In Vivo Determination of the Complex Elastic Moduli of Cetacean Head Tissue

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LONG-TERM GOALS

The overall 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 tissues. This system is ultimately intended to provide a portable diagnostic capability for use in stranded animal assessments.

OBJECTIVES

The primary technical objective is to remotely generate and detect mid-frequency elastic waves within the body of a living cetacean and to use the measured propagation parameters of these waves to obtain the complex elastic moduli by inversion. A further technical objective is to extract moduli in this manner for intracranial tissues. This latter objective carries considerably more technical risk since both the wave-generating ultrasound and the probe ultrasound will be attenuated, distorted and scattered by the passage through the skull. The final objective is to develop a prototype portable version of the technology and use it to perform examinations of stranded animals. Data collected with this system is envisioned to serve two purposes: 1) provide basic knowledge of *in vivo* elastic properties, which is non-existent for marine mammals, and 2) provide a potential basis for non-invasive diagnostics of tissue pathologies, occurring either in nature or as a result of human activity.

APPROACH

The foundation of the work is the capability to remotely generate elastic waves in soft tissues and observe their propagation with an ultrasound-based non-invasive system. The general approach for generation, reception and interpretation of the tissue wave fields is based on an emerging medical imaging technology called radiation force elastography [i]. This class of techniques, which has been demonstrated to some extent on human soft tissues, cannot be directly translated to use on cetacean head tissues due to the need to propagate through much thicker tissues and through skull bone, all the while keeping within safety limitations for ultrasound exposure [ii]. The current focus of the *in vivo* program is to overcome these challenges through novel redesign of the concepts for both elastic wave generation and observation.

A shear wave generation system has been developed wherein a ring-like forcing volume is formed by the ultrasonic source. As the ring radius is changed through a change in the ultrasonic carrier frequency, a fixed receiver measures the change in phase of the waves converging to the center of the ring. This approach, which we refer to as Convergent Field Elastography (CFE), has several potential benefits, which are expected to directly translate to improvements in the robustness of modulus estimation under the challenging constraints of the problem.

The particle displacements associated with the remotely generated elastic waves are detected remotely using a modified version of an ultrasonic Doppler vibration measurement system called NVMS developed at Georgia Tech [iii]. Algorithms have been developed to enable the magnitude and phase of vibration to be determined as a function of range (tissue depth) along the ultrasonic beam. By measuring the differential phase of the shear wave arriving from different drive distances, as can be easily done with the ring force excitation, the propagation speed can be determined. The frequency dependence of the propagation speed is then used to determine the shear loss factor.

The elastic properties of tissue phantoms will be obtained from CFE measurement data and compared with directly measured and published material values. The noninvasive technique will be repeated for tissue phantoms enclosed in a simulated or hydrated real cetacean skull, and with harvested tissue samples. *In vivo* testing will be conducted on Navy dolphins. Ultrasound parameters (peak negative pressure, time averaged intensity) will be consistent with diagnostic limits established as safe for humans, and ultrasound frequencies will be kept high enough to be far above the highest frequency that is thought to be audible to the animals.

WORK COMPLETED

Work in FY13 was focused on system refinement, with the objectives of making system performance more robust and making the physical setup process easier.

RESULTS

The primary accomplishment of FY13 was the modification of the waveform transmission and data acquisition sequence so that contamination of the vibrometer's received signal by extraneous output of the radiation force generation transducer (RF) could be suppressed. When the RF operates, in addition to the desired signals and frequencies intended to remotely impart motion in soft tissues, it produces low levels of high frequency ultrasound in the vibrometer signal processing range. This secondary output appears on the vibrometer as an additive backscatter signal that contains the modulation specified by the RF. There is also a small but measurable signal due to cross talk, both acoustically, because the vibrometer transducer is nested inside the RF, and electronically. While the backscatter contribution appears to be the largest contaminant, a simple process for removing all linearly additive contamination was implemented. This involved making a reference measurement of vibrometer response when the RF was running, but when the vibrometer's active segment was turned off. The reference data were time aligned with and subtracted from normal vibrometer system response data, yielding a contamination-suppressed result. In testing to date, the process was seen to considerably improve vibration measurement signal to noise ratio and repeatability. Until recently, the vibrometer processing band was constrained within a range of frequencies dictated by harmonics emitted from the RF. The contamination suppression process described above enabled a significant expansion of the vibrometer processing bandwidth, which lead to a nearly twofold improvement in the axial resolution of the vibrometer.

The other significant accomplishment from FY13 was the redesign and construction of the fixture for holding the RF and vibrometer transducers in a coaxial, confocal configuration needed for system testing. The new fixture resulted in rapid establishment and maintenance of alignment of the transducer sound beams, while reducing mechanical stresses on the transducer casings in the vicinity of the piezoelectric elements.

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*. The techniques and instrumentation investigated here should also have biomedical diagnostic application, including non-invasive examinations of stranded animals.

RELATED PROJECTS

We applied for and received a NOAA permit to perform ultrasonic system testing on stranded animals.

REFERENCES

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