Knee Surgery, Sports Traumatology, Arthroscopy (2021) 29:2843–2850
https://doi.org/10.1007/s00167-020-06179-y

KNEE

Widening of the popliteal hiatus on sagittal MRI view plays a critical role in the mechanical signs of discoid lateral meniscus

Zhou Li[1] · Weijie Fan[1] · Zhu Dai[1] · Heng Zhao[2] · Ying Liao[1] · Yunliang Lei[1] · Tao Luo[1] · Quanhui Liu[1] · Jian Li[1]

Received: 27 March 2020 / Accepted: 20 July 2020 / Published online: 29 July 2020

Abstract

Purpose This study was undertaken to elucidate the clinical significance of widening of the popliteal hiatus on magnetic resonance imaging (MRI) after a torn discoid lateral meniscus (DLM).
Methods Included are 125 knees with meniscal disorders after arthroscopic surgery, divided according to preoperative MRI and symptoms into group A (torn DLM with mechanical symptoms,11 knees); group B (torn DLM without mechanical symptoms,41 knees); group C (asymptomatic DLM, 19 knees); and group D (medial meniscal tears, 54 knees). Popliteal hiatus width was measured on sagittal and coronal MRI. During arthroscopy, total meniscectomy or central partial meniscectomy combined repair of the remaining part was performed in group A and group B. Outcomes were evaluated with MRI, the Tegner, Lysholm Knee Scoring Scale, and visual analog scale (VAS) scores.
Results The preoperative width of the popliteal hiatus was significantly larger in group A than in groups C and D ($P<0.05$) on both views. Group A had a wider popliteal hiatus on sagittal view compared with group B ($P<0.05$); group B had a wider popliteal hiatus on coronal view compared with group D ($P<0.05$). The width of the popliteal hiatus on sagittal view was significantly reduced after surgery in group A ($P<0.05$). In groups A and B, Lysholm and Tegner scores were improved, while VAS scores were reduced (all $P<0.05$).
Conclusion Widening of the popliteal hiatus on MRI was correlated with torn DLM and accompanied mechanical symptoms. Arthroscopic central partial menisectomy and stabilization of the posterior part of the middle body anterior to the popliteus tendon were effective for the treatment of torn DLM. These findings may help guide appropriate treatment for torn DLM.
Level of evidence II.

Keywords Knee · Popliteal hiatus · Discoid lateral meniscus · MRI · Arthroscopy

Introduction

A discoid lateral meniscus (DLM) has an enlarged thickness and width of the meniscus, in addition to a different ultra structure compared with the normal lateral meniscus [5, 8, 17]. The incidence of DLM is higher in Asian populations [5, 8, 13, 16, 23]. Watanabe et al. first divided the DLM into three types: complete, incomplete, and Wrisberg [8, 23]. The predisposition of the DLM to tear is multifactorial and is, in part, due to abnormal morphology and structure and the degree of shear force is placed on the abnormal substance of the DLM.

Discoid lateral meniscus is generally asymptomatic, unless there is a tear in the meniscal tissue or instability of the peripheral rim. Pain over the lateral compartment is the most common presenting symptom, with occasional mechanical symptoms including snapping and locking [8]. The peripheral rim instability plays an important role in mechanical symptoms, which most likely present with tears in adult patients [17, 22]. According to Klingele et al., peripheral rim instability has a prevalence of 28.1% for symptomatic DLM, and it most commonly involves the anterior third (47.2%) of the meniscus, followed by the posterior

Zhou Li and Weijie Fan contributed equally to this work and should be considered as co-first authors.

✉ Zhu Dai
oliverdai@hotmail.com

1 Department of Orthopedics, The First Affiliated Hospital of University of South China, Hengyang 421001, Hunan, China

2 Department of Radiology, The First Affiliated Hospital of University of South China, Hengyang 421001, Hunan, China

third (38.9%), and less frequently, the middle third (11.1%) [11]. On magnetic resonance imaging (MRI), findings such as parameniscal edema, shape deformation, and meniscal displacement can alert one to the presence of instability in the setting of DLM [17]. Ahn et al. divided DLM into anterocentral shift, posterocentral shift, central shift, and no shift using MRI. These divisions are based on the anatomic location in the joint into which the meniscus is displaced [3]. However, the degree of instability in DLM was difficult to confirm on MRI.

