Morphological study of vastus medialis oblique in recurrent patellar dislocation based on magnetic resonance images

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Research article

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Abstract

Purpose To investigate the morphological parameters of the vastus medialis obliquus (VMO) muscle and delineate its importance in the maintenance of patellofemoral joint stability.

Methods The magnetic resonance imaging (MRI) data of 75 knees (54 patients) with recurrent lateral patella dislocation (LPD) and 75 knees (70 patients with similar age, gender and body mass index) were retrospectively analyzed. Five morphological parameters related to VMO (elevation on sagittal plane and coronal plane, cross-sectional area ratio, craniocaudal extent, muscle-fiber angulation,) and two parameters of patella tilt (patella tilt angle, bisect offset ratio) were measured in MRI images, and the types of trochlear in each patient were recorded. Finally, the differences of these parameters between the two groups were analyzed.

Results Compared with the control group, the patients with recurrent LPD showed significantly higher in sagittal VMO elevation (10.4 ± 2.3 mm vs 4.1 ± 1.9 mm), coronal VMO elevation (15.9 ± 5.7 mm vs 3.9 ± 3.7 mm), muscle-fiber angulation (35.4 ± 8.0° vs 27.9 ± 6.3°), patella tilt angle (25.9 ± 10.7° vs 9.1 ± 5.2°), and bisect offset ratio values (0.9 ± 0.3 vs 0.5 ± 0.1), and significantly lower in craniocaudal extent (13.7 ± 5.3mm vs 16.7 ± 5.1 mm) and cross-sectional area ratio values (0.07 ± 0.02 vs 0.05 ± 0.02).

Conclusions The results showed that the abnormality of VMO were clearly present in recurrent LPD patients compared with normal people, which may be an important factor of patella tilt in LPD patients, so it is necessary to focus on injury condition of VMO during preoperative evaluation.

Introduction

Recurrent lateral patellar dislocation (LPD) is usually secondary to the primary acute patellar dislocation, which mostly occurs in young people aged 10–17 years, with an incidence of three times as many men suffer from this disease as women (1). The incidence of primary acute patella dislocation in general public is 7 to 49 cases per 100,000 (2, 3). With nonoperative management, the rate of recurrent LPD after acute patellar dislocation was reported to be up to 44% (4). Recurrent LPD often causes symptoms including persistent pain, knee weakness and mechanical limitations (5).

Patellofemoral joint stability is maintained by both bone and soft tissue stabilizer. Numerous studies have investigated the effect of osseous factors on LPD, but the influence of soft tissue factors is still in the exploratory stage. The soft tissue can be further divided into active structure stabilizer (quadriceps femoris) and passive structure stabilizer (ligaments), which stabilize the patellofemoral joint together during knee flexion (6). The medial patellofemoral ligament (MPFL), occupies for 50–60% of the total limiting force against LPD, which is generally considered to be the most important structure in medial soft tissue of the patellofemoral joint (1, 7, 8). However, several scholars have confirmed that the quadriceps muscle also plays an imperative role in maintaining the stability of the patella (9–12). The vastus medialis obliquus (VMO) muscle, seems to be a vibrant dynamic stabilizer for neutralizing the lateral force of the patella, it’s importance has been gradually recognized (9, 13, 14). Under normal conditions, the VMO is able to counterbalance the lateral pull of the larger vastus lateralis (VL) to ensure patellar stability. If the VMO is no longer able to counteract the lateral pull of the larger VL, abnormal lateral tracking of the patella may occur. A disruption of this mechanical balance between the VMO and the VL has frequently been attributed to an insufficiency of the VMO secondary to atrophy, hypoplasia (15). Due to the anatomical relationship and characteristics of MPFL and VMO, MPFL tears are usually accompanied by VMO tears, while most MPFL tears occur on the femur side. Loss of the firm attachment to its distal origin, resulting in higher sagittal and coronal elevations of the torn VMO muscle, may result in a decrease in the dynamic medial stabilizing force. Unfortunately, the injure of VMO is associated with approximately 45–93% in primary patella dislocation patients (16). This may lead to secondary atrophy of VMO.

To our knowledge, there are no studies have comprehensively described the morphological characteristics of VMO in patients with recurrent LPD. Magnetic resonance imaging (MRI) is the typical gold standard for assessing soft tissue, which can clearly show the contour of muscle (17). Therefore, the purpose of our study is to investigate the difference of VMO-related morphological parameters between patients with recurrent LPD and control group by MRI.

Materials And Methods

A total of 75 knees (54 patients) with recurrent LPD and 75 knees (70 patients with similar age, gender and body mass index) with no medical history of knee joint were included in this study retrospectively.

