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Widening of the popliteal hiatus on magnetic resonance imaging leads to recurrent subluxation of the lateral meniscus

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Abstract

Purpose This study was undertaken to elucidate the clinical significance of widening of the popliteal hiatus on magnetic resonance imaging (MRI), and to document the clinical results and technical aspects of arthroscopic repair of this finding.

Methods Included are 82 knees after arthroscopic surgery, divided according to arthroscopic diagnosis into group A, hypermobility of lateral meniscus, 8 knees; group B, tear of the anterior horn of the lateral meniscus, 32 knees; and group C, no abnormality of the lateral meniscus, 36 knees with medial meniscal tears and 6 with other conditions. Popliteal hiatus diameter was measured and the popliteal hiatus/lateral tibial plateau (LTP) ratio was calculated on preoperative sagittal and coronal MRI. At arthroscopy, the widened popliteal hiatus in group A was tightened anteriorly by outside-in or all-inside suture and posteriorly with all-inside suture. Outcomes were evaluated with MRI, Lysholm, Tegner and VAS scores.

Results The preoperative diameter of the popliteal hiatus and the popliteal hiatus/LTP ratio were significantly larger in group A than in groups B and C ($p < 0.05$) on both views. Threshold popliteal hiatus/LTP values of 0.16 and 0.18 on the sagittal and coronal views demonstrated diagnostic discrimination, and these values were significantly reduced after arthroscopy in Group A. Lysholm and Tegner scores were improved after tightening of the popliteal hiatus, while VAS scores reduced (all $p < 0.05$).

Conclusion Widening of the popliteal hiatus on MRI may lead to recurrent subluxation of the lateral meniscus. Arthroscopic anterior and posterior tightening of the popliteal hiatus was a safe and effective treatment.

Level of evidence II.

Keywords Knee · Popliteal hiatus · Lateral meniscus · MRI · Arthroscopy

Introduction

The popliteal hiatus is an oblique anterolaterally directed oval-shaped tunnel defined by the superior and inferior fascicles of the lateral meniscus, which permits the popliteal tendon to pursue its course. The posterosuperior and anteroinferior popliteomeniscal fascicles (PMFs) make up the roof and floor of the popliteal hiatus and help to stabilize the lateral meniscus [3, 4]. 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 [3, 4, 21, 28].

At present, there are only a few reports of meniscal lesions involving the popliteal hiatus in nondiscoid meniscus, including PMF injury [2, 10, 21, 25, 28], injuries at the medial edge of the popliteal hiatus, and tears of the anterior and posterior aspects of the popliteal hiatus [2]. These injuries lead to recurrent subluxation and hypermobility of the lateral meniscus and mechanical symptoms including lateral knee pain, locking, and snapping [9, 12]. Hypermobility of the lateral meniscus has drawn more attention in recent years. It is a condition in which the posterior horn of the lateral meniscus has excessive mobility, either because of the congenital absence of or injury to the posterior capsulomeniscal attachment [16, 23, 26]. Recurrent subluxation and

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hypermobility are usually diagnosed at arthroscopy, when the posterior horn of the lateral meniscus is translated to the centre of the lateral tibial plateau during probing or suction [2, 23, 26].

Magnetic resonance imaging (MRI) is the most relied-upon method for the diagnosis of meniscal disorders. However, studies regarding MRI evaluation of the popliteal hiatus are scarce, and are focused on the PMF [24, 28], and there has been no previous study regarding measurement of the popliteal hiatus on MRI. In cases of hypermobile lateral meniscus at arthroscopy, there is no definite evidence of meniscal tear on MRI. In recent years, several patients with mechanical symptoms including snapping and sudden locking of the lateral knee accompanied by isolated widening of the popliteal hiatus and a normal-appearing lateral meniscus on MRI were treated by arthroscopic surgery, who had hypermobility of the lateral meniscus discovered at arthroscopy.

The purpose of this study was to describe the measurement of popliteal hiatus on sagittal and coronal MRI, to evaluate the clinical significance of the finding of widening of the popliteal hiatus on MRI, and to document the clinical results and technical aspects of arthroscopic modification of this condition. It was hypothesized that a widened popliteal hiatus on MRI may lead to recurrent subluxation of the lateral meniscus, and anterior and that posterior tightening of the popliteal hiatus under arthroscopy was safe and effective.

