Cavitation detection and suppression in HIFU

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ISTU Lyon 2003

1 Abstract

Objective: Overpressure (elevated static pressure) was used to suppress bubbles in excised tissue during interleaved RF ultrasound image capture and HIFU exposure. The goal was to provide cavitation feedback and test imaging algorithms.

Materials and methods: Samples were turkey breast placed in an aluminum pressure chamber, unpressurized at 0.1 MPa or pressurized to 10 MPa and held at 37 ºC. A single element PZT transducer (4.1 MHz, 44.5 mm diameter and radius of curvature, over 2000 W/cm²) was ON for 1 s and OFF for 0.1 s for a total of 10 seconds. RF image data were captured during the OFF time through a 2.5-cm acrylic window in the chamber with a C4-2 probe and an HDI-1000 imager. The harmonic content and amplitude of single RF lines were processed offline by a differential comparison to the same line in previous images. Simultaneously, power fluctuations to the transducer and a focused hydrophone normal to the HIFU axis were monitored as cavitation indicators. An inline hydrophone detected increases in tissue attenuation caused by lesion formation.

Results: A hyperechoic region and increased higher harmonic frequencies appeared at the lesion site in the RF echoes of all treatments without overpressure and in none with overpressure. Lesions were created in all cases. Attenuation of echoes from tissue beyond the lesion was pronounced without overpressure.

Discussion: Hyperecho on B-mode ultrasound interlaced with HIFU is useful for image-guidance and is primarily due to bubbles. Hence harmonic imaging can enhance the image contrast and visualize the lesion before hyperecho appears. Suppression of the bubbles by overpressure may lead to detection of the permanent change in attenuation solely due to protein denaturization.

2 Hypothesis

Elevated static pressure (overpressure) suppresses cavitation and can be used to assess the role of bubbles in imaging and therapy. Overpressure can also be used to validate cavitation detection feedback methods.

3 Methods

Tissue samples were treated in an instrumented pressure chamber.

Tissue Samples

- turkey breast
- 37 ºC
- degassed water filled chamber
- max chamber pressure 10 MPa.
- 4.1 MHz, 44.5 mm diameter and radius of curvature, > 2000W/cm²
- Exposure 1 s ON/ 0.1 s OFF for 10 s
- RF data capture with C4-2 probe and an HDI-1000 imager
- acoustic receiver in line with therapy transducer to detect attenuation
- acoustic receiver 90º to therapy transducer to detect harmonics
- voltage and current to therapy transducer monitored

Gel Samples

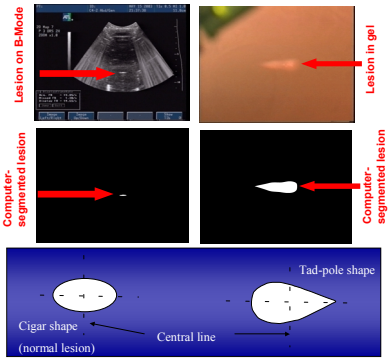
- Polyacrylamide gel and 5% BSA
- CCD camera to record lesion formation
- B-Mode imaging recorded to VHS and digitized
- max chamber pressure 10 MPa.

Algorithms

Spectral analysis [see Results and Reference]

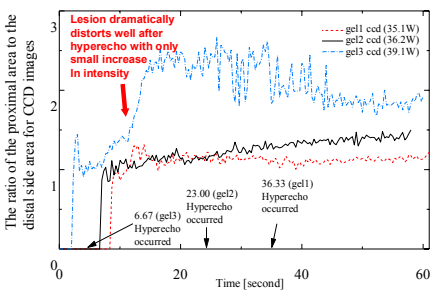
Image recognition to measure lesion size and shape

- In B-mode and CCD images
- Calculated area, length, width, and ratio of lesion area proximal to center line over area distal to center line

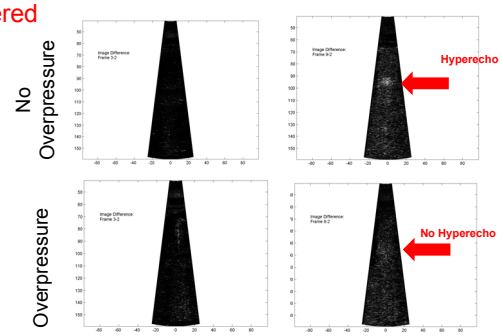


4 Results

Slight increase in HIFU intensity, means lesion forms earlier, hyperecho forms earlier, and lesion shape can change.

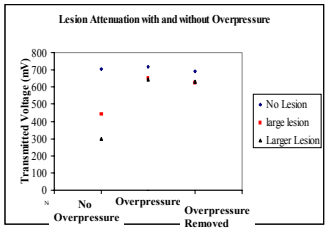


Overpressure suppressed hyperecho on B-Mode; lesion was not altered

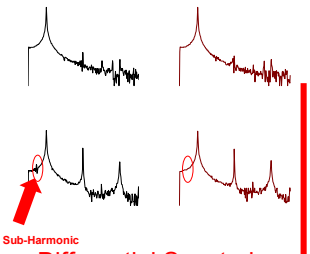


Overpressure suppressed most of the increased attenuation due to the lesion.

- Measure transmission (mV)
- Apply overpressure (dissolve bubbles)
- Measure transmission
- Remove pressure
- Measure transmission
- Apply HIFU, grow lesion
- Repeat

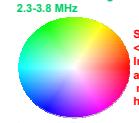


Overpressure suppressed sub-harmonic

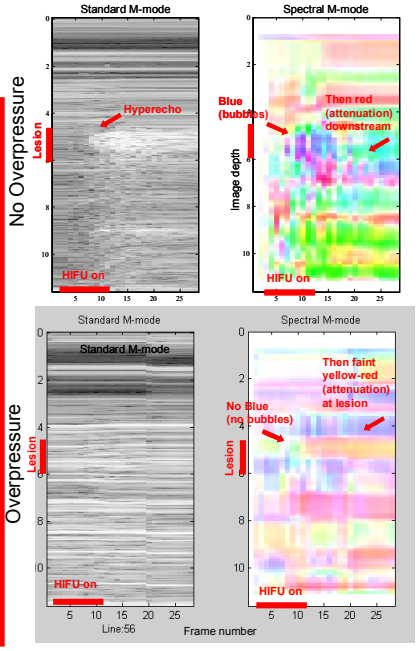


Differential Spectral M-Mode

- Signal sectioned with depth
- FFT taken of section
- Normalized
- Spectral shift from 1st frame denoted as color



Suppression of bubbles reveals elevated attenuation in the lesion



5 Conclusions

Lesion formed, then hyperecho, then distortion, although distortion did not always result.

B-mode is sensitive detector of bubbles.

Bubbles are primary factor in increased attenuation in lesion.

Spectral monitoring of RF is sensitive bubble and attenuation detector.

This system provides and tests cavitation feedback and imaging of HIFU.

6 Acknowledgments

This work was supported by NIH grant R44 CA83244-02, NSF grant BES-0002932, and NSBRI SMS00203.

7 References

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