The lateral meniscus has no attachments to the lateral collateral ligament, with a thin and loose posterior capsule, and there is an interruption of its capsular attachments at the popliteal hiatus. The lateral meniscus connects to the popliteus tendon through the popliteomeniscal fascicles (PMFs) and has greater mobility than the medial meniscus. Injury to the posterolateral part of lateral meniscus results in meniscal hypermobility and subluxation, which are characterized by mechanical symptoms, such as snapping and locking [1, 22]. A previous study showed the widening of the popliteal hiatus of the lateral meniscus on MRI leading to recurrent subluxation of the nondiscoid lateral meniscus [14]. DLM had a high rate of peripheral rim instability, high predisposition to tear, and common mechanical symptoms. However, studies regarding MRI evaluation of the popliteal hiatus of DLM have never been reported before.

Hence, the purpose of this study was to investigate the relationship between the width of the popliteal hiatus on MRI and tears of the DLM, to investigate the role of generation of mechanical symptoms after torn DLM, and to document the clinical results and technical aspects of arthroscopic surgery of this condition. It was hypothesized that (1) a torn DLM would have a wider popliteal hiatus on coronal or sagittal MRI compared with the normal lateral meniscus and asymptomatic DLM; (2) the group with a torn DLM and mechanical symptoms would have widening of the popliteal hiatus on sagittal MRI compared with torn DLM without mechanical symptoms; and (3) central partial meniscectomy and repair of the posterior part of the middle body anterior to the popliteus tendon under arthroscopy would be an effective treatment for torn DLM. This work would help guide appropriate treatment for torn DLM.

Materials and methods

Approval for this study was obtained from the ethics committee of the University of South China (NO.2016002) and written informed consent was obtained from each patient included in this study. Three hundred sixty-four knees (of 355 patients) with meniscal disorders were treated arthroscopically by the senior surgeon in the department of orthopedics from January 2016 to March 2018. Included were patients without a history of acute knee injury and ligament tear. Excluded were patients with combined injury of the knee ligaments ($n=64$), patients younger than 16 years ($n=6$), patients older than 55 years ($n=62$), or those with lateral osteoarthritis of grade 2 or higher on the Kellgren–Lawrence scale on radiographic examination ($n=1$). Patients whose radiologic images were performed in other hospitals ($n=17$) and those with grade 3 tears and defects of the posterior horn and body ($n=2$) of the lateral meniscus were also excluded because an exact examination of the popliteal hiatus could not be performed. Patients with torn nondiscoid lateral meniscus ($n=79$) were not discussed in this study and were, therefore, excluded. As for DLM, the Wrisberg variant ($n=3$; two patients) and noncomplete variant ($n=2$) according to the Watanabe classification [23] and those with an anterocentral shift ($n=1$) and posterocentral shift ($n=4$) tear type according to Ann et al. [3] were also excluded. Two patients with a torn DLM on one side and no symptoms on the contralateral side received an MRI exam on both sides. If DLM was found on the asymptomatic side, these patients were also included in this study. Finally, 125 knees (115 patients) were included in this study and were divided into 4 groups (Table 1). Group A: torn DLM with mechanical symptoms of the lateral side of the knee including snapping and sudden locking. Group B: torn DLM without mechanical symptoms. Group C: asymptomatic complete DLM found in knees with medial meniscal tears and two knees with torn DLM on the contralateral side as mentioned previously; Group D: normal lateral meniscus with medial meniscal tears.

All MRI examinations were performed with a Philips Ingenia 3.0 T MRI scanner (Philips, Amsterdam, Netherlands). Coronal and sagittal images (2.5 mm slices) were obtained with the patient supine and the knees fully extended. The MRI images were read on a picture archiving and communication system (PACS) similar to the previous study [14], and measurements were performed automatically to within one decimal point of accuracy with the built-in line tool. The short tau inversion recovery (STIR) image slices (both views) with the largest popliteal hiatus width were chosen for the study measurements. The slices were identified by drawing a line parallel to the lateral tibial plateau

Table 1 Characteristics of the groups

Groups	Characteristics
Group A	Torn DLM with mechanical symptoms, including snapping and sudden locking
Group B	Torn DLM without mechanical symptoms
Group C	Asymptomatic complete DLM, with or without medial meniscal tears
Group D	Normal lateral meniscus with medial meniscal tears

from the middle point of the edge of the lateral meniscus to the popliteus tendon in both views (Fig. 1). The MRI measurements were performed by a radiologist with 10 years of experience specializing in the musculoskeletal system; the radiologist was blinded to the clinical information. The radiologist performed a second set of measurements 4 weeks after the first set and recorded the mean value. The test–retest reliability was tested using the intraclass correlation coefficient (ICC) with a two-way mixed model and with absolute agreement. ICC levels were classified as poor (0–0.2), fair (0.3–0.4), moderate (0.5–0.6), strong (0.7–0.8), and excellent > 0.8 [15].

