



Decision Theory Applied to High-Intensity Focused Ultrasound (HIFU) Treatment Evaluation

Narendra Sanghvi , Adam Wunderlich, Ralf Seip, Jahangir Tavakkoli

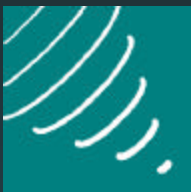
Focus Surgery Inc., Indianapolis, IN

Kris Dines

XDATA Corp., Indianapolis, IN

Michael Bailey, Lawrence Crum

APL, University of Washington, Seattle, WA



Sonablate® HIFU Probe

■ **Dual Element Confocal Transducer:**

Outer Element - Therapy

Inner Element - Imaging

■ **Typical Values for Imaging:**

Focal Length = 3, 3.5, 4cm

Center Frequency = 4MHz

■ Diameter = 12mm

-6dB Beamwidth = 1.5mm

-6dB Depth of Field = 2.6cm

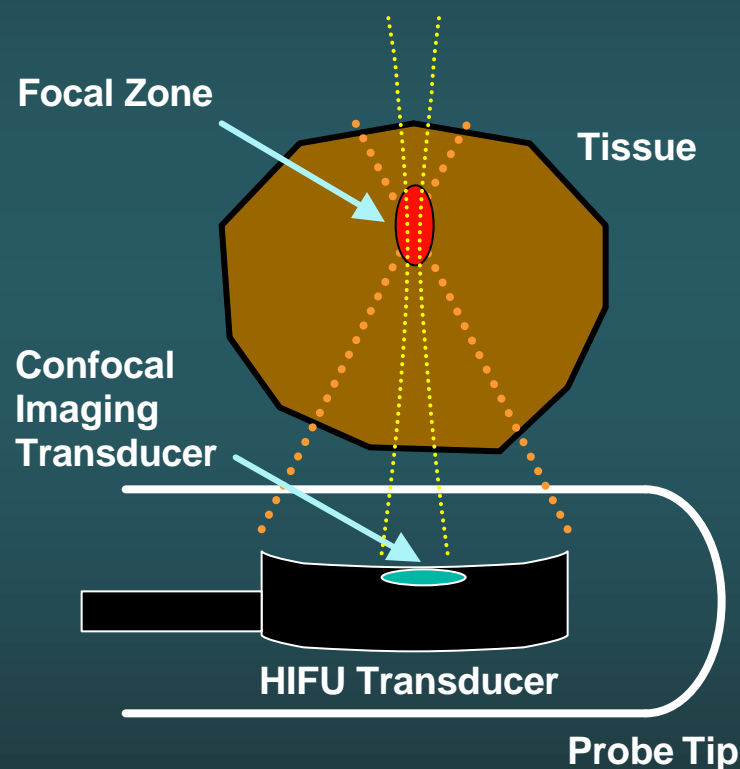
Pulse Length = 5μsec

Bandwidth = 3-5MHz

■ Tissue/Water Signal Ratio ≈ 30 dB

$$TWSR = 10 \log \left(\frac{APS_{Tissue} - APS_{Water}}{APS_{Water}} \right)$$

APS = Average Power Spectrum

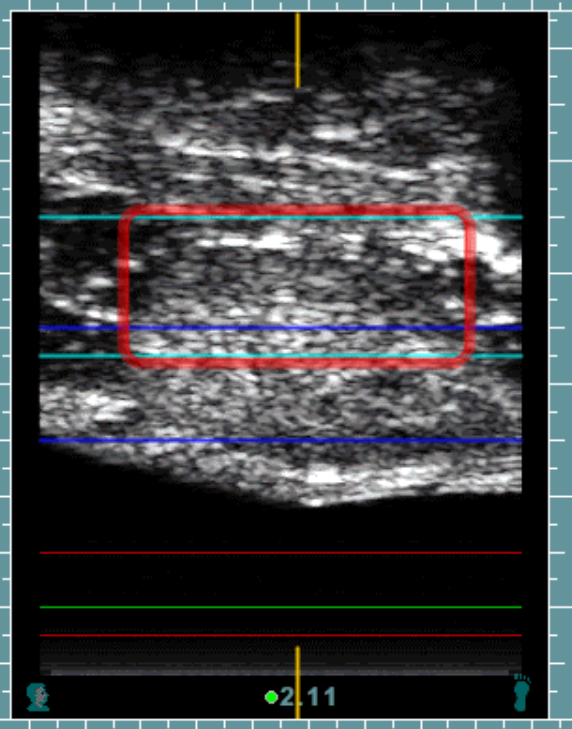
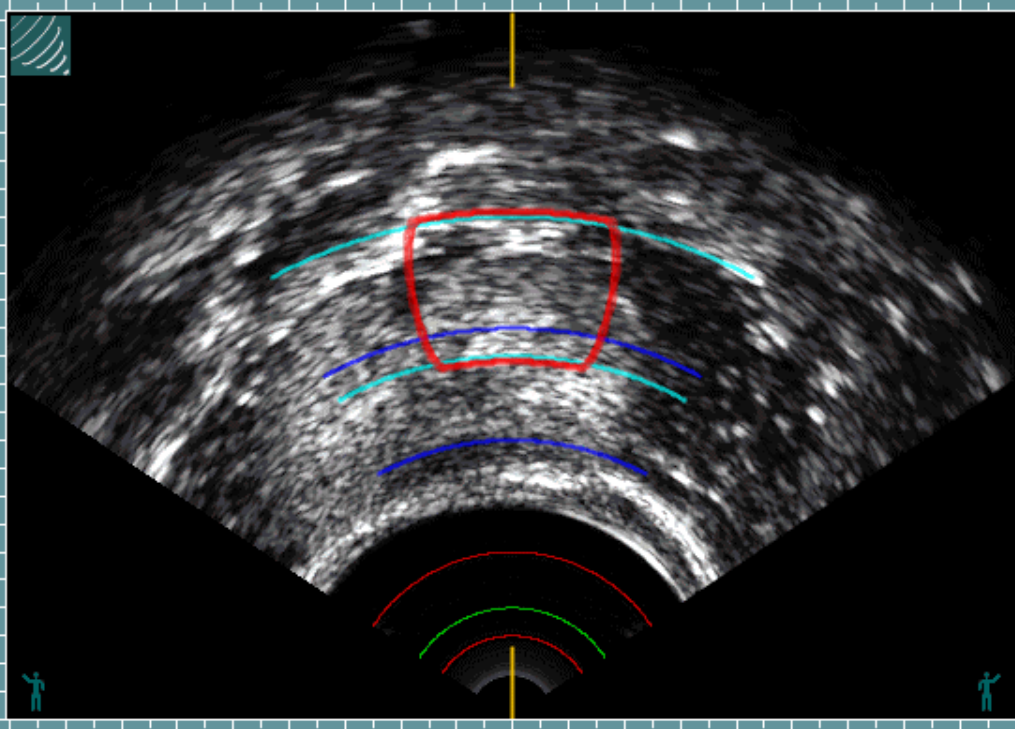


