Patellofemoral contact pressure for medial patellofemoral ligament reconstruction using suture tape varies with the knee flexion angle: A biomechanical evaluation.

（人工靭帯を用いた内側膝蓋大腿靭帯再建時の膝屈曲角度が膝蓋大腿関節接触圧に与える影響）

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Title

Patellofemoral contact pressure for medial patellofemoral ligament reconstruction using suture tape varies with the knee flexion angle: A biomechanical evaluation.

ABSTRACT

Purpose: The purpose of this study was to evaluate the effect of the knee flexion angle during graft fixation on patellofemoral (PF) contact pressure in medial patellofemoral ligament (MPFL) reconstruction using polyester suture tape and knotless anchors.

Methods: Nine human knees (mean age: 71.2 ± 14.2 y) were used in this study. Polyester suture tape was fixed at the medial edge of the patella with two 3.5-mm knotless anchors and then to the femur with a 4.75-mm knotless anchor at four different knee flexion angles (0°, 30°, 60°, and 90°). A pressure sensor was used to measure the maximum contact pressure (MCP) of the medial and lateral PF joints in the intact knee and in post-reconstruction knees at each knee flexion angle (0°, 30°, 60°, and 90°). Each MCP was normalized to that of the intact knee. A statistical comparison was made between MCP in the intact and reconstructed knees.

Results: The normalized MCP of the medial PF joint fixed at either 0° or 30° significantly increased at 60° of knee flexion (p=0.036 and 0.042, respectively) and at 90° of knee flexion (p=0.002 and 0.001, respectively). Conversely, the normalized MCP fixed at 60° and 90°

remained at the same level as the intact knees at all angles of knee flexion. The normalized MCP of the lateral PF joint showed no significant difference at any fixation angle compared with intact knees.

Conclusion: To avoid excessive PF joint contact pressure after MPFL reconstruction, it may be best to fix polyester suture tape between 60º to 90º of knee flexion.

Clinical Relevance: Fixation of the polyester suture tape with a knotless anchor for MPFL reconstruction should be at 60º to 90º of knee flexion to most closely restore PF joint contact pressures to that of the intact knee.

INTRODUCTION

Lateral patellar instability (LPI) is a common problem in young patients and surgical treatment is often recommended.[1, 2] The medial patellofemoral ligament (MPFL) is a major stabilizer controlling lateral displacement of the patella,[3] and it is frequently injured during patellar dislocation.[4, 5] MPFL reconstruction has become an acceptable treatment option[6] that demonstrates excellent clinical results and has a low repeat dislocation rate.[7] Various graft options exist for MPFL reconstruction, and the choice of graft remains the preference of the surgeon; include semitendinosus, gracilis, quadriceps or adductor magnus tendons, part of the patellar tendon, and allografts.[8] Although autologous tendon grafts are most commonly used for

MPFL reconstruction, artificial ligaments have been reported as an alternative option.[9, 10] MPFL reconstruction using an artificial ligament entails no risk on the donor side.[11] Other beneficial characteristics of an artificial ligament are its stiffness and resistance to elongation. Lee et al.[12] reported the use of synthetic material with knotless anchors for MPFL reconstruction. MPFL reconstruction using polyester suture tape and knotless anchors significantly improves the patient's quality of life and results in better postoperative outcomes.[12] A previous study showed that MPFL reconstruction using polyester suture tape and knotless anchors was stronger than a semitendinosus tendon autograft with soft anchors.[13]

One potential complication of MPFL reconstruction with an artificial ligament is postoperative medial patellofemoral (PF) pain caused by an overly constrained patella. This is affected by the fixation angle of the artificial ligament. It is important to maintain normal patellofemoral contact pressure and to achieve reconstruction that is anatomically similar to that of the intact knee. However, the optimal knee flexion angle for graft tension remains a matter of debate.[14-19]

The purpose of this study was to evaluate the effect of the knee flexion angle during graft fixation on PF contact pressure during MPFL reconstruction using polyester suture tape and knotless anchors. It was hypothesized that the optimal fixation of the polyester suture tape is 60° of flexion as reported in previous studies that used a tendon graft.[20]

