Changes in knee extensor strengths before and after medial patellofemoral ligament reconstruction

Matsushita, Takehiko
Araki, Daisuke
Matsumoto, Tomoyuki
Niikura, Takahiro
Kuroda, Ryosuke

(Citation)
The Physician and Sportsmedicine,47(2):220-226

(Issue Date)
2019

(Resource Type)
journal article

(Version)
Accepted Manuscript

Changes in knee extensor strengths before and after medial patellofemoral ligament reconstruction

Abstract

Objective: Quadriceps dysfunction has been suggested as a complication after medial patellofemoral ligament (MPFL) reconstruction. The purpose of this study was to investigate changes in knee extensor strength before and after MPFL reconstruction.

Methods: Twenty patients who underwent MPFL reconstruction for unilateral recurrent patellar dislocation (18 females and 2 males; mean age 20.8 ± 7.6 years) were examined. The peak isometric torque at 60° and 90° of knee flexion and isokinetic knee extensor strength at speeds of 60°/s and 90°/s in operated and non-operated legs were measured using a dynamometer preoperatively and 6 months, 1 year, and 2 years postoperatively. The following parameters were evaluated: (1) body weight-adjusted muscle strength, (2) improvement index (post-/preoperative value × 100) (%), and (3) extensor strength ratio (operated/non-operated value × 100) (%).

Results: The mean knee extensor strength in both operated and non-operated legs significantly increased 2 years after surgery compared with that before surgery. At 2 years postoperatively, the improvement indexes of the isometric knee extensor strength at 60° and 90° and of the isokinetic knee extensor strength at 60°/s and 90°/s were 237%, 192%, 318%, and 186%, respectively, in the operated legs and 144%, 124%, 140%, and 140%, respectively, in the non-operated legs. At 2 years postoperatively, the mean isometric knee extensor strength ratios at 60° and 90° and the isokinetic knee extensor strength ratios at 60°/s and 180°/s were 81%, 84%, 81%, 82%, respectively.

Conclusions: Knee extensor strength was improved in most patients after MPFL reconstruction, at least compared with that before surgery, although an approximately 20% deficit against the non-operated legs remained even 2 years after surgery.

Key words: medial patellofemoral ligament reconstruction, extensor strength, recurrent patellar dislocation, peak isometric torque, peak isokinetic torque

Introduction

The incidence of patellar dislocation is approximately 5.6–7.0 per 100,000 in the general population [1]. After initial patellar dislocation, patients often experience persistent patellar instability and recurrent patellar dislocation [2]. Multiple radiographic findings have been suggested as risk factors for patellar instability, such as trochlear dysplasia, patella alta, lateralized tibial tuberosity relative to the femur, femoral torsion, and increased anteversion of the femoral neck [3-6]. Previous biomechanical studies have shown that the medial patellofemoral ligament (MPFL) is a primary passive restraint against the lateralization of the patella [7-10], and previous clinical studies have reported that the MPFL was damaged in most cases of patellar dislocation [11-13].

In recent years, MPFL reconstruction has been a common surgical choice for the treatment of recurrent patellar dislocations. Most previous studies have reported successful results regardless of graft type and fixation methods [14,15]. A recent systematic review reported a rate of failure, including re-dislocation and subluxation, of 4.8% and an incidence rate of minor complications of 4.0% [16]. Although overall outcomes after MPFL reconstruction are fairly good, several complications such as patellar fracture, pain, and flexion deficit remain to be solved [17-19]. Fisher et al. conducted a systematic review on outcomes, rehabilitation, and return to sports after MPFL reconstruction and found that quadriceps dysfunction was one of the most common complications after MPFL reconstruction [20]. However, knee extensor strength after medial MPFL reconstruction has been described in a limited number of reports, and particularly changes in extensor strength over pre- and postoperative periods remain largely unknown.

In the present study, changes in knee extensor strength after MPFL reconstruction in patients with unilateral recurrent patellar dislocation were investigated. Our hypothesis was that knee extensor strength improves after MPFL reconstruction.

