岩手医科大学
審査学位論文
（博　士）

Morphology of Insertion Sites on Patellar Side of Medial Patellofemoral Ligament

Shuhei Kikuchi[1], MD, Goro Tajima[1], MD, PhD, Jun Yan[2], PhD, Youichi Kamei[1], MD, PhD, Moritaka Maruyama[1], MD, PhD, Atsushi Sugawara[1], MD, PhD, Kotaro Fujino[1], MD, PhD, Sanjuro Takeda[1], MD, PhD, Minoru Doita[1], MD, PhD

[1]Department of Orthopaedic Surgery, Iwate Medical University, Morioka, Japan

[2] Department of Anatomy, Iwate Medical University, Morioka, Japan

Investigation performed at the Department of Anatomy, Iwate Medical University, Morioka, Japan

Corresponding author: Goro Tajima, MD, PhD

Department of Orthopaedic Surgery, Iwate Medical University.

Address:

19-1 Uchimaru

Morioka, Iwate 020-8505, Japan

E-mail: goro.t@triton.ocn.ne.jp

Keywords: Medial patellofemoral ligament, Insertion, Patella, Morphology

Running title: Morphology of Patellar Insertion of Medial Patellofemoral Ligament

Abbreviations:

MPFL: medial patellofemoral ligament

VMO: vastus medialis obliquus

VI: vastus intermedius

3-D: three-dimensional

CT: computed tomography

Financial Support

The authors received no external funding for this study.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 15K01562. The authors wish to thank Emeritus Professor Tadashi Shimamura from the Department of Orthopaedics of Iwate Medical University, and Professors Jiro Hitomi and Yoichi Sato from the Department of Anatomy of Iwate Medial University for their continuous support of this study. We also thank Mr. Masayoshi Kamata from the Department of Radiology of Iwate Medical University Hospital for his technical assistance.

Morphology of Insertion Sites on Patellar Side of Medial Patellofemoral Ligament

ABSTRACT

Purpose: The purpose of this study was to clarify the insertion sites on the patellar side of the medial patellofemoral ligament (MPFL).

Methods: A total of 35 non-paired human cadaveric knees were used in this study. After identification of the MPFL, the insertion sites on the patellar side of the MPFL were marked. Three-dimensional images were created, and the location and morphology of these insertion sites were analyzed.

Results: The morphology of the insertion sites on the patellar side of the MPFL was consistent. The proximal fibers of the MPFL were inserted to the deep fascia of the vastus medialis obliquus (VMO) and medial margin of the vastus intermedius (VI). The distal fibers of the MPFL were inserted to the medial margin of the patella directly. The insertion lengths of the VMO, VI, and patella were 26. 7 ± 5.0, 28.5 ± 4.4, and 18.5 ± 4.4 mm, respectively. The rate of the vertical distance from the superior pole of the patella to the superior edge of the MPFL in relation to the total patellar height was 12 ± 4.4%. At the distal edge, the rate was 58 ± 9.6%.

Conclusion: The insertion sites on the patellar side of the MPFL were consistent. The MPFL inserted into the VMO and VI was significantly longer than into the patella. The clinical relevance of this study is to improve understanding of the anatomy of the insertion sites on the patellar side of the MPFL and the pathophysiology of patellar dislocation.

Key Words: Medial patellofemoral ligament, Insertion, Patella, Morphology, Vastus medialis obliquus

Introduction

The medial patellofemoral ligament (MPFL) is a thin fascial band that is fan-shaped, and has been considered to be the main medial static stabilizing structure of the patella [2, 6, 8, 9]. Several biomechanical studies have reported that this ligament contributes to around 50-60% of the medial stabilizing strength of the patella, and that it is the main medial soft tissue restraint preventing lateral patellar displacement. Especially, the contribution of the MPFL to resisting patellar displacement is greatest with the knee fully extended, and it falls rapidly up to 20° flexion [2, 5, 8, 9]. In cases of patellar dislocation causing pain and functional impairment, there is an associated MPFL tear rate of 95 to 100% [15, 21, 22]. Although there are various reports about the location of the tear of the MPFL, it has been reported that MPFL tears at or near its femoral insertion site in many cases [1, 21, 29].

MPFL reconstruction has been used as a widespread technique for the restoration of patellofemoral stability [23]. Numerous biomechanical studies of MPFL reconstruction have revealed the significance of reproduction of the native ligament: the key point is its positioning in the femoral insertion that is going to restore isometry [17, 23]. Therefore, numerous anatomical and biomechanical studies have focused on the femoral insertion site of the MPFL [14, 17, 19, 25, 26].