Site: IU - LARC Patient: Dog1 Probe: SN5001 4.0/3.0

PREPARE IMAGE PLAN THERAPY VOLUME

Scan Freeze Scan

Flip 4.0



Vertical control panel with multiple sliders and icons for adjusting image parameters.

Navigation and zoom controls for the left image, including a zoom level of 0.0.

Navigation and zoom controls for the right image, including a zoom level of 2.10.

Treatment

0:10:30

hour:min:sec [3.0,6.0]

Plan is complete

Control for treatment sectors, showing 7 sectors and 1 additional parameter.

Control for marking zones, showing 3.00 linear (cm) and 0.00 linear (cm).

37.0

watts

24.0

Erase A Treatment

Erase B Treatment

Grid, Meas., Filter, Zone, Clear, and Order controls.

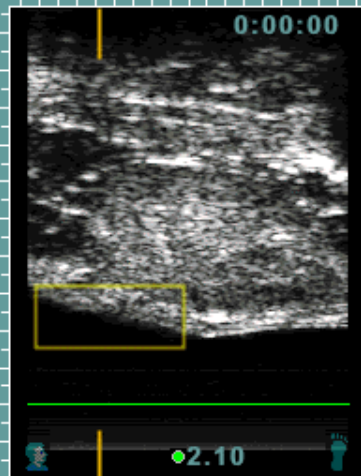
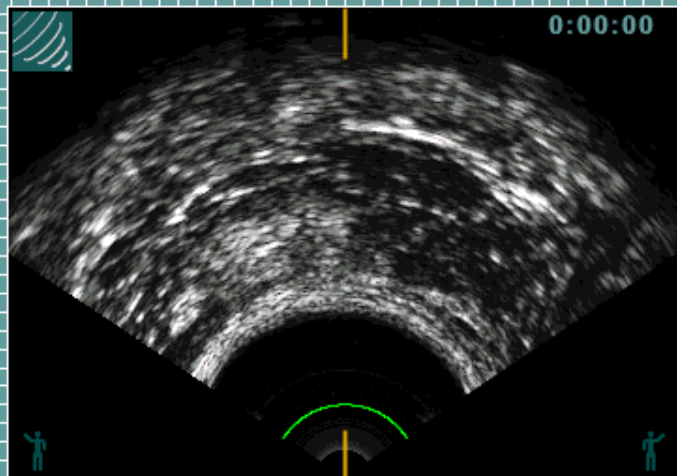
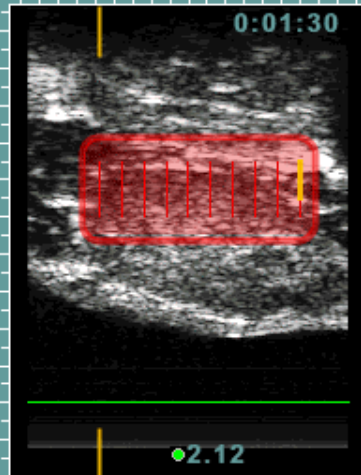
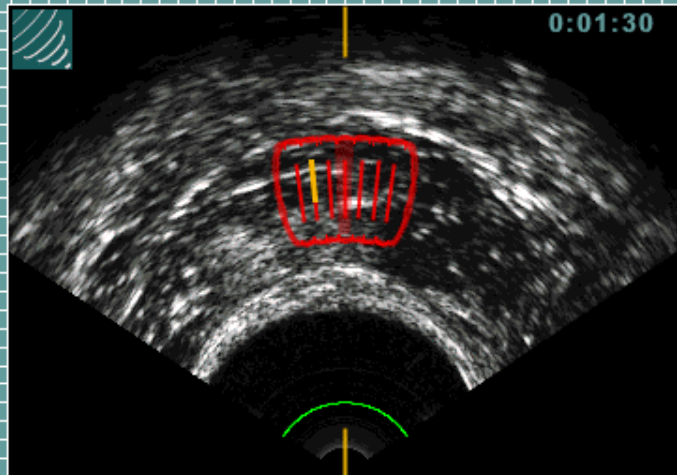
Status: Saving screen to disk file...