Materials and Methods

Patients

Twenty patients who underwent MPFL reconstruction for unilateral recurrent patellar dislocation in our hospital (18 females and 2 males; mean age at the time of surgery, 20.7 ± 7.5 years; mean body weight, 52.2 ± 6.5 kg) were examined. All patients had unilateral patellar dislocations, and patients who had bilateral patellar dislocations were excluded. Surgical indication for MPFL reconstruction was recurrent patellar dislocations that occurred more than 2 times regardless of predisposing factors. Cartilage injury was observed at the patellar side in 6 patients, groove side in 1 patient, and both sides in 4 patients. In all the patients, osteoarthritis grading was none to mild according to the Crosby and Insall grading system [21]. All the patients received a standard physical therapy in our hospital or local clinics before MPFL reconstruction. All the procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee, and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Institutional review board approval was obtained from the ethics committee of our hospital (Approval No. 1496). Informed consent was obtained from all individual participants included in the study.

Measurements of extensor strength

The peak isometric torque of the knee extensor at 60° and 90° of knee flexion, and the peak isokinetic knee extensor strength at speeds of 60°/s and 180°/s in both operated and non-operated legs were measured using a dynamometer (MYOLET RZ-450, Kawasaki Heavy Industries, Ltd., Kobe, Hyogo, Japan) preoperatively and 6 months, 1 year, and 2 years postoperatively. Prior to the muscle strength test, the subjects warmed up using a stationary cycling ergometer at a low resistance for 5 min. The test was performed with the uninvolved leg first. Each subject performed two practice contractions, followed by five maximal effort contractions. The test was then repeated on the operated leg. The following parameters were evaluated: (1) body weight-adjusted muscle strength (value/body weight × 100) (Nm/kg) (%), (2) postoperative improvement index (post-/preoperative value × 100) (%), and (3) extensor strength ratio of the operated legs against the non-operated legs (operated/non-operated value × 100) (%). During the measurements, the patients were asked regarding the presence of pain and their answers were recorded.

Surgical method

MPFL reconstruction was performed by 2 experienced surgeons as previously described [22]. Briefly, the semitendinosus tendon was harvested for the graft. Lateral release was performed in 12 patients arthroscopically from the intra-articular side using a thermal device (VAPR VUE® Radiofrequency System, DePuy Synthes, Zuchwil, Switzerland) if the patellar tilt was more than 15° and the patella could not be inverted to parallel manually by lifting the lateral side of the patella in knee extension [23, 24]. Two suture anchors were inserted into the medial proximal margin and the medial center of the patella. The femoral tunnel position was also confirmed by fluoroscopy using the method reported by Schöttle et al. [25]. After checking the length change pattern, the doubled semitendinosus tendon was placed in the femoral socket and fixed with a metal interference screw (DePuy Synthes, Zuchwil, Switzerland). Before fixing the patellar side, passive knee flexion was repeated several times to obtain a consistent tracking. Then, the patella was held to maintain its position at 20–30° knee flexion. The distal free end of the graft was pulled with minimal tension to avoid elongating the graft and then tied over the patella using sutures attached to the anchors. After confirming that the graft was not too tight, the proximal free end of the graft was fixed in the same manner.

Rehabilitation

Postoperatively, partial weight bearing with a knee brace started from the next day as tolerated. An electric stimulator was applied to stimulate voluntary quadriceps contraction 3 days after surgery. After 1 week, the knee brace was removed, and range of motion exercise was started. Ergometer exercise started 5 weeks after surgery, and half squatting started 8 weeks after surgery. Jogging was permitted 3 months after surgery, and sports activities were permitted 6 months after surgery.

Outcome evaluations

Clinical outcomes were evaluated preoperatively and at 2-year follow-up using the Kujala score [26]. The patellar height was assessed using the Insall–Salvati ratio (ISR) on lateral plain radiographs (mean preoperative ISR: 1.2 ± 0.2) [27]. The congruence angle was measured in the axial view at 30° of knee flexion (mean preoperative congruence angle: 11.2° ± 22.9°). Trochlear dysplasia was evaluated using the Dejour classification system (type A: 3 patients; type B: 10 patients; type C: 3 patients; type D: 4 patients) [28]. The Tibial tuberosity- Trochlear Groove (TT–TG) distance and patellar tilt angle were measured using computed tomography images as previously described [29] (mean preoperative TT–TG distance: 20.5 ± 4.2 mm).

Patients were divided into 2 groups: the high-ratio group and the low-ratio group. Patients who achieved extensor strength ratios of more than 80% in 3 or 4 of the 4 extensor strength measurements were included in the high-ratio group, whereas patients who did not were included in the low-ratio group. Differences in patient demographic data and preoperative extensor strength ratios were compared between the 2 groups to identify factors affecting the muscle strength ratio at 2 years. Patients were also divided into 2 groups depending on trochlear morphology: the mild dysplasia group (type A or B) and the severe dysplasia group (type C or D). Differences in extensor strength in the 2 groups were compared to examine whether the severity of trochlear dysplasia affects the muscle strength ratio at 2 years.

