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Research Article

ANISOTROPY IN COMPRESSIONAL WAVE VELOCITY IN BOVINE BONES

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ABSTRACT

The study reveals that the anisotropy in scapula rib and femur bears the same value when X (along the bone axis) and Y (along the breath/tangential) directions are considered, whereas it differs considerably (scapula: 0.64 ± 0.08; rib: 1.02 ± 0.03; Femur: 0.89 ± 0.03) when measured with respect to the directions, X (bone axis) and Z (along the thickness/radial). The difference in V_y/V_x and V_z/V_x is the same in the cancellous bones (scapula and rib), but it is more than that of the compact bone (femur). However, this difference in the anisotropy is negligible in the femur, which suggests that the scapula and rib are relatively more fibrous than the femur; moreover, the deposition of calcium phosphate in the matrix of the collagen fibres is relatively more homogeneous in the femur, than scapula and rib.

Key Words: *Anisotropy, Rib, Femur, Scapula, Calcium*

INTRODUCTION

The direction of wave's propagation depends on the orientation of the anisotropic medium with respect to the parallel surfaces, as well as the kind of anisotropy. Each sonic path is generally different from the normal to the surface, so the sonic path lengths will be greater than the thickness. For a thin layer, the sonic path lengths may be too short for the wave fronts to become distinctly separate and the received signal may appear to be a somewhat distorted version of the input. Since the effective sonic path is longer than the thickness, the ratio of the thickness to transit time is not the sonic velocity.

If the material is as definitely anisotropic as in the case of bone, the measurement of sonic velocity in several different directions and in different modes is not a straight forward matter. Lang (1970, 1969) makes no mention of the problem. Yoon and Katz (1976) reviewed the theory of elastic wave propagation in an anisotropic medium with hexagonal symmetry, using considerable care, but their selection of the actual planes in the bone specimen from which to measure the transit time was effectively as arbitrary as Lang's. Both investigators considered the principal axes and the plane at 45° to these axes. Lang used bone from a 6 month old calf, while Yoon and Katz used adult human cortical bone, and reported that human cortical bone did not have pseudo hexagonal symmetry. Both investigators made the same set of velocity determinations and reduced their data to the same format. The neither demonstrated isotropy in the transverse plane nor investigated the variation of the plesio-velocity with locus. The plesio-velocity may be approximately the true velocity depending on the internal modes and the path transversed by the wave. For bone the pleso-velocity depends on the local structures, especially the orientation of the infrastructure of the particular site in the bone sample serving as the source of the specimen.

Lee *et al.,* (1979) reported the longitudinal plesio-velocity for various specimens within a single section of adult bovine tibia measured by the pulse echo-method at room temperature of 23°C. The distribution of acoustic properties was determined for the bone sample in its original we state, when dehydrated, and again in the rehydrated state. It was shown that the plesio-velocity in the bone sample was strongly dependent on the direction of sonic wave propagation as well as the site of origin of each specimen. Goss *et.al.,* (1978) cataloged a wide range of sonic velocity and absorption in different bones as determined by many observers. The marked anisotropy of bone would be sufficient to account for the observed variation, but differences between species can also be important as reported (Mohiuddin 1990). Novitskaya *et al.,*

(2011) study the mechanical properties of demineralized and deproteinized cortical bone as a function of anatomical direction.

As there is no systematic studies on the role of anisotropy in compressional wave velocity, especially in Scapula, rib and femur of bovine bone, which is the present case study of investigation.

MATERIALS AND METHODS

In order to study the ultrasonic measurements for bovine bone scapula, rib and femur, the samples were collected from slaughter house. Bone marrow and fleshy material was removed from the bones. The dimensions – length, breadth, thickness, radius of the specimens were obtained by using vernier caliper and screw gauge.

Compensated Ultrasonic Timer Technique (CUTT) (Ramna 1984, 1977) was used for the measurement of transit time of ultrasound of a given frequency through the known thickness of the sample. CUTT, being a digital system, is independent of observational errors, and it is also considered to be a faster tool compared with existing analogue measuring methods.

The transit time of the ultrasound through the bone sample was measured using this technique. The velocity V = l / t was determined. Where 'l' is the travel distance and't' is the delay time of ultrasonic wave in the experimental sample. The parameters of pulse propagating in the bone tissue are: Frequency: 1 MHz, Pulse Length: 6.5 µ sec, Pulse Rate: 400 Hz, Initial delay: Zero and Sweep speed (for oscilloscope): 1 µ sec/cm

The velocity of compressional waves was measured in bovine scapula, rib and femur bones in the direction perpendicular to the bone axis (Z-direction). In order to determine anisotropy, the velocity was measured along the bone axis (X-direction) and in the directions perpendicular to the bone axis (Y and Z direction).