Image: May 6, 2002 10:52:48 AM

Site: IU - LARC Patient: Dog1 Probe: SN5001 4.0/3.0

PREPARE IMAGE PLAN THERAPY VOLUME



4.0 A/B

Grid Meas.
 Zone Zone
 FB Clear

Bypass power



30.0 watts [37.0]

0:10:30 total
 0:01:30 elapsed
 0:09:00 remaining
 14%

probe temperature
 17.4 C
 SonaChill pump chiller

reflectivity index
 10

RF amplifier
 0.0[5.2,6.6] watts
 2.4 seconds

STATUS

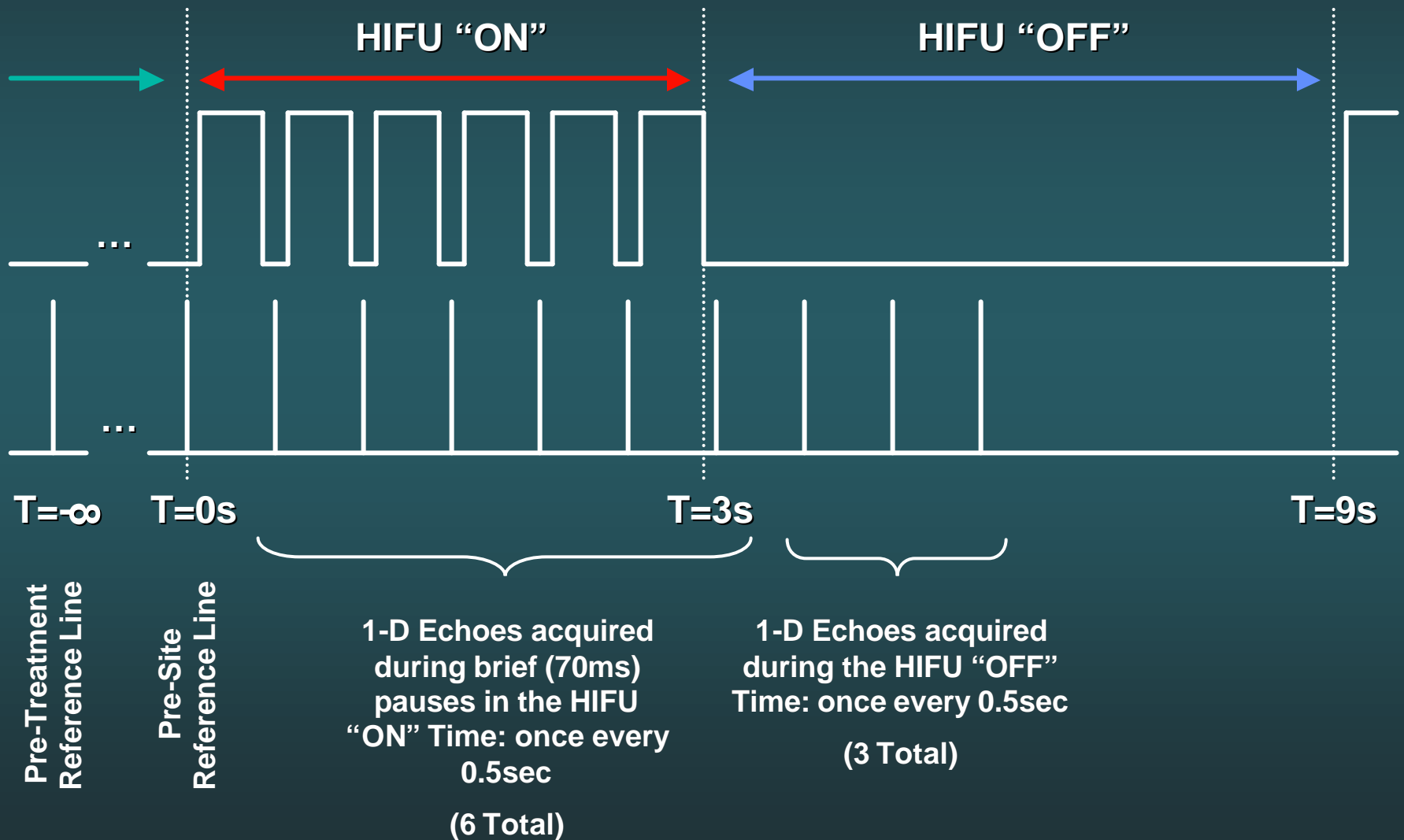
Start HIFU
 Pause HIFU

Scan Freeze Scan

Image verification 06/20/2001 Therapy verification 06/20/2001



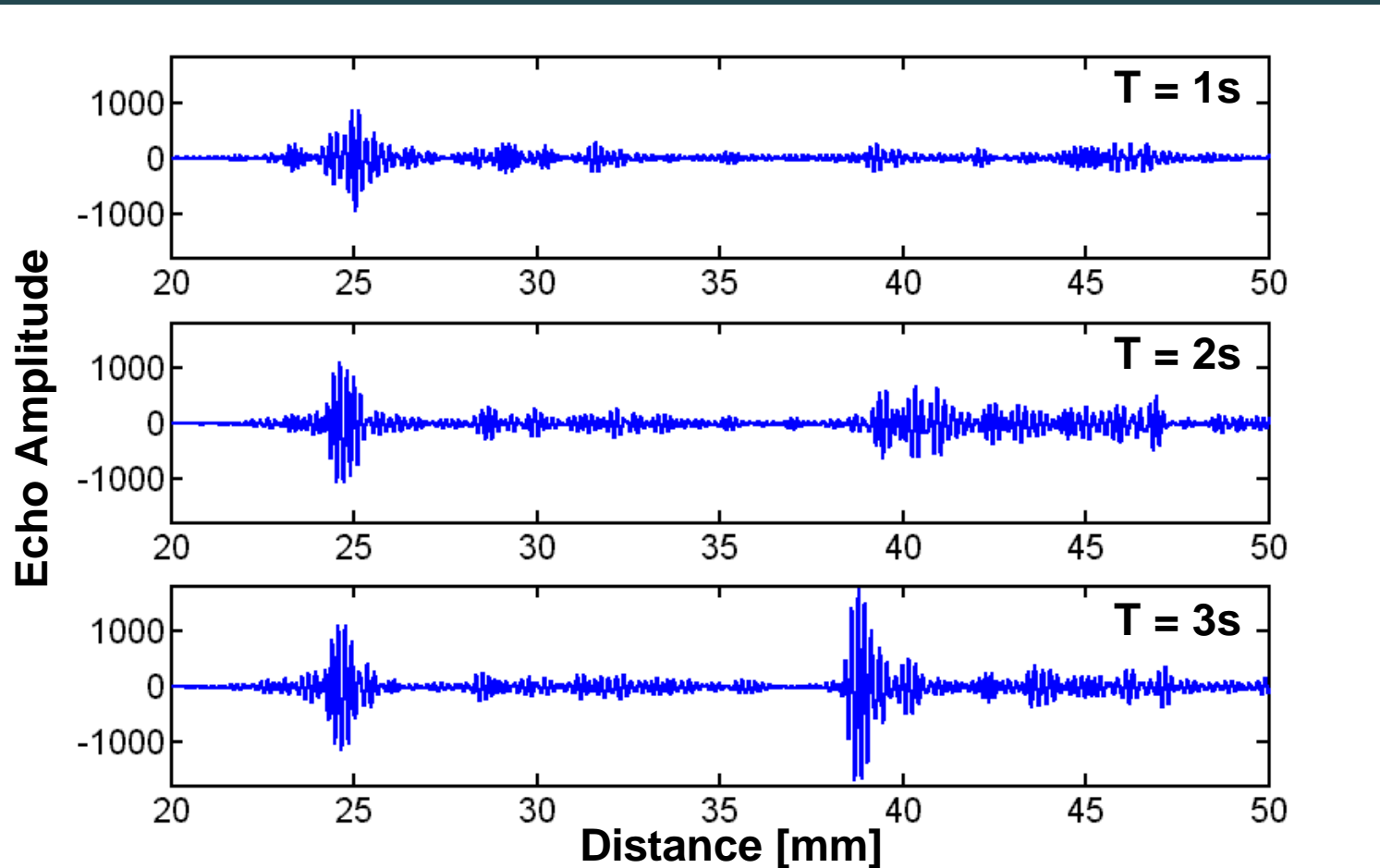
Pulse-Echo Ultrasound Data Acquisition





Pulse-Echo Ultrasound Data Example #1

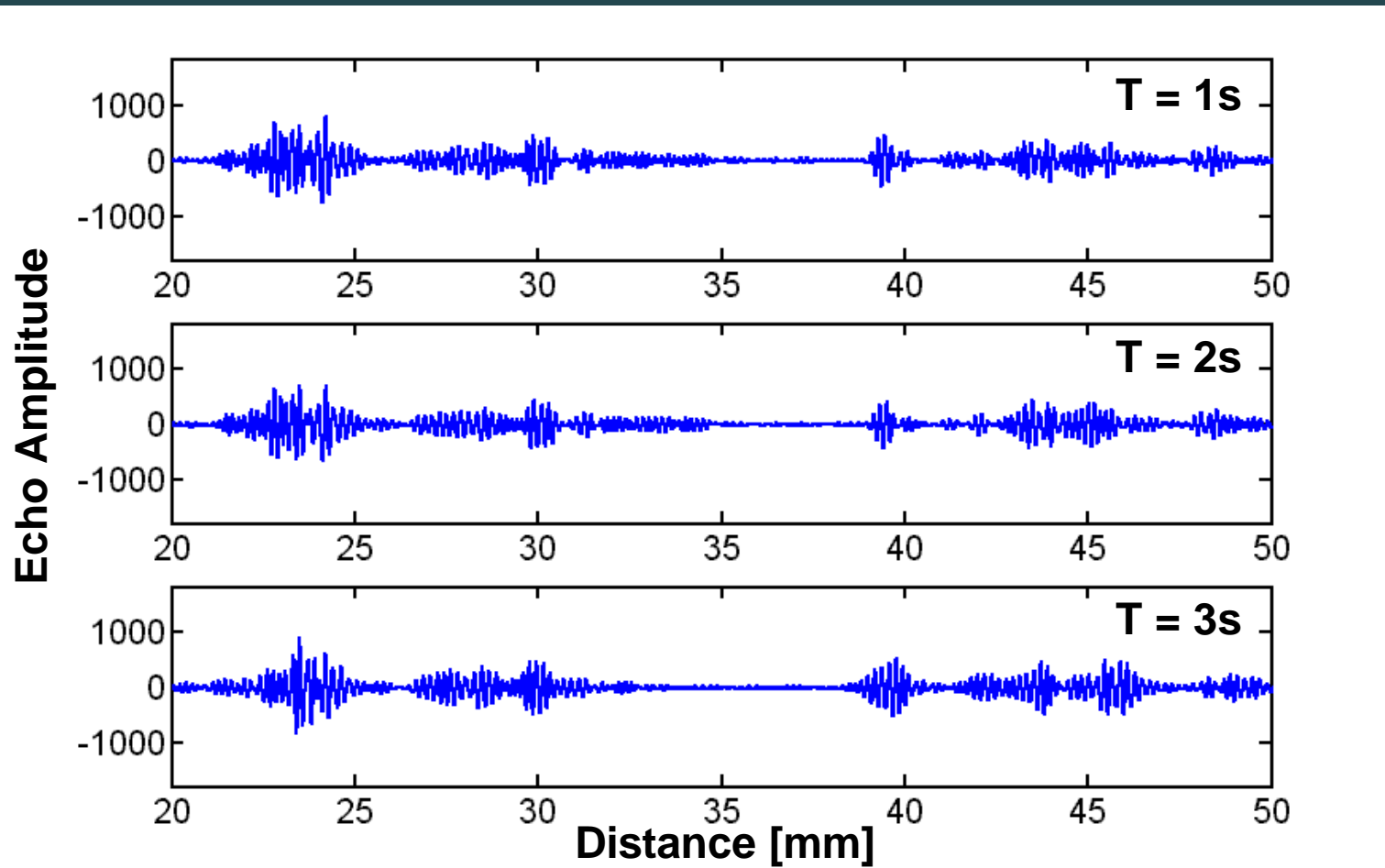
HIFU-Induced Changes Visible in the B-mode Images





