2P1-7

Measurement of Longitudinal Wave Velocity in Newly Formed and Mature Bone in the GHz Range

顕微 Brillouin 光散乱法を用いた新生骨と成熟骨の縦波音速評価

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1. Introduction

Osteoporosis causes bone fractures and decreases the Quality of Life. Titanium implants have attracted attention as useful tools to help different surgical applications such as dental and orthopedic implants. Bone tissues gradually adapt its structure to accommodate the implant. The implant osseointegration, which combines the bone tissues and the implant, is the determinant of the success of intraosseous implant surgery. The osseointegration depends on the mature of the biomechanical properties of newly formed bone tissue near the implant [1]. To judge the growth of bone tissues, we have to investigate the tissues at the implant interface. Here, newly formed bone, which exists between mature bone and implant, has an important role for the implant stabilities. For the evaluation of the implant interface, then, precise measurements in the μm scale is necessary. Nano-indentation technique allows to measure elastic properties in such a small area. However, this technique can only measure elastic properties in the thickness direction. A Brillouin technique is also a useful tool to measure the elastic modulus in a small area and in in-plate directions.

In this study, we measured the longitudinal wave velocity in cortical newly formed and mature bones of rabbits by using a micro-Brillouin scattering technique.

2. Material and Methods

2.1. Specimen

Specimens used were from eight male New Zealand white rabbits. The rabbits were between 6 and 9 months old at the time of implantation. They weighted over 3.5 kg. The animals were housed in a metal hutch in the special environment (ambient temperature 19 °C and a humidity of 55%). Artificial lightening and air conditioning systems were used in the animal housing facility. The animals were fed with commercial food and water was provided. The implant has been inserted in the proximal tibia at the knee articulation. The healing lasted 7 weeks for the samples A to D and 13 weeks for samples E to H. After sacrifice, eight cortical bone specimens were obtained medial-lateral and anterior-posterior plate with the thickness of 280-310 μm. The propagation direction of the ultrasonic waves by a Brillouin scattering was radial.

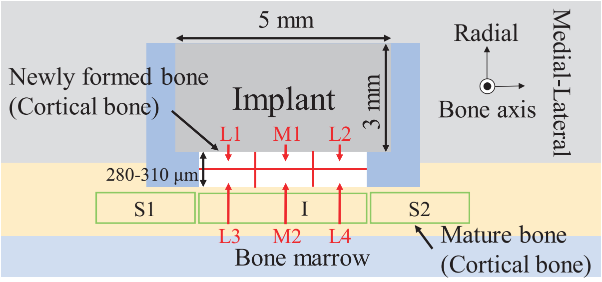

Fig.1 Specimen.

2.2. Brillouin scattering technique

The micro-Brillouin scattering is a non-destructive and non-contact technique to measure wave velocity in the GHz range in the small area. Measurements were carried out with a six-pass tandem TFPI (Fabry-Pérot interferometer, JRS) using a solid state the laser (Spectra-Physics) with wavelength of 532 nm [2]. The actual measured area in the specimen was approximately 10 μm in diameter.

A scattering geometry, called Reflection Induced *Θ* Angle scattering geometry, was used [3]. This geometry enables to observe ultrasound waves propagating in 2 directions ($q^{\Theta A}$ and q^{180}). Here, we focused on the in-plane $q^{\Theta A}$ direction. From following equation, we can obtain wave velocity.

$$v^{\Theta A} = f^{\Theta A}\frac{\lambda_0}{2\sin(\Theta/2)} \qquad (1)$$

Here, $v^{\Theta A}$ is the wave velocity, $f^{\Theta A}$ is the measured shift frequency and λ_0 is the incident light wavelength.

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3. Results and Discussion

Figure 2 shows a typical Brillouin spectrum obtained from mature bone in the sample A. From this shift frequency, the longitudinal wave velocity was estimated as 4.94 $\times 10^3$ m/s.