RESULTS

Table 1 presents the data on the compressional wave velocity (V_p) of ultrasound along with three directions, x, y and z with respect to fiber axis and its anisotropy (V_y/V_x and V_z/V_x) for 15 samples of bovine scapula, rib and femur bones taking 5 specimens of each. The compressional wave velocity (V_x) is found to be comparatively more along x-direction ie., fiber direction than other two mutually perpendicular directions ie., Y and Z, in the case of scapula and femur. While it is less, compared to other direction, in rib. When compared to femur, significant difference is observed between V_y/V_x and V_z/V_x in the bones scapula and rib, which suggests that calcium phosphate deposition, is comparatively more homogenous in femur than scapula and rib.

The average values of anisotropy in compressional wave velocity (V_y/V_x and V_z/V_x), for scapula, rib and femur is not the uncertainty of the measurement but refers to the variability observed among the specimens for the same bone sample. Compressional wave velocity is the same in scapula (3753 ± 77 m/sec) and rib (3709 ± 176 m/sec) but higher than that of femur (3316 ± 72 m/sec), whereas shear wave velocity is the same in rib (2404 ± 153 m/sec) and femur (2140 ± 74 m/sec) and it is considerably high when compared to scapula (1423 ± 55 m/sec) (Mohiuddin et.al. 2005). Anisotropy in compressional wave velocity is significant in the three types of the bones. However, the values of V_y/V_x and V_z/V_x differ considerably in scapula (0.8 ± 0.09 & 0.64 ± 0.08) and rib (0.83 ± 0.03 & 1.02 ± 0.03) when compared with femur (0.09 ± 0.08 & 0.89 ± 0.03).

DISCUSSION

The anisotropy in any physical parameter is an inherent property of the biological tissue, whether its value may be large (soft tissue) or small (hard tissue). The study reveals that the anisotropy in scapula rib and femur bears the same value when X (along the bone axis) and Y (along the breath/tangential) directions are considered, whereas it differs considerably (scapula: 0.64 ± 0.08; rib: 1.02 ± 0.03; Femur: 0.89 ± 0.03) when measured with respect to the directions, X (bone axis) and Z (along the thickness/radial). The difference in V_y/V_x and V_z/V_x is the same in the cancellous bones (scapula and rib), but it is more

Table 1: Anisotropy in compressional wave velocity in Bovine Bones

Identification	Travel distance (cm)			Travel time (µsec)			Velocity(x 10^2 cm/sec)			Anisoropy	
	l_x	l_y	l_z	t_x	t_y	t_z	v_x	v_y	v_z	v_y/v_x	v_z/v_x
Scpula											
S1A	3.03	2.11	0.963	12.06	8.70	5.72	2512	2425	1684	0.97	0.67
S2A	3.04	1.64	0.556	8.82	6.08	2.62	2697	2697	2122	0.68	0.54
S3A	3.54	1.71	0.784	6.58	6.00	3.02	3860	2850	2596	0.74	0.67
S4A	2.99	1.48	0.589	7.14	4.44	3.02	3860	3333	3201	0.80	0.76
S5A	2.49	2.13	1.022	7.02	7.56	4.96	3547	2818	2061	0.79	0.57
Rib											
R1A	3.80	2.14	0.963	10.64	7.23	1.25	3571	3070	3632	0.86	1.02
2A	3.61	1.96	0.963	9.80	6.57	1.21	3684	2983	3785	0.81	1.03
R3A	3.67	1.87	0.963	10.02	6.26	1.28	3663	2987	3797	0.82	1.04
R4A	4.06	1.83	0.963	11.06	5.68	1.27	3671	3222	3858	0.88	1.05
R5A	2.99	1.64	0.963	7.82	5.33	1.29	3824	3077	3651	0.80	0.95
Femur											
F1A	3.15	1.61	0.963	10.64	7.23	1.25	3571	3070	3632	0.86	0.84
F2A	2.92	1.73	0.963	9.80	6.57	1.21	3684	2983	3785	0.94	0..87
F3A	3.14	1.65	0.963	10.02	6.26	1.28	3663	2987	3797	0.89	0.91
F4A	3.54	1.68	0.963	11.06	5.68	1.27	3671	3222	3858	0.88	0.89
F5A	3.39	1.78	0.963	7.82	5.33	1.29	3824	3077	3651	0.94	0.93

than that of the compact bone (femur). However, this difference in the anisotropy is negligible in the femur, which suggests that the scapula and rib are relatively more fibrous than the femur. Moreover, the deposition of calcium phosphate in the matrix of the collagen fibres is relatively more homogeneous in the femur, than scapula and rib.

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