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# ULTRASOUND-BASED NONINVASIVE SHEAR ELASTICITY PROBE FOR SOFT TISSUES

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*Abstract* - An ultrasonic technique for measuring the viscoelastic properties of soft tissues is presented. This technique uses a transducer set up on a vibrator as a source of high frequency waves (ultrasound) and low frequency waves (shear wave) at the same time. Ultrasounds (5 MHz) allow to detect the displacements induced by the shear waves (200 Hz) inside soft biological tissues. These shear waves reveals pieces of information about the shear elasticity and the shear viscosity. Two kinds of media are investigated: agar-gelatin phantoms and in-vivo human biceps.

## I. INTRODUCTION

Previous works have shown the feasibility of using low frequency shear waves to extract the viscoelastic properties of soft tissues [1], [2]. It is shown in [3] that the pulsed generation of shear wave is necessary to avoid some biases in the measurement of their propagation characteristics (velocity and attenuation). More over the shear wave is well described by the Green's function in a semi infinite elastic solid, [4]. Consequently, a good understanding of the low frequency shear waves allows one to use them in medicine or in food industry. The problem in these previous experiments is that the low frequency shear waves are generated by a piston on one side of the medium whereas the ultrasounds are generated by a transducer placed in the opposite side of the medium. Because in many circumstances both sides of the biological medium are not accessible, we have to elaborate a new experimental configuration in which the same source is used for the two kinds of wave.

## II. THE SHEAR ELASTICITY PROBE

The idea is to set the transducer on a low frequency (LF) vibrator and to generate the shear wave with its front face meanwhile it keeps working as a pulsed echo system, Fig.1. The central frequency of our transducer is 5 MHz and the focal is 35 mm. A-scans are recorded in a 9-bit digitizer at a sampling frequency of 50 MHz. The recurrence frequency between successive A-scans is 2000 Hz. The transducer has a 7 mm diameter. The shape and the frequency of the LF vibrations are controlled by a function generator.

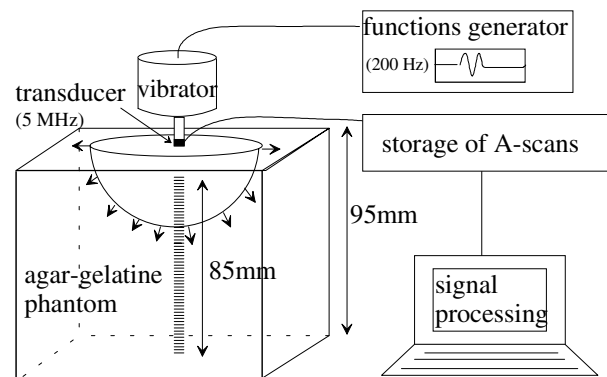


Figure 1: Experimental set-up of the elasticity probe: a 5 MHz transducer is set up on a vibrator. The acoustic impulse (200 Hz) is generated while the transducer works as an emitter-receiver.

An agar-gelatin phantom is tested. The depth of the volume insonified with ultrasound is 85 mm. Then the displacements of tissue slices as function of time and depth are computed with a cross correlation

technique [5]. No measurement can be extracted from the seismic like representation of displacements (Fig.2(a)) for the following reason: the displacements are relative to the moving transducer (moving frame); thus the result is the superposition of apparent displacements and true displacement due to the propagation of low frequency waves. In the particular case of figure 2(a), one can detect the shear wave beyond 40 mm. But in most real cases, because of the size of the medium or because of its attenuation, the shear wave can only be detected in the first 50 mm.

