Displacement and Strain Measurement in Three Dimensions of Articular Cartilage by using MR Images

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Abstract. The aim of this study is to propose a method for measuring the displacement and strain distributions of the articular cartilage in three-dimension by using digital volume correlation with MR images. The compressive experiments of distal end of the femur of porcine are performed in MR device, then the volume images of the articular cartilage are acquired under unloaded and loaded conditions, respectively. The results of the analyses of the volume images shown that the strains are observed at the compressed area at three-dimensions. It is mean that it is possible to measure the displacements and strains throughout the interior of the articular cartilage by using MR images.

Introduction

In recent years, medical care costs are expected to increase with the aging society. The osteoarthritis (OA) of the knee arising due to wear and damage of articular cartilage due to aging is regarded as a society problem. At the early stage of OA, it is possible to suppress the progress by drug treatment but in this stage the patient may not feel pain so it is difficult to diagnose the disease only use the X-ray images that often used in hospitals. Therefore, the minimally invasive diagnostic methods are required for early treatment. Moreover, to evaluate the function of articular cartilage *in vivo*, MR images [1] and ultrasonic technology [2] are also used. Digital volume correlation (DVC) [3], the three-dimensional extension of digital image correlation (DIC), a method to measure internal three-dimensional displacement fields by correlating intensity patterns within the subset, has come to be used for deformation measurement of biomaterials such as bone by using CT images [4,5]. For measuring the deformations of the soft tissue, the three-dimensional deformations and strains of the meniscus are obtained by using MR images [6]. Therefore, a method of measuring the displacement and strain distributions of articular cartilage in three dimensions using DVC with MR images is proposed in this study. To show the effectivity of the MR images used in the proposed method, the compression experiments are performed using a distal end of the femur of porcine in the MR device.

Compression experiment in the MR device of keen joint

Experiment Method. The sample used is a distal end of the femur of porcine of 12 months old, 65 mm long sample including the suboccipital bone and the articular cartilage is taken out from the femur. The compression experiment is performed using a compression device made with acrylic (Fig.1(a)), and the image acquisition is performed using an open-type 0.3 T micro MRI scanner (Compact MRI series, MR Technology, Inc.) under constant room temperature at 21 degrees. All data are acquired with a 3D T1-weighted sequence. Acquisition parameters are: TE = 5 msec, TR = 40 msec. Spatial resolution is 0.4 x 0.4 x 0.8 mm^3, matrix is 384 × 512 pixels(Fig.1(b)), then 65 images are obtained for per volume(Fig.1(c)). The higher spatial resolution (0.4 mm) is applied to capture the deformation caused by the compressive load.

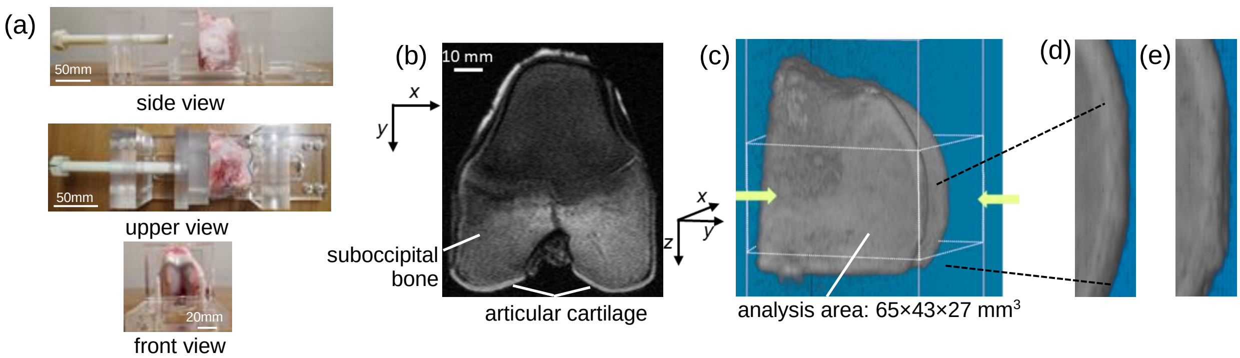

Fig. 1 Compression experiment of the distal end of the femur of porcine, the compressive device with the sample (a), an example of the MRI(b), the 3D reconstructions of the images under unloaded condition (c), enlarged view of most deformation area in the sample under unloaded (d) and loaded conditions (e).

