Study on the effect of physical loading on bone broadband ultrasound attenuation

Chengrui Liu, Haijun Niu, Ling Wang, Yubo Fan, Deyu Li

Key Laboratory for Biomechanics and Mechanobiology of Ministry of Education, School of Biological Science and Medical Engineering, Beihang University, Beijing, China

Abstract— Background: **Physical loading changes bone microstructure and may influence quantitative ultrasound (QUS) parameters. This in vitro study aims at evaluates the effect of physical loading on bone QUS measurement.** *Objective:* **Ten fresh bovine bone specimens were studied. Specimens were scanned by a micro-CT and the density and structure parameters of specimens were calculated. The QUS measurement was performed when specimens subjected to loading, which changed from 0N to 1000N with the step of 100N. Statistical analysis performed to evaluate the difference between nBUA measured with and without loading, and the relationship between nBUA and the parameters measured by micro-CT.** *Results:* **While the loading exerted on bone higher than 200N, the measured nBUA significantly higher than nBUA measured without loading. Accompany with the increasing of loading, which exerted on bone, the values of nBUA also increased. A new parameter, the slope of the linearity fitted curve of nBUA values measured under different loading condition, was introduced to evaluate BMD. The correlation coefficient between the slope and BMD is -0.869 (*P*=0.001).** *Conclusions:* **Physical loading substantially influences bone QUS measurement. QUS measurement performed under loading condition may be a new ultrasound method for osteoporosis diagnosis.**

Keywords— **Osteoporosis, physical loading, bone, QUS, nBUA.**

I. INTRODUCTION

Osteoporosis is defined as a systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, with a concomitant increase in bone fragility and fracture risk [1]. Quantitative ultrasound (QUS) has been investigated for the assessment of fracture risk, using small, portable and low-cost devices [2, 3]. Osteoporotic patients have lower QUS than controls, although there is a large overlap of the values [4, 5]. It is one reason that bone QUS measurement have shown good sensitivity but also demonstrated low specificity [6, 7].

In situ human bones are subjected to repetitive, cyclic loading during routine daily activities. Experimental results showed that the microstructure and physical properties of the bone change significantly under physical loading [8, 9]. As a physical wave, the propagation of ultrasound wave is influenced not only by bone mass but also by bone microstructure and material properties [4, 10]. Therefore, the result of bone QUS measurement may influenced by the physical loading environment. But in previous studies, QUS measurement was normally performed on bone specimens without physical loading. We not found any report about the influence of physical loading on bone QUS measurement.

In our previous study, an interest phenomenon was found that the nBUA (normalized broadband ultrasound attenuation, $dB \cdot MHz^{-1} \cdot cm^{-1}$) at the os calcis were significant changed when physical loading exerted on calcaneus [11]. To verify this phenomenon, this in vitro study performed QUS measurement on bovine cancellous bone under different loading condition, and aims at evaluate the effect of physical loading on nBUA of bone. Furthermore, to evaluate the relationship between bone property and nBUA measured with loading.

M. Long (Ed.): World Congress on Medical Physics and Biomedical Engineering, IFMBE Proceedings 39, pp. 1105–1108, 2013.
www.springerlink.com

II. MATERIALS AND METHORDS

A. Bone Specimens

Ten fresh bovine bone specimens were assessed. Slices (approximately 40×30×15 mm^3, SI×AP×RL) of cancellous bone were cut from the proximal femur in the sagittal plane (Fig. 1). The exact samples size was measured using a vernier caliper.

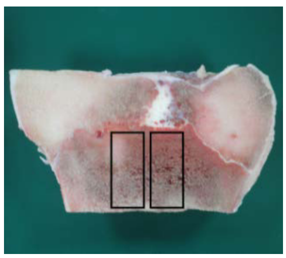

Fig. 1 Position of the slice extracted from the complete specimen

B. Micro-CT measurement

Specimens were scanned by SkyScan 1076 In vivo Microtomograph (SkyScan n.v., Aartselaar Belgium). The cross-section images were reconstructed by SkyScan NRecon package, the pixel size of cross-section images is 18μm. The density and structure parameters of bone specimens were calculated by SkyScan CTAn package. Those parameters are BMD (bone mineral density, g/cm^3), BS (Bone surface, mm^2), BV (Bone volume, mm^3), TV (Tissue volume, mm^3), BS/BV (Bone surface/volume ratio, mm^{-1}), BS/TV (Bone surface density, mm^{-1}) and BV/TV (Percent bone volume, %).