All patients in group A and group B were reexamined at 1, 2, 3, and 6 months and then annually after the operation. All patients were followed for more than 24 months (average 26 months). The width of the popliteal hiatus was reassessed at 6 months or more postoperatively using MRI scanning in six patients (seven knees) from group A; these patients received central partial meniscectomy and repair of the posterior part of the middle body anterior to the popliteal hiatus. Preoperative and postoperative knee functions were estimated using Lysholm scores, the Tegner activity scale, and visual analog scale (VAS) pain scores, all of which were compared. The treatment and follow-up data for group C and group D are not discussed in this study.

Statistical analysis

Statistical analysis was performed using SPSS version 19.0 statistical software (IBM Corp, Armonk, NY, United States). The width of the popliteal hiatus was expressed as mean ± standard deviation. If the data were not normally distributed, the results were presented as median values. Differences in MRI measurements among the groups were analyzed using a Student *t* test. Values within group A were analyzed by paired *t* test. In group A and group B, comparisons of preoperative and postoperative Lysholm scores were performed with the paired *t* test. Tegner scores and VAS scores were assessed using the nonparametric Wilcoxon signed-rank test. An α level of 0.05 indicated significance.

Sample size was estimated utilizing MedSci sample size tools (version 2.1, MedSci, Shanghai, China), accepted α error was 0.05, and the β error was 0.2 to ensure a power of 80%. The calculation revealed that it was necessary to include at least 9 patients in group A and 36 patients in the control group.

Results

Group A included 11 knees (10 patients) with confirmed torn DLM by MRI and arthroscopy. The average symptom duration in this group was 18.2 months (range, 1 month to 10 years). All patients had pain on the lateral side, tenderness on the lateral joint line, and exhibited mechanical symptoms including snapping ($n = 2$) and sudden locking ($n = 2$) or both ($n = 7$). McMurray tests were positive in 9 knees and Apley compression tests were positive in 11 knees. Group B included 41 knees (38 patients) with confirmed torn DLM and had symptoms and signs similar to group A but without mechanical symptoms. The average symptom duration in this group was 25.4 months (range, 1 month to 10 years). Group C included 19 knees of asymptomatic complete discoid meniscus. Seventeen of these knees had a medial meniscus tear without pain on the lateral side and no tenderness on the lateral joint line. DLM was found incidentally on MRI and confirmed by arthroscopy. Another two knees included in group C had been mentioned above. Group D included 54 knees (50 patients) with no history of lateral knee pain or tenderness; all patients had medial meniscal tears, but none had abnormalities of the lateral meniscus on MRI or arthroscopy. The four groups were similar in terms of age, sex, and body mass index.

In group A, total meniscectomy was performed in four knees because of a large, longitudinal tear of the posterolateral peripheral rim and degeneration of the meniscus tissue (Fig. 2). Central partial meniscectomy and repair of the posterior part of the middle body anterior to the popliteal hiatus using 1–2 outside-in vertical mattress sutures were performed in seven knees. Those with hypermobility

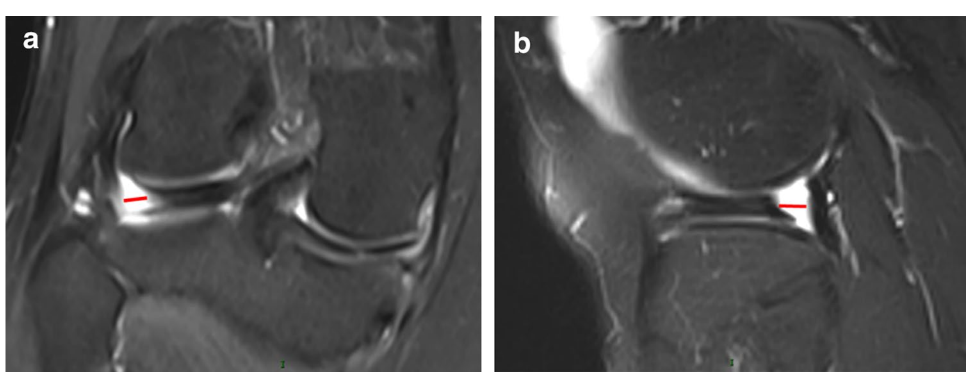

Fig. 1 Measurement of the popliteal hiatus on MRI. **a** Coronal view. **b** Sagittal view. Red line: popliteal hiatus width