It has been reported that double bundle reconstruction of the MPFL, an anatomical concept, with which one tunnel on the femur and two tunnels on the patella form a fan-like shape, led to satisfactory clinical results [10, 12, 23, 28]. According to several studies, both femoral and patellar attachments of the MPFL need to

be reconstructed to restore the inherent anatomical and kinetic characteristics of the ligament [2, 23]. However, the insertion sites on the patellar side of the MPFL have remained unclear. It has been reported that the MPFL is inserted not only to the patella but also to the deep fascia of the vastus medialis obliquus (VMO) and/ or vastus intermedius (VI) tendon [2, 6, 9, 13, 18, 27]. Nevertheless, double bundle reconstruction of the MPFL has been performed with only two tunnels to the patella, ignoring soft tissue attachment.

The aim of this study was to accurately describe anatomical findings of the MPFL, especially regarding the insertion sites on the patellar side. The hypothesis is that characteristic features of the insertion sites on the patellar side of the MPFL can be identified, and that they are consistent.

Materials and Methods

Thirty-five non-paired human cadaveric knees (21 males and 14 females), with no severe macroscopic degenerative or traumatic changes, were used in this study. All cadavers were donated to the Unit of Clinical Anatomy, Iwate Medical University School of Medicine. The average age at the time of death was 81.8 ± 9.9 years (range: 56 to 97 years). All cadavers were fixed in 10% formalin and preserved in 50% alcohol for 6 months. These cadavers were donated to our institute for education and research purposes, and informed consent for donation was obtained from each patient and their family prior to death. Preparation began by removing the skin and soft subcutaneous tissue on the medial side of the knee, and the sartorius, gracilis, and semitendinous muscles were also removed. After the removal of these tissues, the VMO and

consecutive medial retinaculum were peeled off, and the femoral insertion site of the MPFL was identified. The MPFL was released from the articular capsule at the femoral insertion site, in order to isolate the MPFL. After that, using a lateral parapatellar approach, the patella tendon was cut in order to reflect the patella and patella tendon medially, then the capsule was removed from the intra-articular side by careful dissection, and the insertion sites on the patellar side of the MPFL were observed (Fig. 1).

The sites at which the MPFL was firmly inserted into the patella, fascia, and tendon or the termini at which MPFL fibers can be macroscopically traced were defined as the patellar insertion sites of the MPFL. After identification of the MPFL, gross observation of the MPFL and other related structures was performed. All peripheral lines of the insertion sites on the patellar side of the MPFL were marked by soft stainless wire with a diameter of 0.3 mm using an adhesive.

Three-dimensional measurements and visualization

The knees were scanned using a 16-row multislice computed tomography (CT) scanner (ECLOS, Hitachi Medial Corporation, Japan). All digital imaging data were loaded in specific software (Mimics version 15.0 and MedCAD module, Materialise N.V., Belgium), and a 3-dimensional (3-D) image of the knee was also created by combining the data extracted based on the CT values of each tissue using specific software (ZIOSTATION Version 2. 5. 1. 2, Ziosoft Corporation, Japan).

The accurate length and rate of each insertion site on the patellar side of the MPFL on 3-D images were

calculated using specific software. The accuracy of length measurement was less than 0.1 mm. When comparing the accuracy of 3D models generated from CT with the optical scan, the average error was 0.2 ± 0.31 mm or around one third of the pixel size [11].

In order to directly investigate the range of the insertion site of the patella, the rates of the vertical distance from the superior pole of the patella to superior and distal edge of the MPFL in relation to the total patellar height were calculated (Fig. 2).

The distribution of each variable was checked for normality using the Kolmogorov-Smirnov test. One-way analysis of variance followed by Tukey's multiple comparison test was performed to evaluate the insertion length of the MPFL. It was assumed that there was a significant difference when $p < 0.05$. All statistical data were calculated with the SPSS statistical software package (SPSS Version 20.0, IBM, USA).

Results

Macroscopic findings

The insertion sites on the patellar side of the MPFL from the intra-articular side could be observed, due to loose attachment between the articular capsule and MPFL. The proximal side of the MPFL was firmly inserted into the inferior margin of the deep fascia of the VMO, and the inserted medial margin of the VI tendon vertically crossed the longitudinal fibers of the tendon. On the distal side, the MPFL adhered to the deep layer of the medial retinaculum, and directly inserted into the medial margin of the patella (Fig. 3).

