QUANTITATIVE ULTRASOUND TO PREDICT THE MECHANICAL PROPERTIES OF BONE

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Abstract: QUS assessments in vivo have been shown to be predictive of osteoporosis and future fractures. In this study, the ability of quantitative ultrasound parameters to predict the mechanical properties of rabbit's bones under three-point bending was investigated. The calcaneus QUS measurements were conducted on rabbit bone in vivo using clinical instrument. We have selected rabbit's bones that have low BMD and more collagen tissue to predict structure is sensitive to the structure of the bone. Biomechanical studies consisted of compression and three-point bending tests were applied and Elastic modulus, maximum force and energy absorption capacity as the area under the curve are estimated. The results of correlation analysis show that there are relatively high correlation between SOS, BUA and stiffness with mechanical parameters. We conclude that QUS parameters important for the mechanical properties of bones.

Introduction

It has been proposed that ultrasound, which uses no radiation, be used as alternative for detecting osteoporosis and predicting fracture risk. Ultrasound also seems to provide information on bone structure, which they aren't available using radiographic techniques [1-3]. Recently, there have been studies relating speed of sound (SOS) to bone properties. Broadband ultrasound attenuation (BUA) is related to a material's structural characteristics. In this study, the ability of quantitative ultrasound parameters to predict the mechanical properties of rabbit's bones under three-point bending was investigated.

Materials and Methods

A total of 22 three-month old white rabbits weighted 1851gr were anaesthetized by intrapertoneum Ketamin hydrochloride (10%) and Xylazin hydrochloride (2%) injection (3:4, 0.7 mg/kg). The SOS and BUA of femur (n=22) and tibia (n=22) in two regions (up: 1/3 of length and down: 2/3 of length) were measured using a Lunar Achilles+Ultrasound Instrument (Lunar Co, Madison WI). SOS and BUA were measured and averaged for all bones using ACHILLES V 1.0.47 software. The animals were killed with Ether facility protocol. The tissue surrounding the femur and tibia was left intact. Calcaneus QUS, following a standard procedure that is typically used in clinical settings, we assessed speed of sound (SOS) and broadband ultrasound attenuation (BUA) in the femur and the tibia bones at up, and down by means of Lunar Achilles + ultrasound instrument (Lunar, Co., Madison, WI, with centre frequency of 500KHz). This ultrasound densitometry is usually made at the calcaneus, by the system incorporating two transducers, one acting as a transmitter, the other as a receiver. The basic principle of bone measurements is the same. The speed at which ultrasound propagates in bone or the extent of their attenuation through bone are determined by bone density and some physical properties that are intimately correlated with bone strength (Stiffness Index: SI). BUA is derived as the slope of the regression line in a plot showing attenuation vs. frequency (the frequencies used range from 0.2 to 0.6 MHz).

It has been demonstrated that SOS is related to the elasticity and the density of bone whereas BUA is related to the density and structure (4).

The leg's rabbit was placed between the ultrasound transmitter and receiver to obtain parallel sides of the legs perpendicular to ultrasound beam. After localization the beam path with the help of a plastic collimator, the diameter of which was the same as that of the ultrasound beam (1cm). SOS (±4m/s), BUA (±2db/MHz) and stiffness index were measured through the tibia and the femur bones in two regions (up and down) using Achilles V 1.0.47 software. All ultrasound measurements were repeated twice and the mean SOS. BUA and combination of SOS and BUA (stiffness index) values were calculated to reduce experimental variation. In equation 2, stiffness index are introduced:

$$\text{Stiffness Index} = (.67\ \text{BUA} + .28\ \text{SOS}) - 420$$

Biomechanical studies consisted of compression and three-point bending tests (Zwick-477514, Germany). Each specimen was loaded to failure at a rate of 1mm/min using displacement control. The elastic modulus of bone (N.mm-1) was determined from the initial strength line portion of the load-deformation as

ISSN: 1727-1983

the highest point of curve, and the energy absorption capacity (N.mm) as the area under the curve.

Statistical analysis was performed with SPSS V. 11 software (SPSS/PC Inc. Chicago, IL). Summary statistics for all normally distributed variables are presented as mean and standard deviation. After having verified normal distribution and homogenicity variances, Paired student's t-test was done with a significance level of less than .05. Analyses of the Pearson correlations between densitometry and ultrasound parameters with bone thickness were carried out in the characterized regions of the tibia and the femur bones, and Pearson correlation coefficients (r) were estimated. Finally, simple linear regression was used to determine the associations between ultrasonic parameters with tensiometric parameters.

Results

The SOS (m.s-1), BUA (db.MHz-1), combination of SOS and BUA (Stiffness Index) values and results of the mechanical tests of the femur and the tibia bones are presented in Table 1. The fracture loads had variation from 143N to 247N with a medium 194N for femur and from 129N to 201N with a medium161N for tibia bone. The correlation coefficients between the mechanical parameters and QUS are presented in Table 2.

Table 1: The mean ±SD of SOS, BUA and Stiffness Index values and mechanical data in the femur and the tibia bones

Parameters	Femur (N=22)	Tibia (N=22)
SOS (m/s)	1578±31	1523±21
BUA (db. MHz^{-1})	44±6	58±6
Stiffness Index	51±11	48±9
Elastic modulus (N/mm)	90.31±18.36	52.98±13.99
Energy absorption capacity (N. mm)	243.17±39.39	276.21±33.82

Table 2: Pearson correlation coefficients and significant level of QUS (SOS, BUA and stiffness Index: SI) and mechanical parameters (Elastic modulus: EM, Energy absorption capacity: EAC) of rabbit's bones

Para-meters	SOS	BUA	SI	EM	EAC
SOS	1	-.42*	.46*	.49*	-.41*
BUA	.42*	1	.14	-.48*	.29
SI	.46*	.14	1	.18	-.11
EM	.49*	.48*	.18	1	-.16

* Correlation is significant at the 0.01 level (2-tailed)

The regression functions between the mechanical parameters and ultrasonic parameters are presented in Table 3.

Table 3: The results of regression analysis and significant levels of SOS (m/s), BUA (db/MHz) and mechanical parameters {EM (N. mm^{-1}), F_{max}(N) and EAC (N. mm)} of rabbit's bones

Linear regression function	Sig.
1.24 EM-0.49 F_{max}-0.22 EAC+1605.00 = SOS	.00
0.39 EM-0.20 F_{max}-0.01 EAC+41.98 = BUA	.00

Discussion

Several previous studies have shown significant correlation between mechanical strength of femur and SOS and BUA [1-3]. In this study, it was found experimentally that SOS, BUA and SI are a slightly weak predictor of elastic modulus and energy absorption capacity.

Other researcher studied cortical tibia bone as a material and found poor correlation between QCT density values and bone mineral strength [5]. In the present study, all mechanical parameters were assessed by a destructive invasive test and compared to bone mineral density.

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