Statistical analysis

The sample size was calculated using G*Power 3 (Heinrich Heine Universitàt Dùsseldorf, Germany). The minimum required sample size to obtain significant differences among the 4 measurements with a type I error (α) of 0.05, a power (1-β) of 0.80, a correlation among repeated measurements of 0, nonsphericity of 0.334, and an effect size of 0.3 was 17.

Analysis of variance (ANOVA) with repeated measures and univariate ANOVA with Tukey post hoc tests were performed to evaluate extensor strength changes before and after surgery using SPSS for Windows version 16 (SPSS Inc., Chicago, IL, USA). Student's *t*-test or chi-square test was used to compare the difference between 2 groups using Microsoft Excel 2010 (Microsoft Inc., Redmond, WA, USA) and SPSS for Windows version 16. Significance was set at $p < 0.05$. The powers of the comparison between the high and low ratio groups were 0.55, 0.55, 0.57, and 0.35 for isometric knee extensor strength at 60° and 90° knee flexion, and isokinetic knee extensor strength at 60°/s and 180°/s, respectively, with a type I error (α) of 0.05. The powers of the comparison between the mild and severe trochlear groups were 0.80, 0.76, 0.80, and 0.54 for isometric knee extensor strength at 60° and 90° knee flexion, and isokinetic knee extensor strength at 60°/s and 180°/s, respectively, with a type I error (α) of 0.05.

Results

Clinical outcomes

No recurrent dislocation was reported in any of the patients. The Kujala scores were improved in all the patient and the mean score significantly improved from 66.6 ± 19.2 preoperatively to 91.1± 11.7 postoperatively.

Body weight-adjusted muscle strength

The mean isometric knee extensor strength at 60° and 90° of knee flexion, and isokinetic knee extensor strength at 60°/s and 180°/s in the operated and non-operated legs are shown in Table 1 and Figure 1. Overall, the knee extensor strength of the operated legs did not significantly change at 6 months but significantly increased at 1 year and 2 years after surgery compared with that before surgery. In contrast, the knee extensor strength of the non-operated legs significantly increased at 6 months compared with that before surgery but did not further significantly change at 1 year and 2 years compared with that at 6 months.

Postoperative improvement index

In the operated legs, the mean postoperative improvement indexes of the isometric knee extensor strength at 60° and 90° of knee flexion and those of the isokinetic knee extensor strength at 60°/s and 180°/s at 2 years were 237% ± 198%, 192% ± 148%, 318% ± 380%, and 186% ± 108%, respectively. In the non-operated legs, the mean postoperative improvement indexes of the isometric knee extensor strength at 60° and 90° of knee flexion and those of the isokinetic knee extensor strength at 60°/s and 180°/s at 2 years were 144% ± 48%, 124% ± 30%, 140% ± 76%, and 140% ± 40%, respectively. Overall, improvement indexes in the operated legs at 2 years were higher than those in the non-operated legs.

Extensor strength ratios of operated legs against non-operated legs

The mean extensor strength ratios of the operated legs against the non-operated legs before surgery and at 2 years were shown in Figure 2. There were statistically significant differences between the mean preoperative and postoperative extensor strength ratios for isometric strength at 60° of knee flexion and isokinetic strength at 60°/s (Fig. 2). Overall the mean extensor strength ratios at 2years remained approximately 80%.

Four patients obtained extensor strength ratios of more than 80% in all the measurements, and seven patients obtained these ratios in 3 of 4 measurements. Four patients obtained muscle strength ratios of more than 80% in only 1 of 4 measurements, and the extensor strength ratios in all the measurements were below 80% in five patients. To examine the factors affecting the extensor strength ratio at 2 years, patients were divided into 2 groups, the high-ratio group and the low-ratio group. No statistically significant difference was found in the mean age, TT–TG distance, ratio of patients who received MPFL reconstruction combined with lateral release, and ratio of patients who reported pain during the measurements (Table 2). No statistically significant difference was found between the patients who received a MPFL reconstruction combined with lateral release and those who received an isolated MPFL reconstruction in all the measurements. No statistically significant difference in extensor strength ratio was found between the patients with pain and those without pain. The mean preoperative extensor strength ratios in the low-ratio group tended to be lower than those in the high-ratio group. Statistically significant differences were found between the 2 groups in the isometric extensor strength ratio at 60° and isokinetic knee extensor strength ratio at 180°/s (Table 2).