Inclusion criteria: Recurrent LPD was diagnosed by two senior doctors in charge of joint and sports medicine department according to the patient's history, physical examination and MRI images. All patients had no previous experience in rehabilitation department or had any special training related to strengthening quadriceps muscle force. MRI images can be searched within 10 days after recurrent LPD.

Exclusion criteria: Patients with primary patellar dislocation. Traumatic patellar dislocations that occurred as a result of direct trauma to the medial patella or a fall onto the knee joint with concomitant patellar dislocation. Patients with any preexisting knee disorders, any prior knee surgery history, fractures of the distal femur or tibial head, and multi-ligament knee joint injury. Any patient with a history of neuromuscular disease (e.g., polio). Patients with obvious joint effusion.

Sagittal, coronal, and transverse MR images were obtained in all patients. Two experienced orthopaedic surgeons measured the following five parameters related to VMO (elevation on sagittal plane and coronal plane, cross-sectional area ratio, craniocaudal extent, muscle-fiber angulation,) and two parameters of patella tilt (patella tilt angle, bisect offset ratio) in both groups. And the type of femoral trochlear dysplasia in each patient was recorded according to Dejour et al (18) and Lippacher et al (19) classification system. Except for the calculation of cross-sectional area was completed by Image J freeware, other parameters were measured by picture archiving and communications system (PACS) workstation (Centricity, GE Healthcare, St. Gilles, United Kingdom). All parameters were repeatly measured with an interval of two weeks. MRI (Philips MR Systems Ingenia 3.0T, Andover, Massachusetts) protocols in our hospital were routine: all patients were in a supine position with knee naturally extended and quadriceps muscle fully relaxed.

Radiographic Measurements

The measurement of VMO elevation

The VMO elevation was measured on sagittal and coronal planes according to Zhang et al' s (20) measurement method. Briefly, the adductor tubercle could clearly be seen in the transverse slice was defined as the optimally measurable slice, indicated by the blue line (Fig. 1). In this transverse image, the corresponding sagittal and coronal planes were identified.

On the selected sagittal slice, the apex of the anterosuperior border of the bone cortex of the adductor tubercle was set as the starting point. The VMO elevation was defined as the shortest distance from the starting point extending obliquely to the inferior edge of the muscle belly (Fig. 1). On the selected coronal slice, the apex of the medial superior border of the adductor tubercle was set as the starting point. The VMO elevation was defined as the vertical distance from the starting point to the inferior margin of the VMO muscle (Fig. 1).

The measurement of VMO muscle-fiber angulation, craniocaudal extent of VMO and the cross-sectional area ratio of VMO

According to the method introduced by Balcarek et al's (21), VMO muscle-fiber angulation, craniocaudal extent of VMO and the cross-sectional area ratio of VMO were measured on MRI images. Firstly, the longitudinal axis of the patella was established in the central sagittal plane. In this sagittal image, the corresponding transverse slice located at the proximal patellar pole, and the adjacent slices located above and below this reference slice were identified. These transverse planes were used to measure the VMO cross-sectional area by manually drawing disarticulation contours around the muscle boundaries, and the whole thigh area at the corresponding level was also measured.

The cross-sectional area ratio of VMO was designed as the ratio between the cross-sectional area of VMO and whole thigh. Finally, the average value of the cross-sectional area ratio on three slices was calculated. The VMO muscle-fiber angulation, that is the angle between VMO muscle-fiber and the longitudinal axis of the femoral shaft, was measured on the sagittal plane. Furthermore, the lowest point of the VMO was located on this plane and the corresponding horizontal line was established in the sagittal plane centrally of the patella longitudinal axis. The craniocaudal extent of VMO was the vertical distance from this horizontal line to the proximal patellar pole.

The measurement of patella tilt angle and the Patella offset index

The transverse plane, that would allow visualization of the intact Roman arch and posterior femoral condyles was selected. The posterior condylar reference line was drawn tangent to the posterior femoral condyles. The patella tilt angle was formed by the maximal patella width line and the posterior femoral condyle line (Fig. 2).

According to the method of Christopher et al. (22)and Callaghan et al. (23), a line that passes through the deepest portion of the trochlear groove perpendicular to the posterior condylar reference line was drawn. The intersection of this line and the maximal patella width line was defined as point O. On transverse plane of the widest layer of the patella, the innermost point of patella was defined as point A and the outermost point as point B (Fig. 2). The percentage of OB / AB was defined as the bisect offset ratio.

