Bone Imaging Using Tone-Burst Vibro-acoustography and Pulse-Echo Ultrasound: A Qualitative Comparative Study

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Abstract

This paper presents a comparative study between tone-burst (TB) vibro-acoustography (VA) and pulse-echo ultrasound imaging on bone tissue. Vibro-acoustography is an innovative technique that uses the dynamic (oscillatory) radiation force of ultrasound to remotely vibrate an object or a part of it. In response to this force, an acoustic signal is emitted which is related to the object's mechanical properties. By probing the object point-by-point in a raster scanning motion and recording the resulting acoustic emission, an image of the object can be obtained. The goal of this study is to qualitatively evaluate the performance of vibro-acoustography versus pulse-echo ultrasound (C-scan) for bone imaging. In vitro excised rabbit scapulae with and without associated muscles are tested. The results reveal that conventional ultrasound images show speckles which degrade image quality, however the TB VA images are free from this artifact and have high resolution. These results encourage use of TB VA imaging for various applications.

1. Introduction

In the past decade, different techniques have been developed to image the elastic properties of tissue [1-3]. Among these approaches, vibro-acoustography (VA) is shown to produce high-resolution images [4],[5] which are related to the biomechanical properties of tissues, particularly their stiffness or tactile hardness. VA is an innovative ultrasound technique which uses the dynamic radiation force of ultrasound to probe objects at low frequency. The dynamic radiation force is produced by two con-focused ultrasound beams driven at slightly different frequencies. In response to the applied radiation force, the object vibrates and emits an acoustic field. A microphone (or hydrophone in water) measures the radiation force induced acoustic emission. As the focal point of the ultrasound beams is scanned across the object, the amplitude (and/or phase) of the measured signal is used to create an image of the object. VA has been applied as a potential imaging technique in numerous biomedical [4-11] and industrial [12-15] applications.

The purpose of this research is to show some features of the VA imaging technique by comparing qualitatively its corresponding images to conventional ultrasound images. Experiments are performed on excised rabbit bone scapulae with and without associated muscles. VA images show remarkable contrast and details related to bone structure, however those details are difficult to be displayed with the conventional ultrasound due to speckles that degrade the image. These results encourage use of VA as a high resolution and speckle-free technique for various applications.

2. Method

Vibro-acoustography [4],[5] induces a localized harmonic excitation inside a target through the application of two focused ultrasound beams driven at slightly different frequencies f_1 and $f_2 = f_1 + \Delta f$ (Fig. 1). These two beams overlap only at their respective focal regions to generate a localized dynamic (oscillatory) radiation force that causes the target to vibrate at the beat frequency Δf. The radiation force is proportional to the energy density of the incident field. The resultant incident pressure field at the focus is generally expressed as

$$p(t) = P_1 \cos(\omega_1 t) + P_2 \cos(\omega_2 t), \qquad (1)$$

where P_1 and P_2 are the amplitudes, and $\omega_1 = 2\pi f_1$ and $\omega_2 = 2\pi\left(f_1 + \Delta f\right)$ are the angular frequencies of the incident waves. For convenience, it is assumed that the phase of each beam is zero at the focus. Westervelt [16] showed that the normal component of the radiation force caused by a collimated plane wave striking an object is expressed by

$$\left\langle F(t)\right\rangle_T = d_r S \frac{\left\langle p(t)^2\right\rangle_T}{\rho c^2}, \tag{2}$$

where d_r is the drag coefficient which represents the scattering and absorbing mechanical properties of the target, S is the projected area of the object, ρ and c are the density and sound speed in the medium of wave propagation, and T is the average period over which the incident pressure is evaluated. In VA, the period T is defined as $\frac{2\pi}{\omega_1 + \omega_2} \ll T \ll \frac{2\pi}{\Delta\omega}$ to separate the dynamic component of the radiation force. Therefore, the dynamic component is rewritten as

$$F_{\Delta\omega}(t) = d_r S \frac{P_1 P_2}{\rho c^2} \cos\left(\Delta\omega t\right). \tag{3}$$

