Mechanical strength of mediopatellar plica – The influence of its fiber content

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Abstract

Background. The fibrous mediopatellar plica can cause high contact pressure on the adjacent articular cartilage and lead to its degeneration. The purpose of this study was to investigate the biomechanical properties of the plica and to correlate this with the plica’s fiber content and patients’ ages.

Methods. An experimental study on the tensile strength of the mediopatellar plica was conducted using high precision micro-force tensile tests. These tests were undertaken on plica specimens taken from 50 knees of patients with different ages. The force–deflection curves resulting from these tests were recorded and transferred to stress–strain curves to obtain the Young’s moduli of these specimens. In addition, pathological tissue dyeing tests were used to assess the fiber content ratio of each specimen. The relationship of the Young’s moduli of these specimens with the severity of their pathologic change was also evaluated.

Findings. The Young’s modulus of the plica was found to be ranging from 10 to 110 MPa. It has positive correlation with patient’s age. The relationship between the fiber content ratio and Young’s modulus can be fitted properly using a quadratic regression model. The Young’s modulus of the plica was also positively correlated with the severity of its pathologic change.

Interpretation. The test results indicated that as patients get older, the fiber content of the mediopatellar plica and the Young’s modulus of the plica will increase accordingly. We also demonstrated that the Young’s modulus of the medial plica was positively correlated with the severity of the plica lesion.

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1. Introduction

The mediopatellar plica is a fold in the synovium representing an embryologic remnant in the development of the synovial cavity of the knee. It is found along the medial wall of the joint originating superiorly, extending obliquely and inferiorly, and inserted in the synovial lining of the infrapatellar fat pad (Dandy, 1990; Dupont, 1997; Farkas et al., 1997; Tindel and Nisonson, 1992) (Fig. 1). It is generally agreed that this structure can produce knee symptoms and could be successfully treated using arthroscopic resection when it becomes inflamed, thickened, and less elastic (Denti et al., 1994; Dorchak et al., 1991; Flanagan et al., 1994). During arthroscopic examination, many researchers have noticed different degrees of cartilaginous degeneration on the surface of the medial femoral condyle facing the medial plica (Dorchak et al., 1991; Dupont, 1997; Tindel and Nisonson, 1992). Most discussions have focused on the mechanism of the generation of the lesions, and many researchers state that the pathologic medial plica snaps or impinges on the underlying femoral condyle during knee motion and leads to erosive changes of the articular cartilage (Dorchak et al., 1991; Dupont, 1997; Strover et al., 1991; Tindel and Nisonson, 1992). But no literature specifies the material properties of the mediopatellar plica itself.

The purpose of this study was to investigate the mechanical properties of the mediopatellar plica of different aged
patients. The relationship between the Young’s modulus of the mediopatellar plica and the mediopatellar plica’s fiber content will be scrutinized. We postulate that as patients get older, the fiber content of the mediopatellar plica and the Young’s modulus of the plica will increase accordingly.

2. Specimen preparation

The mediopatellar plica specimens were taken from 50 patients with ages ranging from 19 to 77 (mean, 41). These specimens were cut into rectangular pieces measuring 14–20 mm long (mean, 17) and 1.5–3 mm wide (mean, 2.1). The thicknesses of the specimens varied from 0.7 mm to 2.8 mm (mean, 1.5). To carry out the tensile test, a miniature specimen configuration was designed to hold the micrometer-sized plica. Samples were first attached to a graph paper using a high-temperature adhesive and adjusted to 10 mm in length over the gage region. Each specimen was then mounted onto a pair of lightweight steel grips. The critical issues involved in specimen preparation were (1) to prevent plica damage, slipping, or pre-tensioning during the mounting process; (2) to align the specimen precisely; and (3) to keep all specimens the same size.

3. Plica tensile tests

The mechanical strength of the plica can be determined by conducting a micro-force tensile test. The test instruments were constructed as shown in Fig. 2. The major frame contains a MTS machine (MTS Tytron™ 125 Micro-Force Testing Systems, USA), and optical table. The micro-force tester uses a DC linear motor as its actuator and a personal computer as the interface to control the processes and store the collected data during the experiments. The load unit can apply forces varying from 0.01 N to 125 N at a displacement resolution of 0.1 μm. The air distribution system supplies filtered air to cool the DC motor and supply the air-assisted bearing. All of these equipments were installed on an optical table to isolate them from environmental noise.