Materials and methods

Approval for this study was obtained from the ethics committee of the University of South China (No. 2013012) and written informed consent forms were obtained from each patient included in this study. From 2013 to 2016, the senior surgeon in the department of orthopaedics treated 216 knees (208 patients) by arthroscopy. Included were patients with meniscal disorders without history of acute knee injury. Excluded were patients with combined injury of ligaments of the knee ($n=81$) and those with discoid lateral meniscus ($n=37$) because of the inherent luxation of the peripheral rim of the discoid meniscus [11, 14, 15, 17, 20]. Patients with lateral osteoarthritis of grade 2 or higher on the Kellgren–Lawrence scale at radiographic examination ($n=11$) and those with grade 3 tear of the posterior horn ($n=3$) and posterior part of the body ($n=2$) of the lateral meniscus were also excluded. Finally, 82 knees (78 patients) were included in this study and were divided into three groups. In group A (8 knees), knees exhibited mechanical symptoms including snapping and sudden locking, MRI showed isolated widening of the popliteal meniscus, and hypermobility of the lateral meniscus was elicited by probing or suction during arthroscopy. The average symptom duration in this group was 2 years (range 3 months to 5 years). All eight patients had tenderness at the lateral joint line with hypotrophy of the quadriceps femoris, six patients had snapping, and four patients had episodes of sudden locking. McMurray and Apley compression (grinding) tests were positive in six patients, and figure of 4 test was positive in four. The figure of 4 test places the affected knee in flexion, varus, and external rotation. If the popliteal hiatus is widened, it can result in the medial displacement of the lateral meniscus and cause pain [18]. Group B included 32 knees with confirmed tears of the anterior horn of the lateral meniscus, and no instability of the posterior horns was provoked at arthroscopy. Group C included 42 knees of patients with no history of lateral knee pain or tenderness; 36 had medial meniscal tears and 6 had other conditions, but none had abnormalities of the lateral meniscus at arthroscopy. The three groups were similar in terms of age, sex, and body mass index.

All MRI examinations were performed with a Philips Ingenia 3.0T MRI scanner (Philips, Amsterdam, NED). 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), and measurements were performed automatically to within one decimal point of accuracy with the line tool. The slices (both views) that showed the largest diameter of the popliteal hiatus were chosen to the measurement, which were identified by drawing a line parallel to the lateral tibial plateau (LTP) from the middle point of the edge of the lateral meniscus to the popliteal tendon on both views (Fig. 1), The diameter of the LTP on the sagittal view was measured by drawing a line anteroposteriorly along the LTP (Fig. 1a, c) and on the coronal view by drawing a line across the LTP from the lateral edge of the LTP to the insertion of the posterior cruciate ligament (Fig. 1b, d). The ratios of the diameters of the popliteal hiatus and the LTP on both views were calculated. The MRI measurements were performed by a musculoskeletal radiologist with 10 years of experience who was blinded to the clinical information and radiological reports. 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. An ICC value greater than 0.9 was considered excellent. The ICC value of the measurements of the diameter of the LTP on the sagittal view and the coronal view, the diameter of the popliteal hiatus on the sagittal view and the coronal view were all 1.0 and the two measurements were reliable.

At arthroscopy, the knees in group A had obvious widening of the popliteal hiatus (Fig. 2a), with no fresh tear of the PMF, and a regular, smooth, crescent-shaped lateral meniscus, with occasional degenerative rupture at the inner part, but always demonstrating hypermobility