Statistical analysis

SPSS 22.0 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows. Armonk, NY: IBM Corp) was used to process the relevant data. All parameters were presented in the form of mean ± standard deviation. The comparison of continuous and categorical variables between the two groups were analyzed by independent-sample t test and Chi-square test, respectively. P<.05 was considered statistically significant. Moreover, the intraclass correlation coefficient (ICC) also was analyzed for duplicated measurements by two observers.

Results

54 patients (75 knees) diagnosed with recurrent LPD were enrolled in our study. All patients underwent routine MRI of the knee joint. The study group was consisted of 18 males and 36 females. The average age of the patients was 22.11±9.87 years (range, 12-45 years), and their average BMI was 24.1 ± 3.6 kg/m^2. In addition, 70 controls (75 knees) were recruited. The baseline characteristics of the two groups are presented in Table 1. Compared with the control group, recurrent LPD patients showed more severe femoral trochlear dysplasia with high-grade classification (Table 1). Additionally, the intraclass correlation coefficients for inter- and intra-observer variability of all variables were excellent (>0.75).

As shown in the Fig. 1, VMO was attached to the medial femoral condyle on sagittal and coronal sectional-imaging in normal patients, but it was significantly elevated in LPD patients. In addition, the patellofemoral joint was in good alignment

The line, that passed through the deepest portion of the trochlear groove perpendicular to the posterior condylar reference line, passes through near the midpoint of the widest line of patella (Fig. 2 a). However, patellar tilt and displacement were obviously observed in recurrent LPD group (Fig. 2 b).

The mean sagittal and mean coronal VMO elevations were significantly higher in the recurrent LPD group than in the control group (10.4 ± 2.3 mm vs 4.1 ± 1.9 mm, 15.9 ± 5.7 mm vs 3.9 ± 3.7 mm, respectively). Compared with the control group, the recurrent LPD group showed significantly higher muscle-fiber angulation of the VMO (35.4 ± 8.0° vs 27.9 ± 6.3°). But the craniocaudal extent of the VMO was significantly lower in the LPD group than that in the control group (13.7 ± 5.3mm vs 16.7 ± 5.1 mm). The average cross-sectional area ratio of the VMO was 7 % in the patient group and 5 % in the control group.

Compared with the control group, the recurrent LPD group showed a significantly larger patella tilt angle (25.9 ± 10.7° vs 9.1 ± 5.2°), meanwhile, the bisect offset ratio of LPD group was significantly higher than that of the control group (Table 2).

Discussion

It is generally believed that patella maltracking is usually manifested as the subluxation and outward transformation of patella, which is mainly measured the patella tilt angle and bisect offset ratio. The patella tilt angle was used to describe the degree of inclination of the patella, which is regarded as the most sensitive indicator to identify patella instability (24). Lateral displacement of patella was described by bisect offset ratio, which was defined as the percentage of lateral width of the total patellar width (25). Therefore, the patella tilt angle and bisect offset ratio were used to assess patella position in patients with recurrent LPD in our study. Similar to the results of studies with Charleset al (26) and Escala et al (24), our study revealed a statistically significant difference in patellar tilt angle of 9° in control persons and 25° in recurrent LPD patients, respectively. Moreover, another indicator of evaluation of lateral tilt, bisect offset ratio, also showed a significant difference in the two groups of 0.54 and 0.97, respectively. The results mentioned above confirmed the existence of patellar inclination in recurrent LPD patients in our investigation.

The patellar tilt or lateral dislocation may be generated by the elevation of the VMO abnormality. VMO was originally attached intimately to the patella together with MPFL, the pathological elevation means that VMO has no connection to the original attachment point on patella and femur. This can be manifested by the elevation of VMO on coronal and sagittal planes in MRI images, which may lead to the reduction of the limiting force of VMO on medial patellofemoral joint, thus aggravating the extent of lateral inclination of the patella. This conclusion was confirmed in a cadaver study of Goh et al (27), and it was found by comparison that the VMO tension loss caused an increase in lateral displacement of patella and increased the stress of lateral patellar facet during knee flexion.

