Factors associated with medial meniscal subluxation in knees with medial meniscus tears: a cross-sectional study

Xinguang Liu

Peking University International Hospital

Ran Ding

China-Japan Friendship Hospital

Chen Liu

Peking University International Hospital

Bin Yang

Peking University International Hospital

Weiguo Wang (✉ wangweiguo@zryhyy.com.cn)

China-Japan Friendship Hospital

Research article

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Abstract

Background Previous studies have indicated that medial meniscal subluxation (MMS) was associated with special types of medial meniscus tears (MMT) and chondral lesions. However, most of these studies lacked arthroscopic findings and had not adjusted for possible confounders. The purpose of this study was to explore the factors associated with MMS in patients with MMT using multivariate logistic regression analysis.

Methods A retrospective analysis of 115 patients who underwent arthroscopic surgery for MMT was conducted. The medial meniscal extrusion (MME) distance was measured on a single mid-coronal MR image, and the MMS group included patients with $MME \geq 3$ mm (55 patients with 55 knees). Other patients were included as the control group (60 patients with 60 knees). Demographic and clinical data were collected as variates. A multivariate logistic regression analysis was performed to identify the factors associated with MMS.

Results The MME distance was significantly higher in the MMS group (median distance: 3.5 mm, interquartile range: 3.3–4.1 mm) than in the control group (median distance: 1.8 mm, interquartile range: 1.3–2.3 mm, $P < 0.001$). The Outerbridge classification ($P = 0.002$) and the type of MMT ($P = 0.001$) were significantly different between the MMS group and the control group. According to the multivariate logistic regression analysis, the type of MMT ($P = 0.015$) was the independent factor associated with MMS after adjusting for other variates. Compared with horizontal tears, radial tears, PMMRT and complex tears had an approximately 8-fold (OR 7.592, 95 % CI 1.681–34.295, $P = 0.008$), 11-fold (OR 11.451, 95 % CI 1.763–74.379, $P = 0.011$) and 4-fold (OR 4.387, 95 % CI 1.558–12.355, $P = 0.005$) higher association with MMS, respectively.

Conclusion The type of MMT was an independent factor associated with MMS in knees with MMT. Radial tears, PMMRT and complex tears were more likely than horizontal tears to result in MMS. These results suggest that MMT combined with MMS should be noticed when managing MMT, especially radial tears, PMMRT and complex tears. We must not only preserve the meniscus as much as possible but also restore its position to as close to normal as possible.

Background

The menisci are crescent-shaped wedges of fibrocartilage with bony attachments on the tibial plateau. The primary function of the menisci is to transmit load by increasing congruity between the rounded femoral condyles and the flattened surface of the tibial plateau, and other functions include shock absorption, lubrication, proprioception, and joint stability [1–5]. Intact menisci occupy approximately 60% of the contact area between the articular surfaces, and they transmit > 50% of the total axial load of the knee joint [6]. These functions may be compromised when menisci are torn or positioned abnormally.

Medial meniscal extrusion (MME) is defined as medial displacement of the medial meniscus beyond the margin of the tibial plateau. MME results from considerable disruption of either the meniscal root or the

circumferential fiber bundles of the medial meniscus, which impairs the ability to resist the hoop strain that stretches the meniscus in a radial direction during weight bearing [7–10]. A meniscal extrusion distance ≥ 3 mm is considered a pathological condition, and some authors have termed this condition medial meniscal subluxation (MMS) [7, 11].

According to a finite element analysis study, MMS was associated with increased loading of all knee structures, especially the tibia cartilage, and a positive correlation was found between the degree of MMS and the amount of loading on tibia cartilage [12]. The conclusion of this research could explain the results of previous longitudinal studies showing that MMS or MME was related to cartilage degeneration and subchondral bone changes that predict knee osteoarthritis [13, 14].