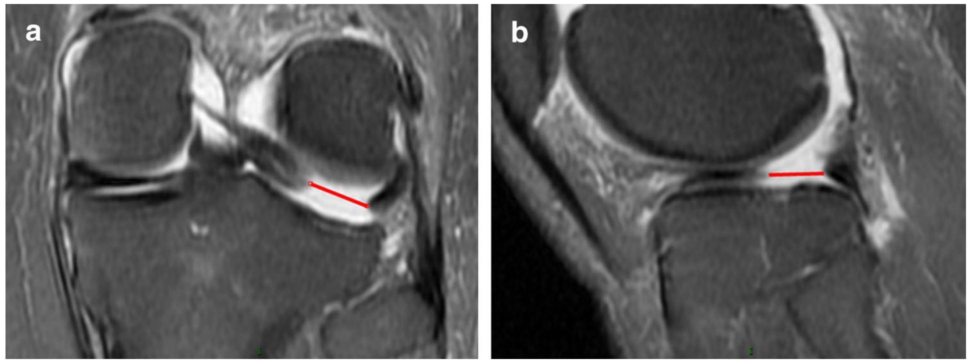

Fig. 2 Image from 1 case in group A. **a** The popliteal hiatus on coronal MRI was 12.7 mm. **b** The popliteal hiatus on sagittal MRI was 10.9 mm. Red line: popliteal hiatus width

of the posterolateral part of the remaining lateral meniscus were identified by careful probing (Fig. 3). In group B, total meniscectomy was performed in two knees, and central partial meniscectomy was performed first in another 39 knees, posterolateral peripheral rim instability was found by careful probing in sevens knees, and repair of the posterior part of middle body anterior to the popliteus tendon was performed. The repair of the posterior part of the popliteal hiatus behind