3-D analysis of the insertion sites on the patellar side of the MPFL

A 3-D image of the insertion sites on the patellar side of the MPFL was observed. The MPFL was inserted into the VMO, VI, and patella (Fig.4). The length of the insertion site of the VMO was 26.7 ± 5.0 mm (range: 18.6 - 37.5 mm), that of the VI was 28.5 ± 4.4 mm (range: 11.0 - 33.4 mm), and that of the patella was 18.5 ± 4.4 mm (range: 9.0 - 25.4 mm). Both the VMO and VI insertions were significantly longer than the patellar insertion ($p < 0.05$). Also, the VI insertion was significantly longer than the VMO insertion ($p < 0.05$).

The rate of the vertical distance from the superior pole of the patella to superior edge of the MPFL in relation to the total patellar height was 12 ± 4.4% (range: 5 - 19%). At the distal edge, the rate was 58 ± 9.6% (range: 27 - 74%) (Fig. 2). These data are summarized in Tables 1 and 2.

Discussion

The most important findings of this study were the clarifications of the insertion sites on the patellar side of the MPFL based on both macroscopic findings and 3-D images. The MPFL firmly inserted into the VMO, VI, and patella, and both VMO and VI insertions were significantly longer than the patellar insertion. The MPFL inserted to the proximal approximately 60% of the patella based on 3-D images.

In our results, the rate of the vertical distance from the superior pole of the patella to distal edge of the

MPFL in relation to the total patellar height was approximately 60%. This anatomic finding is generally in agreement with those of previous anatomical studies [2, 4, 8, 14, 25, 27]. However, various attachments on the patellar side of double bundle reconstruction of the MPFL have been reported [12, 17, 28]. Steensen et al. described the portion of the MPFL extending from the inferior aspect of its patellar attachment to the superior aspect of its femoral attachment as the most isometric, and recommended focusing on the inferior aspect of its patellar insertion [26]. Our findings may be useful for the positioning of the graft during double bundle reconstruction of the MPFL.

This study revealed that the MPFL firmly inserted into the inferior margin of the deep fascia of the VMO, and inserted into the medial margin of the VI tendon, and medial margin of the patella directly. According to previous anatomical studies, the MPFL was widely distributed to the proximal two-thirds of the patella and to the undersurface of the VMO [2, 4, 8, 14, 25, 27]. However, Mochizuki et al. reported that the MPFL was mainly attached to the medial margin of the VI tendon, and loosely attached to the distomedial area of the VMO [13]. They also stated that these differences might be caused by different dissection methods. In their method, the MPFL was observed from the intra-articular side; therefore, they could define the insertion site of the VI tendon [13]. In our results, the proximal side of the MPFL was firmly inserted into the inferior margin of the deep fascia of the VMO. The reason for this difference may be the definition of the insertion site.

This study also revealed the accurate length of the insertion sites on the patellar side on 3-D images. Our

findings regarding the insertion length of the VMO are similar to the observations by Philippot et al., who reported the length of the VMO as 25.7 ± 6.0 mm using a millimetric compass [17]. Nomura et al. reported an average of 20.3 ± 6.1 mm [14]. However, they measured the linear distance on the center line of the MPFL. Few studies have mentioned the insertion length of the VI. Mochizuki et al., using a caliper, reported that the linear distance of the VI averaged 24.3 ± 2.1 mm [13]. Regarding the insertion lengths of the VMO and VI, these results were shorter than our findings. These differences between the sizes that we recorded and those reported in the literature might be due to the method of measurement. Regarding the insertion length of the patella, Philippot et al. [17] and Viste et al. [3], using a scale ruler, reported an average of 24.4 ± 4.8 and 27.0 ± 5.9 mm, respectively. These differences whereby their results were longer than our findings, may be due to ethnicity, including the size of the patella. Our results indicate that the total average length of the insertion sites on the patellar side of the MPFL was 73.7 mm. The femoral insertion site of the MPFL has been reported to typically be 10 - 15 mm wide from proximal to distal [2]. Regarding the pathophysiology of MPFL tear, it has been reported that 90 to 100% of MPFL tears occurred on the femoral insertion side of the MPFL [1, 21]. From our results, the MPFL inserted at the patellar insertion much wider than at the femoral insertion, and the characteristic features suggest that MPFL tears are rare on the patellar insertion side because of dispersal of the tension force.

