Ultrasound Tissue Characterization for Diagnosis of Pulmonary Hypertension

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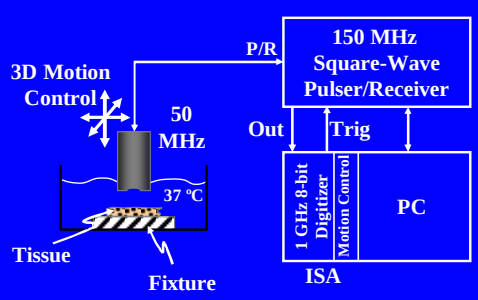
Motivation

- Diagnosis of secondary pediatric pulmonary hypertension is sometimes difficult because no single test permits a complete evaluation.
- High-altitude environments with lower oxygen concentrations exacerbate disease.
- Minimally-invasive and non-invasive ultrasonic techniques that are currently available could potentially improve diagnosis.
- Need exists for improved understanding of the ultrasonic properties of the pulmonary artery wall.

Ultrasound Tissue Characterization

- Architectural alterations in tissue modify the ultrasonic properties (e.g., speed of sound and attenuation).
- Fundamental understanding of the basic acoustics interactions in tissue can enhance the diagnostic utility of ultrasound.
- Tissue state can be evaluated by measurement of the attenuation coefficient (viscosity and relaxation) and the speed of sound (elasticity).

Experimental Setup and Measurement



Protocol (for each branch)

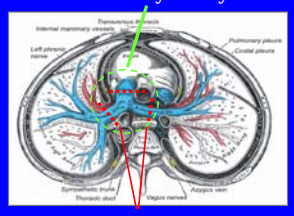
- Cut artery along long axis (open as membrane)
- Orient for measurement in radial direction (R)
- Scan specimen over 2D region-of-interest at high and low amplification
- Save data for offline analysis

Biological Material and Structure

R = Radial
L = Longitudinal
C = Circumferential

Top-down view of chest cross-section

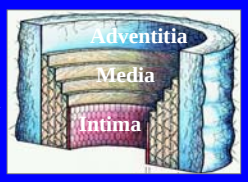
Pulmonary artery



Dissection cuts

Geometry

Artery Section: Cut-Out



3-layered tubular structure — each layer anisotropic

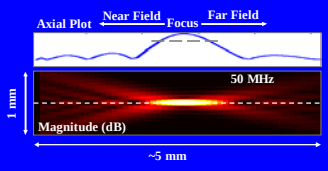
Tissue Remodeling due to Hypertension

- Cells in tissue live under stress.
- Changes in stress can lead to a number of changes including that of mass, metabolism, and internal and extracellular structures.
- Response to changes in stress can modify mechanical properties, sizes and structures, and interaction among cells.
- Studies have shown that arteries remodel in order to normalize the associated increase in stress due to hypertension.

Ultrasonic Pressure Field

Transducer Properties

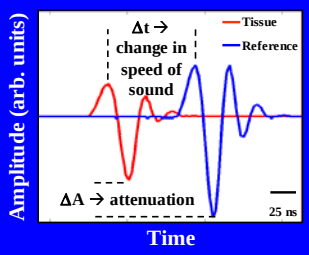
Frequency	= 50 MHz
Wavelength	= 30 µm
Element Diameter	= 6 mm
Focal Length	= 13 mm
Beam Diameter	≈ 90 µm
Depth of Field	≈ 0.7 mm



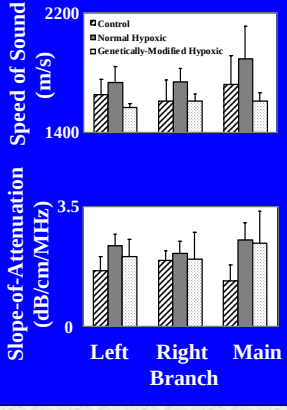
Analysis and Results

- Long-Evans Rat Model Specimens (Age: 12-13 weeks)
  - 6 Normals (Control)
  - 4 Normal Hypoxics (3 weeks in hypobaric chamber)
  - 4 Genetically-Modified Hypoxics (3 weeks in hypobaric chamber)
- Time-Domain Analysis
  Estimate thickness and speed of sound from changes in time-of-flight
- Frequency-Domain Analysis
  Estimate attenuation coefficient from power spectrum with and without tissue present

Ultrasonic Measurements



Radial Direction



Observations and Perspective

- We observed an increased slope-of-attenuation in both hypertensive rat models.
- We observed an (expected) increased speed of sound in normal hypoxic rat models.
- We observed an (unexpected) decreased speed of sound in genetically-modified hypoxic rat models.
- Future efforts will aim to
  - Associate differences in ultrasonic properties to changes in biological composition.
  - Investigate ultrasonic properties at *in vivo* pressure levels (≈5 mm Hg).
  - Determine statistical significance of difference in ultrasonic properties between populations.

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