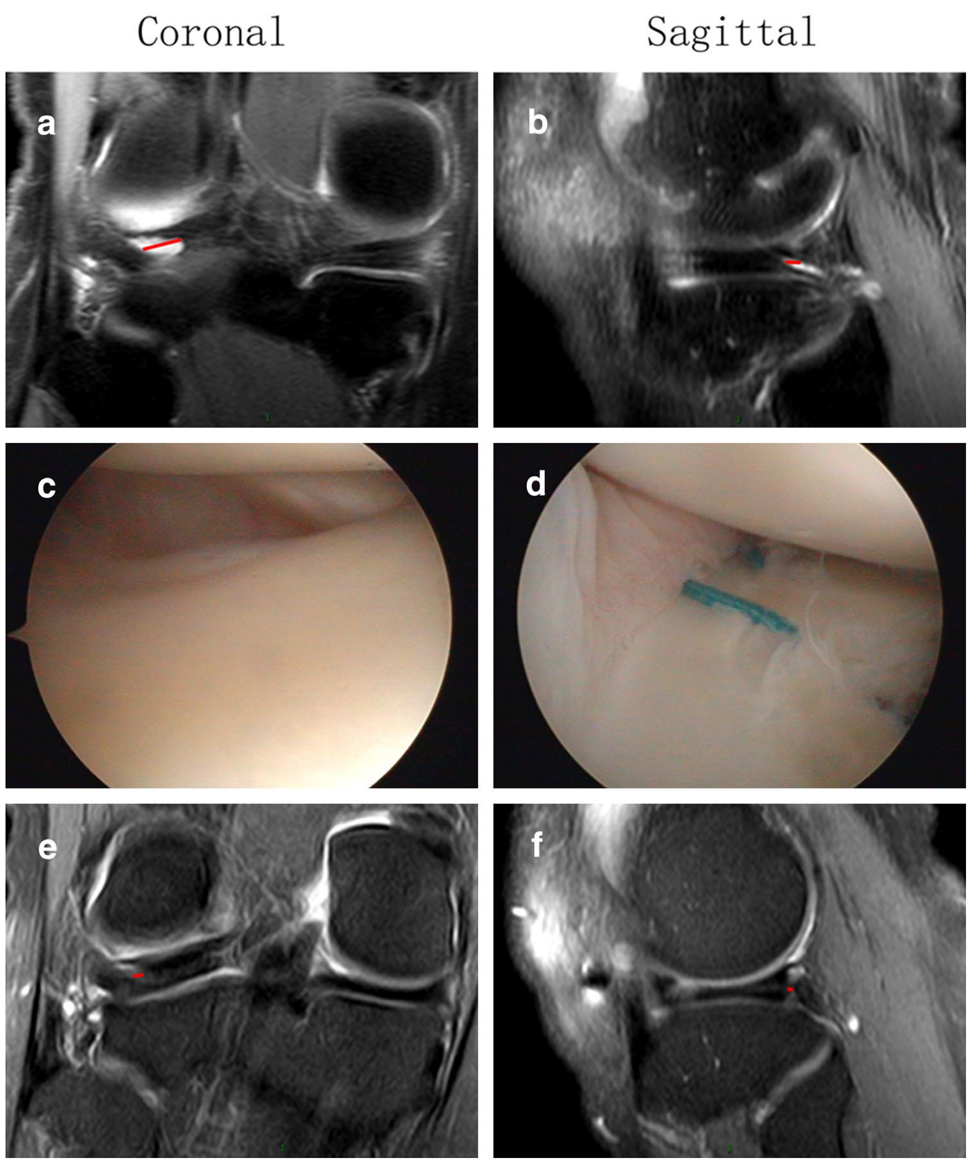

Fig. 3 Image from 1 case in group A. **a, b** The popliteal hiatus on coronal and sagittal MRI was 7.2 mm and 2.2 mm respectively. **c** The enlarged popliteal hiatus under arthroscopy. **d** The width of the popliteal hiatus was reduced after tightening by 2 vertical mattress sutures. **e, f** The coronal and sagittal view on the postoperative MRI shows the reduced width of the popliteal hiatus was 1.9 mm and 1.7 mm. Red line: popliteal hiatus width

the popliteus tendon was achieved using one Fast-Fix (Smith & Nephew, Andover, MA, United States) simultaneously in three knees.

The ICC was greater than 0.9 for all the measurements of the popliteal hiatus width on the coronal and sagittal view; the two measurements were reliable. On the coronal MRI view, the width of the popliteal hiatus was significantly larger in group A compared with that of groups C and D ($P < 0.05$). Further, the width was larger in group B compared with that of group D ($P < 0.05$), and there was no significant difference between group A and B, and group C and D (n.s.). On sagittal MRI, the width of the popliteal hiatus was significantly larger in group A than in group B, C, and D ($P < 0.05$), and there was no significant difference within group B, C, and D (n.s.; Table 2).

In group A and group B, all patients were followed for more than 24 months (average 26 months). During follow-up examination, symptoms of knee pain were relieved, and all patients had a negative McMurray test and Apley grinding test. Symptoms of locking and snapping in group A were resolved. In group A, six patients (seven knees) who received central partial meniscectomy and repair of the posterior part of the middle body anterior to the popliteal hiatus underwent repeat MRI at 6–12 months postoperatively, and the width of the popliteal hiatus was significantly decreased on sagittal view ($P < 0.05$) but similar on coronal views (n.s.). The width of the popliteal hiatus was similar to those of group B, C, and D (n.s.). One-year and 2-year postoperative Lysholm and Tegner scores were also significantly improved vs the preoperative scores ($P < 0.05$), and the VAS pain scores were significantly reduced ($P < 0.05$). There were no significant differences between group A and group B (n.s.; Table 3).

Table 3 Comparison of clinical outcomes of Group A and Group B (mean ± SD)

Variables	Preoperative	1 Years postoperative	2 Years postoperative
Group A ($n = 11$)			
Lysholm scores	65.4 ± 9.1	93.1 ± 2.3*	93.5 ± 1.5*
Tegner scores	3.0(3.0–4.0)	6.0 (5.0–7.0)*	6.5(5.0–7.0)*
VAS scores	2.8 ± 0.4	1.0 ± 0.6*	0.6 ± 0.7*
Group B ($n = 41$)			
Lysholm scores	65.3 ± 8.6	92.0 ± 4.3*	92.5 ± 3.7*
Tegner scores	3.0(3.0–4.0)	6.0 (5.0–7.0)*	6.5(5.0–7.0)*
VAS scores	2.8 ± 0.4	0.8 ± 0.4*	0.6 ± 0.5*

*Significant difference compared with preoperative, $P < 0.05$

Discussion

There were three important findings in the current study. The first was that a tear of the DLM was accompanied by widening of the popliteal hiatus on coronal view or both views on MRI. The second was that the widening of the popliteal hiatus on sagittal MRI was correlated to the mechanical symptoms of a torn DLM. The third was that central partial meniscectomy and suture repair of the posterior part of the middle body anterior to the popliteus tendon were effective in securing the stability of the remaining meniscus tissue of the torn DLM.

The DLM has a high rate of peripheral rim instability compared with the normal lateral meniscus. Klingele et al. reported 28.1% of DLM had peripheral rim instability [12]. Ahn et al. [2] and Hagino et al. [6] also reported 33.7% (30 out of 89 cases) and 15.4% (6 out of 39 cases), respectively, of DLM had severe peripheral rim instability. These authors found peripheral rim instability of the torn and symptomatic DLM under arthroscopy. On MRI, Kang MS et al. found displacement of the middle part of the DLM on coronal view passing through the center of the lateral tibial plateau, and displacement of the anterior or posterior horn on sagittal view in children with torn DLM, a prediction of peripheral rim instability [9]. Recently, Kim JH et al. found peripheral rim instability not only in torn DLM, but also in intact DLM. They found that the anterior horn and posterior horn instabilities were greater in the intact DLM than in the normal lateral meniscus. They concluded that the peripheral rim instability of the DLM was congenital [10].

