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Trabecular bone characterization using ultrasonic backscatter parametric imaging

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1. Introduction

Ultrasonic propagation in trabecular bone reflects information that can be used to evaluate bone statues[1]. Ultrasonic parametric imaging has already been used in the through-transmission technique. With the mean values measured in a similar region of interest (ROI), the stability and reproducibility are improved in the *in-vivo* applications[2]. Ultrasonic backscatter is quite sensitive to the microstructure of trabecular bone. Images acquired by ultrasonic backscatter technique may has greater potential in trabecular bone characterization[3]. In this study, we used a scanning equipment to acquire ultrasonic backscattered signals and images were derived based on apparent integrated backscatter (AIB). The microstructure of the trabecular bone was visible in ultrasonic AIB imaging. Associations between ultrasonic backscatter and bone features were investigated using linear regressions. The feasibility of trabecular bone characterization using ultrasonic backscatter parametric imaging was analyzed in this study.

2. Material and method

2.1 Sample preparation

A total of 35 trabecular bone specimens were obtained from the distal femur of the bovine bone. A handsaw was used to cut the trabecular bone into cubic shaped specimen (2 × 2 × 2cm) along the anatomy directions. The marrow inside the specimen was flushed out using a high pressure water jet.

2.2 μ-CT measurements

Trabeculae bone specimens were immersed in pure water. A vacuum pump was used to degas the air inside the bone specimens. The specimens were scanned by μ-CT (Sky-scan1076, Skyscan, Antwerp, Belgium) with a resolution of 18μm. The trabecular bone images were reconstructed from the data acquired by μ-CT. The bone mineral density (BMD), bone volume fraction (BV/TV), bone volume density (BV/TV), bone surface density (BS/TV), structure model index (SMI), trabecular thickness (Tb.Th), trabecular number (Tb.N), trabecular bone separation (Tb.Sp), degree of anisotropy (DA) and Connectivity density (Conn.D) were calculated from the reconstructed images. Bone apparent density (BAD) can be calculated from the division of bone specimen mass and bone total volume.

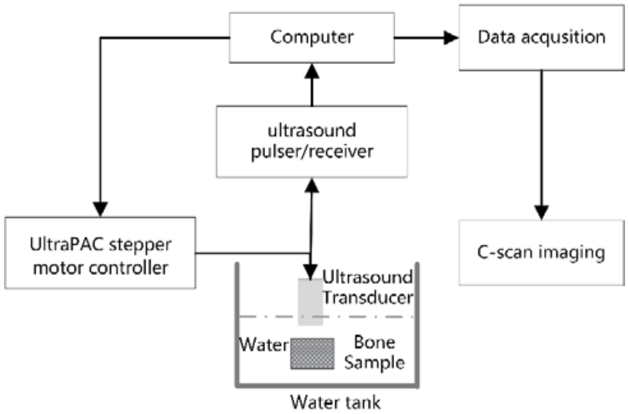

Fig. 1 Experimental setup for the ultrasonic backscatter measurement.

2.3 Ultrasonic backscatter measurements

Fig.1 showed the experimental setup for the ultrasonic backscatter measurements. An ultrasonic scanning system (UPK-T10, UltraPAC, USA) was used to acquire the ultrasonic backscatter signals from the trabecular bone specimens. Ultrasonic transducer (V321, Panametrics, USA) was used to produce a short duration ultrasound wave. The center frequency of the transducer was 7.5MHz. The transducer was focused on the front surface of the trabecular specimen. The ultrasonic scanning system controls the transducer to move parallel to the surface of the trabecular specimen. The ultrasonic backscattered signal was received by the same transducer. A 10mm×10mm region of interest (ROI) was chosen in the middle of the specimen with a scanning interval of 0.05mm. A total of 40000 ultrasonic backscattered signals from different positions for each specimen were acquired and stored in the computer for further analysis. The ultrasonic signal reflected from a surface smooth steel was acquired as the reference signal.

2.4 Signal processing

The parameter of apparent integrated backscatter (AIB) [4] was defined as follows:

$$\mathrm{AIB} = \frac{1}{f_h - f_l}\int_{f_l}^{f_h} 20\log_{10}\left(\frac{A_b(f)}{A_r(f)}\right)df \qquad (1)$$

Where $A_b(f)$ was the amplitude spectrum of the ultrasonic backscattered signal and $A_r(f)$ is the amplitude spectrum of the reference signal.