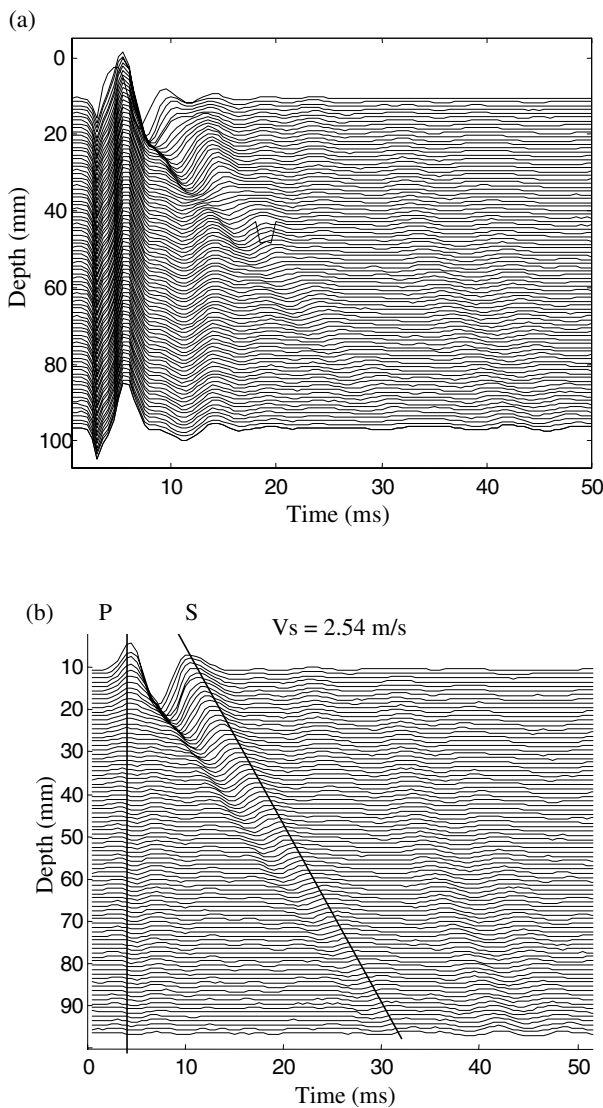


Figure 2: Seismic-like displacements without (a) and with compensation (b) of the motion of the transducer.

Consequently, in order to get rid of the apparent displacements, the following solution is proposed. In the common case where a non moving reference is present on the A-scans (e.g. the echo of the table), its apparent displacements give directly the motion of the transducer. By subtracting these displacements at each depth, one obtains the displacements in the referential of the laboratory, Fig.2(b). Thus, low frequency waves become clearly apparent. The compressional (P) and the shear (S) waves are marked with straight lines. The maximum of the displacements is  $273 \mu\text{m}$ . Then, the shear wave is selected and the phase velocity is computed from a spectral analysis:  $V_s = 2.54 \pm 0.03 \text{ m}\cdot\text{s}^{-1}$ . Neglecting the shear viscosity, the Young modulus is  $E = 2360 \pm 55 \text{ Pa}$ .

### III. IN-VIVO RESULTS

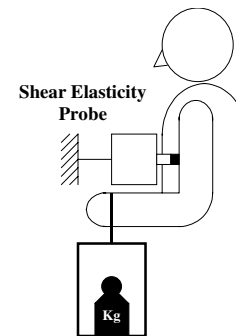


Figure 3: In-vivo experiment: the shear wave velocity is measured on the biceps while the subject is loaded and unloaded.

Two main differences are noticeable between *in-vitro* and *in-vivo* experiments. First, as far as the the human biceps is concerned, the non-moving reference needed for the motion compensation of the transducer is the *humerus* bone whose echo is easily detectable. Second, the central frequency of the acoustic impulse is only 70 Hz to avoid the attenuation at higher frequency. The following experiment is achieved, Fig.3. A subject is loaded with 1.5 Kg weights, up to 9 kg then unloaded. A whole experiment last 1 minute and the signals are analyzed afterwards. For each additional loads, a value of the shear wave velocity is computed. An error bar on the velocity is the standard deviation of the linear fit operated on the experimental phase of

the shear wave. Figure 4 shows that the velocity is increased up to a factor of 4 during the contraction of the muscle. It represents, in a simple elastic model, a factor of 16 on the Young modulus. Besides, the velocity on figure 4 seems to tend toward a maximum and the values during the unloading remains higher than during the loading. Some more works are needed to link this observation to the fatigue of the muscle.

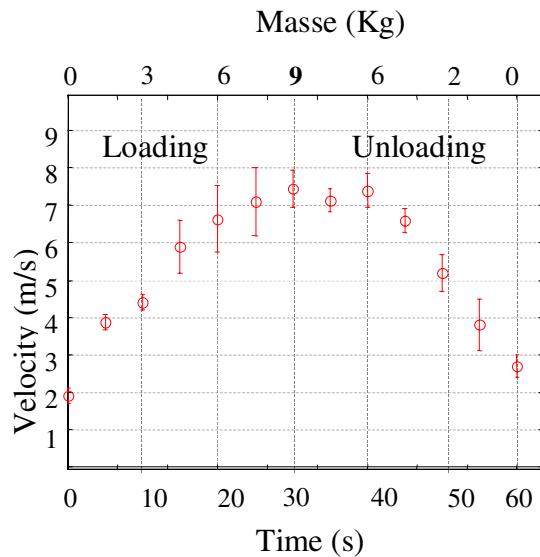


Figure 4: Velocity of the shear wave in a human biceps contracted by various load .

#### IV. CONCLUSION

The future works will consist of a systematic study of the shear velocity in muscles. The attenuation has not been exploited yet and is also a part of our coming research. The ultimate goal is, from the velocity and the attenuation of the shear wave, to obtain the shear elasticity and the shear viscosity.

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