CORRELATION BETWEEN BONE CONDITION FACTOR AND BROADBAND ULTRASOUND ATTENUATION

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INTRODUCTION

Age-related bone quality measurements play a vital role in many areas of research. One area where the assessment of bone quality is essential is in impact biomechanics. This field relies heavily on whole-body cadaveric specimens to determine potential injuries and their mechanisms. It is therefore essential to determine whether bone fractures and other injuries sustained are due to the impact itself or poor bone quality. In an effort to determine how bone quality affects the rate of injury, the thoracic resistance and skeletal quality of cadaveric specimens were evaluated by Sacreste [1] and Koh [2].

Sacreste [1] performed a factorial analysis on the parameters of bone characterization and validated a bone resistance index called the Bone Condition Factor (BCF) as a predictor for bone quality. Koh [2] later used this parameter in his analysis of rib strength during side impact. BCF is a very time consuming, invasive technique and can only be determined after whole body testing is completed. One non-invasive method used clinically to measure the bone quality is quantitative ultrasound (QUS). Based on the success of QUS in the clinical setting, the use of Broadband Ultrasound Attenuation (BUA) to determine bone quality prior to impact testing was explored. The goal of this research was to determine if there was a significant correlation between Broadband Ultrasound Attenuation (BUA) and Bone Condition Factor (BCF).

MATERIALS AND METHODS

A total of 26 human cadaveric subjects ranging from 47 to 95 years of age were included in this study. An ultrasonic bone analyzer (UBA575, Walker Sonix, Inc, MA) was used to determine the BUA of each specimen. BUA was measured in nine areas of the calcaneus or the heel bone and these values were averaged. To calculate the BCF, the sixth and seventh ribs from each specimen were removed. Each rib specimen was subjected to a three-point bending test (Fig 1) followed by shear and mineralization tests. Normal rupture stress and Young's modulus were determined from digital photographs of the bone cross section. BCF was then calculated using the following equation given by Sacreste [1]:

$$BCF = -\left[0.117\,\frac{MMY - 31}{6.7} + 0.128\,\frac{LMY - 0.24}{0.07} + 0.141\,\frac{MFS - 199}{118} + 0.100\,\frac{EFS - 614}{426} + 0.126\,\frac{CFS - 8.6}{5.5} + 0.121\,\frac{MCS - 709}{443} + 0.134\,\frac{WCS - 2.2}{1.33} + 0.131\,\frac{PFS - 158}{93}\right]$$

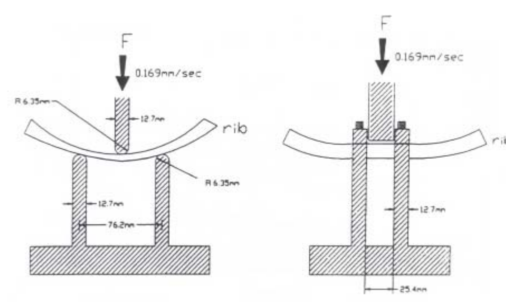

Fig 1: Schematic Diagram of Bone Mechanical Testing [2]

Where, MMY= Ash weight/Wet Weight (Rate of mineralization) [%]; LMY=Ash Mass/ Unit of length [g/cm]; MFS= Maximum Bending force [N]; MCS= Maximum shearing force [N]; WCS= Shearing energy [J]; PFS= Slope of force/deformation curve (from bending test) [N/mm]; CFS= Maximum bending stress [daN/mm^2]; EFS= Young's Modulus [daN/mm^2]. A BCF > 0 represents a lower than average resistance to bone fracture while a BCF < 0 represents a better than average resistance.

A factorial analysis of the average BCF and BUA results found in Table 1 was performed and the factor scores were computed.

A multiple regression analysis was also performed to predict the BUA from age and the factor scores that were obtained.

RESULTS

It was found that BUA had a strong correlation with BCF and Age combined, with $R^2 = 0.5981$, R = 0.773 and p-value of less than 0.01 (Fig 2). BUA could be predicted with the equation:

Predicted BUA = (0.07391×Age) + (16.531×Factor Score) + 59.982.

The correlation coefficient between BUA and BCF without age as a dependent variable was found to be -0.193 with $R^2 = 0.037$ and a significance of 0.377. Thus, indicating that no significant correlation between BUA and BCF exists, if age is not taken into consideration. (Fig 3).