MATERIALS AND METHODS

Specimen preparation

Fourteen amputated human knees from eight male and six female donors (age: 74.9 ± 14.1 y; range: 57-97 y) were used in this study. Informed consent was obtained from the patients or their family, and the study was approved by our institution's ethics committee. Specimens with obvious knee osteoarthritis, such as grade 3 or 4 cartilage lesions, a history of knee surgery, or abnormal laxity were excluded. Five specimens were excluded because those had knee osteoarthritis (3 were grade 3 and 2 were grade 4). Specimens were evaluated by a senior orthopaedic surgeon (PhD). The knees were stored at -20^{o}C and thawed at room temperature for 24 hours before testing. The proximal femur and distal tibia were cut approximately 150 mm from the joint line. The patella, quadriceps tendon, and capsular structures around the patella were left intact and the MPFL was identified. Specimens were kept moist with 0.9% saline during preparation and testing. After preparing the specimens, the proximal part of the femur was fixed to a custom-made mount that allowed for knee movement of 0° to 90° of knee flexion (Fig. 1). A force of 50 N was continuously applied to the quadriceps tendon with a pulley system to simulate physiological quadriceps function.[21]

Surgical procedure

After the MPFL was cut at the midportion, MPFL reconstruction was performed using polyester suture tape (FiberTape®; Arthrex, North Naples, Florida) and knotless anchors (PEEK SwiveLock®; Arthrex, North Naples, Florida).[12] The central portion of the polyester suture tape was fixed with two 3.5-mm knotless anchors on the patella. Fixation points were the proximal to the quadrisect and the distal to the middleon the medial edge of the patella. Then, the two free ends of the polyester suture tape were fixed using 4.75-mm knotless anchor on the femoral side while the patella was kept in the center of the patellar groove (Fig. 2).[13] The femoral fixation point was determined by the insertion of the intact MPFL between the adductor tubercle and the medial epicondyle. The polyester suture tape was fixed with the knee in different angles of flexion (Fix 0°, 30°, 60°, or 90°) in each specimen. The MPFL had excessive tension and limited patella motion over 30° of knee flexion. However, the MPFL gradually relaxed beyond 30° flexion[6]. Previous research[21] indicated that MPFL reconstruction using the gracilis tendon and a knee flexion angle of 60° most closely restored PF contact pressure. Based on these results, the fixed angles for this study were determined to be 0°, 30°, 60°, and 90°. As reported, polyester suture tape was fixed at 2 N, which is suitable for graft fixation.[22, 23] After testing each intact knee, MPFL reconstruction was performed with the knee a randomly assigned flexion angle to avoid performing the reconstruction angle in sequence. Performing pressure distributions in the same knee at different graft flexion angles might have influenced the

measurements performed during this study. To minimize this possibility, the sequence of knee flexion angles was alternated between procedures.

Patellofemoral joint contact pressure

A pressure sensor device (K-SCAN2, 4010N; Tekscan, South Boston, MA, USA) was used to measure PF joint contact pressure. The pressure sensor was inserted in the PF joint and the sensors were calibrated using custom-made loading blocks before each test. The maximum contact pressure (MCP) of the medial and lateral PF joints was measured for the intact knee as well as for each MPFL reconstruction with knee flexion of 0°, 30°, 60°, and 90°.

Statistical analysis

All data input and calculations were performed. MCP values are shown as means and standard deviations. During the power analysis, partial eta squared was calculated as 0.427 from our present data, and the effect size was 0.863. A power analysis for the repeated-measured analysis of variance (ANOVA) showed that we needed eight samples for each fixed group to be able to reject the null hypothesis with a power of 0.80 and type I error probability of 0.05. Finally, we could reject the null hypothesis with a power of 0.954. The values of MCP of each MPFL reconstruction fixed at 0°, 30°, 60°, and 90° were normalized to those recorded for the intact knees. Normalized MCP was compared using a repeated-measures ANOVA, followed by Tukey post-hoc testing. Significance was set as $p=0.05$.