Displacement and strain distributions. Displacement and strain distributions in three-dimension are calculated using the acquired volume images of unloaded and loaded conditions. The analysis area (Fig.1 (c)) is 65 × 43 × 27 mm^3 which the deformation of the cartilage can be confirmed on the images, the green arrows indicate the compression direction (*y* direction). The maximum deformation of the whole sample in compression direction that can be visually confirmed on the MR images is 2 pixels (about 0.8 mm).The subset size used for the analysis is 21 × 21 × 21 pixels and the gauge length when calculating the strain is 21 × 21 × 21 pixels. The calculation step is 2 pixels in each of the *x*, *y* and *z* direction.

Fig.2 (a), (b) and (c) show the displacement in each direction. The distributions shown that displacements occurred conspicuously in the cartilage in all directions. In particular, the range of the displacement in the y direction is from -0.3 mm to 0.5 mm. It is mean that the displacement of whole sample caused by the compression is approximately 0.8 mm in the compression direction. This value roughly agreed with the deformation of the sample that can be visually confirmed in the MR images.

The strain distributions of the analysis area are shown in Fig.2 (d), (e) and (f), respectively. It can be confirmed that the strain locally occurs in the cartilage which is considered to be softer than the suboccipital bone resulting large deformation by the compression. The negative and positive values of stains are obtained in the *x* and *z* directions since deformation spreads around the load point is observed at the cartilage (Fig.1 (d), (e)). However, noticeable concentration on the cartilage has not been obtained in the y strain. This can be improved by examining the image acquisition and analysis parameters.

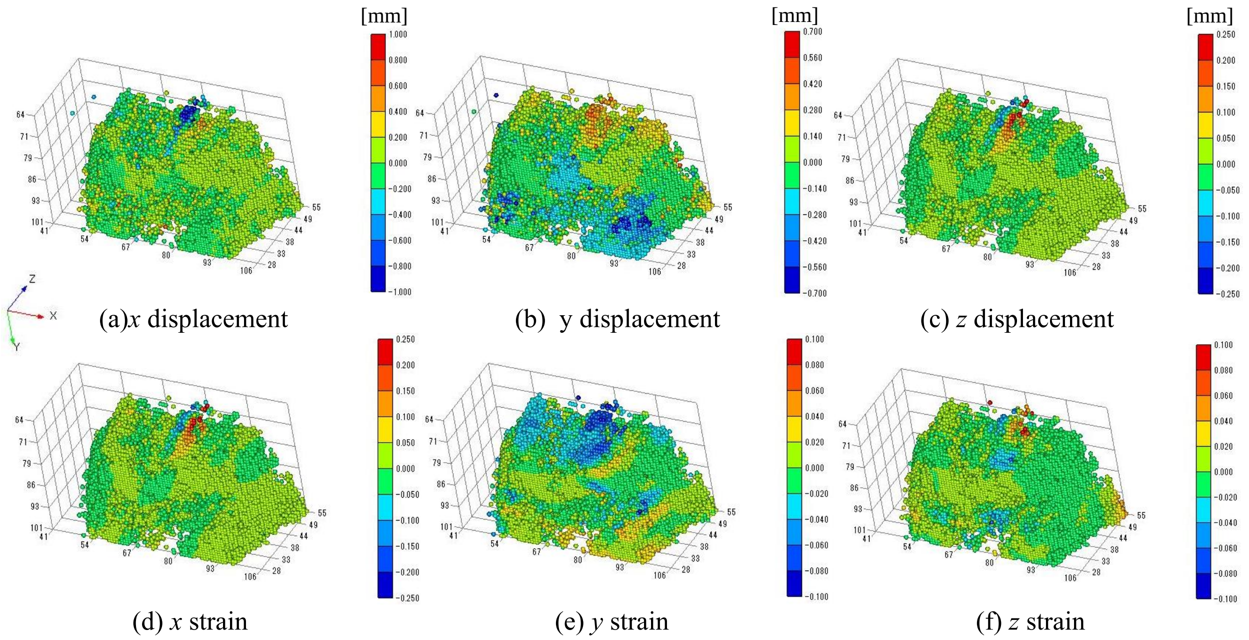

Fig. 2 Displacement and strain distributions of the distal end of the femur of porcine under compressive load.

Conclusion

In this study, DVC with MR images is used to measure three-dimensional deformations and strains of articular cartilage. In order to discuss the effectiveness of MR images for DVC, compression experiments of distal end of the femur of porcine are performed and displacement and strain distributions are calculated from volume images of unloaded and loaded conditions. As a result, the calculated displacement roughly agreed with the displacement observable on the images, so the effectiveness of the proposed method is shown. In the future, it is necessary to examine the image acquisition and analysis parameters to increase the accuracy of measurement.

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