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Composition and Acoustic Properties in Cartilage Phantom

軟骨評価用ファントムの組成と音響特性

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1. Introduction

As the aging population increases, for diagnosing the cartilage status, its quantitative evaluation become important. For example, osteoarthritis (OA) is a typical disease of articular cartilage and it has been reported that the tension of collagen fiber surface layer gradually decreases with cartilage degeneration. On the other hand, the regenerated cartilage in the regenerative medicine has been expected as a fundamental treatment of cartilage diseases, and an establishment of evaluation methods for its maturity is an important subject. Since specific methods suited for the evaluations of regenerated cartilage might be required, it is important to explore and establish appropriate evaluation methods using not only ultrasound but also other applicable modalities.

So far, we comprehensively conducted in vivo measurements of the regenerated cartilage implanted on the back of rat, by using X-rays, magnetic resonance imaging (MRI), ultrasound, etc[1)]. Correlations of these in vivo results with elastic moduli and biochemical properties obtained by in vitro measurements indicated that the evaluation parameters suitable for maturity evaluation existed[1)]. Moreover, the target values of parameters to be reached as the normal or regenerated cartilage were clarified.

In the clinical evaluation of not only regenerated cartilages but also native cartilages, in order to ensure the correctness of the parameter value measured by using the selected modality, the use of a phantom simulating normal cartilage characteristics is effective[2)]. Therefore, in this study, the cartilage phantoms having the target characteristics were produced, and these acoustic characteristics and other physical properties were investigated.

2. Composition of Cartilage Phantom

First, to reach the target value of longitudinal speed of sound (SOS), an acrylamide was used as a base material of cartilage phantom and the concentration was adjusted so that SOS exhibits the value around 1570 m/s.

On the other hand, according to the previous work, T2 and apparent diffusion coefficient (ADC) measured by MRI correlated well with biochemical factors of cartilage[1)]. Therefore, for producing the cartilage phantom, it will be important to adjust T2 and ADC so that these values become close to those of normal cartilage. In order to adjust T2 and ADC, Magnevist® (gadopentetate dimeglumine; Gd) which is MRI contrast agents was added. Figure 1 shows the poly-acrylamide gel-based cartilage phantoms including ten kinds of Gd concentration (0, 0.5, 0.75, 0.85, 0.95, 1.05, 1.34, 1.62, 2, 2.5 mmol/L). Each size is 50 mm x 50 mm x 10 mm.

For these cartilage phantoms, SOS and attenuation coefficient as acoustic properties, Young's modulus, specific gravity, T2 and ADC were measured, respectively.

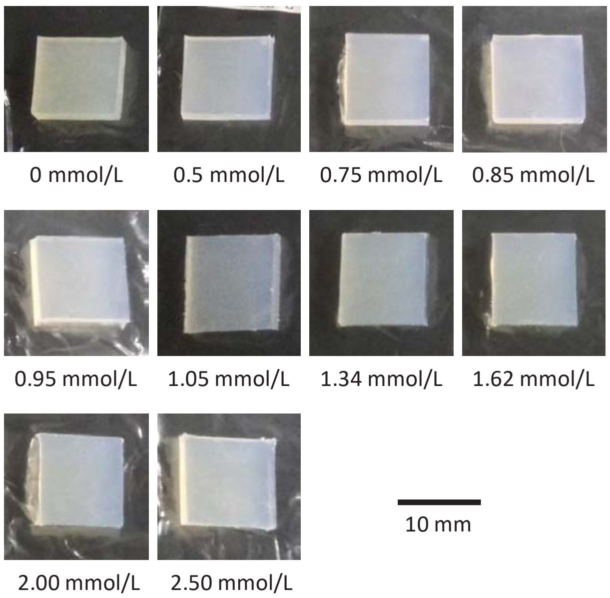

Fig. 1 Phantoms with varying Gd concentration.

