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Pullout failure strength of the posterior horn of the medial meniscus with root ligament tear

Young-Mo Kim · Yong-Bum Joo

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Abstract
Purpose To evaluate the reparability of the posterior horn of the medial meniscus with root ligament tear by measuring the actual pullout failure strength of a simple vertical suture of an arthroscopic subtotal meniscectomized posterior horn of the medial meniscus.
Methods From November 2009 to May 2010, nine posterior horns of the medial meniscus specimens were collected from arthroscopic subtotal meniscectomy performed as a treatment for root ligament rupture of the posterior horn of the medial meniscus. Simple vertical sutures were performed on the specimens, and pullout failure load was tested with a biaxial servohydraulic testing machine (Model 8874; Instron Corp., Norwood, MA, USA). The degree of degeneration, extrusion, and medial displacement of the medial meniscus were evaluated with magnetic resonance imaging (MRI). The Kellgren–Lawrence classification was used in standing plain radiography, and mechanical alignment was measured using orthoroentgenography. Tear morphology was classified into ligament proper type or meniscoligamentous junctional type according to the site of the torn root ligament of the posterior horn of the medial meniscus during arthroscopy.
Results The mean pullout failure strength of the posterior horn of the medial meniscus was 71.6 ± 23.2 N (range, 41.4–107.7 N). The degree of degeneration of the posterior horn of the medial meniscus on MRI showed statistically significant correlation with pullout failure strength and Kellgren–Lawrence classification. Pullout failure strength showed correlation with mechanical alignment and Kellgren–Lawrence classification ($P < 0.05$).
Conclusions The measurement of pullout failure strength of the posterior horn of the medial meniscus with root ligament tear showed a degree of repairability. The degree of degeneration of the posterior horn of the medial meniscus on MRI showed a significant correlation with the pullout failure strength. The pullout failure strength was also not only correlated with the degree of degeneration of the posterior horn of the medial meniscus, but also with mechanical alignment and Kellgren-Lawrence classification, which represent bony degenerative change.

Keywords Posterior horn of medial meniscus · Root ligament tear · Pullout failure strength · Biomechanical study

Introduction

The functions of the meniscus include body weight transfer, shock absorption, stability of the knee joint, lubrication, supplement of nutrients, and proprioceptive sensation. The development of degenerative arthritis after meniscectomy has been well documented [15, 25]. Therefore, the current surgical trend is to preserve the medial meniscus as much as possible [8, 17]. The posterior horn of the medial meniscus (PHMM) is attached to the tibia by the root ligament positioned in front of the posterior cruciate ligament, and root ligament tear of the PHMM can cause degenerative arthritis in the knee joint [14–22]. Allaire et al. [2] performed a biomechanical study using a cadaver to demonstrate that root ligament tear of the PHMM can cause changes in contact force and biomechanics of the knee joint similar to those caused by total meniscectomy.

Y.-M. Kim · Y.-B. Joo (✉)
Department of Orthopaedic Surgery, Chungnam National University College of Medicine, 640 Daesa-dong, Jung-gu, Daejeon 301-721, Korea
e-mail: longman76@hanmail.net

This could be suggested as the theoretical background of many studies that proposed the necessity for arthroscopic repair for root ligament tear of the PHMM [1, 11, 18, 26, 27]. However, many cases of root ligament tear of the PHMM develop after middle age. Magnetic resonance imaging (MRI) of the PHMM reveals associated degenerative changes of the torn edge of the PHMM. Although it is still questionable whether arthroscopic repair of the root ligament tear of the PHMM can be successfully maintained in spite of such degenerative changes, no studies have measured the actual pullout failure strength of a PHMM that has been treated for root ligament tear with degenerative change. The authors hypothesized that root ligament tear of the PHMM after middle age would result in weak pullout failure strength because of the associated degenerative changes of the torn edge of the PHMM. Thus, even if the PHMM could be reattached to the tibia by successful suturing, it would eventually tear again, resulting in suture failure. To examine this hypothesis, the actual pullout failure strength of the PHMM and reparability of PHMM were measured.