The percentage of patients who had severe trochlear dysplasia (type C or D) was higher in the low-ratio group (55.5%) than in the high-ratio group (18.2%), although the difference did not reach statistical significance. Therefore, patients were divided into 2 groups depending on the type of trochlear dysplasia: the mild dysplasia (type A or B) and severe dysplasia (type C or D) groups. The extensor strength ratios in the mild dysplasia group tended to be higher than those in the severe dysplasia group (Table 3). There were significant differences between the 2 groups in the mean muscle strength ratios for isometric knee extensor strength at 60° and 90° and isokinetic knee extensor strength at 60°/s (Table 3).

Discussion

The most significant finding of this study was that the knee extensor strength in the operated legs significantly improved 2 years after MPFL reconstruction in most patients. Although the knee extensor strength in the operated legs tended to be lower than that in the non-operated legs even 2 years after surgery, the knee extensor strength of the non-operated legs also significantly increased after surgery.

Ronga et al. examined clinical outcomes including return to sports, thigh muscle volume, and isokinetic extensor strength ratios after isolated MPFL reconstruction in patients without obvious predisposing factors for patella instability [30]. They found that increase in thigh muscle volume in the operated leg was less than that in the non-operated leg, and the deficit in extensor strength in the operated leg against the non-operated leg persisted even after return to sports. Similarly, Watanabe et al. reported that the mean isokinetic extensor strength ratio of the operated leg at 60°/s after MPFL reconstruction was 86% of the non-operated leg [31]. Fisher et al. conducted a systematic review on MPFL reconstruction and rehabilitation. They found that quadriceps dysfunction comprised 31% of the total 155 reported complications and was the most frequent finding after MPFL reconstruction [20]. These previous reports suggested that a persistent deficit in extensor strength is a common complication after MPFL reconstruction. However, previous reports only examined the postoperative muscle strength, and whether MPFL reconstruction negatively or positively affects extensor strength remains unclear. Similar to those in previous reports, the mean isometric and isokinetic extensor strength ratios in this study were approximately 80–83% 2 years after surgery. However, the extensor strength of both operated and non-operated legs also improved compared with preoperative extensor strength. Of the 20 patients in this study, 18 had a Tegner activity scale score of less than 4 and were not playing any sports before surgery. Therefore, it is possible that muscle strengthening training in the rehabilitation process positively affected the non-operated legs.

The improvement indexes of the operated legs were 185–318%, whereas those of the non-operated legs were approximately 140%, showing that extensor strength more remarkably improved in the operated legs after surgery. To support our results, Smith et al. reported that isometric knee extensor strength at 0°, 40°, and 80° of knee flexion measured using a handheld dynamometer improved 1 year after surgery [32]. Therefore, it is suggested that knee extensor strength tends to improve after MPFL reconstruction in most of the patients, although it tends to remain lower in the operated legs than in the non-operated legs 2 years after surgery.

To clarify the possible reasons for why the extensor strength remains low even 2 years after surgery, subgroup analyses were performed. The mean preoperative extensor strength ratios in the low-ratio group tended to be lower than those in the high-ratio group, suggesting that preoperative extensor strength was one of the factors affecting postoperative extensor strength ratio. Similar tendencies were observed in previous studies that investigated quadriceps strength recovery in patients who underwent anterior cruciate ligament reconstruction [33,34]. Thus, preoperative muscle strength appears to be a major factor affecting the postoperative extensor strength ratio after MPFL reconstruction.

In addition to the preoperative strength ratios, the percentage of patients with severe trochlear dysplasia was higher in the low-ratio group than in the high-ratio group. Furthermore, the extensor strength ratios tended to be higher in the mild dysplasia group than in the severe dysplasia group, whereas they were not significantly different before surgery. These observations suggested that trochlear dysplasia is also a factor affecting improvement in extensor strength after MPFL reconstruction. Therefore, we speculate that patients with severe trochlear dysplasia tended to have lower extensor strength ratio possibly because the patella was not stabilized enough to exert a strong force after MPFL reconstruction. Conversely, it is also possible that surgeons tend to fix the MPFL graft with a strong tension to stabilize the patella in patients with severe trochlear dysplasia, resulting in lower extensor strength ratios. Krych et al. examined muscle strength recovery in athletes who received MPFL reconstruction with or without tibial tubercle transfer and found 21.4% deficit in extensor strength on the contralateral side 6 months after surgery [35]. In contrast to our results, the results of their study indicated that patients with higher preoperative Caton–Deschamps index tended to have a larger deficit in isokinetic extensor strength at 5 rpm or 30°/s and male patients tended to have a larger deficit in isokinetic extensor strength at 30 rpm or 180°/s, although the mechanisms were not clarified. Thus, multiple factors may also affect extensor strength ratio after MPFL reconstruction, and further studies are required to elucidate the mechanism.