In this study, we used elevation on sagittal plane and coronal plane, cross-sectional area, muscle-fiber angulation and craniocaudal extent to comprehensively evaluate the morphological changes of VMO in recurrent LPD patients. Compared with normal patients, VMO was on average raised by about 6mm and 12mm on sagittal and coronal positions, respectively. These results indicated that the VMO was significantly elevated in PLD patients. Furthermore, it has been proved that cross-sectional area can be used to assess the force-producing ability of muscle and was considered feasible to measure on MRI images (28, 29). Therefore, we selected three adjacent three slices on coronal plane to mimic the three-dimensional VMO muscle structure though not exactly representing VMO muscle volume. In contrast, the ratio of VMO cross-sectional area in the corresponding thigh area in recurrent LPD patients was significantly lower than that of the control group. In addition, muscle-fiber angulation and craniocaudal extent may also have an influence on the tension of VMO, a cadaver study have showed that the absent of VMO tension leads to lateral shift of the patella (27). Our results also showed that VMO had significant differences in muscle-fiber angulation and craniocaudal extent, both of which were statistically significant. Muscle-fiber angulation and craniocaudal extent increased by an average of 12° and decreased by 3mm, respectively. Previous cadaver studies indicate that the muscle-fiber angulation of VMO in normal people was 42-52° (30), in our survey, however, the muscle-fiber angulation in the control group and the recurrent LPD patients were 27° and 35° on average, respectively. What is the specific mechanism caused this difference in clinical patient and cadaver studies is still not clear.

VMO acts as a vital dynamic stabilizing device to limit the tendency of patellar dislocation. The patella does not contact with the trochlear at the beginning of knee flexion, and the tendency of patella dislocation is limited by VMO and MPFL. A vitro study have revealed that when the strength of the VMO was weakened, the patellar displacement increased in the range of 0-15° knee flexion (31). During a range of 20° to 90° knee flexion, VMO relaxation can reduce the resistance of patella lateral displacement by 30% (32). As VMO is basically perpendicular (47 °) to the longitudinal axis of patella sagittal position, that can enhance the stability of patella (30), and the angle increased by 2° and 4° respectively in the initial and recurrent patellar dislocation (21). There is no consensus on the role of VMO in the stabilization of patellofemoral joint, some scholars doubted the correlation between patellar instability and VMO (33, 34). Both Balcarek et al [26] and Liu et al [37] studies found that, the cross-sectional area of the VMO showed a decreasing trend in patients with recurrent PLD but without significant differences compared with healthy volunteers; this may be related to their small sample size, as there were only 30 cases in LPD group in both studies. Nevertheless, more studies have shown that VMO has a significant effect on patellofemoral instability. Pattyn et al (15) have proved that VMO atrophy was present in patients with patellofemoral pain and it was a contributing factor in patellofemoral pain syndrome. Moreover, an idea that the functional status of VMO was closely related to recurrent LPD was verified in a diffusion tensor imaging study (35). In a two-year follow-up research, MPFL reconstructive surgery without VMO combined repair had no significant effect on the re-dislocation in patients with primary patella dislocation compared with conservative treatment (36), this suggested that MPFL reconstruction combined with VMO repair may produce better postoperative outcome. Zhang et al (20) also suggested that more attention should be paid to VMO, that the patients with complete femoral-side injury in particular. Hence, in the preoperative evaluation, the orthopaedic surgeon should carefully assess the injury conditions of MPFL and VMO, then individualized treatment should be adopted for each patient.

Innovations and limitations

In conclusion, the results showed that the abnormality of VMO were clearly present in recurrent LPD patients compared with normal people. MRI was used to comprehensively evaluate the morphological parameters of VMO in patients with recurrent LPD, and the VMO elevation on coronal and sagittal position, a lower cross-sectional area ratio, the increase of muscle-fiber angulation and the decrease of craniocaudal extent may have a relationship with patellar inclination. Based on the results of previous biomechanical and clinical studies, we suggest that the injury conditions of VMO should be accurately evaluated in patients with recurrent LPD before the operation. In children and adolescents who require soft tissue surgery alone, MPFL reconstruction combined with VMO repair may yield better results for patients with recurrent LPD. We summarized the methods for evaluating VMO by MRI, which can effectively reduce clinicians assess VMO atrophy exclusively based on visual inspection. By using the individualization index, cross-sectional area ratio of VMO and bisect offset ratio, that is effective to exclude individual differences and evaluate the area of VMO muscle and patella deviation. However, as a retrospective study, patients with recurrent LPD have obvious anatomical abnormalities, which cannot be blind in the diagnosis of the patients during the measurement. Our study revealed only the fact that that VMO was abnormal in recurrent LPD patients, while, our investigation did not indicate whether the abnormality is a contributing factor or secondary to recurrent LPD. In addition, We only focused on the injure of VMO at the distal end, but weakened the description of tear at the proximal end of VMO and MPFL.

Declarations

Authors' contributions

This study was developed by CLB and NQB. The first draft of the manuscript was written by SL. All authors (SL, YX, HHY, CB, CLB, NQB) contributed to interpretation of the results and critical revision of the manuscript. All authors have approved the final manuscript before submission.