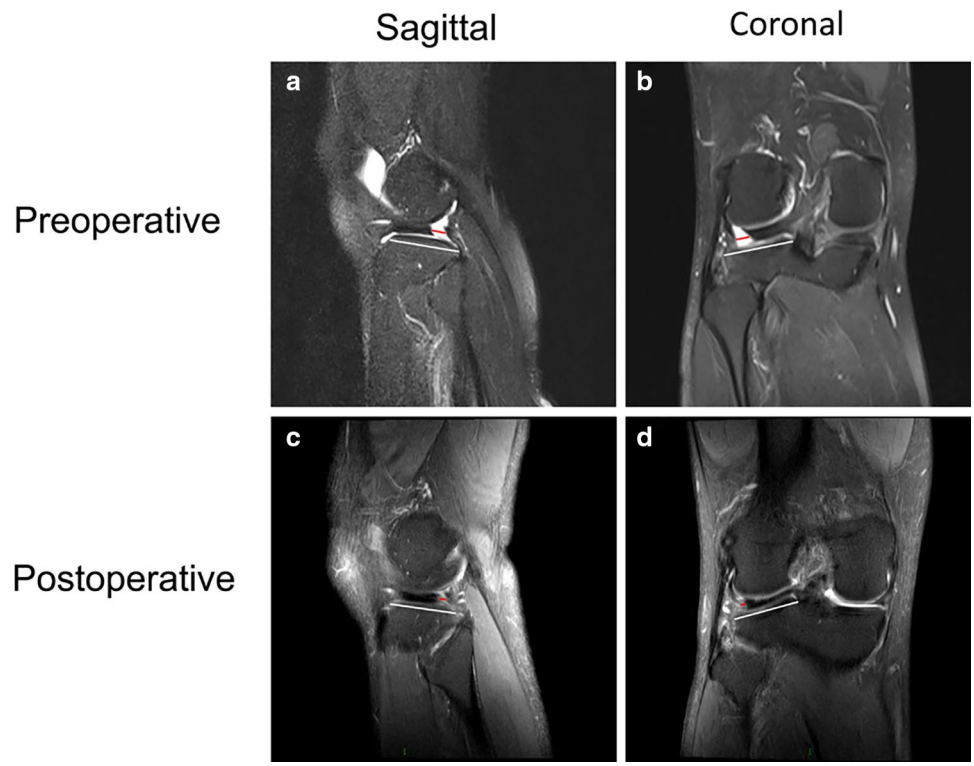

Fig. 1 Representative image from group A. **a** On the sagittal view of the preoperative MRI, the popliteal hiatus measures 7.2 mm and the lateral tibial plateau (LTP) measures 32.3 mm. The posterosuperior and anteroinferior popliteomeniscal fascicles (PMF) are not visible. **b** On the coronal view of the preoperative MRI, the popliteal hiatus measures 6.7 mm and the LTP measures 33.1 mm. The posterosuperior and anteroinferior PMF are not visible. **c** The sagittal view on the postoperative MRI shows the reduced diameter of the popliteal hiatus (popliteal hiatus, 3.9 mm, LTP: 32.1 mm). **d** The coronal view on the postoperative MRI shows the reduced diameter of the popliteal hiatus (popliteal hiatus, 2.4 mm; LTP, 31.4 mm). White line: LTP diameter; red line: popliteal hiatus diameter

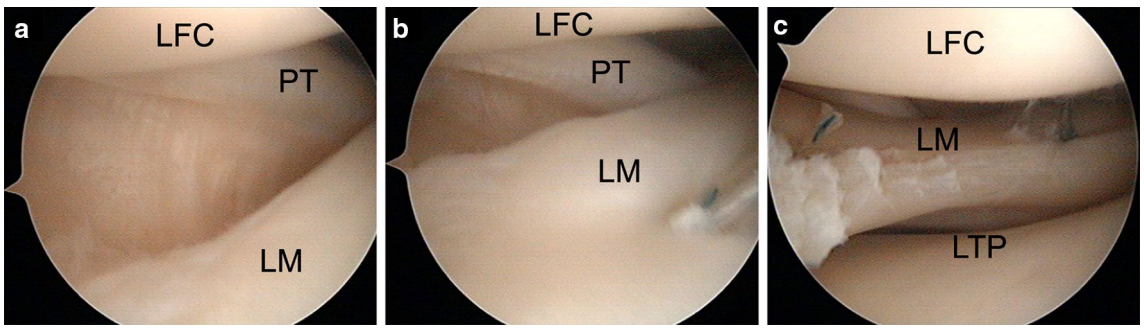

Fig. 2 **a** The enlarged popliteal hiatus under arthroscopy. **b** The diameter of the popliteal hiatus was reduced after tightening by Fast-fix in front of the popliteal tendon. **c** The posterior part and anterior part of the popliteal hiatus were tightened, respectively, by Fast-fix

upon careful probing. Varying degrees of cartilaginous injury (grade I in three knees, grade II in five knees) were observed at the lateral femoral condyle and the LTP, and degenerative cartilage and meniscal tissues were debrided using a shaver or a radiofrequency device (ArthroCare Corporation, Sunnyvale, CA). Debridement of the tissues surrounding the popliteal hiatus, including the meniscus and the surrounding synovium, was performed to refresh the tissues. An all-inside repair of the posterior part of the popliteal hiatus behind the popliteal tendon was performed with the 22° FasT-Fix system (Smith and Nephew, Andover, MA, USA) and the anterior part of the popliteal hiatus was repaired by an outside-in technique using No. 2 Ethibond suture (Ethicon, Somerville, NJ, USA) with a lumbar needle as a thread crossing device or using the FasT-Fix system (Fig. 2b, c), depending on the width of the lateral joint space. Probing was repeated to ensure that the lateral meniscus was stable after suturing.