The insertion lengths of both the VMO and VI were identified as being significantly longer than that of the patella. With regard to patellar stability, the quadriceps have been reported to provide a strong posterior

force vector during knee flexion, contributing to increased patellar stability with knee flexion as a dynamic stabilizer [7]. Fibers of the MPFL that connect the femoral medial epicondyle to the medial edge of the patella directly have been reported to be the most important static medial patellar stabilizer [2, 8, 9, 16]. Several studies have described an association between the MPFL and quadriceps. Amis et al. reported that both the MPFL and VMO are often damaged together; therefore, repair should also include reattachment of the VMO for patellar stability [2]. Philippot et al. described the VMO as providing marked medial stabilization to the patella [17]. Mochizuki et al. described the VI as playing the main role in tensioning the MPFL and stabilizing the patella during knee extension [13]. Therefore, it is suggested that the VMO and VI are significant for patellar stability as dynamic stabilizers, and our results suggest that the MPFL controls the direction of the patellar traction force and contributes to its stability, in coordination with the VMO and VI. It has been reported that double bundle reconstruction of the MPFL, with one tunnel on the femur and two tunnels on the patella, led to satisfactory clinical results [10, 12, 23, 28]. However, Shah et al. reported a complication rate of 26.1% associated with reconstruction of the MPFL [24]. Rood et al. reported that reconstruction of the MPFL with a graft fixed to the bone resulted in a 3 to 5 times higher patellofemoral pressure than the native situation in the patellofemoral joint, which may cause patellofemoral osteoarthritis [20]. Based on our findings, the reconstruction of the MPFL that connects bone to bone and soft tissues, has the possibility of facilitating more normal kinematics of the patellofemoral joint and more ideal MPFL functioning.

This study had several limitations. Firstly, the cadavers that we dissected were mostly elderly. Consequently, there is a possibility that degenerative change influenced our results. Secondly, although accurate 3-D measurement was performed, the method depended on human dissection and decisions, which might introduce a bias. Thirdly, a comparatively small number of cadavers were investigated, and normal anatomical variation cannot be ruled out.

The clinical relevance of this study is that our findings may improve understanding of the anatomy of the patellar side of the MPFL and the pathophysiology of patellar dislocation.

Conclusion

The insertion sites on the patellar side of the MPFL were consistent, and the MPFL was firmly inserted into the VMO, VI, and patella. Furthermore, MPFL insertions into both the VMO and VI were significantly longer than into the patella, and inserted to the proximal approximately 60% of the patella.

References

1. Ahmad CS, Stein BE, Matuz D, Henry JH (2000) immediate surgical repair of the medial patellar stabilizers for acute patellar dislocation. A review of eight cases. Am J Sports Med 28 (6): 804-810.

2. Amis AA, Firer P, Mountney J, Senavongse W, Thomas NP (2003) Anatomy and biomechanics of the medial patellofemoral ligament. Knee 10 (3): 215-220.

3. Anthony Viste, Florian Chatelet, Romain Desmarchelier, Michel-Henri Fessy (2014) Anatomical study of the medial patella-femoral ligament: landmarks for its surgical reconstruction. Surg Radiol Anat 36 (8): 733-739.

4. Aragao J, Reis F, Vasconcelos D, Feitosa V, Nunes M (2008) Metric measurements and attachment levels of the medial patellofemoral ligament: an anatomical study in cadavers. Clinics 63 (4): 541-544.

5. Arai Y, Nakagawa S, Higuchi T, Inoue A, Honjo K, Inoue H, Ikoma K, Ueshima K, Ikeda T, Fujiwara H, Kudo T (2015) Comparative analysis of medial patellofemoral ligament length change pattern in patients with patellar dislocation using open – MRI. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-015-3689-2

6. Baldwin JL (2009) The anatomy of the medial patellofemoral ligament. Am J Sports Med 37 (12): 2355-2361.

7. Colvin AC, West RV (2008) Patellar instability. J Bone Joint Surg Am 90 (12): 2751-2762.

8. Conlan T, Garth WP, Lemons JE (1993) Evaluation of the medial soft tissue restraints of the extensor mechanism of the knee. J Bone Joint Surg Am 75 (5): 682-693.

9. Desio SM, Burks RT, Bachus KN (1998) Soft tissue restraints to lateral patellar translation in the human knee. Am J Sports Med 26 (1): 59-65.

10. Enderlein D, Nielsen T, Christiansen SE, Faunø P, Lind M (2014) Clinical outcome after reconstruction of the medial patellofemoral ligament in patients with recurrent patella instability. Knee Surg Sports

Traumatol Arthrosc 22 (10): 2458-2464.

11. Gelaude F, Vander Sloten J, Lauwers B (2008) Accuracy assessment of CT-based outer surface femur meshes. Comput Aided Surg 13 (4): 188-199.

12. Kang H, Cao J, Yu D, Zheng Z, Wang F (2013) Comparison of 2 Different Techniques for Anatomic Reconstruction of the Medial Patellofemoral Ligament. Am J Sports Med 41 (5): 1013-1021.