RESULTS

MCP values of the medial and lateral PF joints in the intact knees were similar at each knee flexion angle, and we found no significant difference between the medial and lateral PF joints (Table 1). The normalized MCP of the medial PF joint fixed at 0° and 30° was significantly higher than that in intact knees in 60° of knee flexion (p=0.036 and 0.042, respectively) and in 90° of knee flexion (p=0.002 and 0.001, respectively) (Table 2, Fig 3). However, we found no significant difference in MCP with fixations at 60° and 90° compared with the intact group. We found no significant difference in the normalized MCP of the lateral PF joint in any group compared with intact group (Table 3, Fig 4).

DISCUSSION

During this study, we found no significant difference in the normalized MCP of the medial PF joint in knees fixed at 60° and 90° compared with the intact group. These results suggested that MPFL reconstruction using polyester suture tape and knotless anchors should be fixed by suture tape at 60º to 90º of knee flexion.

Few studies have investigated the effects of knee the flexion angle on PF joint pressure during graft fixation. Lorbach et al.[21] conducted a biomechanical study of PF joint pressure after

MPFL reconstruction with a gracilis tendon. Based on that study, the tendon should be fixed at 60º during anatomical MPFL reconstruction. Although our study differed in that we used suture tape, we obtained similar results for the optimal knee flexion angle during fixation. Hopper et al.[24] described a method of FT-MPFL reconstruction and stated the importance of avoiding excessive constraint when fixing the suture tape because excess tension leads to irritation and can result in quadriceps inhibition; however, in that study, the optimal knee flexion angle during graft fixation was not reported for the clinical course or the biomechanical study. Our results suggested that the optimal knee flexion angle at the time of graft fixation is 60º to 90º.

Several previous studies have reported the optimal fixation angle during MPFL reconstruction using autografts. Deie et al.[14] reported that the optimal fixation angle was30° of knee flexion when using a cylindrical bone plug and semitendinosus tendon graft. Kita et al.[16] reported that 45° was the optimal fixation angle when using a double-looped semitendinosus tendon. Nomura et al.[9] recommended fixation at 60° when using polyester tape (Leeds-Keio artificial ligament); they also used a tension spacer between the polyester tape and the femur during fixation to avoid excessive tensioning. Additionally, it was reported[10] that the optimal knee flexion was 90° for fixation using a polyester ligament during MPFL reconstruction. Because these were clinical reports, and because biomechanical studies have not been conducted, the optimal knee flexion angle for MPFL reconstruction using artificial ligaments

remains unknown. Patel et al.[25] conducted a systematic review of the optimal knee flexion angle during graft fixation and, based on the flexion angle during graft fixation, separated subjects into low (0-30°) and high (45-90°) flexion angle groups; they concluded that there was no difference between the two groups. However, that study included a variety of MPFL reconstruction techniques, and it cannot always be said that the flexion angle at the time of fixation does not affect outcomes.

Lorbach[21] reported that with fixation at 60°, the PF joint contact pressure was equivalent to that of the intact group. In our study, fixation at 60° and fixation at 90° were found to be equal to that of the intact group. These results may have been affected by the characteristics of the suture tape. Polyester suture tape is an ultra-high-strength tape consisting of long chains of ultra-high-molecular-weight polyethylene. Because this tape does not elongate over time, as compared to autografts or allografts, the polyester suture tape fixation angle may need to be equal to or greater than that used for autografts or allografts. These results were consistent with those of this experiment.