Postoperative rehabilitation was supervised by specialist knee physiotherapists. The patients in group A used an adjustable hinge brace to protect the knee for 4 weeks, and neither full weight bearing, nor flexion to > 45°, was permitted during the first 4 weeks after operation. Flexion was limited to 90° until 8 weeks after surgery, and to 120° until 12 weeks. Straight-leg raising exercises were continued for 3–6 months postoperatively, depending on the progress of the individual patient. Full range of motion training was allowed at 6 months after surgery. Patients

in groups B and C had routine arthroscopic repairs and standard postoperative rehabilitation according to their diagnoses.

Follow-up

All patients in group A were reexamined at 1, 2, 3, and 6 months and then annually after operation. The diameter of the popliteal hiatus was rechecked by MRI in six patients at 6 or more months postoperatively. Pre- and postoperative knee function estimated using Lysholm scores and Tegner activity scale, and VAS pain scores, were compared. The follow-up data for groups B and C are not investigated further.

Statistical analysis

Statistical analysis was performed using SPSS version 19.0 statistical software. The diameter of the popliteal hiatus, the popliteal hiatus/LTP ratio, and the Lysholm scores were expressed as means ± standard deviations. Differences on MRI measurements between group A and group B or group C were analysed with the Student's *t* test. In group A, comparisons of pre- and postoperative Lysholm scores were performed with the paired *t* test. Tegner scores and VAS scores were assessed using the non-parametric Wilcoxon signed-rank test. Alpha (α) = 0.05 indicated significance. Sample size was estimated utilizing MedSci sample size tools (version 2.1, Medsci, Shanghai, China), accepted alpha error was 0.05, and the beta error was 0.2 to ensure a power of 80%. The calculation revealed that it was necessary to include at least 8 patients in Group A and 32 patients in control groups.

Results

The MRI diameters of the popliteal hiatus and the popliteal hiatus/LTP ratios were significantly larger in group A than in group B and group C on both views (both $p < 0.05$) (Table 1), and the posterosuperior and anteroinferior PMF were not visible on MRI in group A (Fig. 1a, b). The popliteal hiatus/LTP ratio ranged from 0.08 to 0.30 on the sagittal view and from 0.17 to 0.46 on the coronal view. Threshold popliteal hiatus/LTP ratios of 0.16 on the sagittal view and 0.18 on the coronal view showed 75% and 88% sensitivity and 100% and 95% specificity for widening of the popliteal hiatus.

In Group A, all wounds healed by primary intention with no complications such as infection, stiffness of the knee, or injury to the common peroneal nerve. All patients were followed for more than 24 months (average 28 months). During follow-up, the symptoms of knee pain, locking, and snapping disappeared, and all patients had negative McMurray test, Apley grinding test, and figure of 4 test at the final follow-up. Six patients (6 knees) underwent repeat MRI at 6–12 months postoperatively, and the diameter of the popliteal hiatus and the popliteal hiatus/LTP ratio were significantly decreased on both sagittal and coronal views ($p < 0.05$), and were similar to those of group B and group C. One-year and 2-year postoperative Lysholm and Tegner scores were also significantly improved versus preoperative scores ($p < 0.05$), and the VAS pain scores were significantly reduced ($p < 0.05$) (Table 2).

Discussion

There are two most important findings of the current study. The first is that mechanical symptoms and pain and tenderness on the lateral side of the knee accompanied by a

Table 1 Diameters of the popliteal hiatus and the lateral tibial plateau (LTP) and popliteal hiatus/LTP ratios

Parameter	Group A ($n=8$)	Group B ($n=32$)	Group C ($n=42$)	Postoperative group A ($n=6$)
Diameter of popliteal hiatus				
Sagittal (mm)	5.6 ± 2.3	2.1 ± 1.0*	2.8 ± 1.3*	2.7 ± 0.9*
Coronal (mm)	6.6 ± 2.1	2.7 ± 1.7*	3.2 ± 1.2*	2.9 ± 0.7*
Diameter of LTP				
Sagittal (mm)	32.1 ± 3.0	29.7 ± 4.4	32.4 ± 4.2	32.0 ± 3.3
Coronal (mm)	29.4 ± 3.3	27.8 ± 3.6	29.0 ± 3.2	29.7 ± 3.2
Popliteal hiatus/LTP				
Sagittal	0.18 ± 0.08	0.07 ± 0.07*	0.09 ± 0.04*	0.09 ± 0.03*
Coronal	0.23 ± 0.09	0.10 ± 0.04*	0.11 ± 0.05*	0.10 ± 0.02*