13. Mochizuki T, Nimura A, Tateishi T, Yamaguchi K, Muneta T, Akita K (2013) Anatomic study of the attachment of the medial patellofemoral ligament and its characteristic relationships to the vastus intermedius. Knee Surg Sports Traumatol Arthrosc 21 (2): 305-310.

14. Nomura E, Inoue M, Osada N (2005) Anatomical analysis of the medial patellofemoral ligament of the knee, especially the femoral attachment. Knee Surg Sports Traumatol Arthrosc 13 (7): 510-515.

15. Oliveira V, Souza V, Cury R, Camargo O Avanzi O, Severino N, Fucs P (2014) Medial patellofemoral ligament anatomy: is it a predisposing factor for lateral patellar dislocation? Int Orthop 38 (8): 1633-1639.

16. Panagiotopoulos E, Strzelczyk P, Herrmann M, Scuderi G (2006) Cadaveric study on static medial patellar stabilizers: the dynamizing role of the vastus medialis obliquus on medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc 14 (1): 7-12.

17. Philippot R, Chouteau J, WegrZyn J, Testa R, Fessy MH, Moyen B (2009) Medial patellofemoral ligament anatomy: implications for its surgical reconstruction. Knee Surg Sports Traumatol Arthrosc 17 (5): 475-479.

18. Placella G, Tei MM, Sebastiani E, Criscenti G, Speziali A, Mazzola C, Georgoulis A, Cerulli G (2014) Shape and size of the medial patellofemoral ligament for the best surgical reconstruction: a human cadaveric study. Knee Surg Sports Traumatol Arthrosc 22 (10): 2327-2333.

19. Reider B, Marshall JL, Koslin B, Ring B, Girgis FG (1981) The anterior aspect of the knee joint: an anatomical study. J Bone Joint Surg Am 63 (3): 351-356.

20. Rood A, Hannink G, Lenting A, Groenen K, Koeter S, Verdonschot N, van Kampen A (2015) Patellofemoral pressure changes after static and dynamic medial patellofemoral ligament reconstructions. Am J Sports Med 43 (10): 2538-2544.

21. Sallay PI, Poggi J, Speer KP, et al (1996) Acute dislocation of the patella: A correlative pathoanatomic study. Am J Sports Med 24 (1): 52-60.

22. Sanders TG, Morrison WB, Singleton BA, Miller MD, Cornum KG (2001) Medial patellofemoral ligament injury following acute transient dislocation of the patella: MR findings with surgical correction in 14 patients. J Comput Assist Tomogr 25 (6): 957-962.

23. Schottle PB, Hensler D, Imhoff AB (2010) Anatomical double-bundle MPFL reconstruction with an aperture fixation. Knee Surg Sports Traumatol Arthrosc 18 (2): 147-151.

24. Shah JN, Howard JS, Flanigan DC, Brophy RH, Carey JL, Lattermann C (2012) A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. Am J Sports Med 40 (8): 1916-1923.

25. Smirk C, Morris H (2003) The anatomy and reconstruction of the medial patellofemoral ligament. Knee 10 (3): 221-227.

26. Steensen RN, Dopirak RM, McDonald WG 3rd (2004) The anatomy and isometry of the medial patellofemoral ligament: implications for reconstruction. Am J Sports Med 32 (6): 1509-1513.

27. Tuxoe JI, Teir M, Nielsen PL (2002) The medial patellofemoral ligament: a dissection study. Knee Surg Sports Traumatol Arthrosc 10 (3): 138-140.

28. Wang C, Ma L, Zhou J, Ji G, Wang H, Wang F, Wang J (2013) Double-bundle anatomical versus single-bundle isometric medial patellofemoral ligament reconstruction for patellar dislocation. Int Orthop 37 (4): 617-624.

29. Zheng L, Shi H, Feng Y, Sun BS, Ding HY, Zhang GY (2015) Injury patterns of medial patellofemoral ligament and correlation analysis with articular cartilage lesions of the lateral femoral condyle after acute lateral patellar dislocation in children and adolescents: An MRI evaluation. Injury 46 (6): 1137-1144.

