SY22 Real-time Measurement of Growth Plate Consolidation under a Cyclic Loading Condition

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1. Introduction
The growth plate is responsible for the longitudinal growth of skeletons. Although long bone growth is known to happen via endochondral ossification which is modulated by mechanical stimulation of the growth plate, our understanding of the detailed mechanical behavior of growth plate is limited.

Various studies have shown that material properties and matrix structures in growth plate and articular cartilage are similar. However, the consequences of the endochondral ossification in both cartilage layers are different, as growth plate is completely ossified while articular cartilage remains cartilaginous in adult skeletons.

We believed that the differences in endochondral ossification are related to different mechanical situations in both cartilage tissues. In this study, we aimed to measure the real-time cartilage deformation when a joint sample was loaded in a cyclic compressive loading. We also aimed to compare the deformational characteristics in both cartilage tissues to understand the differences in endochondral ossification under different mechanical conditions.

2. Method
2.1. Samples
We have tested adolescent sheep knee samples. Only tibio-femoral joint was cored from sheep hind limbs to be fitted into a specially designed cyclic compressive loading device.

2.2. Cyclic Loading
A special pneumatic MR compatible loading device was developed to continuously create a cyclic loading to a sample while a MR scanner kept image the joint specimen (Fig.1).

2.3. MR Imaging & Post-processing
Joint samples were imaged by using 4.7T MRI scanner. A custom segmented gradient echo sequence was used. Imaging of a single slice was completed in 2.5 min with 58μm² in-plane resolution and 1 mm slice thickness. One slice in the central load-bearing slice was continuously monitored in every 2.5 min during 1 hour of compression and 2.5 hours of relaxation. Articular cartilage and growth plate were segmented by using a custom automatic segmentation program in each time step (Fig.2).

Fig.2 Sample MR image, (a) articular cartilage segmentation and (b) growth plate segmentation example

3. Results
Volume changes of articular cartilage and growth plate were calculated in each time step and shown in Fig.3. Time-constant for the matrix consolidation was found to be 1.31±0.62 min (growth plate) and 5.53±0.62 min (articular cartilage). Time-constant for the matrix relaxation was found to be 1.63±0.01 min (growth plate) and 17.71±6.01% (articular cartilage).

4. Conclusion
The rapid deformation of growth plate may be related to a relatively free metaphyseal fluid boundary allowing rapid fluid exchange with the adjacent cancellous bone. Free fluid flow may significantly impair the generation of hydrostatic pressure in the growth plate. Insufficient hydrostatic pressure may lead premature ossification of the growth plate while well-sealed articular cartilage surfaces successfully develop hydrostatic pressure.