Previous studies have indicated that MMS or major MME (an MME distance > 3 mm) was associated with medial meniscus tears (MMT), especially extensive tears, complex tears, radial tears and root tears [7–9]. MMS has also been correlated with chondral lesions [9]. However, most of these previous studies lacked arthroscopic findings and had not adjusted for possible confounders. The purpose of this study was to explore the factors associated with MMS in patients with MMT using multivariate logistic regression analysis. We hypothesized that BMI, the type of MMT and chondral lesions involving the ipsilateral medial compartment were the factors associated with MMS.

Methods

Sample selection and grouping

We retrospectively evaluated 1,008 patients who underwent arthroscopic surgery for MMT from June 2014 to May 2020. Patients with isolated MMT were chosen for the study. The exclusion criteria were as follows: MMT combined with ligament injuries, lateral meniscal tears, rheumatoid arthritis, septic arthritis or tumors; a previous history of knee surgery; and unavailability of MR images of sufficient quality. All arthroscopic surgeries were performed within two weeks of the MRI examination. Patients were divided into an MMS group and a control group on the basis of whether MMS was present on MR images.

MRI protocol and measurement

All patients underwent MRI examinations in the supine position. MRI examinations were performed with a 3T MRI unit (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) using a quadrature extremity coil. The MRI protocol incorporated the following sequences: a T1-weighted turbo spin-echo (TSE) sequence in the sagittal plane (FOV: 160 mm, slice thickness: 4 mm, interslice gap: 0.5 mm, TR: 800 ms, TE: 12 ms, matrix: 256 x 256 mm) and a proton density-weighted TSE sequence with fat saturation in the coronal, sagittal and transversal planes (FOV: 160 mm, slice thickness: 4 mm, interslice gap: 0.5 mm, TR: 3300-3600 ms, TE: 48 ms, matrix: 256 x 256 mm).

The MME distance was measured using the General Electric Healthcare PACS program (GE, Centricity Universal Viewer Zero Footprint, version 5.0 sp7.1). The MME distance was quantified in millimeters

(mm) on a coronal MR image obtained at the midpoint of the medial femoral condyle. Two vertical lines were drawn that intersected the outer edge of the medial meniscus and the outer margin of the medial tibial plateau. The distance between the two lines was defined as the MME distance (**Fig 1**). Osteophytes were excluded when determining the medial margin of the tibial plateau.

Measurement of medial meniscal extrusion: Using a mid-coronal MR image, the first vertical line was drawn to intersect the medial edge of the medial tibial plateau (dotted line a), and the second vertical line was drawn to intersect the medial edge of the medial meniscus (solid line b). The distance between the two lines (arrow line c) was defined as the medial meniscal extrusion distance.

Two trained surgeons who were blinded to the study design, clinical information and radiological reports measured the MME distance. The mean distance was used in the assessment. An MME distance ≥ 3 mm was considered to indicate MMS. The interobserver reliability of the measurements between the two surgeons was analyzed using the intraclass correlation coefficient (ICC), with an ICC of 0.40 indicating poor reproducibility, an ICC of 0.40–0.75 indicating fair to good reproducibility, and an ICC greater than 0.75 indicating excellent reproducibility [15]. The ICC was 0.887 (range: 0.841–0.921).

Demographic and clinical data

Demographic and clinical data included sex, age, body mass index (BMI), side of the affected knee, duration of symptoms, severity of chondral lesions involving the ipsilateral medial compartment and type of MMT. The duration of symptoms was defined as the amount of time with knee pain before the operation was performed. The severity of chondral lesions involving the ipsilateral medial compartment was described according to the Outerbridge classification: Grade 0 signified normal cartilage; Grade I lesion referred to cartilage with softening and swelling; Grade II lesion described a partial-thickness defect with fissures that did not exceed 0.5 inches in diameter or reach subchondral bone; Grade III lesion was characterized by chondral fissures with a diameter >0.5 inches with an area reaching subchondral bone; and Grade IV indicated erosion of the articular cartilage that exposed subchondral bone [16]. The types of MMT were categorized as horizontal tears, longitudinal tears, bucket-handle tears, radial tears, posterior medial meniscus root tears (PMMRT), and complex tears. These data were collected as variates for multivariate logistic regression analysis.

