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SOS and Thickness of a Trabecular Bone

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Abstract

Background: *Assessing the SOS and thickness of a trabecular bone (TB) sample was found as an important issue in defining TB's properties. Proposed here are methods for assessing the SOS and thickness of these samples.*
Methods: *Three methods are present for assessing its SOS, based on US pulse transmission through a TB sample. Two of them were compared, based on the 'pulse start time' and the 'pulse peak time' of the US received (Rc) signals.*
The third method is based on the 'time-shift' of the received pulse, between that of a TB sample and from an equivalent distance in water; From there, the estimated SOS and the thickness in TB sample was evaluated.
Results: *Good estimations for the SOS in TB were obtained using the 'start time' of the received pulse. Similarly, for the thickness of TB.*
Conclusions: *The presented methods for assessing the SOS and thickness in TB are simple, thus may be applied routinely in many applications in Medicare, where the SOS knowledge is important.*

Keywords: *Ultrasound (US), Trabecular bone (TB), Speed of Sound (SOS), pulse start, pulse peak, time shift.*

Introduction

The Speed of Sound (SOS) of an Ultrasound (US) wave that propagates through a Trabecular Bone (TB), was discussed theoretically and in various directional applications by several authors [1-5], where the SOS measurement can be performed in several ways, as described in [1-3].
We compare here between three measuring methods, where in all of them - a pulsed US was applied. Presented are the advantages of each one of the measuring systems [6, 7], which are summarized as follows:
Inspection of the SOS variability with TB samples (obtained from a porcine hips) and the measuring method ('pulse start time' and 'pulse peak time').
Thickness measurements on the same samples of TB, with the mentioned methods.

The inspection of the SOS variability was performed as follows:
(1) Measurement of SOS in TB, by a direct cursor's position readings on a screen of a scope.
(1.1) By 'pulse start time' of the received signal.
(1.2) By 'pulse peak time' of the received signal.
(2) Estimation of TB thickness and its SOS from measurements of the pulse 'time-shift' between the one received from a TB slice and from water.

Methods

All the presented measurements were performed on TB samples, sliced from hips of a porcine, obtained from a slaughterhouse.

The electronic parameters of the US pulsed signal:
Pulse repetition frequency (PRF) = 500 Hz;
Resonant US frequency (fr = f_{US}) = 5 MHz.

The following US transducers were applied in these experiments:
Panametrics, type C310, f_{US} = 5 MHz

Piezo-Technologies, type RI-4524-SCB1, f_{US} = 5 MHz

Transmission mode: 3 pulses per burst

The experiments were performed on 4 TB samples (see Fig. 1), where 2 of them were sliced from the same hip.

The US SOS measurements were performed using the following three methods:
a. Using two (2) transducers, in transmission mode (T_r: Panametrics 5MHz and R_c: Piezo-Technologies 5MHz), the SOS was assessed from measurements at two locations on the screen:
The start-time (beginning) of the received pulse.
The peak-time of the received pulse.
b. Measuring the time-shift of the received pulse, between this in the TB and in water (for the same distance) – from where the SOS was assessed.

The thickness of the sample was measured also mechanically, by means of a caliper (with an accuracy of 1/100 mm).