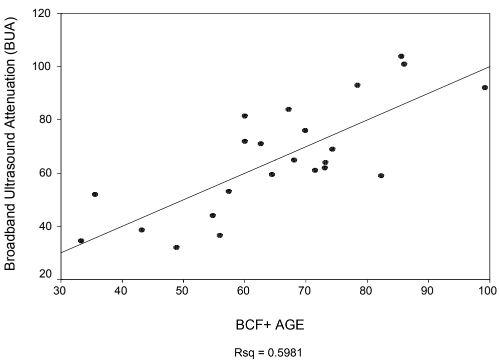

Fig 2: BUA vs BCF + Age (p<0.01)

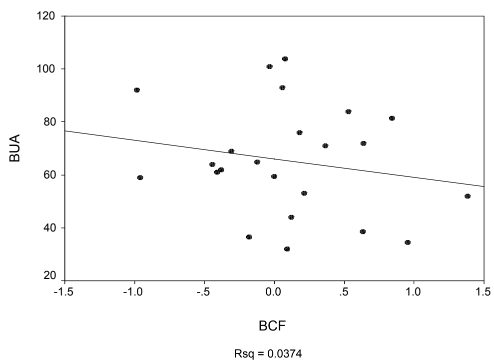

Fig 3: BUA vs BCF (p>0.05)

DISCUSSION

Based on the techniques developed by Sacreste [1], BCF has evolved as an invasive, post-test means to determine the quality of bone. Although BCF is proven and validated, a non-invasive, pre-test determination of bone quality would be of great use to researchers in specimen selection. Given the increased interest in the development of non-invasive diagnostic techniques for the detection of osteoporosis, the transfer of this clinical technology to the research environment seems logical. Since BUA is portable and easy to use, its application in the laboratory setting is quite feasible.

The use of the calcaneus bone provides a metric for bone mineral density based on the amount of trabecular bone. Changes in the speed and amplitude of the ultrasonic wave through this fluid-filled porous solid provide significant information on the underlying architecture and bone mineral density [3]. Since trabecular bone changes as a person ages [4], this age dependence is incorporated into the measurement.

The use of the rib bones to determine BCF makes it highly dependent on the properties of cortical bone. Cortical bone is stronger, stiffer and less porous than trabecular bone and therefore does not experience the same degree of change with age. However, the incorporation of age as a factor into overall BCF equation does not increase nor decrease its predictive ability [2]. In the current analysis, the BUA measurement takes into account the age of the specimen by virtue of the amount of trabecular bone in the calcaneus. Therefore, the higher correlation seen between BCF and BUA/age than BUA alone is logical.

Our results have shown a significant correlation between BCF/age and BUA. This relationship between BUA and BCF could be significant in studies of impact biomechanics where it is beneficial to know the bone quality prior to testing. BUA is a suitable replacement for BCF and could offer significant advantages in reducing the number of human cadaveric specimens required in future studies.

Table1: BCF and BUA data

Specimen #	Age	Sex	Average BCF	BUA
WSU 025	63	M	0.3631	71.0
WSU 091	80	M	0.2124	53.0
WSU 164	51	M	-0.4456	64.0
WSU 170	95	F	0.6337	38.5
WSU 558	81	F	0.1813	76.0
WSU 625	81	M	0.0942	32.0
WSU 804	91	M	0.6396	72.0
WSU 299	72	M	-0.0343	101.0
WSU 730	88	F	1.3833	52.0
WSU 755	84	F	0.1217	44.0
WSU 788	79	F	-0.3800	62.0
WSU 864	76	F	0.8414	81.5
WSU 731B	58	M	-0.4100	61.0
WSU 682B	77	F	0.5300	84.0
WSU 665B	74	M	0.0800	104.0
UM 004	47	M	0.0580	93.0
UM 006	78	M	-0.9616	59.0
UM 991	76	F	-0.1790	36.5
UM 992	76	F	0.0009	59.5
UM 993	71	M	-0.9860	92.0
UM 994	56	M	-0.1220	65.0
UM 998	70	F	0.9548	34.5
UM 999	66	M	-0.3067	69.0

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