Statistical analysis

The normality of continuous data distributions was assessed using the Kolmogorov-Smirnov test. Normally distributed data were expressed as the mean ($\pm$ standard deviation), and the median (interquartile range) was used to express data with a skewed distribution. Categorical data were presented as frequencies and percentages. Differences in numerical data between the MMT group and control group were determined by independent-sample t-test for continuous data with a normal distribution and Mann-Whitney U test for continuous data that were not normally distributed. The chi-squared test was used to compare categorical data. Factors associated with MMS were identified by multivariate logistic regression analysis. The odds ratio (OR) and 95 % confidence interval (CI) were

calculated as an approximate index of the relative risks. Statistical analysis was performed with SPSS software (version 25, SPSS, Chicago, IL). A P value less than 0.05 was considered statistically significant.

Results

A total of 115 patients were enrolled in the study, and they included 66 male patients and 49 female patients with a median age of 53 years (interquartile range: 39–61 years), a mean BMI of 26.1 ($\pm$ 3.3), and a median MME distance of 2.80 mm (interquartile range: 1.70–3.50 mm).

The MMS group consisted of 55 knees in 55 patients with a median age of 55 years (interquartile range: 40–62 years) and a mean BMI of 26.4 ($\pm$ 3.2). The control group consisted of 60 knees in 60 patients with a median age of 51 years (interquartile range: 39–61 years) and a mean BMI of 25.9 ($\pm$ 3.5). The MME distance was significantly higher in the MMS group (median distance: 3.5 mm, interquartile range: 3.3–4.1 mm) than in the control group (median distance: 1.8 mm, interquartile range: 1.3–2.3 mm, $P < 0.001$). A summary of the demographic data and arthroscopic findings of the patients in the two groups was presented in Table 1 and Table 2, respectively. There were no significant differences in sex ($P = 0.085$), age ($P = 0.182$), BMI ($P = 0.405$), side of affected knee ($P = 0.217$), or duration of symptoms ($P = 0.890$) between the two groups. The Outerbridge classification ($P = 0.002$) and the type of MMT ($P = 0.001$) were significantly different between the MMS group and the control group.

Table 1
Demographic data of patients in the MMS group and control group

Demographic data	Control group (n = 60)	MMS group (n = 55)	P
Sex (n (%))			0.085
Female	21 (18.3%)	28 (24.3%)	
Male	39 (33.9%)	27 (23.5%)	
Age (years)	51 (39–61)	55 (40–62)	0.182
BMI	25.9 ($\pm$ 3.5)	26.4 ($\pm$ 3.2)	0.405
Side of affected knee (n (%))			0.217
Left	32 (27.8%)	23 (20.0%)	
Right	28 (24.3%)	32 (27.8%)	
Duration of symptoms (n (%))			0.890
< 3 months	18 (15.7%)	17 (14.8%)	
$\geq$ 3 months, < 12 months	21 (18.3%)	17 (14.8%)	
$\geq$ 12 months	21 (19.2%)	21 (18.3%)	
MMS, medial meniscal subluxation; BMI, body mass index; The duration of symptoms was defined as the amount of time with knee pain before the operation was performed.			

Table 2
Arthroscopic findings of patients in the MMS group and control group

Arthroscopic findings	Control group (n = 60)	MMS group (n = 55)	P
Outerbridge classification (n (%))			0.002*
Grade 0 - II	50 (43.5%)	31 (27.0%)	
Grade III - IV	10 (8.7%)	24 (20.9%)	
Type of MMT (n (%))			0.001*
Horizontal tears	35 (30.4%)	12 (10.4%)	
Longitudinal tears	4 (3.5%)	1 (0.9%)	
Bucket-handle tears	2 (1.7%)	2 (1.7%)	
Radial tears	4 (3.5%)	11 (9.6%)	
PMMRT	2 (1.7%)	9 (7.8%)	
Complex tears	13 (11.3%)	20 (17.4%)	
MMS, medial meniscal subluxation; MMT, medial meniscus tears; PMMRT, posterior medial meniscus root tears.			
* Statistically significant (P < 0.05)			