2. Results and discussion

Fig.2 shows the image of a trabecular bone specimen using the AIB parameter. The red color means strong scattering occurs when ultrasound interacted with trabeculae. While the blue color indicates there was an absence of trabeculae in the ultrasound propagation path. The anatomy of the trabeculae can be clearly seen in the image. The lateral resolution of the ultrasonic transducer is 0.157mm, which is comparable to the trabecular bone thickness (in the range of 0.1mm - 0.2mm). The pixel resolution of the ultrasonic image was 0.05mm (i.e., the ultrasonic scanning interval). Therefore, the AIB image has the ability to distinguish trabecular bones from bone marrow or water.

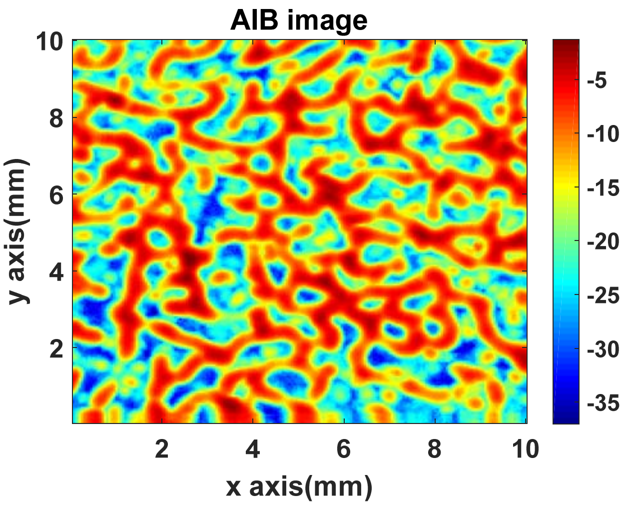

Fig. 2 Trabecular bone parametric imaging using ultrasonic backscatter parameter AIB.

Table I shows the descriptive statistics of μ-CT and ultrasound measured parameters. The mean, standard derivation, minimum and maximum values of bone features are listed in the Table I.

Table I Descriptive statistics of measured parameters

Name	Unit	Mean	SD	Min	Max
BAD	g/cm^3	0.32	0.17	0.11	0.75
BMD	g/cm^3	0.24	0.07	0.12	0.46
BV/TV	%	26.59	9.82	11.39	52.90
BS/BV	mm^{-1}	17.43	4.46	11.94	29.53
BS/TV	mm^{-1}	4.34	1.10	2.28	6.81
SMI	1	0.31	1.36	-6.20	1.77
Tb.Th	mm	0.20	0.04	0.12	0.27
Tb.N	mm^{-1}	1.30	0.38	0.65	2.29
Tb.Sp	mm	0.63	0.15	0.35	0.96
DA	1	1.94	0.39	1.31	2.96
Conn.D	mm^{-3}	10.17	9.15	-16.60	41.51
AIB	dB	-38.91	1.94	-43.24	-35.89

SD means standard derivation

Table II shows the simple correlation between AIB and bone features. AIB yielded negative and significant correlations (R= -0.85 - -0.79, $p<0.001$) with bone densities (i.e., BAD, BMD and BV/TV). Significant correlations ($|R|=$ 0.38 - 0.85, $p<0.05$) were also observed between AIB and trabecular bone microstructure (BS/BV, BS/TV, SMI, Tb.Th, Tb.N and Tb.Sp). However, AIB was not significantly correlated with DA or Conn.D. Pearson correlation results showed that AIB image has the ability to reflect trabecular bone density and microstructure information.

Table II Pearson correlation between AIB and bone features

R	AIB	P value
BAD	-0.85	<0.001
BMD	-0.79	<0.001
BV/TV	-0.83	<0.001
BS/BV	0.49	< 0.01
BS/TV	-0.85	<0.001
SMI	0.60	<0.001
Tb.Th	-0.38	<0.05
Tb.N	-0.85	<0.001
Tb.Sp	0.75	<0.001
DA	-0.17	n.s.
Conn.D	-0.24	n.s.

n.s. means not significant

3. Conclusion

The results of this paper showed that ultrasonic backscatter parametric imaging has the ability to clearly distinguish trabecular bone from water or marrow. Ultrasonic backscatter parametric imaging using AIB has the ability to reflect both trabecular bone density and microstructure information. Ultrasonic backscatter parametric imaging method proposed in this paper maybe useful in trabecular bone characterization.

Acknowledgment

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