Diameter of the popliteal hiatus and width of the LTP are in millimetres. Data in parentheses are presented as means ± standard deviations

*Significant difference compared with Group A

Table 2 Comparison of clinical outcomes of Group A (mean ± SD)

Variables	Preoperative	1 years postoperative	2 years postoperative
Lysholm scores	67.7 ± 5.9	93.3 ± 2.4*	93.7 ± 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	0.5 ± 0.5*	0.3 ± 0.5*

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

widened popliteal hiatus on MRI with a popliteal hiatus/LTP ratio > 0.16 on the sagittal view and > 0.18 on the coronal view may portend recurrent subluxation of the lateral meniscus. The second is that securing the popliteal hiatus using FasT-Fix posteriorly (behind the popliteal tendon) and suture or FasT-Fix anteriorly (in front of the popliteal tendon) can be safe and effective for preventing recurrent subluxation caused by widening of the popliteal hiatus.

The anatomy of the popliteal hiatus has been described previously. Osti et al. examined the anatomic dimensions of the popliteal hiatus in the knees of 30 cadavers by removing the popliteal tendon and measuring the diameter from the medial edge of the popliteal hiatus to the lateral capsule, and reported that the average mediolateral diameter of the popliteal hiatus was 9.83 ± 2.16 mm [19], while Cohn and Mains [4] reported that the length of the popliteal hiatus along its superior surface was 1.3 ± 0.1 cm. The popliteal hiatus is oblique and oval shaped, and it may be that Osti et al. measured the minor axis and Cohn and Mains measured the major axis. On MRI, the lateral meniscus and the popliteal tendon were low signal and clear, while the lateral capsule had comparable higher signal and was not clear. Therefore, the gap between the meniscus and the popliteal tendon on routine coronal and sagittal view of the knees was measured in the current study, which are not parallel to the axes of the popliteal hiatus, and which is why the measurements were much smaller than those of Osti et al. [19] and Cohn and Mains [4]. There have been several other reports describing the MR imaging features of the popliteal hiatus of the lateral meniscus, mostly considering the PMF [24, 28]. However, although injuries to the PMF would affect the diameter of the popliteal hiatus, none of them mention the dimensions of the popliteal hiatus.

The maximum transverse diameters of the popliteal hiatus on preoperative MRI in eight knees in group A were compared with the same measurements from knees with tears of the anterior horn of the lateral meniscus (group B) and knees with normal lateral meniscuses in the presence of medial or other injuries (Group C), and the popliteal hiatus was wider in group A on both sagittal and coronal MRI. Knees with discoid lateral meniscus were not included in this study because widening of the popliteal hiatus is much more common in those knees due to the inherent instability of the peripheral rim [11, 14, 15, 17, 20]. On the other hand, widening of the popliteal hiatus has never been reported in nondiscoid lateral meniscus, nor was it mentioned in the reported PMF injuries. It is thought that obsolete or occult injury to the lateral meniscus or the PMF may be a cause of widening of the popliteal hiatus. The PMF is inevitably stretched or injured when the popliteal hiatus is enlarged, and it is difficult to distinguish whether the PMF abnormality is primary or secondary on MRI or even under arthroscopy. Isolated widening of the popliteal hiatus is generally occult and has no definite mechanism. As such, the diagnosis and treatment are almost always delayed.

Common symptoms of recurrent subluxation of the lateral meniscus include snapping and locking, and the physical examination mainly shows tenderness at the lateral compartment of the knee. Patients may also have a positive figure of 4 test. Four patients in group A had positive figure of 4 test, and subluxation of the lateral meniscus was confirmed by arthroscopy. Ahn et al. have reported similar symptoms in association with subluxation of the lateral meniscus, which included torn PMF and peripheral tears of the posterior horn of the lateral meniscus presenting with no remarkable signs of meniscal tear on MRI [2]. In the current study, the widening of the popliteal hiatus on MRI was measurable. Subluxation of the nondiscoid lateral meniscus is seldom reported, and the diagnostic nomenclature is not clear. It is possible that the widening of the popliteal hiatus of the lateral meniscus that described here is an aspect of recurrent subluxation of the lateral meniscus that was not mentioned in Ahn et al.'s study [2].