Materials and methods

With the approval of the institutional review board from IRB Administrator of Chungnam National University Hospital (IRB number is CNUH2011-07-004), this study involved nine patients who underwent en bloc arthroscopic subtotal meniscectomy for complete root ligament tear of the PHMM from November 2009 to May 2010. This prospective study was performed by collecting 1.5- to 2-cm-long PHMM specimens acquired during the surgeries. The median age of the patients (two male and seven female patients) was 61.8 years (range, 44–79 years). The collected PHMM specimens comprised six left knee joint and three right knee joint. To collect specimens without damaging the edge of the torn PHMM, only arthroscopic scissors (Arthrex, Naples, FL, USA) were used (Fig. 1). Our specimen inclusion criteria were [1] a smooth PHMM surface, [2] no horizontal tear on the medial margin, and [3] no horizontal intrasubstance tear of the PHMM after acquisition under arthroscopy. However, specimens showing slight marginal fraying of the PHMM were included, and the state of joint cartilage was not considered. Cases with degenerative changes on the surface of the PHMM, degenerative horizontal tearing under arthroscopy, intrasubstance horizontal tearing after acquisition of the specimen, and irreparable root ligament tearing of the PHMM on gross examination under arthroscopy due to degenerative changes in the PHMM were excluded.

The degree of degeneration of the PHMM, medial displacement grade of the PHMM by the root ligament tear, and degree of meniscal extrusion were measured on MRI. The PHMM degenerative grade was determined by modifying the conventional degeneration classification of the intervertebral disc [29]. When coronal T2-weighted MRI of the meniscus showed complete black without any white spots, the images were classified as grade 0; images showing overall black with slight presence of white spots were classified as grade 1; images showing <50 % white were classified as grade 2; images showing >50 % white were classified as grade 3; and images showing white with slight presence of black were classified as grade 4. Grade 4 was defined as the most severely degenerative condition (Table 1).

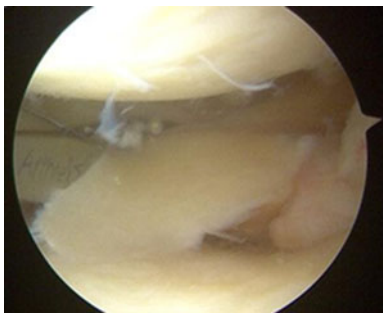

Fig. 1 Specimen obtained from arthroscopic subtotal meniscectomy

The degree of medial displacement of the PHMM was evaluated by measuring the distance from the edge of the torn root ligament of the PHMM to the tibial cartilaginous border of the tibial attachment site of the posterior cruciate ligament on the coronal view (Fig. 2). Meniscal extrusion was measured as described by Costa et al. [12] and was defined as the distance from the medial edge of the tibial cartilage to the most extruded point of the medial meniscus on the coronal image. The authors defined root ligament tear of the PHMM as a tear between the site just medial to the attachment of the PHMM to the coronary ligament and the tibial attachment site in front of the posterior cruciate ligament (Fig. 3). Thus, root ligament tear of the PHMM is expected to occur at the position where the PHMM meets the root ligament (meniscoligamentous junctional tear), within the root ligament (ligament proper tear), and at the tibial attachment site of the root ligament (avulsion tear). According to the torn section observed during the arthroscopic surgery, our cases were classified into the above three types, which were then compared with the MRI images. Each case was classified according to the Kellgren–Lawrence (K–L) classification in standing plain radiography, and mechanical alignment was measured with orthoroentgenography. The presence of additional injuries was identified from the MRI images or during the arthroscopic procedure.

A single simple vertical suture was placed at a point 7 mm medial from the border of the torn root ligament of