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Availability of data and materials

All data are included in the manuscript.

Ethics approval and consent to participate

The Ethics Committee of Wuhan University Zhongnan Hospital concluded that no approval is necessary for study based on its retrospective design.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests associated with this manuscript.

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Abbreviations

ICC: intraclass correlation coefficient

LPD: lateral patella dislocation

MRI: magnetic resonance imaging

MPFL: medial patellofemoral ligament

PACS: picture archiving and communications system

VMO: vastus medialis obliquus

VL: vastus lateralis

References

1. Colvin AC, West RV. Patellar instability. J Bone Joint Surg Am. 2008;90(12):2751–62.
2. Gravesen KS, Kallemose T, Blønd L, Troelsen A, Barfod KW. High incidence of acute and recurrent patellar dislocations: a retrospective nationwide epidemiological study involving 24.154 primary dislocations. Knee Surg Sports Traumatol Arthrosc. 2018;26(4):1204–9.
3. Tan SHS, Ibrahim MM, Lee ZJ, Chee YKM, Hui JH. Patellar tracking should be taken into account when measuring radiographic parameters for recurrent patellar instability. Knee Surg Sports Traumatol Arthrosc. 2018;26(12):3593–600.
4. Hawkins RJ, Bell RH, Anisette G. Acute patellar dislocations. The natural history. Am J Sports Med. 1986;14(2):117–20.
5. Stefancin JJ, Parker RD. First-time traumatic patellar dislocation: a systematic review. Clin Orthop Relat Res. 2007;455.
6. Petri M, von Falck C, Broese M, Liodakis E, Balcarek P, Niemeyer P, et al. Influence of rupture patterns of the medial patellofemoral ligament (MPFL) on the outcome after operative treatment of traumatic patellar dislocation. Knee Surg Sports Traumatol Arthrosc. 2013;21(3):683–9.
7. Philippot R, Boyer B, Testa R, Farizon F, Moyen B. The role of the medial ligamentous structures on patellar tracking during knee flexion. Knee Surg Sports Traumatol Arthrosc. 2012;20(2):331–6.
8. Panagiotopoulos E, Strzelczyk P, Herrmann M, Scuderi G. Cadaveric study on static medial patellar stabilizers: the dynamizing role of the vastus medialis obliquus on medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc. 2006;14(1).
9. Brunet ME, Brinker MR, Cook SD, Christakis P, Fong B, Patron L, et al. Patellar tracking during simulated quadriceps contraction. Clin Orthop Relat Res. 2003(414):266–75.
10. Sarkar A, Razdan S, Yadav J, Bansal N, Kuhar S, Pahuja P. Effect of isometric quadricep activation on "Q" angle in young females. Indian J Physiol Pharmacol. 2009;53(3):275–8.