The DLM is predisposed to tears, with the complete type being more frequently affected than the incomplete type. The peripheral rim instability of the DLM is also the cause of the vulnerability of the DLM, and tears including horizontal,

Table 2 Diameters of the popliteal hiatus

Parameter	Group A ($n = 11$)	Group B ($n = 41$)	Group C ($n = 19$)	Group D ($n = 54$)	Postoperative Group A ($n = 7$)
Diameter of popliteal hiatus					
Coronal	5.6 ± 3.8	3.8 ± 3.5	2.5 ± 2.3*	2.6 ± 1.7*#	3.0 ± 0.9
Sagittal	3.6 ± 2.9	1.3 ± 1.5*	1.4 ± 1.7*	1.6 ± 1.0*	2.3 ± 0.7*

Diameter of the popliteal hiatus values are in millimeters. Data in parentheses are presented as means ± standard deviations

*Indicate significant difference compared with Group A

Indicate significant difference compared with Group B

longitudinal, radial, and complex in the DLM will increase instability [11, 17, 24]. In the current study, in group A and B, with a tear in the DLM, the peripheral rim instability becomes inevitably aggravated, with resultant widening of the popliteal hiatus on coronal view or both coronal and sagittal view.

In accordance with Smillie's 1948 original explanation of snapping in DLM, mechanical signs such as snapping and locking come from instability or meniscal tears that permit a large meniscal fragment to migrate freely [17]. Mechanical signs were common in torn DLM. In anterior peripheral rim instability, posterior subluxation and anterior reduction of the anterior horn are suggested to generate the clicking symptom [9]. Knees with anterior peripheral rim instability were excluded in this study because of the difference in the mechanism of mechanical signs compared with that of group A. In Wrisberg DLM, there is a lack of posterior meniscal attachments resulting in meniscal hypermobility, and the meniscus tissue subluxates anteriorly on flexion, often producing a clunk when reducing in extension [7]. Hypermobility or recurrent subluxation of the lateral meniscus has drawn more attention in recent years. It is a condition in which the posterior portion of the lateral meniscus has excessive mobility, either because of congenital absence of or injury to the posterior capsulomeniscal attachment; however, these series did not include DLM cases [1, 14, 19, 22]. In a torn DLM, the peripheral rim instability gradually aggravated or acutely into a longitudinal tear of the peripheral rim after trauma, followed by progressive posterolateral meniscal displacement. The meniscal displacement then would progress to mechanical signs just like hypermobility or recurrent subluxation of the lateral meniscus.

The popliteal hiatus is an oblique anterolaterally directed oval-shaped tunnel defined by the superior and inferior PMF of the lateral meniscus, which permits the popliteus tendon to pursue its course. The popliteal hiatus is an important component of the posterolateral structure of the knee and is a key contributor to the stability of the lateral meniscus [4, 14]. On coronal view of the MRI, the width of the popliteal hiatus theoretically indicates the loosening of the attachment of the posterior horn and capsule. The more the anterior displacement of the posterior horn, the wider the gap between the meniscal edge and the popliteus tendon. On sagittal MRI, the more medial displacement of the middle part of the lateral meniscus, the larger the gap between the meniscal edge and the popliteus tendon, which indicates the stability of the middle part of the lateral meniscus. Although group B had a similar width of the popliteal hiatus compared with group C, it had an increased width of the popliteal hiatus on coronal view but not on sagittal view compared with group D. Mobility of the posterior horn increased mainly anteriorly and the range was limited. In group A, both the width of the popliteal hiatus on coronal and sagittal view was increased compared with group C and group D, which indicates the loosening of the posterolateral part of the DLM including the posterior horn and posterior part of the middle body.