All variates, including sex, age, body mass index (BMI), side of the affected knee, duration of symptoms, severity of chondral lesions involving the ipsilateral medial compartment and type of MMT, were input into the multivariate logistic regression analysis. The results showed that the type of MMT (P = 0.015) was an independent factor associated with MMS after adjusting for other variates. Compared with horizontal tears, radial tears, PMMRT and complex tears had an approximately 8-fold (OR 7.592, 95% CI 1.681–34.295, P = 0.008), 11-fold (OR 11.451, 95% CI 1.763–74.379, P = 0.011) and 4-fold (OR 4.387, 95% CI 1.558–12.355, P = 0.005) higher association with MMS, respectively (Table 3).

Table 3
Factors associated with MMS identified by the multivariate logistic regression analysis

Variates	P	OR	95% CI	
			Minimum	Maximum
Type of MMT	0.015*			
Horizontal tears	-	1.00 (Reference)	-	-
Longitudinal tears	0.934	0.904	0.085	9.579
Bucket-handle tears	0.221	3.899	0.442	34.424
Radial tears	0.008*	7.592	1.681	34.295
PMMRT	0.011*	11.451	1.763	74.379
Complex tears	0.005*	4.387	1.558	12.355
OR, odds ratio; CI, confidence interval; MMT, medial meniscus tears; PMMRT, posterior medial meniscus root tears.				
* Statistically significant (P < 0.05)				

Discussion

The menisci are crescent-shaped wedges of fibrocartilage that are anchored to the tibia by anterior and posterior root attachments. They consist of a sparse cell population and dense extracellular matrix that is composed primarily of water (72%) and collagen (22%), with other constituents including glycosaminoglycans, DNA, adhesion glycoproteins and elastin [17, 18]. Collagen is the major fibrillar component of the menisci. The main collagen fiber bundles predominantly exhibit a circumferential orientation [8]. During weight bearing, the compressive force applied on the wedge-shaped meniscus results in hoop strain, which stretches the collagen bundles in a radial direction [8, 19]. However, the meniscus mainly responds to loading by compressing rather than extruding because the tensile strength of the meniscus, which depends on the circumferential collagen fiber bundles and the anatomical insertions of the anchoring horns (anterior and posterior root attachments), counteracts extrusion [17]. Hence, the disruption of either the circumferential collagen fiber bundles or the meniscal root attachments can result in MME [7].

Costa et al. reviewed one hundred and five knee MR images, and they found that MME distance > 3 mm was associated with severe meniscal degeneration, extensive tears, complex tears, large radial tears and root tears [8]. Lerer et al. concluded that MMS was associated with moderate and large medial compartment marginal osteophytes, moderate to severe medial compartment cartilage loss, radial tears and root pathology by evaluating 205 consecutive knee MR images of patients with knee pain [7]. However, these two reports lacked arthroscopic findings, which are the gold standard for diagnosing the type of MMT and for evaluating the severity of chondral lesions. Choi et al. analyzed 248 patients with

MMT who underwent arthroscopic meniscectomy. They found that MMS was significantly correlated with root tears and that the severity of chondral lesions involving the medial femoral condyle depended on the arthroscopic findings [9]. However, these studies mentioned above could not identify the most relevant factors associated with MMS because the confounders had not been controlled.

In this study, we found that the type of MMT was an independent factor associated with MMS. Compared with horizontal tears, radial tears, PMMRT and complex tears had an approximately 8-fold, 11-fold and 4-fold higher association with MMS. This result was consistent with the histological and anatomical morphology of the menisci. Radial tears that are perpendicular to the long axis of the circumferential collagen fiber bundles completely disrupt the ability to resist hoop strain and lead to major extrusion [8, 19]. Meniscal root tears impair the attachments of the menisci which are anchored to the tibial plateau, and most tears that occur at or near the meniscal roots are radial tears [20, 21]. Complex tears significantly alter hoop strain resistance because of extensive structural disruption of more than one cleavage plane through the collagen fiber bundles [8]. Horizontal tears and longitudinal tears that are oriented parallel to the circumferential collagen fiber bundles cause minor impairment and thus are not associated with extensive MME [8, 10]. We found that bucket-handle tears ($P = 0.221$) were not more prone to MMS than horizontal tears were. A possible explanation for this finding is that bucket-handle tears are a type of longitudinal tear, but the sample size ($n = 4$) of bucket-handle tears was small in our study.