C. Bone QUS measurement under loading condition

QUS measurement was performed using a Panametrics 5800PR ultrasonic pulser-receiver with a pair of V303-SU unfocused 1MHz transducers (Olympus NDT, Waltham, MA USA). During measurement, the two transducers were fixed coaxially on both sides of the specimen by a caliper (ultrasound propagation path is perpendicular to sagittal plane) and were coupled to bone tissue through the coupling gel. The received signal was digitized at a sampling rate of 200MS/S by a 12 bit A/D converter GaGe CompuScope 12400 (GaGe Applied Technologies, Lockport, IL USA) for the calculation of nBUA. Fig. 2 shows the block diagram of QUS measurement system. The loading exerted on specimens was changed from 0N to 1000N with a step of 100N. Ultrasound signal been recorded on each step of loading changed.

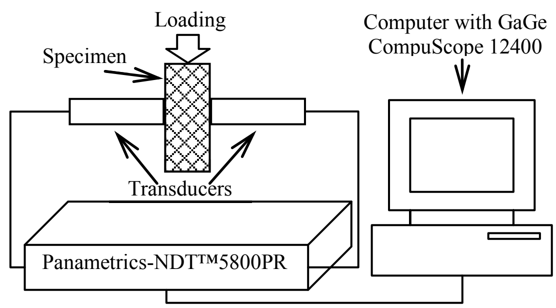

Fig. 2 Block diagram of QUS measurement system

III. RESAULTS

Some specimen failure when the loading higher than 700N, so the nBUA values for analysis were limited to the values measured when the loading range is 0~700N. Tale 1 shows the mean and standard deviation (SD) values of the density and structure parameters of bone specimens. Table 2 shows the nBUA values of specimens.

Table 1 Descriptive statistics of density and structure parameters

	Mean	SD
BMD (g/cm^3)	0.649	0.184
BS (mm^2)	36200.254	9766.083
BV (mm^3)	1374.547	466.350
TV (mm^3)	9020.128	1893.744
BS/BV (mm^{-1})	27.331	5.773
BS/TV (mm^{-1})	4.006	0.934
BV/TV (%)	15.081	4.175

Table 2 nBUA values measured under different loading condition

Loading (N)	nBUA (dB·MHz^{-1}·cm^{-1})	
	mean	SD
0	82.668	34.536
100	83.355	34.229
200	85.249*	33.327
300	85.757*	32.728
400	86.022*	34.068
500	87.377*	32.027
600	88.776*	32.691
700	89.256*	32.526

*, significant different to nBUA value measured when loading=0 (P<0.01)

As shown in Table 2, the result of Paired-Samples T Test reveals that when the loading exerted on bone specimen higher than 200N, the measured nBUA values were significantly higher than nBUA measured without loading (loading=0) (P<0.01).

For each specimen, when the loading increased from 0N to 700N, the nBUA values also increased (Table 2). The linear regression analysis between nBUA and loading reveal that the nBUA values were higher correlated to loading (R^2=0.777~0.870, for each specimen respectively). Fig 3 shows the linear regression between nBUA and loading of specimen No.2.

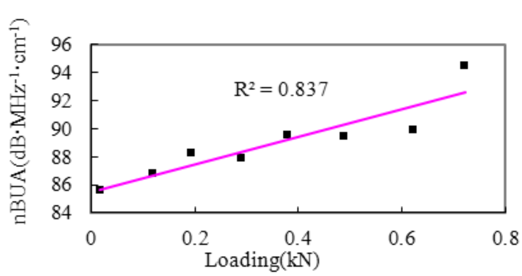

Fig. 3 Linear regression between nBUA and loading of specimen No.2

The slope of the linearity fitted curve of nBUA values measured under different loading condition reveals the influence of physical loading on nBUA. Table 3 shows the correlation coefficients between the slope and bone density and structure parameters. The slope was significantly negatively correlated with BMD, BV and BV/TV.