11. Hinckel BB, Gobbi RG, Kihara Filho EN, Demange MK, Pécora JR, Camanho GL. Patellar Tendon-Trochlear Groove Angle Measurement: A New Method for Patellofemoral Rotational Analyses. Orthop J Sports Med. 2015;3(9):2325967115601031.
12. Hinckel BB, Gobbi RG, Kihara Filho EN, Demange MK, Pécora JR, Rodrigues MB, et al. Why are bone and soft tissue measurements of the TT-TG distance on MRI different in patients with patellar instability? Knee Surg Sports Traumatol Arthrosc. 2017;25(10):3053–60.
13. Pal S, Besier TF, Draper CE, Fredericson M, Gold GE, Beaupre GS, et al. Patellar tilt correlates with vastus lateralis: vastus medialis activation ratio in maltracking patellofemoral pain patients. J Orthop Res. 2012;30(6):927–33.
14. Pal S, Draper CE, Fredericson M, Gold GE, Delp SL, Beaupre GS, et al. Patellar maltracking correlates with vastus medialis activation delay in patellofemoral pain patients. Am J Sports Med. 2011;39(3):590–8.
15. Pattyn E, Verdonk P, Steyaert A, Vanden Bossche L, Van den Broecke W, Thijs Y, et al. Vastus medialis obliquus atrophy: does it exist in patellofemoral pain syndrome? Am J Sports Med. 2011;39(7):1450–5.
16. Seeley M, Bowman KF, Walsh C, Sabb BJ, Vanderhave KL. Magnetic resonance imaging of acute patellar dislocation in children: patterns of injury and risk factors for recurrence. J Pediatr Orthop. 2012;32(2):145–55.
17. Samim M, Smitaman E, Lawrence D, Moukaddam H. MRI of anterior knee pain. Skeletal Radiol. 2014;43(7):875–93.
18. Dejour D, Saggin P. The sulcus deepening trochleoplasty-the Lyon's procedure. Int Orthop. 2010;34(2):311–6.
19. Lippacher S, Dejour D, Elsharkawi M, Dornacher D, Ring C, Dreyhaupt J, et al. Observer agreement on the Dejour trochlear dysplasia classification: a comparison of true lateral radiographs and axial magnetic resonance images. Am J Sports Med. 2012;40(4):837–43.
20. Zhang G-Y, Zheng L, Shi H, Liu W, Zhang L, Qu S-H, et al. Correlation analysis between injury patterns of medial patellofemoral ligament and vastus medialis obliquus after acute first-time lateral patellar dislocation. Knee Surg Sports Traumatol Arthrosc. 2018;26(3):719–26.
21. Balcarek P, Oberthür S, Frosch S, Schüttrumpf JP, Stürmer KM. Vastus medialis obliquus muscle morphology in primary and recurrent lateral patellar instability. Biomed Res Int. 2014;2014:326586.
22. Powers CM, Shellock FG, Pfaff M. Quantification of patellar tracking using kinematic MRI. J Magn Reson Imaging. 1998;8(3):724–32.
23. Callaghan MJ, Guney H, Reeves ND, Bailey D, Doslikova K, Maganaris CN, et al. A knee brace alters patella position in patellofemoral osteoarthritis: a study using weight bearing magnetic resonance imaging. Osteoarthr Cartil. 2016;24(12):2055–60.
24. Escala JS, Mellado JM, Olona M, Giné J, Saurí A, Neyret P. Objective patellar instability: MR-based quantitative assessment of potentially associated anatomical features. Knee Surg Sports Traumatol Arthrosc. 2006;14(3):264–72.

25. Draper CE, Besier TF, Fredericson M, Santos JM, Beaupre GS, Delp SL, et al. Differences in patellofemoral kinematics between weight-bearing and non-weight-bearing conditions in patients with patellofemoral pain. J Orthop Res. 2011;29(3):312–7.
26. Charles MD, Haloman S, Chen L, Ward SR, Fithian D, Afra R. Magnetic resonance imaging-based topographical differences between control and recurrent patellofemoral instability patients. Am J Sports Med. 2013;41(2):374–84.
27. Goh JC, Lee PY, Bose K. A cadaver study of the function of the oblique part of vastus medialis. J Bone Joint Surg Br. 1995;77(2):225–31.
28. Bamman MM, Newcomer BR, Larson-Meyer DE, Weinsier RL, Hunter GR. Evaluation of the strength-size relationship in vivo using various muscle size indices. Med Sci Sports Exerc. 2000;32(7):1307–13.
29. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. J Appl Physiol. 2000;88(4):1321–6.
30. Farahmand F, Senavongse W, Amis AA. Quantitative study of the quadriceps muscles and trochlear groove geometry related to instability of the patellofemoral joint. J Orthop Res. 1998;16(1):136–43.
31. Sakai N, Luo ZP, Rand JA, An KN. The influence of weakness in the vastus medialis oblique muscle on the patellofemoral joint: an in vitro biomechanical study. Clin Biomech (Bristol Avon). 2000;15(5):335–9.
32. Senavongse W, Amis AA. The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: a biomechanical study in vitro. J Bone Joint Surg Br. 2005;87(4):577–82.
33. Powers CM, Landel R, Perry J. Timing and intensity of vastus muscle activity during functional activities in subjects with and without patellofemoral pain. Phys Ther. 1996;76(9).
34. Pattyn E, Verdonk P, Steyaert A, Van Tiggelen D, Witvrouw E. Muscle functional MRI to evaluate quadriceps dysfunction in patellofemoral pain. Med Sci Sports Exerc. 2013;45(6):1023–9.
35. Liu L-S, Zheng Z-Z, Yuan H-S. Significance of Diffusion Tensor Imaging of Vastus Medialis Oblique in Recurrent Patellar Dislocation. Chin Med J. 2017;130(6):642–6.
36. Christiansen SE, Jakobsen BW, Lund B, Lind M. Isolated repair of the medial patellofemoral ligament in primary dislocation of the patella: a prospective randomized study. Arthroscopy. 2008;24(8):881–7.