We found ten knees (16.7%) with an Outerbridge classification of grade III–IV among 60 knees in the control group versus 24 (43.6%) of 55 knees in the MMT group. The severity of chondral lesions involving the ipsilateral medial compartment was significantly different between the two groups. These results were similar to those of previous studies [7, 9]. Because our study was cross-sectional, we could not verify a causal relationship between MMS and chondral lesions. Choi et al. performed a longitudinal observational study including forty patients who showed MMS on MR images without cartilage degeneration. After two years of follow-up, cartilage degeneration on the ipsilateral medial femoral condyle was observed in twenty-five patients (62.5%), and the amount of MMS was related to the degree of progression of cartilage degeneration [14]. Therefore, MMS is more likely to precede the development of chondral lesions, and abnormal stress distribution patterns of the knee joint caused by MMS lead to increased focal loading on articular cartilage and subsequent chondral loss.

In a longitudinal study, BMI was reported to be a risk factor for the development of MME (OR 3.04, 95% CI 1.04–8.93) [22], but we found that BMI was not associated with MMS. In our study, patients were in a supine non weight-bearing position when the MRI was performed, therefore, BMI might have little influence on MME. The results may be altered when patients are in a weight-bearing position.

There were some limitations of this study. First, the sample size was relatively small, and only five patients with longitudinal tears and four patients with bucket-handle tears were included in the study. Second, the nature of the cross-sectional design of this study did not allow us to confirm the temporal order of incidents; hence, a causal relationship between variates and MMS could not be determined.

Third, because of the paucity of long-leg radiographs, knee malalignment was not assessed in our study. Therefore, longitudinal investigations with larger samples and more variates should be performed to identify the risk factors for further study.

Conclusions

Our results demonstrated that the type of MMT was an independent factor associated with MMS in knees with MMT. Radial tears, PMMRT and complex tears were more likely than horizontal tears to result in MMS. The results suggest that MMT combined with MMS should be noticed when managing MMT, especially radial tears, PMMRT and complex tears. We must not only preserve the meniscus as much as possible but also restore its position to as close to normal as possible.

List Of Abbreviations

MME Medial meniscal extrusion

MMS Medial meniscal subluxation

MMT Medial meniscus tears

ICC Intraclass correlation coefficient

PMMRT Posterior medial meniscus root tears

OR Odds ratio

CI Confidence interval

Declarations

Ethics approval and consent to participate

The study was approved by the Ethical Review Committee of Peking University International Hospital (NO. 2019-070). The Ethical Review Committee determined that patient approval and informed consent were not required for reviewing images and records.

Consent for publication

No applicable

Availability of data and materials

All data generated or analyzed during this study are included in this article.

Competing interests

The authors declare that they have no competing interests.

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Author's contributions

Xinguang Liu: Conceptualization, Methodology, Data Curation, Writing-original draft. Ran Ding: Investigation. Bin Yang: Investigation. Chen Liu: Data Curation, Supervision. Weiguo Wang: Conceptualization, Methodology, Writing - Review & Editing. All authors have read and approved the final manuscript.

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Figures

Figure 1

Measurement of medial meniscal extrusion on an MR image Measurement of medial meniscal extrusion: Using a mid-coronal MR image, the first vertical line was drawn to intersect the medial edge of the medial tibial plateau (dotted line a), and the second vertical line was drawn to intersect the medial edge of the medial meniscus (solid line b). The distance between the two lines (arrow line c) was defined as the medial meniscal extrusion distance.