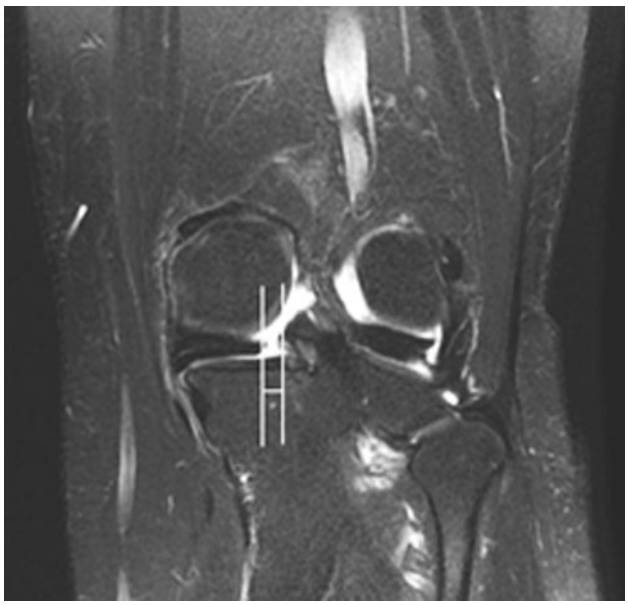

Fig. 2 Medial displacement of the posterior horn of the medial meniscus with root ligament tear

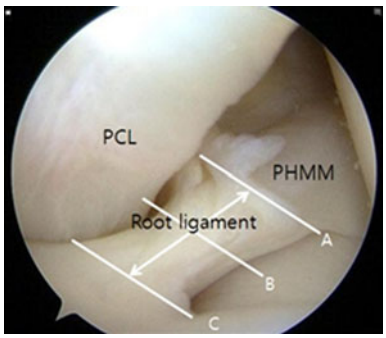

Fig. 3 Classification by tear site of the root ligament of the posterior horn of the medial meniscus. **a** Meniscoligamentous junctional tear. **b** Ligament proper tear. **c** Avulsion tear. (*PCL* posterior cruciate ligament)

the PHMM with 0 Ethibond (Ethicon, Somerville, NJ, USA) on the collected 1.5- to 2-cm-long PHMM specimens (Fig. 4a). A baseball suture was placed at the anterior and posterior resection surfaces of the meniscus with 0 Ethibond. The specimens were stored at −70 °C after covering them with gauze soaked in normal saline (Fig. 4b). All procedures were performed aseptically. The specimens were thawed at 4 °C for the first 18 h and then at room temperature (22 °C) for the next 6 h before biomechanical testing. The pullout failure strength was tested with a biaxial servohydraulic testing machine (Model 8874; Instron Corp., Norwood, MA, USA). Specimens were tested in random order, and the failure testing was performed at a speed of 5 mm/min (Fig. 5). Sgaglione et al. [19] reported

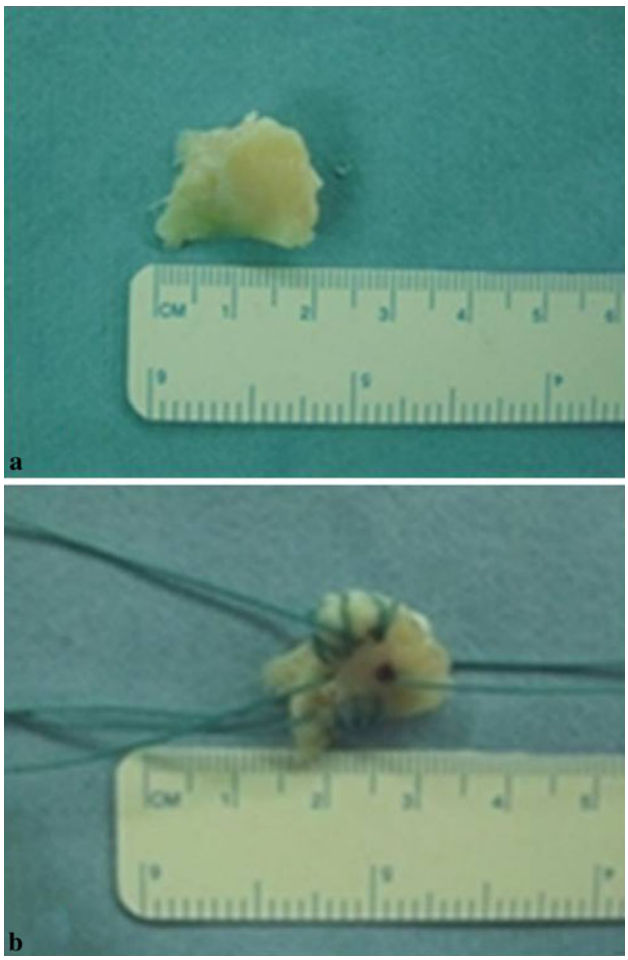

Fig. 4 Specimen obtained through subtotal meniscectomy. Left side of the specimen is the attachment site of the root ligament of the posterior horn of the medial meniscus. **a** Photograph of a specimen. **b** Simple vertical sutures were placed using a 0 Ethibond, and two sutures were used for baseball sutures

that this amount of pullout strength is loaded on the meniscus during early rehabilitation exercises, slow walking in daily life, stepping up and down, and squatting after meniscal repair.