Tables

Table 1 The basic characteristics of patients in two groups

Group	Age, mean ± SD (range), y	Sex (male/female)	BMI, mean ± SD (kg/m^2)	Trochlear dysplasia (n)		
				Normal	Low-grade	High-grade
Control	24.0 ± 6.5 (19–38)	25/45	23.3 ± 2.6	57	18	0
Recurrent LPD	22.1 ± 9.9 (12–45)	18/36	24.1 ± 3.6	0	16	59

LPD: Lateral patellar dislocation

Table 2 Comparison of study group and recurrent LPD group

	Mean VMO elevation (mm)		Muscle-fiber angulation (°)	Craniocaudal extent (mm)	Cross-sectional area ratio	Patella tilt angle (°)	Bisect offset ratio
	Sagittal	Coronal					
Control	4.1 ± 1.9	3.9 ± 3.7	27.9 ± 6.3	16.7 ± 5.1	0.07 ± 0.02	9.1 ± 5.2	0.54 ± 0.06
Recurrent LPD	10.4 ± 2.3	15.9 ± 5.7	35.4 ± 8.0	13.7 ± 5.3	0.05 ± 0.02	25.9 ± 10.7	0.97 ± 0.33
P value	0.00	0.00	0.00	0.005	0.000	0.00	0.00

LPD, lateral patellar dislocation; VMO, vastus medialis obliquus.

Figures

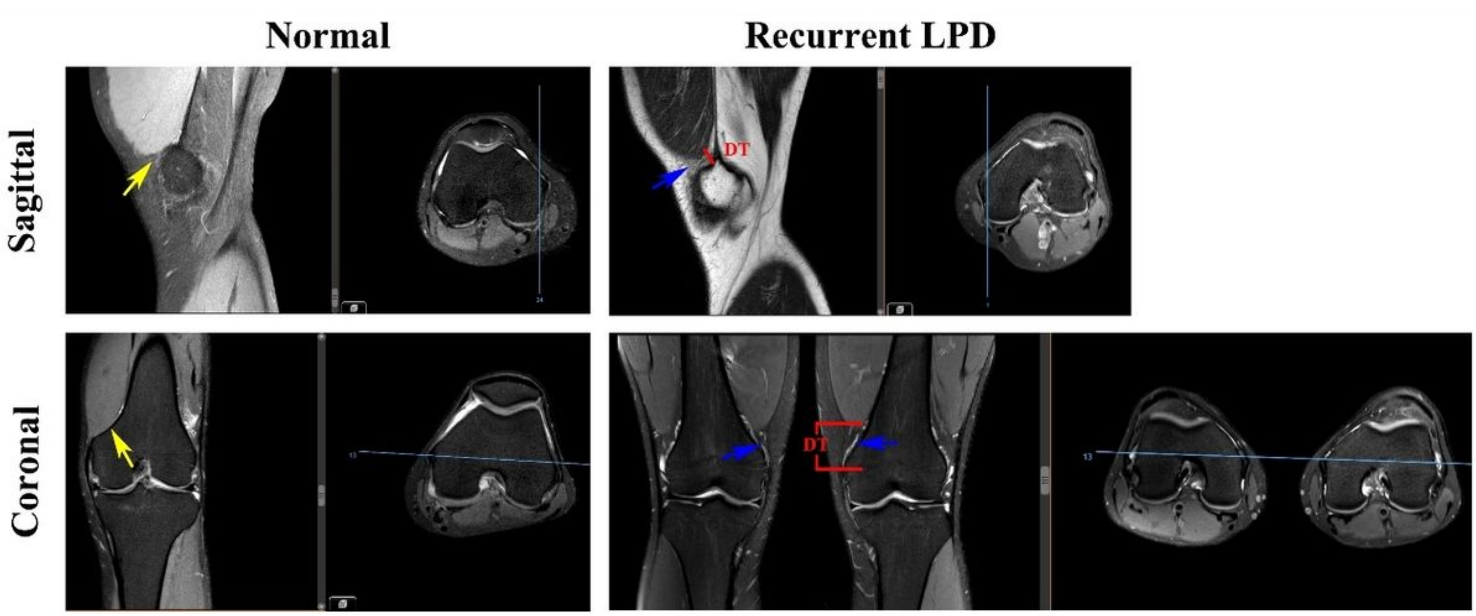

Figure 1

The measurement of VMO elevation, and typical cases in control and LPD groups. DT represented the elevation distance of vastus medialis obliquus (VMO) on sagittal and coronal planes. Under normal conditions, VMO was attached to the medial femoral condyle on sagittal and coronal sectional-imaging (indicated by yellow arrow), but it was significantly elevated in recurrent lateral patellar dislocation (LPD) patients (indicated by blue arrow).