Pulse-Echo Ultrasound Data Example #2

HIFU-Induced Changes NOT Visible in the B-mode Images





Multiple HIFU Exposures vs. Single Exposure

- **Tissue properties are not the same for all HIFU exposures**
 - Local physiological differences
 - Bulk thermal deposition during treatment affects future treatment sites.
- **Tissue motion between exposures**
 - e.g. due to breathing, blood circulation, muscle contraction

⇒ **Randomness!**



Paradigm: Statistical Decision Theory

- Base a decision on a particular statistics computed for each exposure.
- Model the statistic as a random variable, x .
- Two Possibilities for Decision Outcome:
 - H_0 : untreated (null hypothesis)
 - H_1 : treated (alternative hypothesis)
- Compute statistics for two treatments:
 - Sham (no HIFU) -- H_0
 - Normal Treatment -- H_1
- Use a *statistically* based decision rule to decide between the two outcomes.



A Decision Theoretic Approach

- Given statistics for both sham and actual treatments, estimate the PDFs: $p(x|H_0)$ and $p(x|H_1)$, using histograms
- Use a likelihood ratio test for decision rule:

$$\frac{p(x|H_1)}{p(x|H_0)} \geq I \Rightarrow H_1 \quad \frac{p(x|H_1)}{p(x|H_0)} < I \Rightarrow H_0$$

- Find the threshold, λ , such that a desired false alarm rate is met.

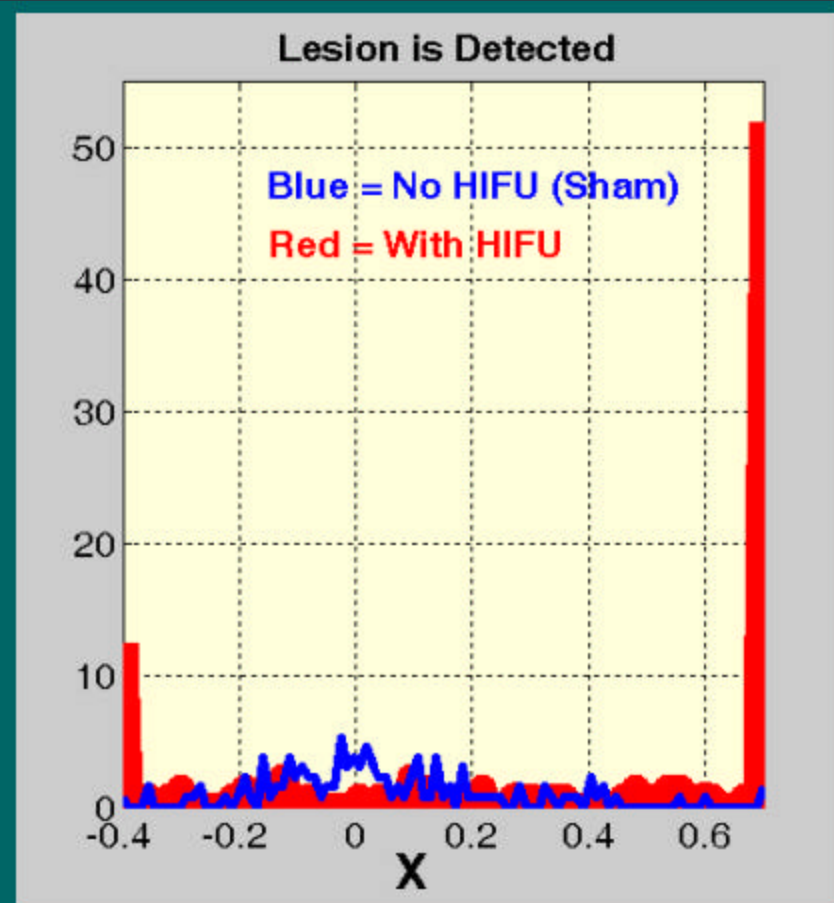
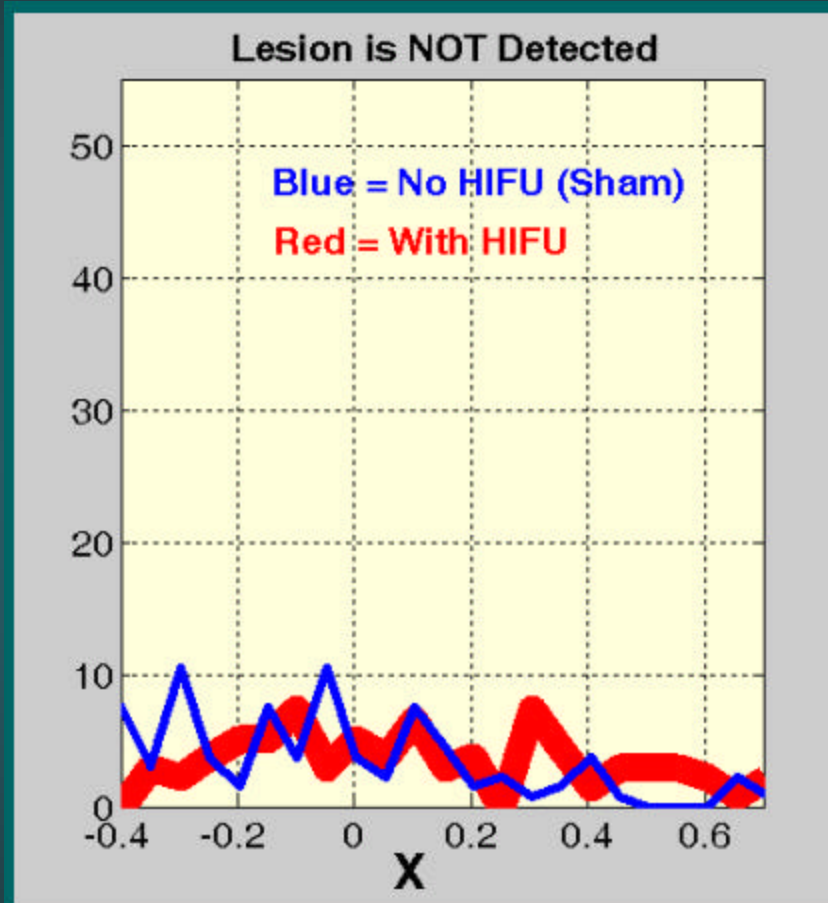