Several studies have demonstrated that the anatomical placement of the graft is critical during MPFL reconstruction. Sanchis-Alfonso[26] reported that the optimal graft position on the femur is critical and contributes to outcomes after MPFL reconstruction. MPFL attachment footprints have been well-described by cadaveric studies.[27-29] Schottle et al.[30] were the first to

report reliable radiographic landmarks for an anatomic femoral attachment during MPFL reconstruction. The MPFL was identified as a thickened, bandlike condensation of tissue extending from the patella to the medial femur. The location of the femoral origin of the MPFL is between the adductor tubercle and the medial epicondyle (Fig 2). Dornacher[31] reported that anatomical double-bundle MPFL reconstruction more closely restored PF joint contact pressure to that of the intact knee. Stephen et al.[32] stated that the correct femoral tunnel position restored normal joint kinematics and PF joint contact pressure. In this study, anatomical double-bundle reconstruction was performed in the same way as reported by previous studies to reduce the influence on PF joint contact pressure.

Limitations

There were several limitations to the present study that need to be mentioned. Because this was a biomechanical study of amputated knees, the results may not be completely transferable to clinical situations. The surrounding soft tissue may significantly influence PF joint contact pressure further, even if a constant pull of 50 N was applied to the quadriceps tendon to simulate physiological quadriceps tension. This study involved knees without a history of disease or patellar instability, which might differ from actual clinical conditions. Sensor film was fixed to the patella using multiple simple stitches, and its influence on dynamic pressure distributions cannot be ruled out. Another limitation was the possibility of deviation

due to the surgical technique. The techniques used in this study were comparable to those used in vivo to assess anatomic fixation points. It may not be possible to completely reach anatomic attachment in all knees, as recently shown by Ziegler et al.,[33] because this is dependent on the surgeon's experience. A slight difference in femoral and patellar tunnel placement can potentially occur during reconstruction. Another limitation was that measurements of the PF joint contact pressures were only obtained medially and laterally. There was no significant difference in the lateral PF joint contact pressure in this study; therefor, contact pressure measured in more areas of the joint should be investigated. Another limitation was that this was a time-zero study that did not consider the cyclic loading. Cyclic loading may affect the stiffness of suture tape and fixation strength.

CONCLUSION

To avoid excessive PF joint contact pressure after MPFL reconstruction, it may be best to fix polyester suture tape between 60º to 90º of knee flexion.

REFERENCES

1. Ji G, Wang F, Zhang Y, et al. Medial patella retinaculum plasty for treatment of habitual patellar dislocation in adolescents. *Int Orthop* 2012;36:1819-1825.

2. Christensen TC, Sanders TL, Pareek A, et al. Risk factors and time to recurrent ipsilateral and contralateral patellar dislocations. *Am J Sports Med* 2017;45:2105-2110.

3. Zaffagnini S, Colle F, Lopomo N, et al. The influence of medial patellofemoral ligament on patellofemoral joint kinematics and patellar stability. *Knee Surg Sports Traumatol Arthrosc* 2013;21:2164-2171.

4. Tompkins MA, Rohr SR, Agel J, Arendt EA. Anatomic patellar instability risk factors in primary lateral patellar dislocations do not predict injury patterns: an MRI-based study. *Knee Surg Sports Traumatol Arthrosc* 2018;26:677-684.

5. Askenberger M, Arendt EA, Ekström W, et al. Medial patellofemoral ligament injuries in children with first-time lateral patellar dislocations: A magnetic resonance imaging and arthroscopic study. *Am J Sports Med* 2016 Jan;44:152-158.

6. Chouteau J. Surgical reconstruction of the medial patellofemoral ligament. *Orthop Traumatol Surg Res* 2016;102:S189-S194.

7. Lippacher S, Dreyhaupt J, Williams SR, Reichel H, Nelitz M. Reconstruction of the medial

patellofemoral ligament: Clinical outcomes and return to sports. *Am J Sports Med* 2014;42:1661-1668.

8. Krebs C, Tranovich M, Andrews K, Ebraheim N. The medial patellofemoral ligament: Review of the literature. *J Orthop* 2018;15:596-599.

9. Nomura E, Horiuchi Y, Kihara M. A mid-term follow-up of medial patellofemoral ligament reconstruction using an artificial ligament for recurrent patellar dislocation. Knee 2000;7:211-215.

10. Ellera Gomes JL. Medial patellofemoral ligament reconstruction for recurrent dislocation of the patella: a preliminary report. Arthroscopy 1992;8:335-340.