Figure

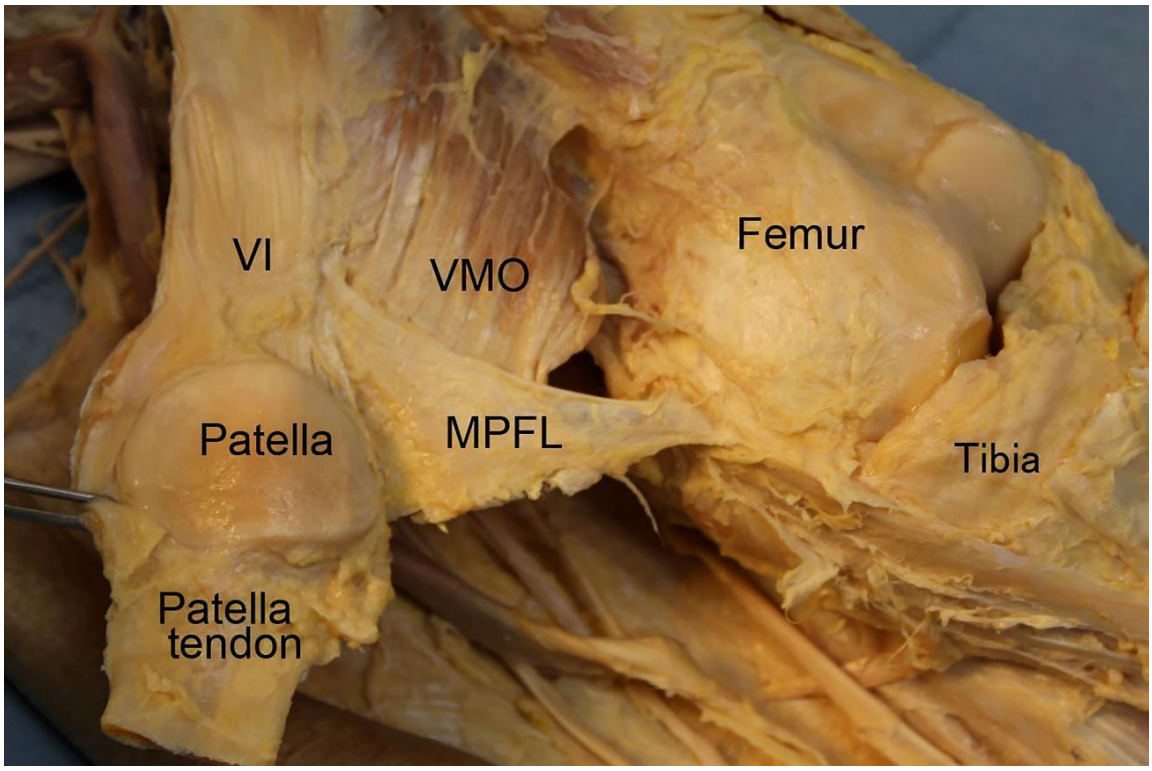

Fig. 1 The insertion sites on the patellar side of the MPFL were observed from the intra-articular side. Using a lateral parapatellar approach, the patella tendon was cut in order to reflect the patella and patella tendon, and then the capsule was removed