Statistic: Max. Cumulative Energy Change

- Divide each RF-line into overlapping windows over the region of interest (windows are typically 5mm long)
- Compute relative change in signal energy for each window relative to the reference line ($t=0$)
- Compute the cumulative energy change over all A-lines for a particular window
- Find the maximum cumulative energy change over all windows



Histograms



X = Maximum Cumulative Energy Change



In Vivo Canine Prostate Results

<u>Dog</u>	<u>% Lesion Detection</u>	<u>Total Sites</u>
1	92.1	140
2	89.5	228
3	96.2	105
4	83.1	272
Average	88.6	745

All Detection Percentages with a 4.3% False Alarm Rate

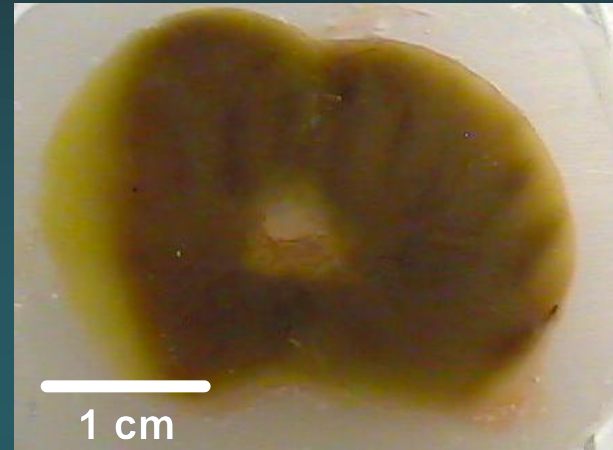


***In Vivo* Canine Prostate Results**

30 Minutes Post-HIFU



Parafin Block Fix



24 Hours Post-HIFU, Formalin soaked



Slide H&E Stained



***In Vitro* Dosage Experiment: Details**

- Fresh turkey breast tissue
- Focal length = 3.5 cm
- TAP = 20.4 W, 27.2 W, and 34.0 W
- 2.5 cm tissue depth to focus
- All power level produced a fully visible lesion over treatment area, from focus to near tissue surface
- 133 sites for each treatment and sham



***In Vitro* Dosage Experiment: Results**

<u>Power</u>	<u>Lesion Detection%</u>
20.4 W	77.8
27.2 W	85.1
34.0 W	95.6

All Detection Percentages with a 3.8% False Alarm Rate



Extension: Spatial Resolution

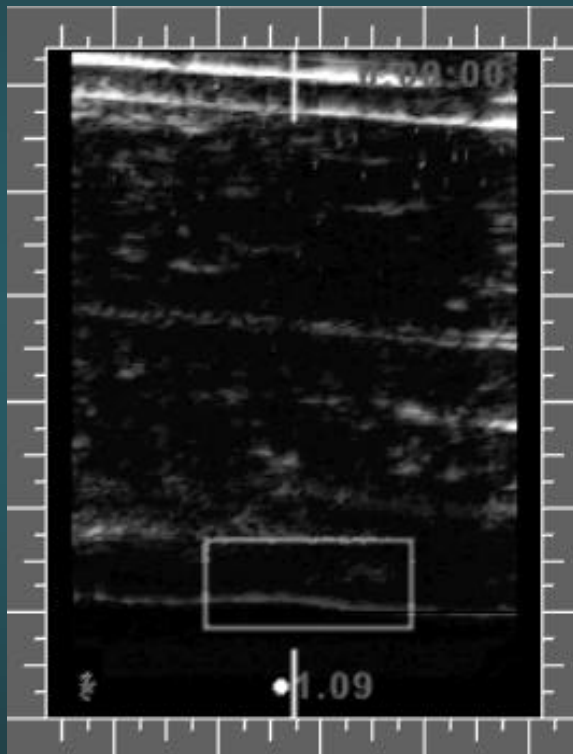
- 5mm long, 50% overlapping windows
- Instead of one statistic for each site, we now get one for each depth.
- Compute the PDFs and decision threshold separately for each window, i.e. one decision rule for each depth
- Find an average Detection% for each depth



