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Tissue Identification Based on Evoked Vibration Signatures with Ultrasound Examination: A Novel Method of Ultrasound Analysis

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Abstract

Objective: Ultrasound is a rapid and noninvasive method to examine anatomies, as sound waves penetrate tissue layers and the reflected waves are analyzed to identify structures. Ultrasound analysis, however, requires extensive training and experience, and the process can be subjective and inexact. We discovered that tissues not only reflect the probing ultrasound waves, but also absorb some of these waves and vibrate according to the inherent tissue structural integrity and density, thus exhibiting a unique signature. We now report that this unique signature can be used as an objective method of identifying tissues during ultrasound examination.

Methods: While ultrasound examination is in progress, a portable dynamic signal analyzer is placed adjacent to the examined tissue to record its vibration signatures. Signatures are stored in a database and analyzed *via* algorithm to define unique signatures.

Results: Different tissue types are examined by ultrasound, and the recorded signatures are interpreted based on time, amplitude, dampening, and frequency analysis *via* either single or multiple degrees of freedom. Each tissue type exhibits unique vibration signatures based on its tissue structure and integrity.

Conclusion: We devised a method to record the vibration signatures seen under ultrasound stimulation, and these characteristic signatures can be used as a novel method of identifying tissues being examined with ultrasound.

Keywords: Ultrasound; Vibration; Signatures; Tissue; Diagnosis; Algorithm; Examination

Introduction

Ultrasound utilizes sound waves to chart the physical environment, and the technology was made possible by two discoveries. Firstly, the Curie brothers in the 19th century discovered the inverse piezoelectric effect, with which one could stimulate crystals with electricity to produce ultrasound. Afterwards, Sproule et al. in the 1940s separately developed sensors to detect ultrasound waves reflected by structures. Combining these advances, scientists were able to develop tools based on sound wave propagation and reflection, such as sonar in World War II. Applying the technique to medicine, George Ludwig pioneered the use of ultrasound for clinical diagnosis when he identified gallstones in tissues.

Ultrasound is now one of the most common methods of medical imaging. It is fast, non-invasive, and does not require ionizing radiation like X-rays or CAT scans. Despite the popularity of ultrasound, however, the interpretation of ultrasound images can be difficult and requires extensive training. This task is difficult even with the most trained experts; studies show that experienced radiologists can miss up to 32% of liver cirrhosis using ultrasound [1-5].

We now detail a novel method of tissue identification based on tissues' vibration signatures under ultrasound stimulation. We have previously demonstrated that materials with different chemical compositions can exhibit unique vibration signatures when stimulated with radiofrequency waves.

Utilization of such vibration signatures can aid in identifying pottery shards from different geographical locations and civilizations. Similarly, vibration signatures can be used to identify precious materials, and we demonstrated the method to identify semiprecious gemstones based on their stimulated vibration signatures.

We now report that human tissues also exhibit unique vibration signatures during ultrasound examination: In addition to reflecting probing ultrasound, tissues also absorb some of the sound energy and uniquely vibrate based on the natural harmonics frequency of each tissue type. We developed a method to record such vibration signatures as the tissue is being examined by ultrasound. The ultrasound user can use these vibration signatures to help identify the tissue in question.

Material and Methods

The method of using vibration signatures as a method to identify tissue types requires an ultrasound system, a vibration detection system, and a signal analysis component. The butterfly iQ+portable ultrasound system (Figure 1) was used in the current study, and the butterfly iQ ultrasound app was used as the interface to connect to an iPhone Xs Max running iOS 14.6 (Apple, Cupertino, CA).

While the ultrasound probe is placed on the body surface to analyze the tissue underneath, the vibration detector is placed on the surface approximately 1 cm away from the ultrasound probe. The vibration signal is detected by a portable dynamic signal analyzer, the digiducer USB digital accelerometer, model 333D01 (Figure 2).

The Accelerometer is then connected to a separate iPhone *via* the lightning-to-USB Camera Adapter (Figure 3). The detected vibration signal is analyzed by VibroChecker (ACE Controls, Farmington Hills, MI). Each acquired signature of tissues is stored in an image database and presents a unique identification of a specific tissue type [6-9].

Figure 1: Butterfly iQ+portable ultrasound.

Figure 2: USB digital accelerometer.

Figure 3: Lightning-to-USB camera adapter.

Results

Ultrasound images were obtained from community volunteers in compliance of the NIH human subjects research guidelines. Non-invasive surface ultrasound images were obtained of different tissue types, including liver and muscular tissues and the signature of eachtissuewas compared to the signature library. The vibration signatures were compared by time analysis, amplitude analysis, dampening analysis, and frequency analysis based on single or multiple degrees of freedom. Representative ultrasound image and vibration signatures are illustrated in (Figures 4-7).

The liver was examined *via* surface ultrasound, displayed in (Figures 4 and 5). As hepatic tissues reflected ultrasound waves, images were captured by the ultrasound sensor and displayed on the iPhone, as seen in (Figure 4). The hepatic tissues do not reflect probing sound waves with 100% efficiency since they also absorb some sound energy. Tissue layers thus stimulated by the sound waves vibrate based on the tissues' inherent harmonics frequency, which is determined by tissue quality, structure, water content, and cellular density. The vibration signature was detected by the digital accelerometer and found to have a harmonics vibration signature of 0.1 Hz, as seen in Figure 5.