In torn DLM, the mechanical symptoms group had a wider popliteal hiatus on sagittal view but not on coronal view compared with that of the group without mechanical symptoms. This indicated that the stability of the middle body of the lateral meniscus anterior to the popliteus tendon was critical to the production of mechanical symptoms. In the middle body of the DLM, the middle perforating bundle is tightly connected with the joint capsule; here, horizontal cleavage tears occur more frequently than longitudinal tears [17]. In Klingele et al.'s study, the peripheral rim instability of the middle part was much less than that of the anterior horn and posterior horn [11]. Kim JH et al. found inborn peripheral rim instability in the anterior horn and posterior horn in comparison to the normal lateral meniscus, but the stability of the middle body was similar [9]. Inability of the posterolateral part of the lateral meniscus was associated with injury of the PMF [9, 12]. In Suganuma J et al.'s study, in nondiscoid lateral meniscus, a significantly high incidence of abnormal posterosuperior PMF was found in recurrent subluxation of the lateral meniscus and contralateral knees. However, abnormal anteroinferior PMF was found only in the knee joints with recurrent subluxation of the lateral meniscus. They concluded that an abnormal anteroinferior PMF is, therefore, the essential lesion to allow the at-risk lateral meniscus to become unstable enough for locking symptoms [20]. The posterosuperior PMF covers the posterosuperior aspect of the popliteus tendon [4, 18, 21], any injury of which would increase the anterior displacement of the posterior horn and widen the popliteal hiatus on coronal view. The anteroinferior PMF covers the anteroinferior aspect of the popliteus tendon [4, 18, 21], any injury of which would lead to medial displacement of the middle body of the DLM and widen the popliteal hiatus on sagittal view in the current study. In peripheral rim instability DLM knees, suture repair of the middle part of the remaining meniscal tissue anterior to the popliteal hiatus was essential. In group A and part of group B, we used vertical mattress sutures to reduce the stability of posterolateral part of the lateral meniscus; the result on clinical follow-up was improved. Interestingly, on postoperative MRI of group A, the width of the popliteal hiatus was only decreased on sagittal view but not on coronal view; however, the mechanical symptoms had resolved.

This study has several limitations. First, there was no control group of individuals with normal knees. Second, the popliteal hiatus was not measured under arthroscopy because of the limited field and, therefore, did not compare with the measurement on MRI. Third, the measurements were based on routine coronal and sagittal views of MRI, with a 2.5 mm slices, the slices we selected may not have been exactly the widest portion of the popliteal hiatus. An oblique view along the axis of the popliteal hiatus should be used in future studies to reduce this bias. However, this study describes the relationship between the widening of the popliteal hiatus and the torn DLM. This study emphasizes the importance of the posterior part of the middle body anterior to the popliteus tendon, and these findings may help guide appropriate treatment for torn DLM.

Conclusions

Widening of the popliteal hiatus on MRI was correlated with torn DLM and accompanied mechanical symptoms. Arthroscopic central partial menisectomy and stabilization of the posterior part of the middle body anterior to the popliteus tendon were effective for the treatment of torn DLM.

Acknowledgements We thank Dr. Zhijun Yang for assistance in the statistical analysis of our data and preparation of figures of this article.

Compliance with ethical standards

Conflict of interest This work was supported by grants from the Natural Science Foundation of Hunan Province (2019JJ40270), and grants from the Scientific Research Fund Project of Hunan Province Health Commission (20201907). Zhou Li, Weijie Fan, Zhu Dai, Heng Zhao, Ying Liao, Yunliang Lei, Tao Luo, Quanhui Liu, Jian Li declare that they have no conflict of interest.

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Approval for this study was obtained from the ethics committee of the First Affiliated Hospital of University of South China and informed consent forms were signed by each patient included in this study.

