated by the Terason
Before & After Ultrasound Heating with the SAHUS



Before



After

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

Measurement of CBE with animal heating devices such as the SAHUS should be possible after eliminating noise.

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 Hyperthermia with Ultrasound
- Scanning Ultrasound Reflector Linear Array
- Other Clinical Hyperthermia Systems