11. 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.

12. Lee PYF, Golding D, Rozewicz S, et al. Modern synthetic material is a safe and effective alternative for medial patellofemoral ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2018;26:2716-2721.

13. Tsushima T, Tsukada H, Saaki S, et al. Biomechanical analysis of medial patellofemoral ligament reconstruction: FiberTape® with knotless anchors versus a semitendinosus tendon autograft with soft anchors. *J Orthop Sci* 2019;24:663-667.

14. Deie M, Ochi M, Adachi N, Shibuya H, Nakamae A. Medial patellofemoral ligament reconstruction fixed with a cylindrical bone plug and a grafted semitendinosus tendon at the original femoral site for recurrent patellar dislocation. *Am J Sports Med* 2011;39:140-145.

15. Han H, Xia Y, Yun X, Wu M. Anatomical transverse patella double tunnel reconstruction of medial patellofemoral ligament with a hamstring tendon autograft for recurrent patellar dislocation. *Arch Orthop Trauma Surg* 2011;131:343-351.

16. Kita K, Horibe S, Toritsuka Y, et al. Effects of medial patellofemoral ligament reconstruction on patellar tracking. *Knee Surg Sports Traumatol Arthrosc* 2012;20:829-837.

17. Matthews JJ, Schranz P. Reconstruction of the medial patellofemoral ligament using a longitudinal patellar tunnel technique. *Int Orthop* 2010;34:1321-1325.

18. Panni AS, Alam M, Cerciello S, Vasso M, Maffulli N. Medial patellofemoral ligament reconstruction with a divergent patellar transverse 2-tunnel technique. *Am J Sports Med* 2011;39:2647-2655.

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

20. Lorbach O, Zumbansen N, Kieb M, et al. Medial patellofemoral ligament reconstruction: Impact of knee flexion angle during graft fixation on dynamic patellofemoral contact

pressure - A biomechanical study. *Arthroscopy* 2018;34:1072-1082.

21. Lorbach O, Haupert A, Efe T, et al. Biomechanical evaluation of MPFL reconstructions: differences in dynamic contact pressure between gracilis and fascia lata graft. *Knee Surg Sports Traumatol Arthrosc* 2017;25:2502-2510.

22. Beck P, Brown NA, Greis PE, Burks RT. Patellofemoral contact pressures and lateral patellar translation after medial patellofemoral ligament reconstruction. *Am J Sports Med* 2007;35:1557-1563.

23. Stephen JM, Kittl C, Williams A, et al. Effect of Mmedial patellofemoral ligament reconstruction method on patellofemoral contact pressures and kinematics. *Am J Sports Med* 2016;44:1186-1194.

24. Hopper GP, Heusdens CHW, Dossche L, Mackay GM. Medial patellofemoral ligament repair with suture tape augmentation. *Arthrosc Tech* 2019;8:e1-e5.

25. Patel NK, de Sa D, Vaswani R, et al. Knee flexion angle during graft fixation for medial patellofemoral ligament reconstruction: A systematic review of outcomes and complications. *Arthroscopy* 2019;35:1893-1904.

26. Sanchis-Alfonso. Guidelines for medial patellofemoral ligament reconstruction in chronic lateral patellar instability. *J Am Acad Orthop Surg* 2014;22:175-182.

27. Shea KG, Martinson WD, Cannamela PC, et al. *Am J Sports Med* 2018 Feb;46:363-369.

28. Kruckeberg BM, Chahla J, Moatshe G, et al. Quantitative and qualitative analysis of the medial patellar ligaments: An anatomic and radiographic study.

29. Shea KG, Styhl AC, Jacobs JC Jr, et al. The relationship of the femoral physis and the medial patellofemoral ligament in children: A cadaveric study. A*m J Sports Med* 2016;44:2833-2837.

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

31. Dornacher D, Lippacher S, Nelitz M, et al. Impact of five different medial patellofemoral ligament-reconstruction strategies and three different graft pre-tensioning states on the mean patellofemoral contact pressure: a biomechanical study on human cadaver knees. *J Exp Orthop* 2018;28:1-10.