As a result of the applied force, the object produces a sound field called "acoustic emission" in the medium. The amplitude of the acoustic emission field can be expressed as [4],[5]

$$\Phi_{\Delta\omega} = \rho c^2 H_{\Delta\omega} Q_{\Delta\omega} F_{\Delta\omega}(t), \tag{4}$$

where $H_{\Delta\omega}$ represents the transfer function of the propagation medium and receiver, and $Q_{\Delta\omega}$ is a function that represents the object's mechanical properties. By probing the object point-by-point in a raster scan motion, values of $\Phi_{\Delta\omega}$ are recorded and used to construct the images.

3. Experiment

Experiments were conducted on excised rabbit scapulae with and without associated muscles at room temperature. The two scapulae were excised from a euthanized rabbit and immediately immersed in 0.9% saline solution. One of them was carefully cleaned from muscles. They were then kept refrigerated for one hour before the measurements were made. The animal experiments complied with legal requirements and institutional guidelines. The scanning process was performed as shown in Fig. 1, with the Tone-Burst VA mode at Δf = 32 kHz.

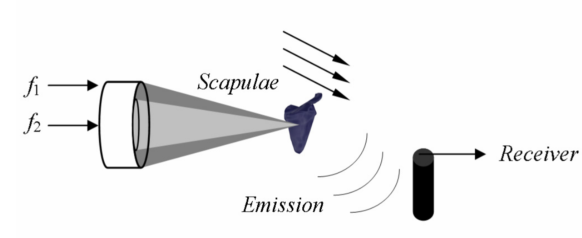

Fig.1: Vibro-acoustography setup.

Each image covered an area of 60 mm by 50 mm, scanned at 0.25 mm/pixel. The VA images for the scapulae with and without associated muscles are shown in Fig. 2-a and Fig. 2-b respectively.

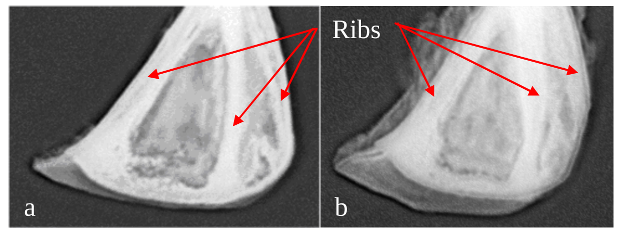

Fig.2: VA images of the scapulae at Δf = 32 kHz. a- Bare-bone scapula. b- Scapula with associated muscles.

The second experiment was performed by switching the transducer to the pulse-echo (or conventional ultrasound) mode. The transducer operated at 3 MHz and was scanned across the scapulae as shown in Fig. 1. The conventional ultrasound images were scanned at the same step-size and area as used in the VA experiments. The conventional ultrasound images for the scapulae with and without associated muscles are shown in Fig. 3-a and Fig. 3-b respectively.

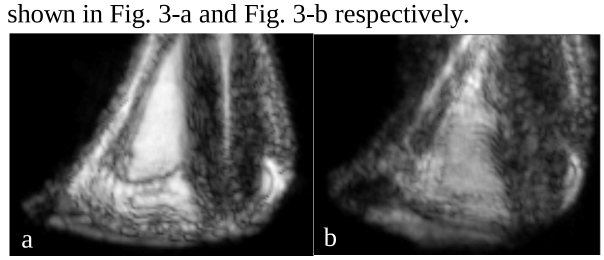

Fig.3: C-scan images at 3 MHz. a- Bare-bone scapula. b- Scapula with associated muscles.

4. Discussion and conclusion

The experimental VA and C-scan images presented here prove that VA is a high-resolution imaging technique, which is sensitive to the tissue mechanical and acoustical properties, as well as being free from speckle. By comparing qualitatively these images, one can notice that the VA images reveal important characteristics of scapula bone, which are related to its physiology. The three ribs in each of the scapulae are well displayed (Fig.2), however with the conventional ultrasound, these ribs were hardly seen. Future applications for *quantitative* imaging of bone will be considered.

5. References

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