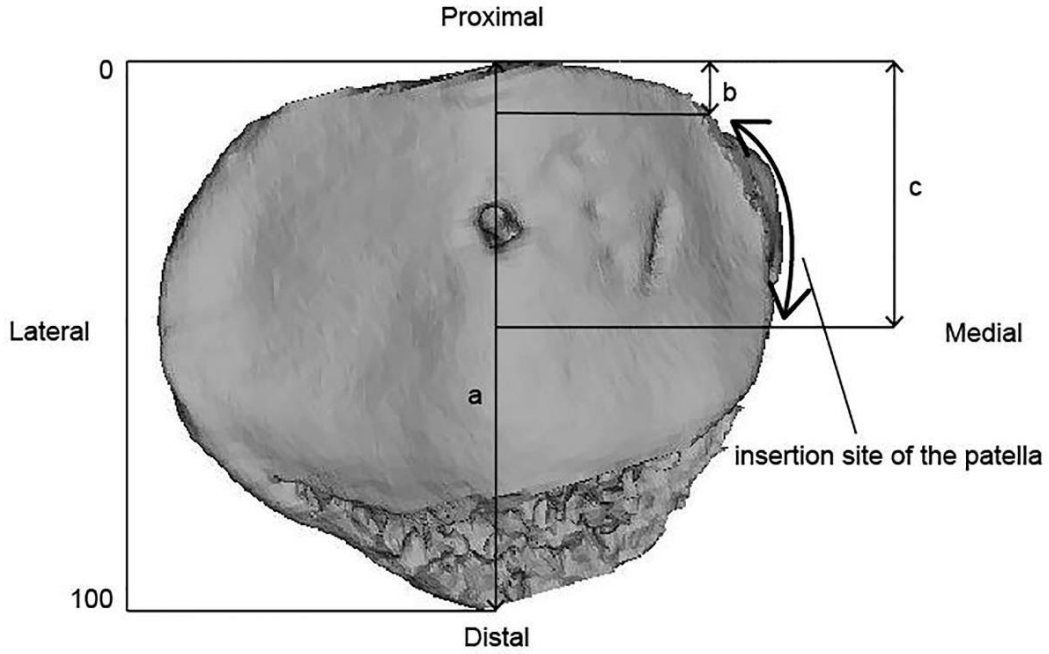

Fig. 2 This figure shows the patella, observing from the intra-articular side. The rate of the vertical distance from the superior pole of the patella to the superior and distal edge of the MPFL in relation to the total patellar height was calculated, in order to investigate the range of the direct insertion of the patella. The total patellar height was defined as the line drawn on the central ridge of the patella on a 3-D image. The rate of the vertical distance from the superior pole of the patella to the superior edge of the MPFL in relation to the total patellar height is b/ a, and that of the distal edge is c/ a.

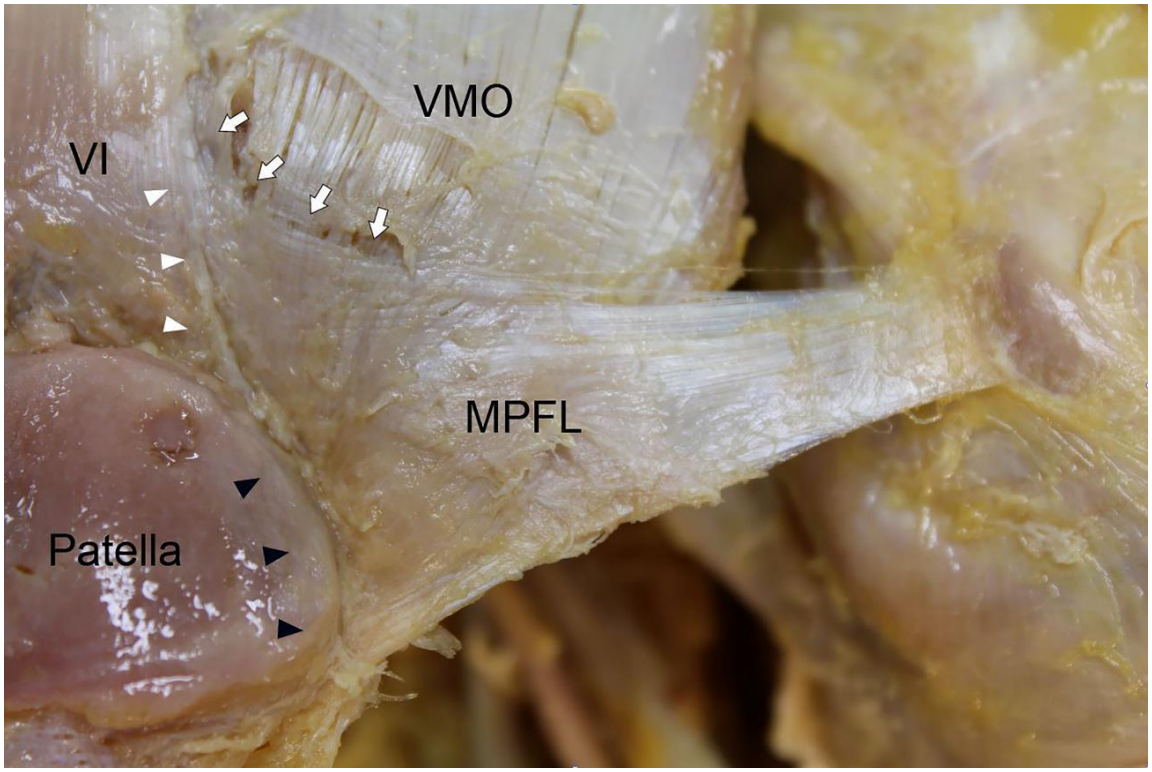

Fig. 3 The MPFL firmly inserted into the deep fascia of the VMO (white arrow), directly inserted into the medial margin of the VI on the proximal side (white triangle), and inserted into the medial margin of the patella both firmly and directly on the distal side (black triangle).