Statistical analysis

For the statistical analysis, SPSS version 12.0 (SPSS Inc., Chicago, IL, USA) was used, and Spearman's rho test and Kendall's *tau*-b test were performed to investigate the correlation of the type of PHMM root ligament tear with medial displacement, the degenerative grade of the PHMM on MRI images, meniscal extrusion, K–L classification, and mechanical alignment of the lower extremity. The Mann–Whitney *U* test was used to analyse the correlation of the region of the torn root ligament of the PHMM under arthroscopy with the above variables. The *P* value was considered significant at < 0.05.

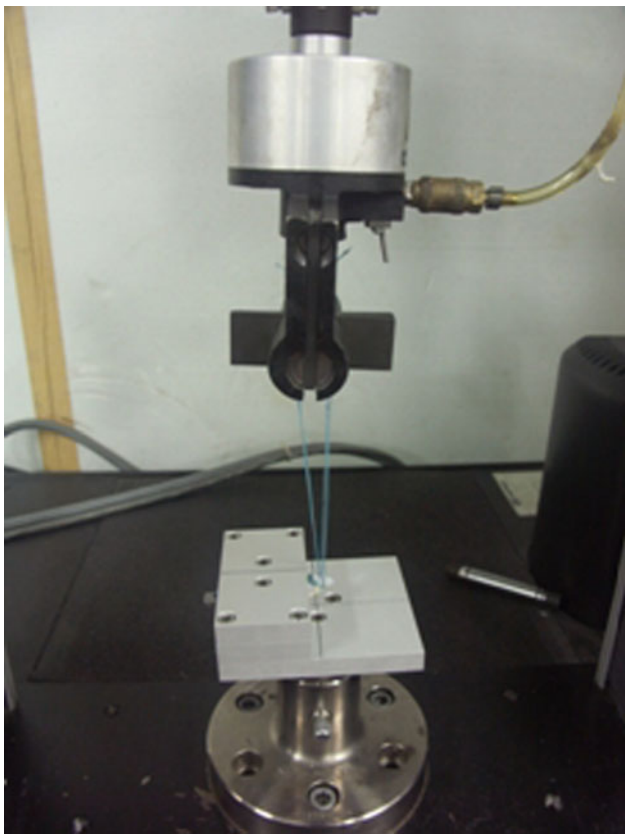

Fig. 5 Biomechanical study was performed using a biaxial servohydraulic testing machine (Model 8874; Instron Corp., Norwood, MA, USA)

Results

On MRI, three of nine cases were degenerative grade 1, three were grade 2, and three were grade 3. The mean medial displacement of the PHMM was 4.6 mm (range, 2.6–8.1 mm), and the mean meniscal extrusion was 4.5 mm (range, 2.7–5.6 mm). K–L classification revealed three cases each of grade 1, 2, and 3. Mechanical alignment measured from orthoroentgenography showed genu varum in eight cases, excluding one case of 0°. The mean varus angle was 4.7° (range, 0–9.3°).

Root ligament tears classified under arthroscopy revealed six cases of ligament proper tear and three cases of meniscoligamentous junctional tear. When comparing the torn position observed on the MRI images with the position observed during the arthroscopic examination, five of nine cases coincided.

The pullout failure strength in our study was 71.6 ± 23.2 N (range, 41.4–107.7 N). The mean pullout failure strength by MRI degenerative grade was 102.0, 56.4, and 56.4 N in grades 1, 2, and 3, respectively. Specimens showed maximum and minimum values in grades 1 and 3, respectively. One grade 2 specimen showed a low pullout failure strength of 42.7 N, which caused the mean value of grade 3 to be slightly higher than that of grade 2 (Table 2).