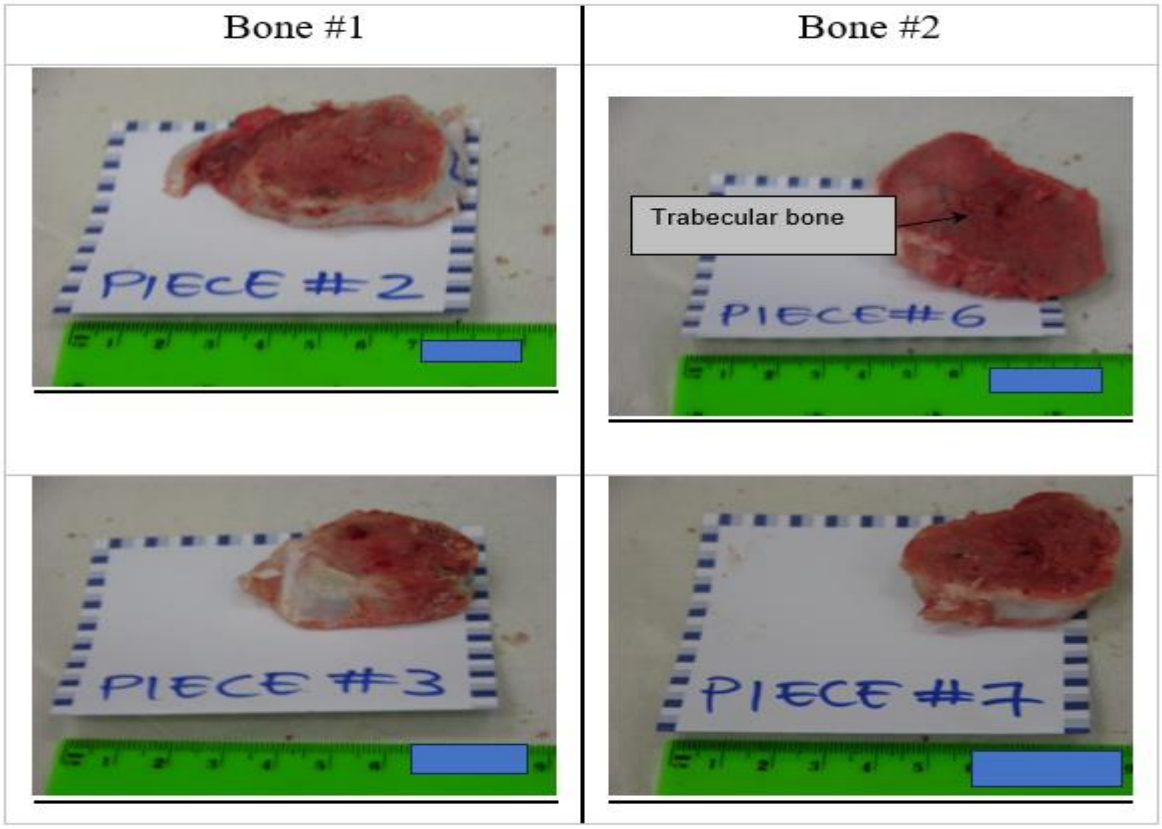

Figure 1: TB samples, from hips of a porcine, for assessing their SOS and thickness.

Experiments and Results

Experiment No. 1

SOS in TB, based on 'peak time' of the received signal (pulse).

Measurement of the SOS in TB, using the cursors on scope's screen.

As described in the section of Methods, the US transmitted signal was received by an US transducer, after propagating through the TB sample. From the US transducer, it was connected directly to the input of the oscilloscope. Thus, the received signal was amplified and finally displayed on its screen – enabling to perform directly its measurements (start time and peak time).

This typer of measurement is simple and enabled to define the following parameters for these measurements:

The start time of the pulse.

The end time of the pulse.

The peak (maximum height) of the pulse.

These definitions were applied in real-time, during the measurement, and enabled the SOS assessments.

Each measurement was repeated 10 times, followed by calculating their average value (AV) and the standard deviation (STD) from the mean, which enabled to obtain reliable measured results.

Results

The measurements described above were performed on 4 samples (No. 2, 3, 6 and 7), as described in Fig.1.

The thickness of each sample was measured by a caliper, with a resolution of 10^{-2} mm.

For comparison purposes, the SOS is presented in Table 1 by the following methods:

The peak time, as measured at the 'peak' of the received (Rc) signal – as performed in Experiment 1.

The start time, as measured at the 'starts point' of the Rc signal – as performed in Experiment 2.

Sample No.	Sample thickness [mm]	Pulse starts time [µsec]	Pulse ends time [µsec]	SOS in TB (based on start time) [m/s]	SOS in TB (based on the peak time) [m/s]
2	13.25	7.60	9.54	1743.42	1388.89
3	12.90	7.68	9.56	1679.69	1349.37
6	12.35	6.50	8.78	1900.00	1406.61
7	12.50	6.56	9.12	1905.49	1370.61
mean				1859.27	1378.24
STD				100.77	21.31

Table 1: Comparing the US SOS in TB samples, as assessed by two measuring methods (i) 'start time' of the received pulse (from Experiment 2) and (ii) its 'peak time' (Experiment 1).