The diameter of popliteal hiatus will vary with the diameter of tibial plateau in different patients. As such, popliteal hiatus/LTP ratios are more valuable for detecting widening of the popliteal hiatus. Popliteal hiatus/LTP ratios were larger in group A than in group B and group C. It is suggested that if, combined with the symptoms described above, the popliteal hiatus/LTP ratio is > 0.16 on sagittal MRI or > 0.18 on coronal MRI, then recurrent subluxation of the lateral meniscus should be suspected, and arthroscopic exploration and repair can be recommended.

Several authors have reported techniques for restoring the popliteal hiatus of the lateral meniscus. Feng et al. used a suture hook and an all-inside technique to suture the popliteal hiatus of the lateral meniscus and reported successful treatment in 30 knees [8], all of which were asymptomatic after operation. At second-look arthroscopy in 26 of those knees, 25 were completely healed, 1 was partially healed,

and there were no obvious operative complications. Ahn et al. sutured tears of the posterior horn of the lateral meniscus behind the popliteal tendon using a modified all-inside technique with a suture hook [2] and sutured the meniscal midbody in front of the popliteal tendon using an outside-in technique in seven cases and reported excellent clinical results after a median follow-up of 41 months. However, all-inside suture repair of the posterior horn is technically difficult. Song et al. reported side-by-side repairs of radial tears involving the popliteal hiatus in the posterior horn in four cases [22], with additional repair of the meniscal capsule by FasT-Fix and Rapidloc, and found that healing of the longitudinal tear in the popliteal hiatus had failed at second-look arthroscopy in two cases. This may be because the midbody in the anterior part of popliteal hiatus was not sutured. Repair of the posterior part of the popliteal hiatus by an outside-in or inside-out technique requires a safe posterior incision because of the proximity of the peroneal nerve to the posterolateral articular capsule [5, 13]. This increases the invasiveness of the surgery, but may lower the risk of nerve injury.

In the patients in group A, the widened popliteal hiatus was visualized under arthroscopy, and hypermobility of the lateral meniscus was elicited by careful probing. The portion of the popliteal hiatus behind the popliteal tendon was tightened via an all-inside repair with the 22° FasT-Fix system, and the portion of the hiatus in front of the tendon was tightened using an outside-in suture or FasT-Fix. These procedures were performed with the knees in a figure of 4 position to increase the lateral joint space and reduce the risk of peroneal nerve injury [1, 5, 6, 27]. For the anterior revision, a vacuum tube, such as a lumbar puncture needle, can be used for suturing by the outside-in technique, with 1–2 vertical stitches placed at a distance of about 5 mm. These sutures were stable and healing was satisfactory. Comparable techniques have been previously reported, with safe and satisfactory repair of similar meniscal instability by meniscoplasty in patients with discoid lateral meniscus [7].

This study has several limitations. First, the number of cases is small because of the low incidence of this condition. Second, there would be some selection bias because it is possible that some patients with recurrent subluxation declined arthroscopic surgery due to negative findings on MRI and unconfirmed diagnosis, and were, therefore, not included in this study. Third, there was no control group of individuals with normal knees. Fourth, the measurements were based on routine coronal and sagittal views of MRI, which obliquely crossed the major and minor axes of the popliteal hiatus, and the measurement would be affected by the choice of the MRI view. An oblique view along the axis of the popliteal hiatus should be used in future studies. Fifth, the popliteal hiatus was not measured under arthroscopy because of the limited field and, therefore, did not compare with the measurement on MRI. Nonetheless, this study is the first to describe a new measurement of the diameter of the popliteal hiatus and examines the clinical significance of the MRI finding of widening of the popliteal hiatus. These findings could facilitate early diagnosis of recurrent subluxation of the lateral meniscus and help guide appropriate treatment.

Conclusion

Widening of the popliteal hiatus on MRI portended recurrent subluxation of the lateral meniscus, and threshold values for the popliteal hiatus/LTP ratio of 0.16 on sagittal MRI and 0.18 on coronal MRI demonstrated high diagnostic discrimination. Arthroscopic revision of the popliteal hiatus anteriorly and posteriorly under arthroscopy was safe and effective for limiting signs and symptoms of recurrent subluxation in patients with widening of the popliteal hiatus on MRI.

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Compliance with ethical standards

Conflict of interest Zhou Li, Heng Zhao, Zhu Dai, Zhiwei Chen, Ying Liao, Dehong Fu, Yunliang Lei, Tao Luo, and Quanhui Liu declare that they have no conflict of interest.

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Ethical approval 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.

Informed consent Informed consent forms were signed by each patient included in this study.

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