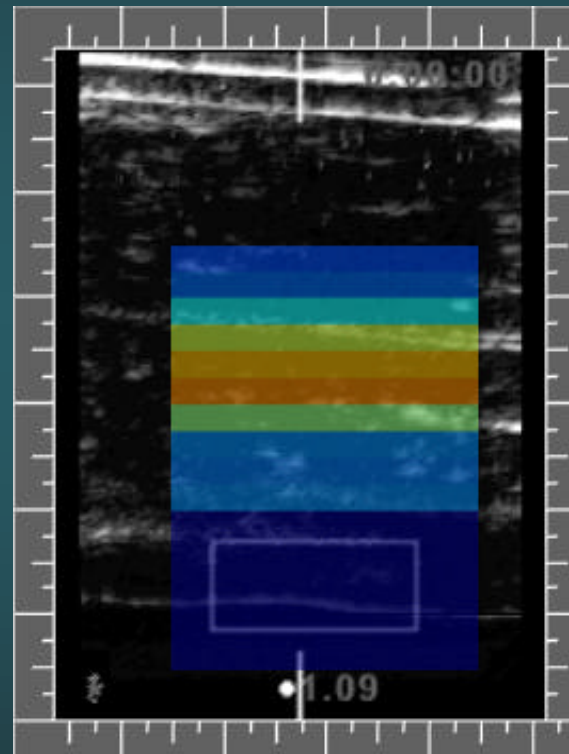
In Vitro Turkey Tissue - 20.4W

FL = 3.5cm

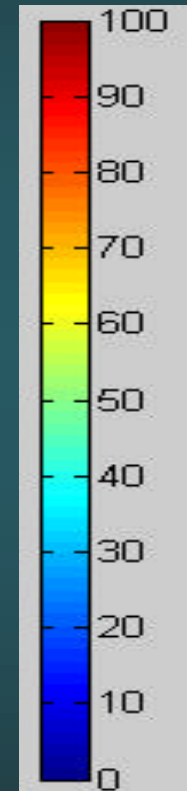
Lesion Detection%



B-mode



B-mode with overlay

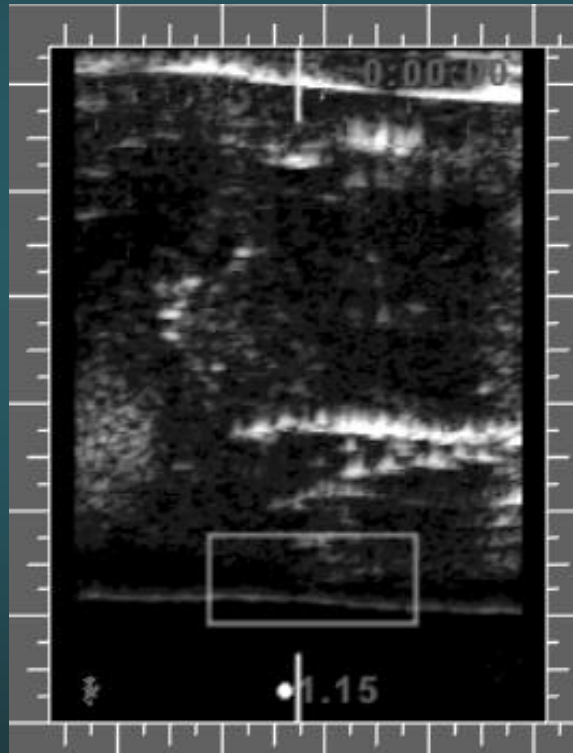




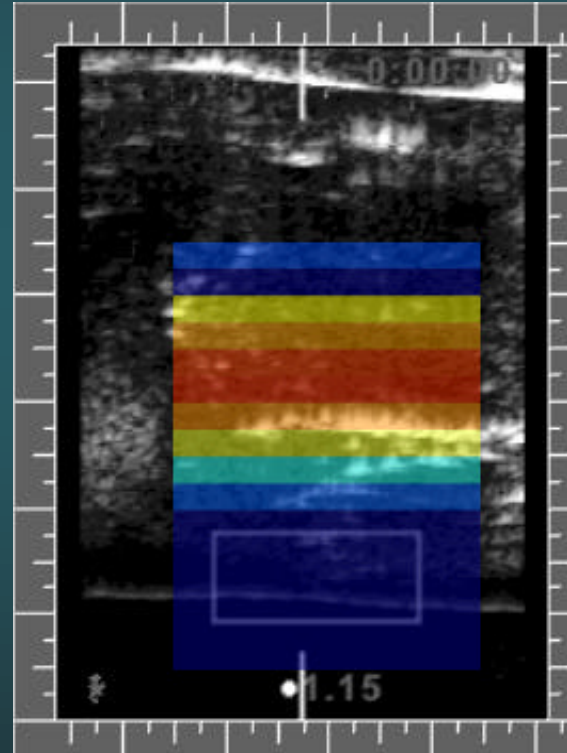
In Vitro Turkey Tissue - 27.2 W

FL = 3.5cm

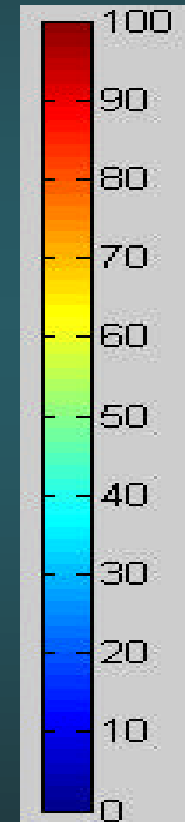
Lesion Detection%



B-mode



B-mode with overlay

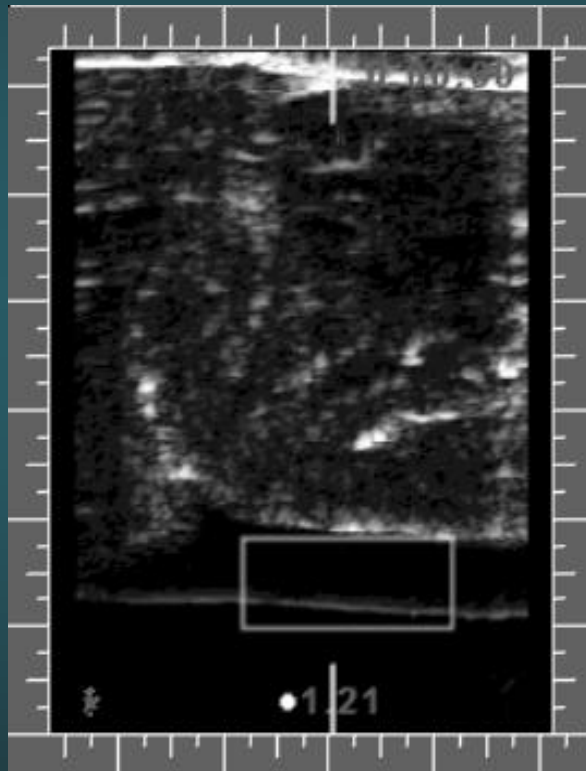




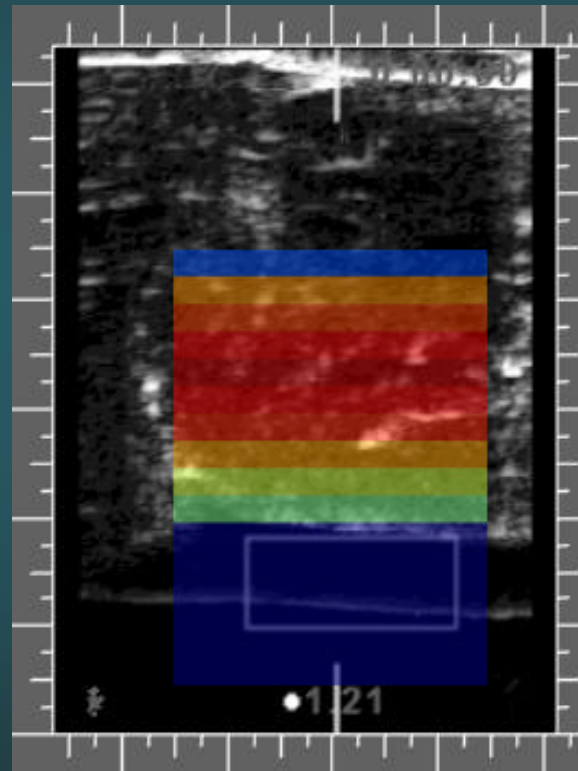
In Vitro Turkey Tissue - 34 W

FL = 3.5cm

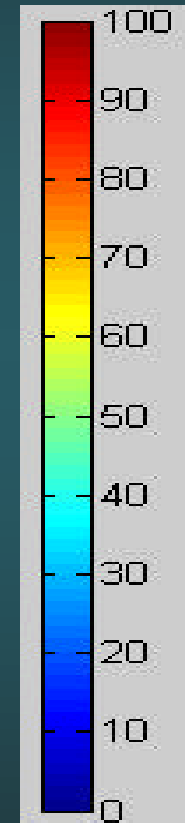
Lesion Detection%



B-mode