Table 1 shows the averaged longitudinal wave velocities in A-H specimens from the rabbit cortical bones. Compared to the wave velocities in the mature bone of 7 weeks, those of the bones of 13 weeks were 0.5 % higher. The estimated ages of the rabbits correspond to those of young human (16-18 years) [4]. Since bone tissue is still remodeling, we probably find velocity differences in mature bones depending on the healing time.

The averaged wave velocities in newly formed bones were lower than those in mature bones (**Table 1**). In addition, the wave velocities in newly formed bones of the 13 weeks were higher than those of 7 weeks. Vayron et al. have reported similar studies and showed velocities in the tangential direction near the titanium implant by the micro-Brillouin scattering technique (**Table 1)** [5]. They also reported that the longer the healing times were, the higher longitudinal wave velocities became. Compared to the velocities in newly formed bone in the radial direction, the velocities in the tangential direction were higher.

Table 2 shows the averaged velocities in newly formed bones at the measurement sites. The measurement sites of L1, M1 and L2 were near the implant, and those of L3, M2 and L4 were near the mature bone. In the newly formed bones of both 7 weeks and 13 weeks, the averaged velocities were similar. The data indicate that the growth of newly formed bones seems to be independent of the sites.

Table 3 shows the standard deviation of velocities in A-H specimens. The averaged standard deviation in newly formed bones were higher than those in mature bones. Newly formed bones were in the growth stage. We can expect that heterogeneities in newly formed bones are higher than those in mature bones.

4. Summary

Using cortical bones of rabbits, longitudinal wave velocities in newly formed and mature bones were investigated by the micro-Brillouin scattering technique. The averaged wave velocities in newly formed bones were lower than those in mature bones. In addition, the longer the healing times were, the higher the wave velocities became. The averaged standard deviation in newly formed bones were higher than those in mature bones. It indicates that heterogeneities in newly formed bones are stronger than those in mature bones because newly formed bones were in the growth stages.

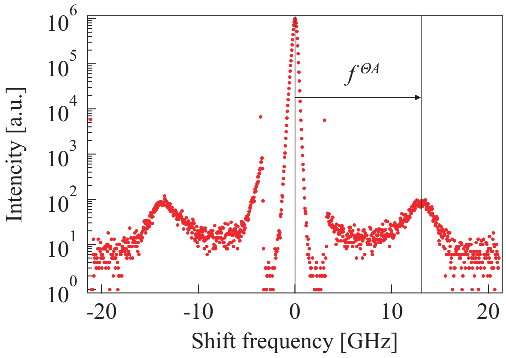

Fig. 2 An observed spectrum of Brillouin scattering from a mature cortical bone of the sample A.

Table1 Averaged wave velocities in newly formed and mature bones.

Unit: m/s

Healing weeks	**Bone**	**Velocity (radial)**	**Velocity (tangential)** [5]
7 (A~D)	Mature	5277	5305
	Newly formed	4867	4966
13 (E~H)	Mature	5305	5360
	Newly formed	4993	5030

Table 2 Averaged wave velocities in newly formed bones at the measurement sites.

Unit: m/s

Healing weeks	**Measurement site**	**Velocity**	**SD**
7 (A~D)	L1・M1・L2	4865	± 37
	L3・M2・L4	4866	± 37
Healing weeks	**Measurement site**	**Velocity**	**SD**
13 (E~H)	L1・M1・L2	4999	± 59
	L3・M2・L4	4981	± 38

Table 3 Standard deviation (SD) of wave velocities in newly formed and mature bones.

Unit: m/s

Healing weeks	**Bone**	**A**	**B**	**C**	**D**	**Average SD**
7 (A~D)	Mature	± 8	± 8	± 2	± 2	± 10
	Newly formed	± 36	± 33	± 23	± 39	± 23
Healing weeks	**Bone**	**E**	**F**	**G**	**H**	**Average SD**
13 (E~H)	Mature	± 2	± 16	± 27	± 15	± 9
	Newly formed	±33	± 24	± 25	± 48	± 47

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