Statistical analysis showed a negative linear correlation between the pullout failure strength and the MRI degenerative degree ($P = 0.023$). In addition, a positive linear correlation was found between the degenerative degree and K–L classification. This indicates that the bony degenerative changes identified on the plain radiographic images had effects on the degeneration of the medial meniscus ($P = 0.050$).

The results of this study showed a positive linear correlation between the mechanical alignment and K–L classification ($P = 0.047$), and the K–L classification also showed a positive linear correlation with pullout failure strength ($P = 0.035$). No significant relationship was observed with other variables.

The Mann–Whitney U test for the classification of the tear position under arthroscopy showed a significant relationship with meniscal extrusion, but no significant relationship was observed with other variables. The rank correlation analysis of ligament proper tears and meniscoligamentous junctional tears showed a frequent occurrence of extrusion in the former ($P = 0.020$).

Discussion

The most important findings of the present study were the facts that the degenerative classification of the PHMM on MRI scans was significantly correlated with the pullout failure strength of the PHMM and that the mechanical alignment and K–L classification could have effects on the degree of degeneration in the PHMM.

This study was performed to evaluate the reparability of PHMM with root ligament tear by measuring the actual pullout failure strength of a simple vertical suture in arthroscopic subtotal meniscectomized PHMM. The authors hypothesized that because the pullout failure strength of the torn root ligament of the PHMM found in middle-aged patients is weak and already has developed degeneration, the ligament could be easily torn again despite the fact that the PHMM is successfully reattached to the tibia. However, most reports about root ligament tear at the PHMM mainly discussed surgical repair. There are no reports measuring the actual pullout failure strength of the PHMM with root ligament tear. The authors defined root ligament tear of the PHMM as a tear between the site just medial to the attachment of the PHMM to the coronary ligament and the tibial attachment site in front of the posterior cruciate ligament. On the basis of these anatomical characteristics, the authors judged that partial meniscectomy is not useful to treat root tears of the PHMM; thus, subtotal meniscectomy was performed. The authors also

Table 1 Classification of meniscal degeneration

Grade	Colour of meniscus
0	Pure black
1	Generalized black and mild white colour
2	Amount of white colour <50 %
3	Amount of white colour >50 %
4	Generalized white and mild black colour

performed en bloc subtotal meniscectomy with 1.5- to 2-cm-long PHMM specimens for sufficient removal of meniscus to prevent post-operative collision at the tibiofemoral joint, and testing was performed using the collected PHMM specimens acquired during the surgeries. Additionally, considering the fact that the easiest and most generally applicable suturing technique for root ligament tear of the PHMM is the vertical suture, this study was performed using only simple vertical sutures. To the best of the authors' knowledge, this is the first study to measure the actual pullout failure strength, which was 71.6 ± 23.2 N (range, 41.4–107.7 N), using PHMM specimens confirmed to have root ligament tear that were identified among middle-aged patients during arthroscopic surgery.

Root ligament tear of the PHMM can cause meniscal extrusion, injuries to the joint cartilage, and eventual narrowing of the medial joint space. In particular, meniscal extrusion can reduce the resistance to hoop stress and instigate cartilaginous injuries due to axial load. Furthermore, narrowing of the joint space can cause arthritis of the knee joint [6]. There are many disputes on the best treatment for root ligament tears. However, most reports on this subject have discussed surgical treatment; there has been no study on the reparability of the root ligament, and no report has measured the actual pullout failure strength from the torn root ligament of the PHMM [1, 7, 11, 17, 18, 23, 24, 26, 27]. Kocabey et al. [19] performed a biomechanical study to measure the pullout failure strength of several suturing techniques on the medial meniscus of 1-year-old bovines after creating a vertical longitudinal incision on the medial meniscus. They reported that the pullout failure strength of oblique, vertical, and horizontal sutures was 171.9 ± 25.9, 145.9 ± 32.3, and 88.2 ± 8.2 N, respectively. Kohn and Siebert [20] conducted a biomechanical study using cadavers and compared the pullout failure strengths of the following four suturing techniques: knot-end suture, arthroscopic technique using a loop placed on the meniscus, open vertical stitching suture, and open horizontal suture. Pullout failure strengths in their study were 24 ± 9, 89 ± 4, 105 ± 4, and 44 ± 18 N, respectively. Rimmer et al. [28] reported pullout failure strengths of vertical and horizontal sutures in a longitudinal tear model at the lateral meniscus of a cadaver as 67.3 and 29.3 N, respectively. Aros et al. [4] reported the pullout failure strength of the second-generation suture tool RapidLoc (Mitek Surgical Products, Westwood, MA, USA) as 70 ± 12 N in a biomechanical study after producing a longitudinal tear in a 1-year-old bovine lateral meniscus. Arnoczky and Warren [3] reported that the anterior and posterior horns of the meniscus have a rich blood supply because they are covered with a venous synovial fluid membrane. Lee et al. [21] reported that the arthroscopic pullout suture in a short-term follow-up study resulted in alleviation of symptoms caused by a meniscal tear and that such suturing could be applicable to patients with a degenerative joint cartilage of degree <3. On the basis of such a theoretical background in this study, measurement of the actual pullout failure strength of the torn root ligament of the PHMM in middle-aged patients was 71.6 ± 23.2 N (range, 41.4–107.7 N). Although these values are considered to represent a significantly positive result and provide an explanation for the appropriateness of placing sutures in the site, a limitation is that this study did not involve the cyclic load test.