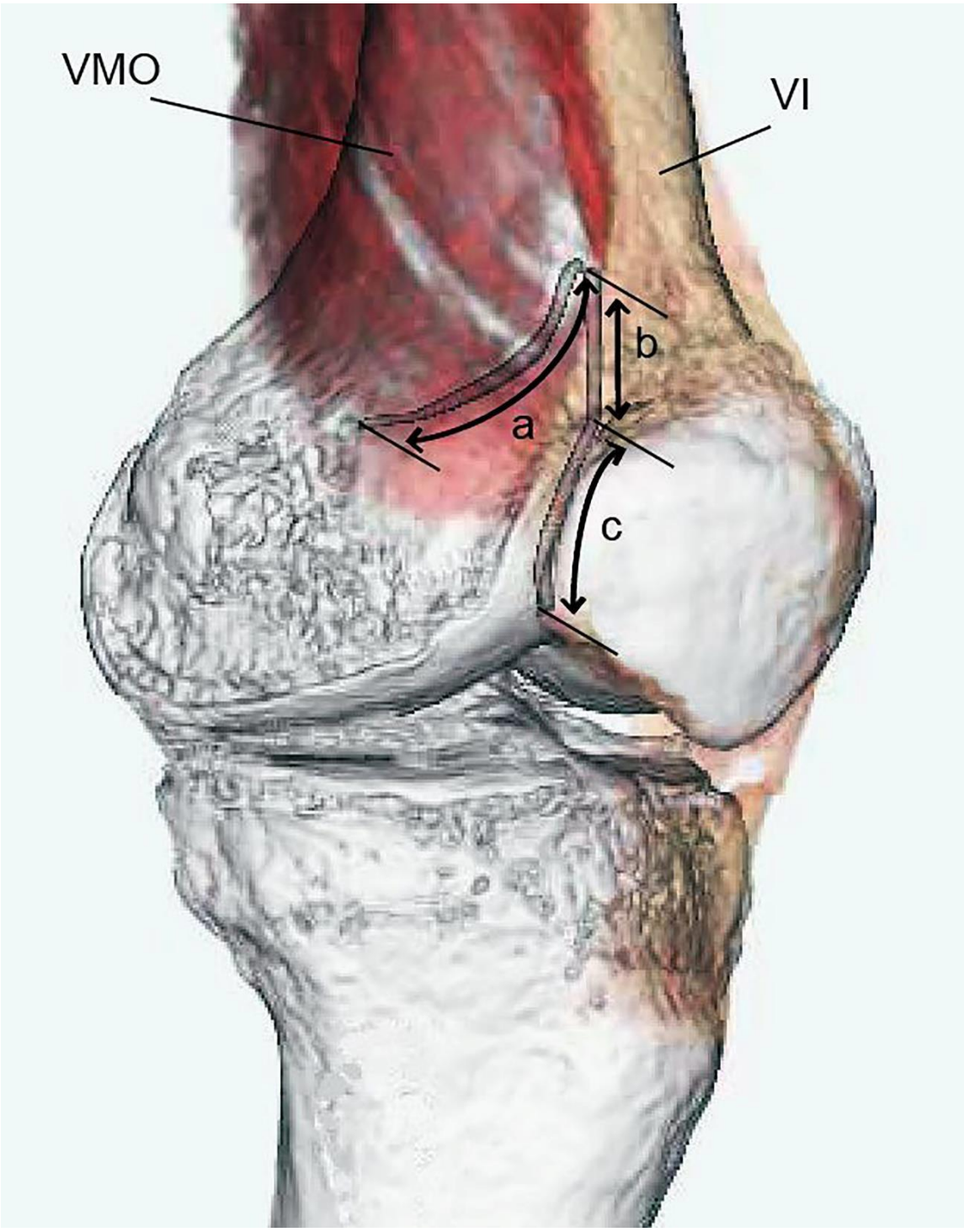

Fig. 4 A 3-D image of the knee was created using specific software (ZIOSTATION Version 2. 5. 1. 2, Ziosoft Corporation, Japan). All of the periphery of the insertion sites on the patellar side of the MPFL was marked by soft stainless wire with a diameter of 0.3 mm using an adhesive (gray line). The MPFL was

inserted into the VMO, VI on the proximal side, and patella on the distal side. The length of the insertion site of the VMO is a, that of the VI is b, and that of the patella is c. The accurate length of each insertion site on the patellar side of the MPFL on 3-D images was calculated using specific software.

Table 1 The insertion length on the patellar side of the MPFL on three-dimensional images

	VMO	VI	Patella
Insertion length (mm)	26.7±5.0* (18.6-37.5)	28.5±4.4* ** (11.0-33.4)	18.5±4.4 (9.0-25.4)

Data are presented as the mean ± SD, range.

*Significant difference compared with the length of the insertion site of the patella. **Significant difference compared with the length of the insertion site of the VMO. ($p < 0.05$, Tukey's multiple comparison test)

Table 2 The rate of the vertical distance from the superior pole of the patella to the superior and distal edge of the MPFL in relation to the total patellar height

	Superior edge (b/a)	Distal edge (c/a)
The rate of the vertical distance (%)	12 ± 4.4 (5-19)	58 ± 9.6 (27-74)

Data are presented as the mean ± SD, range.