B-mode with overlay

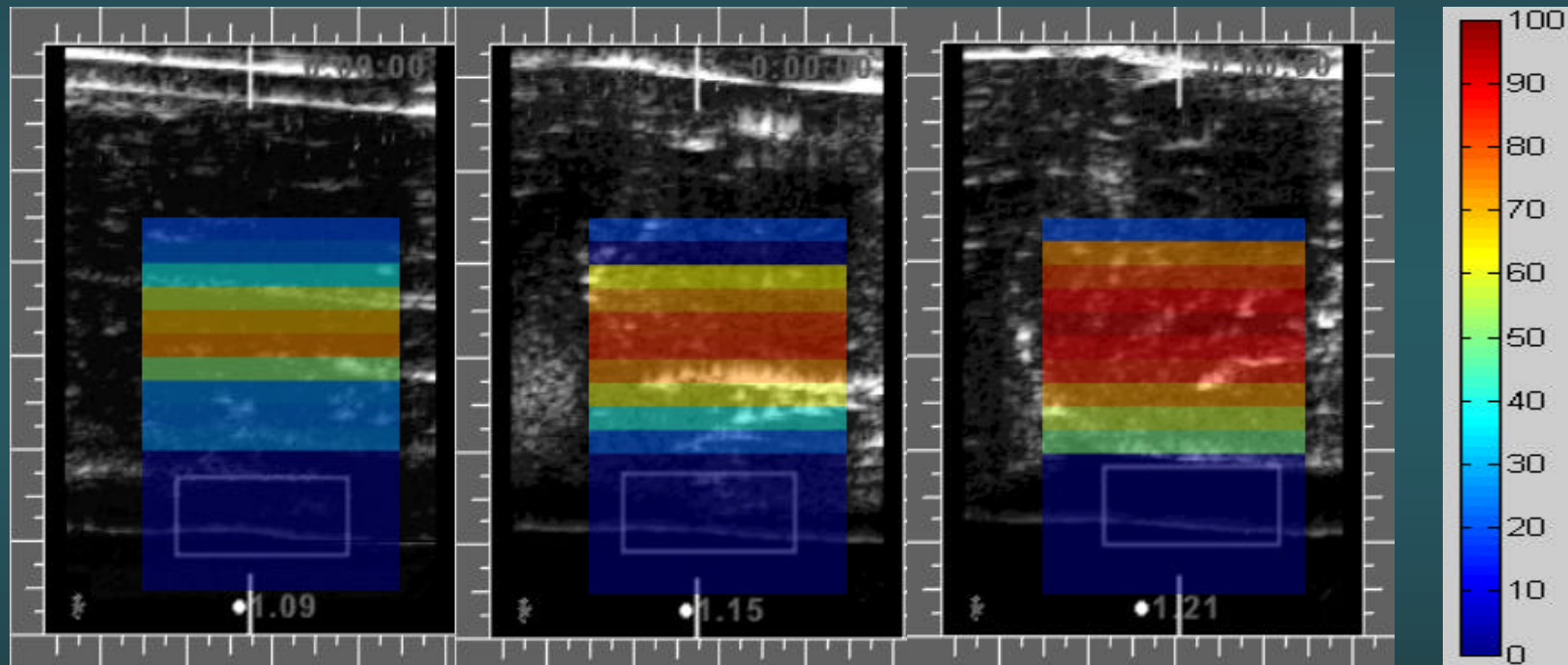




Lesion Detection at Different Power Levels

In Vitro Turkey Tissue

Lesion Detection%



20.4W

27.2 W

34 W



Conclusions

- RF Signal Energy provides a useful indicator of HIFU-induced tissue changes.
- Statistical decision theory provides an effective methodology for HIFU lesion evaluation in light of randomness during treatment.



Future Work

- Investigate effectiveness of the method for real-time monitoring and control of HIFU treatments.



Acknowledgements

This work was partially funded by NIH
SBIR Grant: 2 R44 CA83244-02.