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Improvement of In Vivo Measurement of Speed of Sound in Cartilage

生体内軟骨の音速測定における高精度化の検討

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1. Introduction

Osteoarthritis (OA) is a degenerative disease of cartilage that develops most commonly in weight-bearing regions. OA begins with a structural change in collagen and a decrease in proteoglycan and water content. In early stages of OA, water content increases with the relaxation of the collagen, often resulting in swelling and softening. As OA progresses, cartilage thickness decreases and mechanical properties deteriorate until the eventual destruction of cartilage.

Degeneration of cartilage can be assessed via biochemical testing, diagnostic imaging, and arthroscopy. However, all these techniques have some drawbacks. Biochemical testing is effective for a differential diagnosis, but it is invasive and not very effective. Further, diagnostic imaging by X-rays and magnetic resonance imaging (MRI) cannot identify early stages of OA. Finally, although arthroscopy can enable both diagnosis and treatment, its invasiveness is a drawback.

Some studies have used ultrasound to assess the degenerate cartilage; in particular, degenerative changes, surface roughness, and thickness changes have been assessed using high-frequency ultrasound. However, all studies performed the assessment in vitro over a relatively narrow area. In contrast, the pulse-echo method can enable high-resolution, real-time imaging of articular and periarticular structures. Using this method enables visualization of tissue boundaries such as that between the bone and cartilage as a high-intensity band image.

Evaluation of changes in the thickness and elasticity of cartilage is important for assessing its degeneration. Further, some studies have compared the measurement results of cartilage thickness using ultrasound with those obtained using optics, needles, microscopes in vitro.

Conventional ultrasound elastography based on speckle tracking has been used as a noninvasive method for evaluating elasticity in several types of tissue, but the absence of any echoes inside cartilage makes it difficult to use in that setting. As an alternative, the elasticity of cartilage can be measured through its correlation with the speed of sound (SOS), which is calculated from the thickness and propagation time measured for a given cartilage sample. The theoretical reasoning behind the technique of evaluating the biomechanical properties of tissue based on the SOS (longitudinal wave velocity) in that tissue is based on the properties of the pulse-echo method.

So far, we have presented a methof for evaluating the elasticity of regenerating cartilage during culturing before transplantation[1-2)]. However, the regenerating cartilage tissue after transplantation must be evaluated noninvasively. Therefore, we have also presented in vivo measurement method of SOS by combining ultrasound and magnetic resonance (MR) images, on the basis of correlation between the SOS and elasticity[3)]. Since this method for calculating SOS is based on the image processing of ultrasound and MR images, the accuracy of SOS measurement is affected by resolution of these images.

In this paper, with the aim of improving of measurement accuracy of SOS in vivo on the basis of the above method, the relation between the accuracy of SOS measurement and the image resulusions was investigated.

2. In Vivo Measurement of SOS in Cartilage

The principle of this method is shown in **Fig. 1**. As shown in **Fig. 1**, in the MR and ultrasound images obtained at same portion of the target, the thickness of each image is measured.

Ultrasound imaging (USI) devices have a specific SOS. Therefore, the following relation is obtained when it is assumed that the MRI measurement gives the actual cartilage thickness.

$$\text{SOS of cartilage/specific SOS of USI device} = \text{thickness (MRI) / thickness (USI)} \qquad (1)$$

Here, we used a nominal SOS of 1530 m/s for the ultrasound device. In the combination method, the SOS of cartilage can be calculated as follows.

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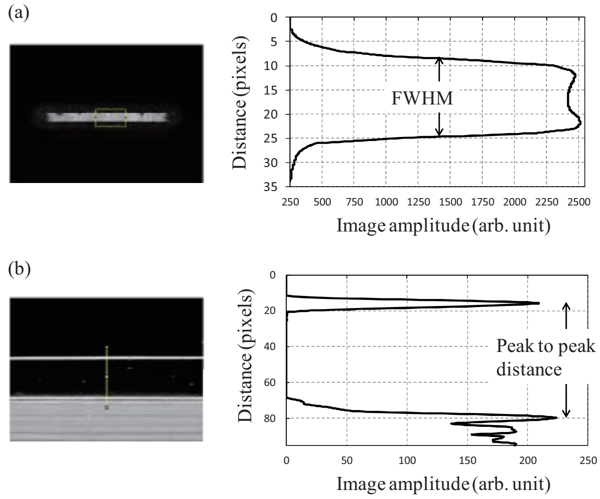

Fig. 1 Thickness measurements using the full width at half maximum (FWHM) in MR image (a), and the peak-to-peak distance of the ultrasound image (b).

