USE OF CONTRA-SOUNDING PRINCIPLE FOR DETECTION OF ULTRASOUND VELOCITY AND ATTENUATION IN HUMAN COMPACT BONE

Juris Saulgozis, Inese Pontaga, and Augusts Balodis
Laboratory of Biomechanics, Latvian Medical Academy
Duntes Str.12/22, LV 1005, Riga, Latvia

Abstract:The contra-sounding principle is realized to improve the measurents of ultrasound velocity and attenuation in human bone.The velocity is independent from the test base length, recording the signals with respect to their arrival. The coefficients of variation of the velocity and attenuation for the bone specimens are 0.47 and 7.3%, for the tibia in vitro- 0.63 and 9.2%, in vivo - 0.69 and 10.4%,respectively. The attenuation tests halves the error at least. A fixed test base shall be used measuring the attenuation from the amplitude of the first half wave.

INTRODUCTION

At a bone fracture or osteoporosis, knowledge of the bone mechanical integrity is a critical need. In contrary to the vibration technique,which estimates the global stiffness of bone,the ultrasound determine locally the mechanical properties of the tissue [1]. However,the application of ultrasound on whole bone and in vivo [2] suffered from the contact errors between the transducers and the bone.In this paper a measurement technique for decreasing the errors from variety of the bone - transducer connectings is presented.

METHOD

The ultrasound velocity and attenuation are measured by the original apparatus "Bone Health Meter" [3]. The transducer set-up is based on the contra - sounding principle: sounding the measuring base sequently in the 2 opposite directions.Averaging measured values it is possible to decrease errors from the variety of electroacoustic coupling (contact errors, differences in the time dely in transducers etc.). It will be shown below in the case of attenuation measurements where the coupling errors are of most critical nature. The device consists of two transmitters (2 and 3) and two receivers (1 and 4) located on the surface of the material (Figure 1).The measuring base is fixed L=40 mm.Longitudi-

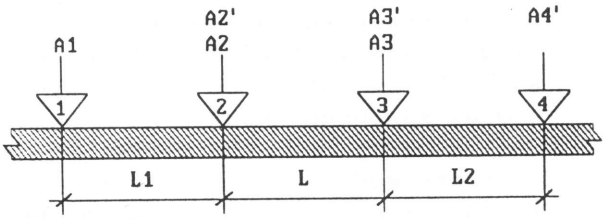

Fig.1.Arrangement of the transducers.

nal waves along the specimen are exited and received due to the cross deformations arised in the bone compact layer. Transmitters are exited by short 300 V electrical pulses and they oscillates at 200 kHz resonant frequency with exponential delay. The propagation time of the front of acoustic signal and amplitude of the first half wave is used.Therefore the duration of ultrasound pulses are not significant.The attenuation is measured by supplying the transducers 2 and 3 by signals with amplitudes A2 and A3 at which the receiver 1 records vibrations with the same amplitude A1:

$$A1=A2\ k2\ e^{-\alpha L1}=A3\ k3\ e^{-\alpha(L1+L)} \quad (1),$$

where α - the attenuation coefficient; k2 and k3 - the contact 2 and 3 error coefficients,respectively; L1 and L2- the distance between transducers (25 mm). The signals from transducers 2 and 3 reach also receiver 4 with amplitude A4':

$$A4'=A2'k2\ e^{-\alpha(L2+L)}=A3'k3\ e^{-\alpha L2} \quad (2).$$

From (1) - (2) there follows

$$\alpha=(1/2L)\ln(A3/A2)+(1/2L)\ln(A2'/A3').$$

So,the effect of the contact errors k2 and k3 is eliminated. A similar result can also be achieved by interchange of the transmitters with receivers. Thus,the attenuation coefficient is expressed in terms of the ratios of the amplitudes of sounding pulses propagated in opposite directions.For a constant measurement base L the attenuation coefficient can be represented in the form of a sum of two readings from the scale of a suitably graduated logometric instrument.

For orthotropic materials (as compact bone tissue) whose properties may vary widely, construction of dispersion curves presents serious difficulties, since dispersion effects associated with the physical and geometric properties of the specimen lead to a certain indeterminacy of the acoustic qualities measured. This is one of the reasons why it is still not possible to use phase and group velocities for diagnostics in the case of bone tissue. The propagation velocity of the signal measured should be regarded as the velocity of the vibrations in an infinite medium and not as the velocity in a rod, especially where the measurement base is small.

We therefore conducted the following additional experiments: a) estimation of the accuracy of measurement of the ultrasound velocity and attenuation in a bone specimen and in a model material - (TS-8/3-250 glass- reinforced plastic with unfinished surface) with reference to the reproducibility of the results when the transducers are reapplied to their surfaces; b) estimation of the dependence of the ultrasound propagation time and attenuation determined for the leading part of the signal, on the length of the measurement base for a glass-reinforced plastic specimen. The bone specimens are taken from middiaphysis of the tibiae of 10 male accident victims aged between 20-40 yrs. After a radiographic check has shown that there are no pathological changes from a diaphysis are machined 12 restangular plates (125x5x 1 mm). In order to prevent local overheating bone tissue is cut at a low speed and continuosly cooled with a cool water. The dimensions of 10 plastic specimens are identical to those of investigated bone tissue specimens.

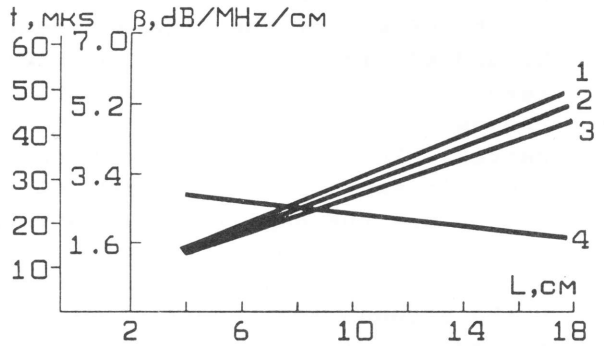

Fig.2. Ultrasound attenuation and time dependence on measuring base.

Table 1. Coefficient of variation of ultrasound velocity and attenuation.

Material	C, m/s	β, dB/cm MHz	ω, according to transmission direction, % for C ←	for C →	for C ← →	for β ←	for β →	for β ← →
Specimens:								
bone	3472	5.1	.77	.52	.47	13	14	7
plastic	3427	2.3	.25	.20	.19	18	19	7
Tibia in:								
vitro	3614	5.8	.78	.64	.63	16	15	9
vivo	3547	5.5	.81	.73	.69	16	14	10

The ultrasound velocity and attenuation is determined in vivo and in vitro in the intact tibiae of 53 and 37 males, respectively, without history of the bone disease (age 25-40 yrs.). The transducers are placed on planum tibiae, using an ultrasound contact gel between the bone and the transducers. The attenuation is calculated as $\beta = \alpha / f$, but a variation coefficient ω - from tenfold irradiation of a specimen.

RESULTS

The test results are presented in Table 1 and Fig.2. The ultrasound attenuation and propagation time as function of the measuring base for the glass reinforced plastic is shown on Figure 2. The t-L dependences are established by comparing signals at the maxima of the first half wave/1/, the 0.5 level of the maxima/2/, and on arrival /3/. The attenuation /4/ is determined from the amplitude of the first half wave.

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