Table 2 Results of pullout strength and radiologic evaluation

No.	Age	Sex	Failure load (N)	MRI degeneration classification	Medial displacement (mm)	Meniscal extrusion (mm)	Mechanical alignment	K–L classification of medial joint
1	66	F	41.4	3	6.1	3.9	3.1	1
2	70	F	64.4	2	3.5	5.5	9.3	3
3	57	F	66.6	3	3.3	5.6	3.2	2
4	55	F	99.2	1	6.6	5.3	4.2	3
5	70	F	99.1	1	4.7	4.4	4.6	2
6	44	M	42.7	2	2.6	2.7	4.7	2
7	53	F	107.7	1	3.5	4.1	8.9	3
8	79	M	62.1	2	8.1	4.3	0	1
9	63	F	61.3	3	3.3	5.1	4.3	1
Average	61.8		71.6		4.6	4.5	4.7	

Arthritis in the knee joint reportedly has an important relationship with age and body weight [10], and lesions of the meniscus are related to early symptoms of arthritis [13]. Bin et al. [7] reported that the mean age of patients with root ligament tear of the PHMM was 56.3 years (range, 31–77 years), and the crouching posture and sitting lifestyle of the Korean population reportedly increase the load on the medial meniscus, causing degenerative changes of the knee joint. Oczkoc et al. [27] reported that Turkish people at a mean age of 55.8 years (range, 38–72 years) showed increased numbers of degenerative changes due to their cultural habits, which force flexion of the knee joint and internal rotation of the leg posture to induce a varus force onto the knee joint. The mean patient age in our study was 61.8 years (range, 44–79 years), and the patients were found to already have degenerative changes in their PHMM at the time of suture placement, which was confirmed from their preoperative MRI scans. Costa et al. [12] classified the degenerative grade of the meniscus to be absent when no single strength could be detected, mild when the signal strength was <25 %, moderate when the signal strength ranged from about 26–50 %, and severe when it exceeded 50 %. They reported that substantial medial meniscus extrusion of >3 mm is related to degeneration and to the degree and range of tearing. We determined the medial meniscus degeneration grade by modifying the degenerative changes in intervertebral discs suggested by Weishalupt et al. [29]. In the present study, the degenerative degree of the medial meniscus had no significant relationship with the degree of medial meniscus extrusion ($P = 0.370$), but there was a negative correlation between the MRI degeneration grade and the pullout failure strength ($P = 0.035$). This indicates that the degeneration level observed on the MRI images reflected the degree of medial meniscus degeneration and that the pullout failure strength decreases as the degeneration grade increases. It also suggests the appropriateness of the classification used in our study.

The K–L classification is used to evaluate the bony degenerative change in the knee joint. The higher the classification grade is, the more progressive are the degenerative changes. To the best of the authors' knowledge, no study has reported the relationship between K–L classification and the degenerative degree of the meniscus. Our study shows a positive linear correlation between K–L classification and the degenerative degree of the medial meniscus.