SOS of cartilage

= 1530 × thickness (MRI) / thickness (USI) (2)

3. Accuracy of SOS Measurement

Accuracy of SOS measurement was evaluated experimentally. First, agar-based phantoms with various thicknesses were prepared. These were made from 3 % (W/v) of agar powder (010-15815, Wako Pure Chemical Industries, Japan), which was dissolved in deionized water. True SOS of the phantom was measured as shown in **Fig. 2**. After that, the SOS is calculated on the basis of **Fig. 1**, eqs.(1)-(2), and compared with the true SOS for evaluating errors of SOS. In the SOS calculation, the ultrasound device with a center frequency of 10 MHz (EUB-7500; Hitachi Medical Corporation, Tokyo, Japan) and MRI device (Intera Achieva; Philips Medical Systems, Best, Netherlands) were used. In the MRI device, morphological isotropic voxel images were acquired at a pixel size of 0.3 mm. Evaluated errors are shown in **Fig. 3**. Here, the ultrasound image resolution was fixed at a pixel size of 0.1 mm. As shown in this figure, large errors occurs, especially when the cartilage thickness is thin. After that, the MRI image was interpolated and reconstructed at a pixel size of 0.1 mm, and the errors of SOS were calculated as shown in **Fig. 3**. Obviously, errors of SOS decreased and the accuracy of SOS measurement was improved.

4. Conclusion

The accuracy of SOS measurement was evaluated in this study, and improved by increasing image resolutions. Although these results are easily predictable, these are important for evaluating whether or not the practical accuracy can be obtained.

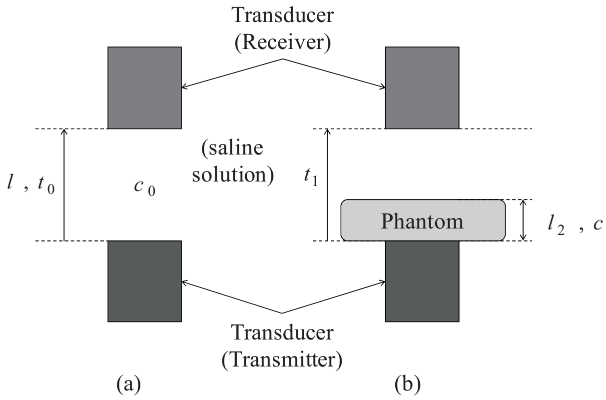

Fig. 2 True SOS measurement setups. (a) a setup for SOS measurement of surrounding saline solution, and (b) SOS measurement of cartilage using SOS of saline solution measured in (a). True SOS (c) is calculated by the relation, $c = 1/((t_1\text{-}t_0)/l_2+1/c_0)$

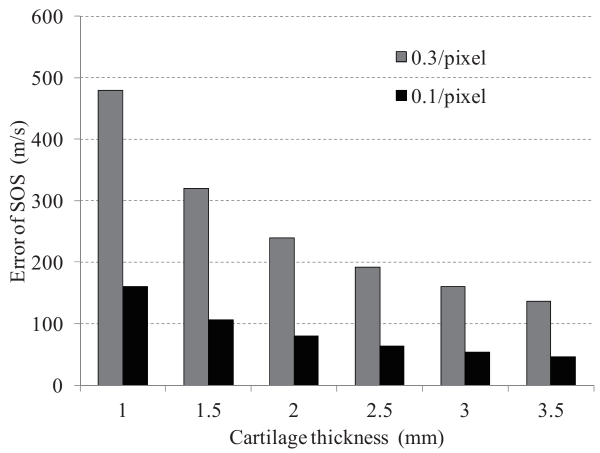

Fig. 3 Accuracy of SOS measurement according to ultrasound and MR image resolutions. Errors of SOS were evaluated for various cartilage thicknesses.

Acknowledgment

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References

1. N. Nitta, M. Misawa, K. Homma and T. Shiina: Jpn. J. Appl. Phys. **51** (2012) 07GF15.
2. N. Nitta, K. Hyodo, M. Misawa, K. Hayashi, Y. Shirasaki, K. Homma and T. Shiina: Jpn. J. Appl. Phys. **52** (2013) 07HF24.
3. T. Aoki, N. Nitta and A. Furukawa: Radiol. Phys. Technol. **6** (2013) 480.