Conclusions

Based on the 'starts time' of the received pulse (Experiment No. 2):
The measured SOS is between 1679 m/sec and 1905 m/sec.
The SOS measured on two samples from the same hip (samples 6 and 7) was similar.
Based on the 'peak time' of the received pulse (Experiment No. 1):

The assessed SOS was found to be more similar for all the 4 samples, thus the STD is smaller than in Experiment 2.

Note:
The SOS that appears in Experiment No. 2, is highlighted by yellow color in Table 1.]

Experiment 2:
To assess the SOS in TB, the following experiments were performed:
SOS in TB, based on 'start time' of the received signal.
The 'shift time' of the pulse, obtained from the TB and from water, as obtained for the same distance.

Details
The first experiment is similar to Experiment No.1, but here was measured the 'start-time' of the received signal.

For the 'time shift' measurements, the velocity of US in TB (C_{bone}), was calculated according to:

$$C_{water} \cdot t_{water} = C_{bone} \cdot t_{bone} \quad (1)$$

$$C_{bone} \cdot t_{bone} = C_{water} (t_{bone} + \Delta t) \quad (2)$$

This is since $C_{bone} > C_{water}$.
Therefore:

$$C_{bone} = C_{water} (t_{bone} + \Delta t) / t_{bone} \quad (3)$$

In a separate measurement it was found:
C_{water} = 1495 m/s in these experiments.

Results

Table 2 describes measurements of the 4 TB samples (the same samples as of experiment No. 1).
The SOS was assessed here from the 'start time' of the received signal (pulse) from TB.
Table 2 also contains the SOS that was assessed from the 'peak time' of the received signal (pulse) - as assessed in experiment 1).
Table 2 includes also the estimated US thicknesses of the TB samples. This was performed by measuring the time difference between the measured pulse obtained from TB and the one from water.

A comparison was made of the 'start-time' to the 'peak time' - of the received signals from TB.

			Start of pulse		Peak of pulse		Distance measured by caliper [mm]
Sample #2	SOS in TB [m/s]	Exp 1	1743.42		1388.89		
		Exp 2	1720.81		1677.92		
	Estimated TB thickness [mm]	bone	13.22	0.22%	14.26	-7.62%	13.25
		water	13.26	-0.075%	14.31	-8%	
Sample #3	SOS in TB [m/s]	Exp 1	1679.69		1349.37		
		Exp 2	1635.62		1656.90		
	Estimated TB thickness [mm]	bone	13.22	-2.4%	14.38	-11.5%	12.90
		water	13.26	-2.79%	14.43	-11.86%	
Sample #6	SOS in TB [m/s]	Exp 1	1900.00		1406.61		
		Exp 2	2539.45		2157.68		
	Estimated TB thickness [mm]	bone	11.12	9.95%	12.17	1.45%	12.35
		water	11.16	9.63%	12.21	1.13%	
Sample #7	SOS in TB [m/s]	Exp 1	1905.49		1370.61		
		Exp 2	1950.43		1404.50		
	Estimated TB thickness [mm]	bone	11.78	5.76%	12.53	-0.24%	12.50
		water	11.82	5.44%	12.57	-0.56%	

Table 2: (a) SOS in TB, by measuring the 'start-time' of the received pulse as compared to the 'peak time' - obtained in Experiment no. 1; (b) TB thickness measured by these two US methods and comparing them to the mechanical one.

Conclusions

Results with small differences were obtained for the SOS in TB, in both experiments presented in this study.
The assessed SOS resembles the result that were obtained with the 'start time' method. Thus, the SOS is better to measure by the 'start time'.
In all the cases, related to the SOS in TB, the error is smaller than 10% and similarly, for TB thickness estimations.

When estimating the distance between transducers, their results (of bone and water) are close in all the measured cases (red and yellow values, in Table 2).
Similar results for TB thickness were obtained by 2 US methods and the mechanical one.

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