The two-tip fixtures (Fig. 2) were screwed tight to the load unit and both were fixed on the multi-axial moveable stage. We designed the span of two-tip fixtures so that they could be adjusted vertically to fit differential thickness of specimen. The distance was verified using a charge coupled device camera (SONY XC-75, Japan), observational monitor, and multi-axial moveable stage before each test to ensure that the load was applied on the midway line between the two-tip fixtures. Once the plica sample was placed on the two-tip fixtures, the displacement control movement moved the thimble that pulled the plica until the total strain up to 20%. The test conditions were under a 0.01 mm/s tension rate with a 25°C operation temperature. The force and deflection data would be registered during the experiments. Because the plica samples had various thicknesses, we measured them one by one before each test. The average engineering strain was determined by dividing the displacement by the gage length. The engineering stress
was calculated by dividing the applied force by the original cross-sectional area. According to the above definition, the test data was converted to the engineering stress versus engineering strain curves. All these curves have basically the same appearance, where a nonlinear elastic stress–strain relation occurs through the initial 0.4–5% strain and is followed by continued linear stress–strain increment. The Young’s modulus that represents the stiffness of the plica was measured as the slope of each stress–strain curve in the linear stress–strain region. The results were plotted against a patient’s age (Fig. 3). We observed that the Young’s modulus of the plica was found to be ranged from 10 to 110 MPa, and increased with age.

4. Effect of fiber content and regression analysis

To examine the percentage of fiber content in each plica sample by direct observation under microscopy, each test sample was cut into small pieces from the tensile breaking area and dyed. The sampled tissue was immediately fixed in a 10% formalin solution, dehydrated, and paraffin-embedded using the usual tissue processing technique. A 3-μm thickness section was taken and prepared using hematoxylin and eosin stain and Masson’s trichrome stain (Carson, 1997). Most of the plica tissue was composed of collagen fibers (blue color$^1$) (Fig. 4). Therefore, the distribution of areas of the dyed fibers can be measured by coupling the microspectrophotometric photo with imaging processing software. The estimated fiber content ratio data were plotted against the Young’s modulus of the plica (Fig. 5). The relationship between these two variables is characterized by a mathematical model called the regression model. The model is given by

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \epsilon$$  \quad (1)

where $y$ is a response that depends on $p$ variables (for example, $x_1, x_2, \ldots, x_p$). The parameters $\beta_j, j = 0, 1, \ldots, p$, are called the regression coefficients, and $\epsilon$ is the random error. This model describes a hyperplane in the $p$-dimensional space of the regression variables $\{x_j\}$. With the polynomial regression model given above, we can find the best fit to be

$$Y = 90.848 - 3.334X + 0.037X^2$$  \quad (2)

where $Y$ is Young’s modulus, and $X$ is the fiber-containing ratio with an effective range from 46% to 92%. The statistical significance was found. $R = 0.9119$, $R^2 = 0.8315$, adjusted $R^2 = 0.8243$, and standard error = 11.1739. A comparison of the prediction from Eq. (2) and the experimental data is shown in Fig. 5. The predicted result fits well with the experimental data. Moreover, Eq. (2) also indicates that the Young’s modulus increasing with respect to the quadratic of fiber content ratio.

$^1$ For interpretation of color in Fig. 4, the reader is referred to the web version of this article.
5. Effect of the severity of the plica lesion

We further examined the relationship of Young’s modulus with the severity of plica lesion. We classified these plicae into five grades of severity according to their gross appearance (Lyu and Hsu, 2006). A Grade I plica looks like a membrane; its medial margin is somewhat transparent. It is soft in consistency when palpated by a probe. A grade II plica loses its transparency. It is hypertrophied and thickened. But it is still soft in consistency. A grade III plica looks like a fibrotic band. It is thicker than grade II plica and is elastic in consistency. In a grade IV plica, in addition to fibrosis, the sign of wearing appears. Its medial margin becomes frail and fibrillated. A grade V plica represents an inflamed grade IV lesion. It can be clearly seen in Fig. 6 that the severity of the plica lesion is positively correlated with the Young’s modulus of the plica.

6. Discussion

According to our previous clinical study (Lyu and Hsu, 2006), we found that medial plica was more commonly found in patients with osteoarthritic knees. Cartilaginous degeneration on the surface of the medial femoral condyle could be found in most of the knees having the structure of medial plica. The severity of the degeneration was positively correlated with the severity of the medial plica and patient’s age. Therefore, the mechanical properties of the plica is worth to be evaluated. In this study, we successfully developed a novel method to investigate the tensile strength of medial plica by using high precision micro-force tensile test. We found that there was a wide range of the Young’s modulus of the medial plica and it has positive correlation with patient’s age. This could be explained by our observation of the increasing fiber content ratio with age. The results of these tests also confirmed our previous clinical observation by showing that the severity of the plica lesion is positively correlated with the Young’s modulus of the plica.

7. Conclusion

This study investigated the biomechanical properties of medial plica under tensile loads. Micro-force tensile tests were successfully used to obtain the stress–strain curves for plicae taken from patients of different ages. According to our study, the Young’s modulus of the plica increased dramatically when the fiber content ratio was over 80%. The relationship between the fiber content ratio and Young’s modulus can be fitted properly using a quadratic regression model. We also found that the Young’s modulus of the medial plica is positively correlated with a patient’s age and the fiber content ratio of the plica. Time-dependent properties such as creep and stress relaxation of the medial plica are presently undergoing research and will be reported in a future paper.

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References