INTRODUCTION:
The human knee joint has the role to transmit and absorb the load, especially the menisci and cartilage play an important role [1, 2]. It is assumed that the load of more than 5 times body weight could be transmitted to the soft tissue during athletic activities. Therefore, injury in the menisci or cartilage is a common problem among athletes. A finite element analysis after meniscectomy has been discussed by several authors [3, 4], but to simulate the process of injury has not been confirmed. To reproduce the process of the injury, we constructed a 3D human-knee finite element model (3D FEM) including soft tissues from 3D MRI. The aim of this study was to build a FEM that includes detail construction of the cartilage and menisci, and that can be used to elucidate the mechanism of the meniscus injury.

METHODS:
The subject was 22-year-old male who had no previous history of knee pain or injury. MR images were obtained from his left knee at 0 degree of flexion using 1.5T machine (Signa, GE, USA). 3D-GRASS sequence was used with the slice thickness of 0.4mm (sagittal), 0.4mm (coronal) and 0.8mm (axial) (Fig.1). The contour of the femur, tibia, articular cartilage and menisci were manually segmented in each image using a visualizing software AMIRA (TGS, USA). These data were transferred to the software, where the main surfaces and solid version of the model were reconstructed (Fig.2). With tetrahedral elements, the bone, cartilage and menisci were constructed. A total number of 5853 elements for tibia, 1642 elements for cartilage and 505 elements for menisci were used. These segmented 3D human knee model was brought into FEM analysis software MARC/MENTAT (MSC Software, USA), where finite element analysis of 3D model was performed with arbitrary load. The material properties of the bone, cartilage and menisci were chosen from the data available in the literature [5].

Loads and boundary conditions were defined as follows; the analysis model was from the menisci up to the tibia for simplification, so undersurface of the menisci was fixed. Only inferior-superior motion was allowed in the analysis. A combined load of 1600 N in compression of the femur at flexion of 0 degree. Regarding the stress concentration area, the meniscus had higher stress than the cartilage. The average stress in the medial meniscus was 1.6 MPa, and was almost equivalent to that in the lateral meniscus. The total load through the medial meniscus was 1.4 times higher than the lateral meniscus. The highest stress was observed in posterior horn of the medial meniscus with a maximum of 4.8 MPa, while the lateral meniscus had the highest stress of 5.1 MPa in anterior horn. Table 1 shows the areas (mm²) which had more than 3 MPa stress at two different slice levels; slice A was sectioned at middle of the meniscus in the axial plane, and slice B was sectioned at 1mm superior to the slice A. The medial meniscus had larger loading areas than the lateral meniscus.

RESULTS:
Figure 3 shows the distribution of the normal stress under the compression of 1600N to the femur at flexion of 0 degree. Regarding the stress concentration area, the meniscus had higher stress than the cartilage. The average stress in the medial meniscus was 1.6 MPa, and was almost equivalent to that in the lateral meniscus. The total load through the medial meniscus was 1.4 times higher than the lateral meniscus. The highest stress was observed in posterior horn of the medial meniscus with a maximum of 4.8 MPa, while the lateral meniscus had the highest stress of 5.1 MPa in anterior horn. Table 1 shows the areas (mm²) which had more than 3 MPa stress at two different slice levels; slice A was sectioned at middle of the meniscus in the axial plane, and slice B was sectioned at 1mm superior to the slice A. The medial meniscus had larger loading areas than the lateral meniscus.

DISCUSSION:
To elucidate the mechanism of meniscus injury, it is needed to establish a set of procedure to construct 3D FEM of the knee including the soft tissues. This study presented 3D FEM consisted of femur, tibia, articular cartilage and menisci, and analyzed the distribution of compressive stress in menisci. Other investigator reported that the maximal compression stress in medial meniscus was 3.3MPa under an axial compression load of 1150N using FEM [4]. To consider the difference in the applied loads, our results showed good agreement with their results, and this fact supports the validity of our model.

Our results showed that the stress in the medial meniscus was slightly larger than that in the lateral meniscus. Moreover, the stress concentrated in the posterior part of the medial meniscus. This result also agrees with the clinical fact that the injury of the meniscus is mostly seen in the posterior horn.

This model has a potential to calculate the loading conditions at any arbitrary flexion postures under the complex and repeated loads. Thus, our knee model can be a useful tool to investigate the stress distribution under the great impact loads and to analyze how the injury such as meniscal tear occurs at the joint during athletic activities.

REFERENCES


Table 1. The loading area with a stress more than 3MP (mm²)

<table>
<thead>
<tr>
<th>Slice</th>
<th>Lateral</th>
<th>Medial</th>
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<tr>
<td>A</td>
<td>106(14%)</td>
<td>70(11%)</td>
</tr>
<tr>
<td>B</td>
<td>64(13%)</td>
<td>35(10%)</td>
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