Biomechanical Assessment of Meniscal Repair Using a Novel Mechanically-Reinforced Atelocollagen Meniscus Substitute for Meniscal Defects in Miniature Pig Model

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Introduction

Since preservation of the meniscus is mainstream to prevent osteoarthritis, a mechanically-reinforced atelocollagen substitute (ACMS) for the meniscal defect was newly developed. The ACMS has an inter-connected pore structure that is 10–200 μm and can serve as a cellular scaffold for cell infiltration to form a matrix. The present study aimed to histologically and biomechanically assess the effect of ACMS on meniscal defects.

Method

Ten- to 12-month-old miniature pigs were dissected and full-thickness defects (3 × 8 mm) at the anterior to the middle region in the medial meniscus (MM) were created by a well-trained orthopaedic surgeon. In the ACMS group, the defect region was implanted by ACMS the same size as the defect. In the Defect group, the defect region was left untreated. At 6 months postoperative, the animals were sacrificed, and their knees were dissected down. The histological characteristics of both groups and normal MM harvested from healthy miniature pigs were compared. Tissue sections were stained with hematoxylin and eosin (HE), Safranin-O, and type 2 collagen antibody (immunohistochemical analysis) according to the manufacturer's instructions.
In the mechanical test, cyclic sinusoidal wave displacement up to 6% strain was applied to the MM defect region using a material testing machine (ElectroForce 5500, TAinstruments) installed with a 3 mm diameter spherical indenter. The stiffness and viscoelastic properties (storage and loss modulus) were calculated based on the sinusoidal wave output of displacement and its related load. The mechanical test was performed in 3 points set as no overlap in the defect region in the same MM. The parameters were compared between ACMS, Defect, and Control groups. The control was set as the anterior to the middle region in the lateral meniscus.

Results

In the ACMS group, defects were filled with repair tissue, and most of the implanted atelocollagen substitute had disappeared. Fibrochondrocyte-like cells were identified in the repaired area similar to those observed in normal menisci, and the surrounding matrix could be stained with safranin O and type II collagen antibody (Fig. 1). In the defect group, the defect remained, and repair tissue was only identified in some areas of the defects, with severe deformation of the meniscus. Fibrous scar tissue at the repair site contained numerous fibroblasts, and the extracellular matrix was not stained with safranin O and type II collagen antibody (Fig. 1).
In the mechanical test, there were no significant differences between each group. In the trend, the ACMS group showed greater stiffness, 23 N/mm, compared to the other 2 groups, and storage and loss modulus of 16 MPa and 2.3 MPa, respectively, were similar to the Control group. Although the defect group showed a similar stiffness to the control group, it showed a low storage modulus and varied loss modulus (Fig. 2).

Discussion

The present study is the first report to indicate the biomechanical effectiveness of the ACMS in the meniscal repair of the meniscal defect.
The morphologically functional repaired tissue without deformation was regenerated in the defect region at 6 months after implantation of ACMS while the Defect group did not show rich tissue regeneration. In addition, the regenerated tissue in the ACMS group showed similar and steady trends in characteristics as the control menisci in viscoelasticity while the varied values were showed in the Defect group.

Significance

The ACMS functions as a scaffold for migrating cells and results in normal meniscal morphology without deformity, which potentiates the production of a functional extracellular matrix in the meniscal defect region.

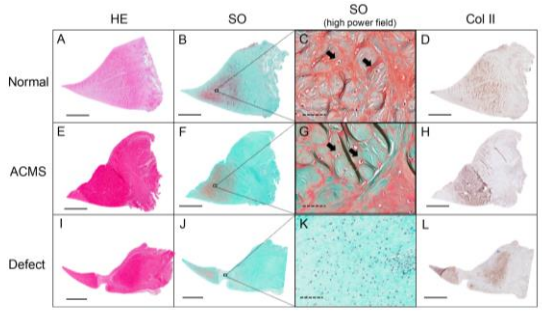

Figure 1 Histological evaluation of the defect region in the MM at 6 months postoperatively

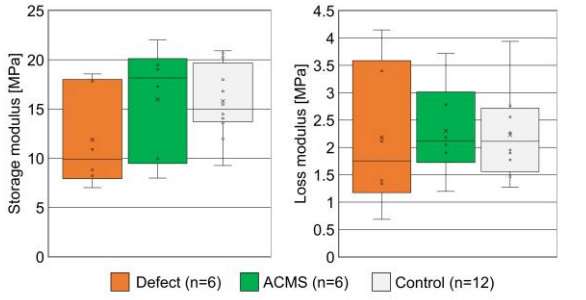

Figure 2 Storage modulus (left) and loss modulus (right) of the defect region in the MM at 6 months postoperatively