This study certainly has limitations. First, most of the patients were female, and the results may be different in male patients. However, patellar dislocations are generally prevalent in females, and therefore, the results are likely to reflect at least an aspect of patients who undergo MPFL reconstruction. Second, patients with patellar instability in bilateral knees were not included in this study and changes in knee extensor strength could be different in those patients. Third, this study included a small number of patients and the subgroup analyses were performed based on availability without a formal power calculation. Fourth, although extensor strength was examined at 60° and 90° knee flexion and at speeds of 60°/s and 180°/s, respectively, these conditions were not verified as an optimal condition for patients with patellar instability. Therefore, the result might be different if other measurement conditions were used. Despite all these limitations, the present study provided an important basic information on changes in knee extensor strength before and after MPFL reconstruction.

Conclusion

The results of this study suggest that knee extensor strength tended to improve in most patients after MPFL reconstruction, at least compared with that before surgery, although an approximately 20% deficit against the non-operated legs remained even 2 years after surgery.

Funding

The authors did not receive any funding or financial support that may be perceived to have biased the study.

Declaration of interest

The all authors declare that they have no conflict of interest associated with this study.

References

1. Duthon VB. Acute traumatic patellar dislocation. Orthop Traumatol Surg Res 2015;101:S59-67
2. Fithian DC, Paxton EW, Stone ML, et al. Epidemiology and natural history of acute patellar dislocation. Am J Sports Med 2004;32:1114-112
3. Colvin AC, West RV. Patellar instability. J Bone Joint Surg Am 2008;90:2751-2762
4. Elias DA, White LM. 2004 Imaging of patellofemoral disorders. Clin Radiol 59;543-557
5. Diederichs G, Kohlitz T, Kornaropoulos E, et al. Magnetic resonance imaging analysis of rotational alignment in patients with patellar dislocations. Am J Sports Med 2013;41:51-57
6. Askenberger M, Janarv PM, Finnbogason T, et al. Morphology and Anatomic Patellar Instability Risk Factors in First-Time Traumatic Lateral Patellar Dislocations: A Prospective Magnetic Resonance Imaging Study in Skeletally Immature Children. Am J Sports Med 2017;45:50-58
7. Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the

human knee. Am J Sports Med 1998;26:59-65

8. Conlan T, Garth WP, Jr., Lemons JE. Evaluation of the medial soft-tissue restraints of the extensor mechanism of the knee. J Bone Joint Surg Am 1993;75:682-693

9. Hautamaa PV, Fithian DC, Kaufman KR,et al. Medial soft tissue restraints in lateral patellar instability and repair. Clin Orthop Relat Res 1998;349:174-182

10. Panagiotopoulos E, Strzelczyk P, Herrmann M, et al. 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;14:7-12

11. Sanders TG, Morrison WB, Singleton BA, et al. Medial patellofemoral ligament injury following acute transient dislocation of the patella: MR findings with surgical correlation in 14 patients. J Comput Assist Tomogr 2001;25:957-962

12. Elias DA, White LM, Fithian DC. Acute lateral patellar dislocation at MR imaging: injury patterns of medial patellar soft-tissue restraints and osteochondral injuries of the inferomedial patella. Radiology 2002;225:736-743

13. Nomura E, Horiuchi Y, Inoue M. Correlation of MR imaging findings and open exploration of medial patellofemoral ligament injuries in acute patellar dislocations. Knee 2002;9:139-143

14. Buckens CF, Saris DB. Reconstruction of the medial patellofemoral ligament for treatment of

patellofemoral instability: a systematic review. Am J Sports Med 2010;38:181-188

15. Mackay ND, Smith NA, Parsons N, et al. Medial Patellofemoral Ligament Reconstruction for Patellar Dislocation: A Systematic Review. Orthop J Sports Med 2014;2:2325967114544021

16. Stupay KL, Swart E, Shubin Stein BE. Widespread Implementation of Medial Patellofemoral Ligament Reconstruction for Recurrent Patellar Instability Maintains Functional Outcomes at Midterm to Long-Term Follow-up While Decreasing Complication Rates: A Systematic Review. Arthroscopy 2015;31:1372-1380

