Augmentation of the *In Vivo* Elastic Properties Measurement System to Include Bulk Properties

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LONG-TERM GOALS

The goal of this project is to develop and demonstrate a system for non-invasive *in vivo* measurement of the complex elastic moduli (stiffnesses and loss factors) of cetacean head soft tissues. This system is ultimately intended to provide a portable diagnostic capability for use in stranded animal assessments.

OBJECTIVES

Under a separate award, the investigators have been developing an ultrasound-based system for non-invasive *in vivo* determination of the complex shear elastic moduli (stiffness and loss) of cetacean head soft tissues. The objective of the present work is to augment the capabilities of the system (referred to as “CFE”, for Convergent Field Elastography), to include determine bulk tissue speed and attenuation. Such data would provide previously unavailable *in vivo* information useful for applications such as cetacean sound exposure models and blubber thickness assessments, which have employed *ex vivo* data. Particularly critical in the bulk properties assessment is the attenuation as a function of frequency, and the extent to which it changes post mortem.

Knowledge of bulk properties may also be used to enhance the operation of the CFE system. Sound speed uncertainty introduces errors in shear speed estimation as a consequence of beam refraction, although these errors are expected to be small over the range of expected tissue parameters. Knowledge of bulk attenuation may be used to estimate in situ radiation force magnitudes, which in turn would allow refinement of shear estimates based on measured displacement magnitudes.

APPROACH

The bulk properties measurement methods are intended to run concurrently with the existing CFE system. Bulk speed and attenuation in the 1-3 MHz range will be estimated using transmission and scattering data in the CFE system’s primary operating band. Estimation of lower frequency (1-100kHz) properties will be based on the observation of sound generated at the modulation rate of the CFE system’s force generation transducer. Methods in both frequency ranges will make use of reference measurements made on tissue phantoms whose properties were independently determined, with refinement through the use of an analytical layered tissue model from which properties may be found through inversion. Bulk properties estimation procedures will be tested on tissue phantoms with known properties. If successful, the methods will be incorporated into the CFE system for animal testing.

WORK COMPLETED

Potential errors in the *in vivo* attenuation estimation process were quantified using a combination of simulations and experiment data analysis [1]. Two types of error sources were reviewed: those associated with unknown *in vivo* sound speed, and those associated with non-uniform backscatter.

Additional simulations were developed in order to demonstrate the impact of tissue sound speed on CFE transducer patterns.

RESULTS

Calculations made with *in vivo* ultrasonic data collected extracranially on one *Delphinapterus leucas* and two *Tursiops truncatus* showed no evidence of distinct scattering strength transitions in the 1-4 MHz, 1-4cm depth range. As such, depth-averaged attenuation calculations appear to be valid in these ranges. If the ultrasound backscatter data indicate clear transitions (as expected when acquiring data over greater tissue depths), the analysis can be subdivided to estimate layer-specific attenuations. Based on a literature review, the *in vivo* data sets are the first of their kind for cetacean soft tissues.

Simulations of the impact of sound speed uncertainty on attenuation estimation in the existing *in vivo* data sets indicated that for sound speeds between 1425 and 1650 m/s, the impact on attenuation estimates was minimal. For example, at 3.6 MHz, the maximum error was no more than 4%.

Simulations of CFE transducer patterns for a range of soft tissue sound speeds were used to quantify the impact on shear speed estimation. These results, showing CFE forcing beam radial shifting and lobe dilation, will be used to develop an iterative model for estimation of bulk speed and refinement of shear speed calculations.

IMPACT/APPLICATIONS

There is considerable interest in the development of structural acoustic models for the cetacean head for two main reasons: 1) to better understand biomechanics of sound reception and production in cetaceans, and 2) to understand and hopefully mitigate any harmful effects of man-made sound on their health and behavior. The development and validity of these models is severely limited by an almost complete lack of knowledge of the mechanical properties of the constituent living tissue. There is thus considerable interest in being able to measure these properties *in vivo*.

RELATED PROJECTS

The CFE system, on which the bulk properties project is based, was successfully tested with a tissue phantom whose properties are in the range reported for mammalian muscle tissue. Initial testing has begun with a second phantom having properties in the range reported for mammalian brain tissue.

REFERENCE

[1] Gray, M., Rogers, P., Cameron, P., "In vivo ultrasonic attenuation in cetacean extracranial soft tissues", presented at the 167th meeting of the Acoustical Society of America, Providence, RI, May 2014