The meniscus is a C-shaped fibrocartilaginous tissue, and most of its cells are fibrocartilaginous cells. Most of the matrix comprises type I collagen fibre. Small amounts of type II, III, V, and VI collagen fibres exist, and the outer surface is formed of a collagen fibrillar network to allow for strong structural support. However, because the meniscal intrasubstance is relatively weak compared with the outer surface, the degenerative changes mostly occur within the intrasubstance [5, 6, 9]. Jones et al. [16] reported that the circumferential arrangement of collagen fibres in the meniscus helps the meniscus to resist hoop stress and distribute the body weight load. Thus, the cartilage of the knee joint can effectively protect against injuries. It is assumed that the emergence of the suturable pullout failure strength is deeply attributed to such structural characteristics of the meniscus despite the fact that the intrasubstance of the meniscus is weak in patients with degenerative changes. Root ligament tear of the PHMM was shown to have a positive correlation with meniscus extrusion; we also found a significant relationship between the torn position classified under the arthroscopic examination and medial meniscus extrusion. The agreement between the arthroscopic classification and the MRI classification of torn sites provided relatively low accuracy in that just five of nine cases (55 %) were in agreement, but this result is considered to be related to the discontinuity of the MRI section. In clinical work, the degenerative classification of the PHMM on MRI scans may indicate pullout failure strength of the PHMM.

There are some limitations to this study. No comparison was made between meniscal thickness of the needle insertion point and the pullout failure strength. Because curved needles were used in the experiment, the suture may not have been inserted vertically at the 7-mm position of the torn root ligament of the PHMM. The small number of specimens is another limitation. This study also did not include the cyclic load test. Moreover, because this study was not a biological study that reviewed the results of suturing for torn root ligament of the PHMM, there are limitations in terms of drawing the conclusion that healing after repair is possible. Therefore, additional studies are necessary.

Conclusions

The pullout failure strength of simple vertical suturing for root ligament tear of the PHMM indicates that it is reparable. However, although adequate pullout failure strength is available even in degenerative tears, reparability has not been confirmed, and additional studies are thus necessary. This biomechanical study confirmed that the degenerative classification of the PHMM on MRI scans was significantly correlated with the pullout failure strength of the PHMM and that the mechanical alignment and K–L classification could have effects on the degree of degeneration in the PHMM.