17. Shah JN, Howard JS, Flanigan DC, et al. A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med 2012;40:1916-1923

18. Parikh SN, Nathan ST, Wall EJ, et al. Complications of medial patellofemoral ligament reconstruction in young patients. Am J Sports Med 2013;41:1030-1038

19. Matsushita T, Oka S, Araki D, et al. Patient-based outcomes after medial patellofemoral ligament reconstruction. Int Orthop 2017;41:1147-1153

20. Fisher B, Nyland J, Brand E, et al. Medial patellofemoral ligament reconstruction for recurrent patellar dislocation: a systematic review including rehabilitation and return-to-sports efficacy. Arthroscopy 2010;26:1384-1394

21. Crosby EB, Insall J. Recurrent dislocation of the patella. Relation of treatment to osteoarthritis. J Bone Joint Surg Am 1976;58:9-13

22. Matsushita T, Kuroda R, Oka S, et al. Clinical outcomes of medial patellofemoral ligament reconstruction in patients with an increased tibial tuberosity-trochlear groove distance. Knee Surg Sports Traumatol Arthrosc 2014;22:2438-2444

23. Christoforakis J, Bull AM, Strachan RK, et al. Effects of lateral retinacular release on the lateral stability of the patella. Knee Surg Sports Traumatol Arthrosc 2006;14:273-277

24. Pagenstert G, Wolf N, Bachmann M, et al. Open lateral patellar retinacular lengthening versus open retinacular release in lateral patellar hypercompression syndrome: a prospective double-blinded comparative study on complications and outcome. Arthroscopy 2012;28:788-797

25. Schöttle PB, Schmeling A, Rosenstiel N, et al. Radiographic landmarks for femoral tunnel placement in medial patellofemoral ligament reconstruction. Am J Sports Med 2007;35:801-804

26. Kujala UM, Jaakkola LH, Koskinen SK, et al. Scoring of patellofemoral disorders. Arthroscopy 1993;9:159-163

27. Insall J, Salvati E. Patella position in the normal knee joint. Radiology 1971;101:101-104

28. Dejour D, Le Coultre B. Osteotomies in patello-femoral instabilities. Sports Med Arthrosc

2007;15:39-46

29. Dejour H, Walch G, Nove-Josserand L, et al. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 1994;2:19-26

30. Ronga M, Oliva F, Longo UG, et al. Isolated medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med 2009;37:1735-1742

31. Watanabe T, Muneta T, Ikeda H, et al. Visual analog scale assessment after medial patellofemoral ligament reconstruction: with or without tibial tubercle transfer. J Orthop Sci 2008;13:32-38

32. Smith TO, Mann CJ, Donell ST. Does knee joint proprioception alter following medial patellofemoral ligament reconstruction? Knee 2014;21:21-27

33. Ueda Y, Matsushita T, Araki D, et al. Factors affecting quadriceps strength recovery after anterior cruciate ligament reconstruction with hamstring autografts in athletes. Knee Surg Sports Traumatol Arthrosc 2017;25:3213-3219

34. Eitzen I, Holm I, Risberg MA. 2009. Preoperative quadriceps strength is a significant predictor of knee function two years after anterior cruciate ligament reconstruction. Br J Sports Med 2009;43:371-376

35. Krych AJ, O'Malley MP, Johnson NR, et al. Functional testing and return to sport following

stabilization surgery for recurrent lateral patellar instability in competitive athletes. Knee Surg Sports Traumatol Arthrosc 2018;26:711-718

Figure legends

Figure 1. Changes in knee extensor strength before and 6 months, 1 year, and 2 years after MPFL reconstruction. ♦ indicates non-operated legs. ■ indicates operated legs. *p < 0.01. NS, not statistically significant.

Figure 2. Extensor strength ratios 2 years pre- and postoperatively. *p < 0.01. NS, not statistically significant.

Table 1. Changes in knee extensor strength before and after MPFL reconstruction. Values are expressed as mean ± SD (Nm/kg) (%).

Table 2. Comparison of the high-ratio and low-ratio groups. Data are expressed as mean ± SD. *p < 0.01. NS, not statistically significant.

Table 3. Comparison of patients with mild dysplasia (type A or B) and severe dysplasia (type C or

D) with respect to extensor strength ratio. Data are expressed as mean ± SD (%).