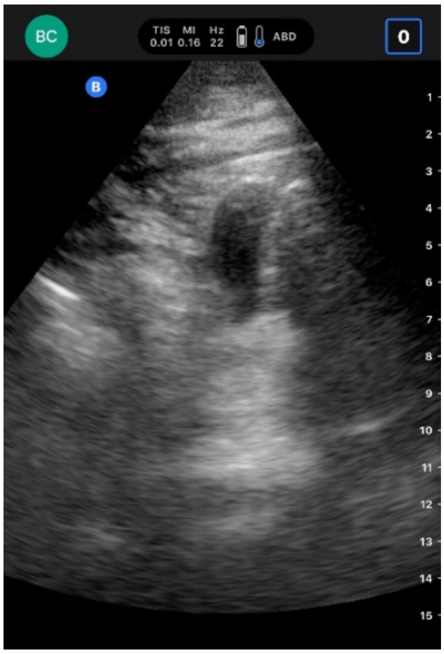

Figure 4: Ultrasound image of liver captured by the butterfly iQ app.

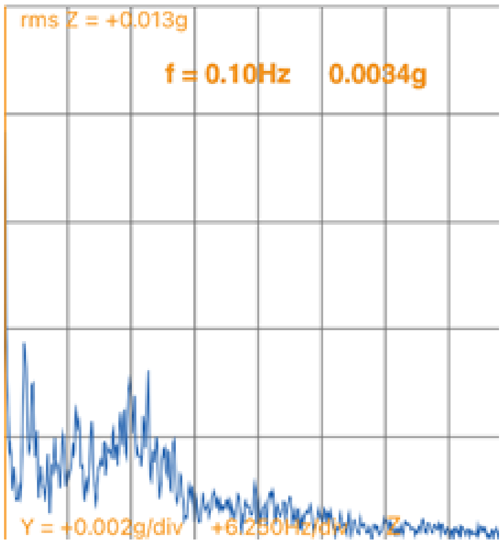

Figure 5: Vibrational signature of liver captured by the USB digital accelerometer and vibro checker app.

The rectus femoris muscle was similarly examined by ultrasound and the digital accelerometer and displayed in Figure 3; the ultrasound image is displayed in Figure 6. The muscle vibration frequency was also detected by the digital accelerometer, with the vibration signature found to be 7.45 Hz, as seen in Figure 7.

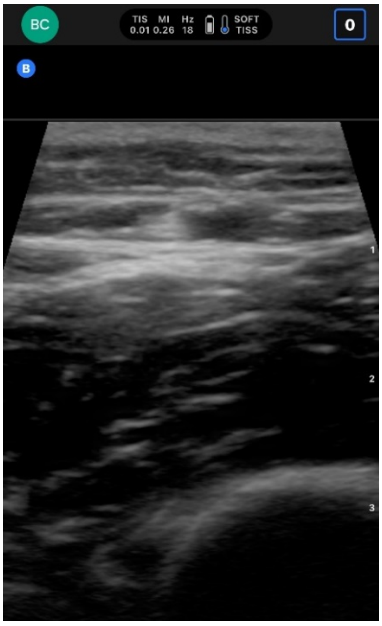

Figure 6: Ultrasound image of skeletal muscular tissue, captured by the butterfly iQ app.

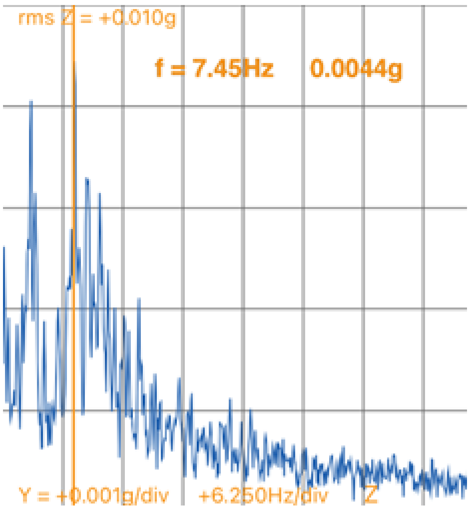

Figure 7: Vibrational signature of skeletal muscular tissue captured by the USB Digital accelerometer and vibro checker app.

Conclusion

Reading ultrasound images requires trained expertise and can be subjective and influenced by individual interpretation. In addition, the subtle differences that occur during the disease process, such as early cirrhosis or early malignant transformation, may not be readily perceived by the human eye until the histological changes are more prominent.

Ultrasound interpretation is also limited by geography, as expertise is not universally shared across the world. Instead, many regions of the world lack adequate numbers of ultrasound experts. As ultrasound becomes more prevalent, including with the increased presence of smartphone-based ultrasound machines, the use of ultrasound is increasing exponentially. However, the ability to interpret ultrasound remains limited.

We now present an objective method to supplement reading ultrasound images. In addition to standard images acquired by the ultrasound, the user has additional information of the vibration frequency of the tissue under examination. It is hoped that the additional information can help increase the accuracy of ultrasound interpretation. A database of ultrasound signatures is currently under investigation in order to provide a quick reference for users of ultrasound to identify the tissue under examination.

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