3. Measurement of Acoustic Properties

Figure 2 shows a measurement system of acoustic properties including SOS and attenuation

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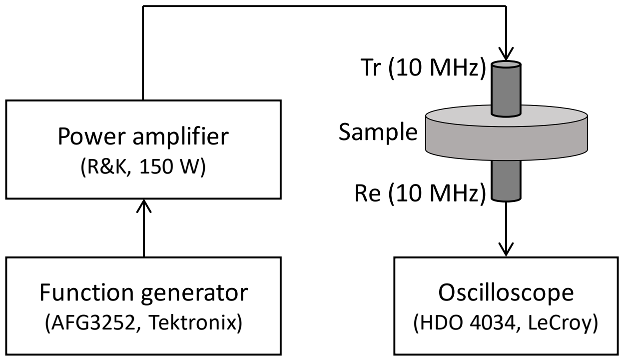

Fig. 2 A measurement system for acoustic properties of a cartilage phantom.

coefficient. These were measured by using a pulse transmission method with a frequency of 10 MHz. By separating the transmitter from the receiver and using multiple reflections, the measurement accuracies were improved.

As other physical properties, Young's modulus, specific gravity, T 2, ADC were measured. Young's modulus was measured by using an Instron-type testing machine (AG-500NX, Shimadzu), and the specific gravity was measured by using a specific gravity meter (MD-300S, Alpha Mirage). In addition, T2 and ADC were measured by using a 2T-MRI equipment (Biospec, Bruker).

4. Results

In this paper, as typical characteristics, the relationships between Gd concentration, and T2 and SOS are shown.

Figure 3 shows the relationship between Gd concentration and T2. T2 decreased with increasing Gd concentration, while the dependency on Gd concentration to ADC was small (not shown here). This result means that 0.85 mmol/L corresponds to the Gd concentration at which T2 coincided with 0.1 s.

Figure 4 shows the relationship between Gd concentration and SOS. The relationship does not exhibit larger dependencies on Gd concentration than T2.

5. Discussion

After the acrylamide concentration was determined so that SOS approaches to the target value, the Gd concentration was adjusted in the poly-acrylamide gel-based cartilage phantoms so that T2 and ADC approach to the target values. As a result, it was found that the Gd concentration affected T2, and did not affect the acoustic characteristics, especially SOS. For example, if T2 should be adjusted while keeping the SOS constant in the case of producing a phantom with the target values, these findings will be useful.

In addition, it can also be considered that this phantom is useful as not only a phantom for the ultrasound measurement but also a phantom for the measurement using MRI.

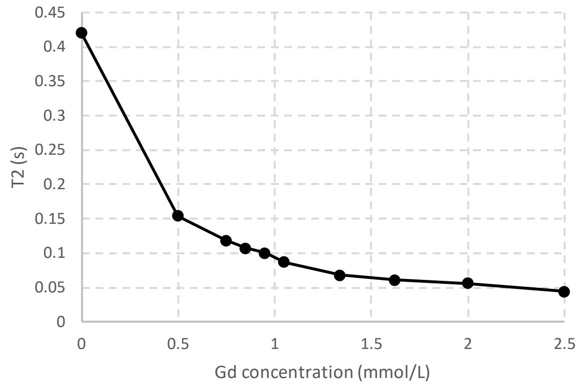

Fig. 3 A relationship between T2 and Gd concentration.

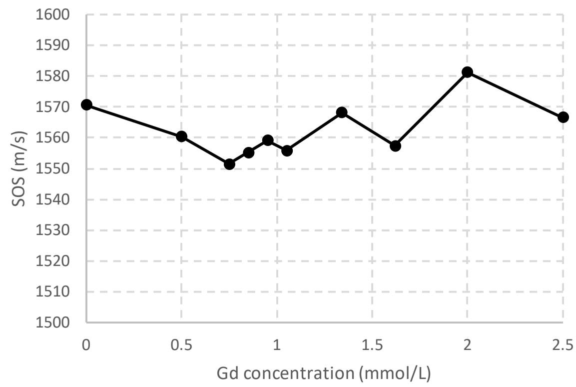

Fig. 4 A relationship between SOS and Gd concentration.

4. Conclusion

In this study, a cartilage phantom with the target cartilage characteristics was produced, and acoustic and other physical properties were measured. The results suggested that it is possible to produce a phantom that realizes the target value, and it was found that this phantom is useful for not only ultrasound but also MRI measurements. In the future work, the temporal change of the phantom characteristics will be also investigated.

References

1. Y. Fujihara, N. Nitta et al., Tissue Eng., Part C **22**, 429 (2016).
2. N. Nitta et al., IEICE Technical Report **116** (465), 1 (2017).