References

1. Ahn JH, Lee SH, Kim KI, Nam J (2018) Arthroscopic meniscus repair for recurrent subluxation of the lateral meniscus. Knee Surg Sports Traumatol Arthrosc 26:787–792
2. Ahn JH, Lee SH, Yoo JC, Lee YS, Ha HC (2008) Arthroscopic partial meniscectomy with repair of the peripheral tear for symptomatic discoid lateral meniscus in children: results of minimum 2 years of follow-up. Arthroscopy 24:888–898
3. Ahn JH, Lee YS, Ha HC, Shim JS, Lim KS (2009) A novel magnetic resonance imaging classification of discoid lateral meniscus based on peripheral attachment. Am J Sports Med 37:1564–1570
4. Aman ZS, DePhillipo NN, Storaci HW, Moatshe G, Chahla J, Engebretsen L, LaPrade RF (2019) Quantitative and qualitative assessment of posterolateral meniscal anatomy: defining the popliteal hiatus, popliteomeniscal fascicles, and the lateral meniscotibial ligament. Am J Sports Med 47:1797–1803
5. Choi YH, Seo YJ, Ha JM, Jung KH, Kim J, Song SY (2017) Collagenous ultrastructure of the discoid meniscus: a transmission electron microscopy study. Am J Sports Med 45:598–603
6. Hagino T, Ochiai S, Senga S et al (2017) Arthroscopic treatment of symptomatic discoid meniscus in children. Arch Orthop Trauma Surg 137(1):89–94
7. Jose J, Buller LT, Rivera S, Carvajal Alba JA, Baraga M (2015) Wrisberg-variant discoid lateral meniscus: current concepts, treatment options, and imaging features with emphasis on dynamic ultrasonography. Am J Orthop (Belle Mead NJ) 44:135–139
8. Kinugasa K, Hamada M, Yonetani Y, Matsuo T, Mae T, Nakata K, Horibe S (2019) Discoid lateral meniscal repair without saucerization for adolescents with peripheral longitudinal tear. Knee 26:803–808
9. Kang MS, Kim JM, Park SS, Bin SI (2019) Prediction of the peripheral rim instability of the discoid lateral meniscus in children by using preoperative clinicoradiological factors. J Pediatr Orthop 39:e761–e768
10. Kim JH, Bin SI, Lee BS, Kim JM, Kim NK, Lee CR (2018) Does discoid lateral meniscus have inborn peripheral rim instability? Comparison between intact discoid lateral meniscus and normal lateral meniscus. Arch Orthop Trauma Surg 138:1725–1730
11. Klingele KE, Kocher MS, Hresko MT, Gerbino P, Micheli LJ (2004) Discoid lateral meniscus: prevalence of peripheral rim instability. J Pediatr Orthop 24:78–82
12. LaPrade RF, Konowalchuk BK (2005) Popliteomeniscal fascicle tears causing symptomatic lateral compartment knee pain: diagnosis by the figure-4 test and treatment by open repair. Am J Sports Med 33:1231–1236
13. Lee DH, D'Lima DD, Lee SH (2019) Clinical and radiographic results of partial versus total meniscectomy in patients with symptomatic discoid lateral meniscus: a systematic review and meta-analysis. Orthop Traumatol Surg Res 105:1–7
14. Li Z, Zhao H, Dai Z, Chen Z, Liao Y, Fu D, Lei Y, Luo T, Liu Q (2019) Widening of the popliteal hiatus on magnetic resonance imaging leads to recurrent subluxation of the lateral meniscus. Knee Surg Sports Traumatol Arthrosc. https://doi.org/10.1007/s00167-019-05800-z
15. McDougall CJ, Gallie P, Whitehouse SL (2016) Preoperative assessment of femoral rotation and its relationship with coronal alignment: a magnetic resonance imaging study. J Orthopaed 13:290–293
16. Park YB, Kim SH, Ha CW, Han JW, Noh JW (2020) A predictive model with radiographic signs can be a useful supplementary diagnostic tool for complete discoid lateral meniscus in adults. Knee Surg Sports Traumatol Arthrosc. https://doi.org/10.1007/s00167-020-05972-z
17. Restrepo R, Weisberg MD, Pevsner R, Swirsky S, Lee EY (2019) Discoid meniscus in the pediatric population: emphasis on MR Imaging signs of instability. Magn Reson Imaging Clin N Am 27:323–339
18. Stäubli HU, Birrer S (1990) The popliteus tendon and its fascicles at the popliteal hiatus: gross anatomy and functional arthroscopic evaluation with and without anterior cruciate ligament deficiency. Arthroscopy 6:209–220
19. Steinbacher G, Alentorn-Geli E, Alvarado-Calderón M, Barastegui D, Álvarez-DíazCugat PR (2018) Meniscal fixation is a successful treatment for hypermobile lateral meniscus in soccer players. Knee Surg Sports Traumatol Arthrosc 27:354–360
20. Suganuma J, Mochizuki R, Inoue Y, Yamabe E, Ueda Y, Kanauchi T (2012) Magnetic resonance imaging and arthroscopic findings of the popliteomeniscal fascicles with and without recurrent subluxation of the lateral meniscus. Arthroscopy 28:507–516
21. Terry GC, LaPrade RF (1996) The posterolateral aspect of the knee. Anatomy and surgical approach. Am J Sports Med 24:732–739
22. Van Steyn MO, Mariscalco MW, Pedroza AD, Smerek J, Kaeding CC, Flanigan DC (2016) The hypermobile lateral meniscus:

a retrospective review of presentation, imaging, treatment, and results. Knee Surg Sports Traumatol Arthrosc 24:1555–1559
23. Watanabe M, Takeda S, Ikeuchi H (1978) Atlas of arthroscopy. IgakuShoin, Tokyo, p 88
24. Yilgor C, Atay OA, Ergen B, Doral MN (2014) Comparison of magnetic resonance imaging findings with arthroscopic findings in discoid meniscus. Knee Surg Sports Traumatol Arthrosc 22:268–273