32. Stephen JM, Kaider D, Lumpaopong P, Deehan DJ, Amis AA. The effect of femoral tunnel position and graft tension on patellar contact mechanics and kinematics after medial patellofemoral ligament reconstruction. *Am J Sports Med* 2014;42:364-372.

33. Ziegler CG, Fulkerson JP, Edgar C. Radiographic reference points are inaccurate with and without a true lateral radiograph: The importance of anatomy in medial patellofemoral ligament reconstruction. *Am J Sports Med* 2016;44:133-142.

FIGURE LEGENDS

Figure 1. Testing apparatus and specimen. Knee specimens were fixed to a custom-made mount that allowed for 0° to 90° of knee flexion. Pressure sensors were sutured to the undersurface of the patella.

Figure 2. Computed tomography (CT) image of the right knee after medial patellofemoral ligament reconstruction using polyester suture tape and knotless anchors. The central portion of the polyester suture tape was fixed by two 3.5-mm knotless anchors on the medial border of the patella (arrow) and the two free ends of the polyester suture tapes were fixed using a 4.75-mm knotless anchor on the femoral side (arrowhead). The femoral fixation point is located between the abductor tubercle (AD) and medial epicondyle (ME).

Figure 3. Normalized maximum contact pressure (MCP) of the medial patellofemoral (PF) joint. The normalized MCP of the medial PF joint fixed at 0° and 30° was significantly higher than that in intact knees at 60° of knee flexion ($p=0.036$ and 0.042, respectively) and at 90° of knee flexion ($p=0.002$ and 0.001, respectively). *$p < 0.05$ compared to the intact group.

Figure 4. Normalized maximum contact pressure (MCP) of the lateral patellofemoral (PF) joint. The normalized MCP of the lateral PF joint showed no significant difference in any group compared with the intact group.

TABLES

Table 1. Average values of the maximum contact pressure of the medial and lateral patellofemoral joints in intact knees.

Flexion angle	Medial PF joint (N/cm^2)	Lateral PF joint (N/cm^2)
0°	9.32 ± 4.00	10.56 ± 4.48
30°	9.56 ± 2.74	10.11 ± 2.85
60°	9.43 ± 3.43	9.67 ± 3.54
90°	8.00 ± 2.78	8.44 ± 3.78

Joint pressures are expressed as mean ± standard deviationSD.

TABLE 2. Average values of the normalized maximum contact pressure of medial patellofemoral joint.

Flexion angle	Fix 0°	Fix 30°	Fix 60°	Fix 90°
0°	1.09 ± 0.31	1.09 ± 0.43	0.90 ± 0.17	0.82 ± 0.13
30°	1.40 ± 0.57	1.18 ± 0.28	0.97 ± 0.09	0.94 ± 0.18
60°	1.56 ± 0.56	1.55 ± 0.62	1.01 ± 0.12	0.98 ± 0.16
90°	1.69 ± 0.46	1.76 ± 0.40	1.22 ± 0.20	1.15 ± 0.23

Joint pressures are expressed as mean ± standard deviation (N/cm2).

*$p < 0.05$ compared with the intact group

TABLE 3. Average values of the normalized maximum contact pressure of the lateral patellofemoral joint.

Flexion angle	Fix 0°	Fix 30°	Fix 60°	Fix 90°
0°	**1.04 ± 0.28**	**1.01 ± 0.26**	**0.81 ± 0.18**	**0.75 ± 0.24**
30°	**1.15 ± 0.27**	**1.07 ± 0.35**	**0.93 ± 0.21**	**0.87 ± 0.24**
60°	**1.12 ± 0.27**	**1.03 ± 0.25**	**1.04 ± 0.22**	**1.00 ± 0.13**
90°	**1.09 ± 0.60**	**0.90 ± 0.33**	**1.00 ± 0.18**	**1.04 ± 0.26**

Joint pressures are expressed as mean ± standard deviationSD (N/cm2).