Table 3 correlation coefficients between slope of linearity fitted curve of nBUA and bone density and structure parameters

	R	*P*
BMD	-0.869	0.001
BS	-0.552	0.098
BV	-0.727	0.017
TV	-0.257	0.474
BS/BV	-0.486	0.155
BS/TV	0.448	0.194
BV/TV	-0.758	0.011

IV. Discussion

Generally, the weight of cattle is approximately 400kg to 500kg. As the gravity acceleration g=9.8N/kg, the weight caused loading is about 3920N to 4900N. So the loading subjected on single leg is about 980N to 1250N. Then the upper limitation of loading subjected to specimens was set to 1000N.

In our previous study, when calcaneus subjected to the weight caused loading, the nBUA values were significantly higher than that measured without loading. It is verified by this study. As shown in Table 2, the nBUA values were increased accompany with the increasing of loading. And the nBUA is positive correlated with the loading (Fig 3). To explain this conclusion, previous studies [8, 12] may provide some hints to us. It is reported that the loading subjected on bones may leads to the strain of bones. While the ultrasound transmitted in bone, the volume of ultrasound path is a constant value, but the loading induced strain will leads to a decrease of trabecular spacing, it means more bone tissue was compressed into the ultrasound path, and then the attenuation of ultrasound increased correspondingly.

In this study, a new parameter, the slope of the linearity fitted curve of nBUA values measured under different loading condition, was introduced. This parameter is demonstrated the rate of loading leaded changing on nBUA. The slope is highly correlated with BMD (R=-0.869, P=0.001), this parameter may estimate BMD effectively. Furthermore, by consider that BMD is the golden standard of osteoporosis diagnosis, bone QUS measurement performed under loading condition may be a new ultrasound method for osteoporosis diagnosis.

V. CONCLUSIONS

This study reveals that loading is an important factor of QUS measurement, and furthermore, proposed a new QUS osteoporosis diagnosis method, QUS measurement performed under loading condition.

VI. ACKNOWLEDGEMENTS

This study was supported by the National Key Technology R & D Program 2009BAI79B03 and the National Nature Science Foundation of China 10925208.

VII. REFERENCES

1. Anonymous (1993) Consensus development conference: diagnosis, prophylaxis, and treatment of osteoporosis. Am J Med 94: 646-50
2. John A K (2002) Diagnosis of osteoporosis and assessment of fracture risk. The Lancet 359: 1929-1936
3. Gluer C C (1997) Quantitative ultrasound techniques for the assessment of osteoporosis: expert agreement on current status. J Bone Miner Res 12: 1280-1288
4. Njeh C F, Fuerst T, Diessel E et al. (2001) Is quantitative ultrasound dependent on bone structure? A reflection. Osteoporos Int 12: 1-15
5. Adami S, Giannini S, Giorgino R et al. (2003) The effect of age, weight, and lifestyle factors on calcaneal quantitative ultrasound: the ESOPO study. Osteoporos Int 14: 198-207
6. Hartl F, Tyndall A, Kraenzlin M et al. (2002) Discriminatory ability of quantitative ultrasound parameters and bone mineral density in a population-based sample of postmenopausal women with vertebral fractures: results of the Basel Osteoporosis Study. J Bone Miner Res 17: 321-30
7. Minnock E, Cook R, Collins D et al. (2008) Using risk factors and quantitative ultrasound to identify postmenopausal caucasian women at risk of osteoporosis. J Clin Densitom 11: 485-493
8. Muller R, Gerber S C, Hayes W C (1998) Micro-compression: a novel technique for the nondestructive assessment of local bone failure. Technol Health Care 6: 433-44
9. Qin Y X, Lam H, Zhang M et al. (2007) Dynamic skeletal muscle contraction induced bone fluid pressure and its role in adaptation. J Biomech 40: S37-S37
10. Biot M A (1956) Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid. II. Higher Frequency Range. The Journal of the Acoustical Society of America 28: 179-191
11. Liu C R, Li D Y, Fan Y B (2010) The possibility of diagnosing osteoporosis by quantitative ultrasound under loading conditions: Preliminary study. Bone 47, Supplement 3: S392-S393
12. Wright T M, Vosburgh F, Burstein A H (1981) Permanent deformation of compact bone monitored by acoustic emission. J Biomech 14: 405-9

Address of the corresponding author:

Author: Deyu Li
Institute: Key Laboratory for Biomechanics and Mechanobiology of Ministry of Education, School of Biological Science and Medical Engineering, Beihang University
Street: Xueyuan Road No. 37
City: Beijing
Country: China
Email: deyuli@buaa.edu.cn