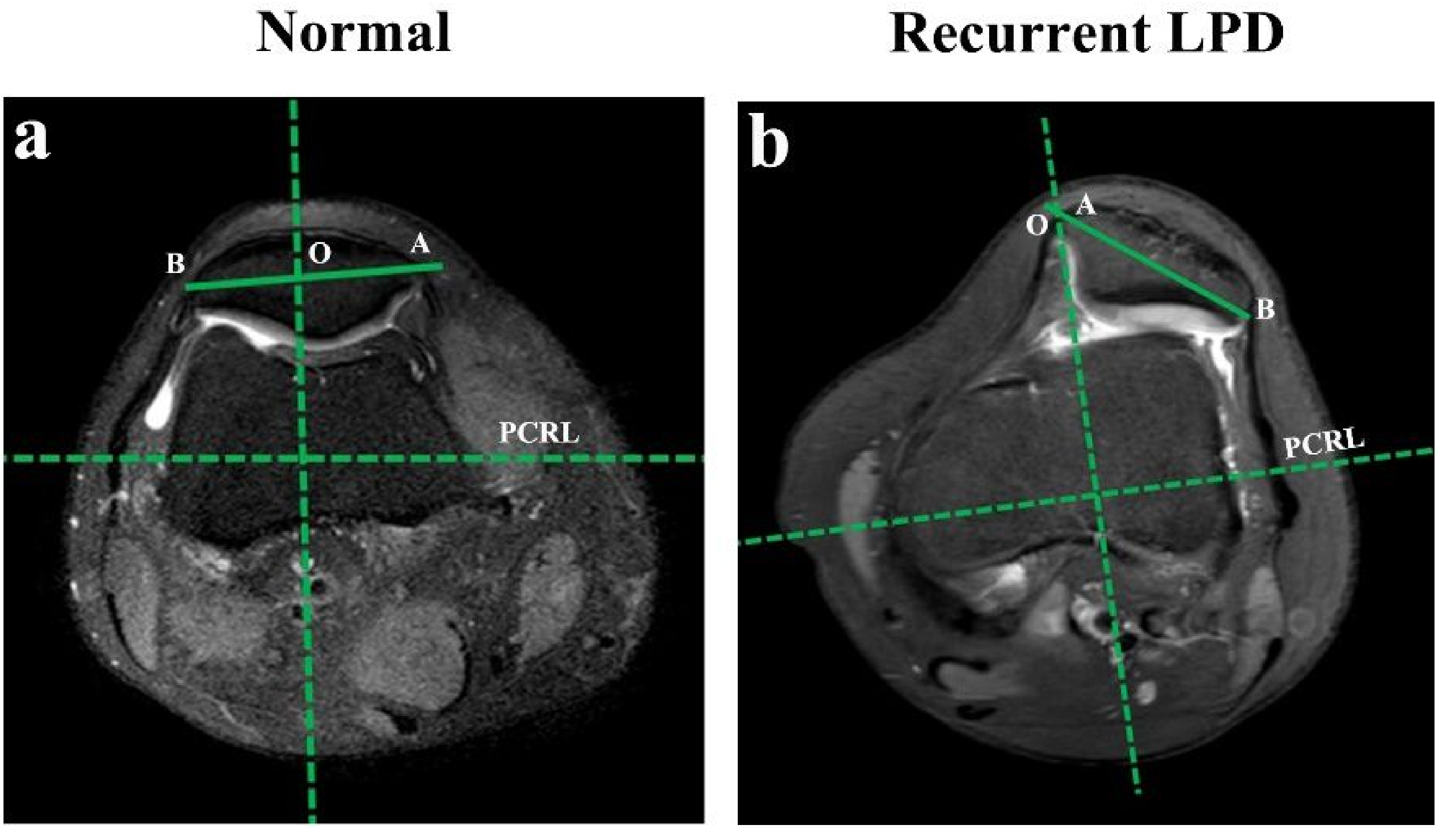

Figure 2

The measurement of patella tilt angle and bisect offset index, and typical cases in control and recurrent LPD groups. The posterior condylar reference line (PCRL) was drawn tangent to the posterior femoral condyles. The patella tilt angle was measured between the PCRL (dashed line) and the maximal patella width line (solid line). A line that passed through the deepest portion of the trochlear groove and perpendicular to the PCRL was drawn. The intersection of this line and the maximal patella width line was defined as point O. On transverse plane of the widest layer of the patella, the innermost point of patella was defined as point A and the outermost point as point B. The percentage of OB / AB was defined as the bisect offset ratio.