References

1. Ahn JH, Wang JH, Yoo JC, Noh HK, Park JH (2007) A pull out suture for transection of the posterior horn of the medial meniscus: using a posterior trans-septal portal. Knee Surg Sports Traumatol Arthrosc 15(12):1510–1513
2. Allaire R, Muriuki M, Gilberson L, Harner CD (2008) Biomechanical consequences of a tear of the posterior root of the medial meniscus. Similar to total meniscectomy. J Bone Joint Surg Am 90(9):1922–1931
3. Arnoczky SP, Warren RF (1983) The microvasculature of the meniscus and its response to injury. An experimental study in the dog. Am J Sports Med 11(3):131–141
4. Aros BC, Pedroza A, Vasileff WK, Litsky AS, Flanigan DC (2010) Mechanical comparison of meniscal repair devices with mattress suture devices in vitro. Knee Surg Sports Traumatol Arthrosc 18(11):1594–1598
5. Beaupré A, Choukroun R, Guidouin R, Garneau R, Gérardin H, Cardou A (1986) Knee menisci. Correlation between microstructure and biomechanics. Clin Orthop Relat Res 208:72–75
6. Berthiaume MJ, Raynauld JP, Martel-Pelletier J et al (2005) Meniscal tear and extrusion are strongly associated with progression of symptomatic knee osteoarthritis as assessed by quantitative magnetic resonance imaging. Ann Rheum Dis 64(4):556–563
7. Bin SI, Kim JM, Shin SJ (2004) Radial tears of the posterior horn of the medial meniscus. Arthroscopy 20(4):373–378
8. Bolano LE, Grana WA (1993) Isolated arthroscopic partial meniscectomy. Functional radiographic evaluation at five years. Am J Sports Med 21(3):432–437
9. Bullough PG, Munuera L, Murphy J, Weinstein AM (1970) The strength of the menisci of the knee as it relates to their fine structure. J Bone Joint Surg Br 52(3):564–567
10. Calle EE, Thun MJ, Petrelli JM, Rodtiguez C, Heath CW Jr (1999) Body-mass index and mortality in a prospective cohort of U.S. adults. N Engl J Med 341(15):1097–1105
11. Choi NH, Son KM, Victoroff BN (2008) Arthroscopic all-inside repair for a tear of posterior root of the medial meniscus: a technical note. Knee Surg Sports Traumatol Arthrosc 16(9):891–893
12. Costa CR, Morrison WB, Carrino JA (2004) Medial meniscus extrusion on knee MRI: is extent associated with severity of degeneration or type of tear? AJR Am J Roentgenol 183(1):17–23
13. Englund M (2004) Meniscal tear—a feature of osteoarthritis. Acta Orthop Scand Suppl 75(312):1–45
14. Gale DR, Chaisson CE, Totterman SM, Schwartz RK, Gale ME, Felson D (1999) Meniscal subluxation: association with osteoarthritis and joint space narrowing. Osteoarthr Cartil 7(6):526–532
15. Johnson RJ, Kettelkamp DB, Clark W, Leaverton P (1974) Factors effecting late results after meniscectomy. J Bone Joint Surg Am 56(4):719–729
16. Jones RS, Keene GC, Learmonth DJ et al (1996) Direct measurement of hoop strains in the intact and torn human medial meniscus. Clin Biomech (Bristol, Avon) 11(5):295–300
17. Jørgensen U, Sonne-Holm S, Lauridsen F, Rosenklint A (1987) Long-term follow-up of meniscectomy in athletes. A prospective longitudinal study. J Bone Joint Surg Br 69(1):80–83
18. Kim YM, Rhee KJ, Lee JK, Hwang DS, Yang JY, Kim SJ (2006) Arthroscopic pull out repair of a complete radial tear of the tibial attachment site of the medial meniscus posterior horn. Arthroscopy 22(7):795.e1-4
19. Sgaglione NA, Steadman JR, Shaffer B et al (2003) Current concepts in meniscus surgery: resection to replacement. Arthroscopy 19(Suppl 1):161–188
20. Kohn D, Siebert W (1989) Meniscus suture techniques: a comparative biomechanical cadaver study. Arthroscopy 5(4):324–327
21. Lee JH, Lim YJ, Kim KB, Kim KH, Song JH (2009) Arthroscopic pullout suture repair of posterior root tear of the medial meniscus: radiographic and clinical results with a 2-year follow-up. Arthroscopy 25(9):951–958
22. Lerer DB, Umans HR, Hu MX, Jones MH (2004) The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. Skeletal Radiol 33(10):569–574
23. Lim HC, Bae JH, Wang JH, Seok CW, Kim MK (2010) Non-operative treatment of degenerative posterior root tear of the medial meniscus. Knee Surg Sports Traumatol Arthrosc 18(4): 535–539
24. Marzo JM, Gurske-DePerio J (2009) Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications. Am J Sports Med 37(1):124–129
25. McGinity JB, Geuss LF, Marvin RA (1977) Partial or total meniscectomy: a comparative analysis. J Bone Joint Surg Am 59(6):763–766
26. Nicholas SJ, Golant A, Schachter AK, Lee SJ (2009) A new surgical technique of arthroscopic repair of the meniscus root tear. Knee Surg Sports Traumatol Arhrosc 17(12):1433–1436
27. Ozkoc G, Circi E, Gonc U, Irgit K, Pourbagher A, Tandogan RN (2008) Radial tears in the root of the posterior horn of the medial meniscus. Knee Surg Sports Traumatol Arthrosc 16(9):849–854
28. Rimmer MG, Nawana NS, Keene GC, Pearcy MJ (1995) Failure strengths of different meniscal suturing techniques. Arthroscopy 11(2):146–150
29. Weishalupt D, Zanetti M, Hodler J, Boos N (1998) MR imaging of the lumbar spine: prevalence of intervertebral disk extrusion and sequestration, nerve root compression, end plate abnormalities, and osteoarthritis of the facet joints in asymptomatic volunteers. Radiology 209(3):661–666