JIMA Vol. 75, No. 3 (Aug 2023) pp. 109-119.

Original

The morphological characteristics of the medial patellotibial ligament and its insertion sites using three-dimensional computed tomography: a cadaveric study

Yasutaka Ohya, Goro Tajima, Moritaka Maruyama, Atsushi Sugawara, Shinya Oikawa and Minoru Doita

Department of Orthopedic Surgery, School of Medicine, Iwate Medical University, Yahaba, Japan

(Received on January 13, 2023 & Accepted on February 9, 2023)

Abstract

To identify the insertion sites of the medial patellotibial ligament (MPTL), eighteen nonpaired human cadaveric knees were used in this study. The MPTL was clearly identified in 16 of 18 knees, and was a thin uniform band-like tissue appearing as a capsular ligament. The insertion site on the patella was located midway between the medial patellofemoral ligament and the patellar tendon and was in contact with the medial side of the patellar tendon. The ratio of the vertical distance from the superior pole of the patella to the superior end of the MPTL to the total patellar height was 70.1 ± 3.3% at the proximal end. At the distal end, the ratio was 84.2 ± 3.5%. The insertion site on the tibia was 16.2 ± 2.5 mm distal to the tibial anterior edge, which was 21.4 ± 2.9 mm proximal to the medial aspect of the tibial tuberosity groove in which the proximal pes anserinus attached. We clarified the MPTL insertion sites on both the patellar and tibial sides. The clinical relevance of this study is that understanding the anatomy of the MPTL was improved, and our findings may assist surgeons in performing successful reconstruction of the MPTL.

Key words : medial patellotibial ligament, insertion, morphology, patella, tibia

I. Introduction

The medial patellotibial ligament (MPTL) is a thin ligament with a uniform width and has been considered an important stabilizing structure of the patella, acting mainly during knee joint flexion [1,2]. The MPTL was first described by Terry in 1989, as a condensation of the medial retinaculum that originates inferiorly and medially in the patella and that inserts distal from the joint line on the anteromedial tibia [3]. Several biomechanical studies have reported that the MPTL contributes 0%-26% of the medial stabilizing strength of the patella during knee joint extension and as much as 20%-46% during knee joint flexion, and that the MPTL is a medial soft tissue constraint that prevents lateral displacement of the patella [2,4-8].

MPTL reconstruction has received much

Corresponding author: Goro Tajima
gorot@iwate-med.ac.jp

attention as part of a broad tech-niques for restoring patellofemoral stability, and several biomechanical studies of MPTL reconstruction have revealed the importance of anatomical replication of the original ligament[9-11]. In particular, for habitual patellar dislocation, in which the patella dislocates laterally during knee joint flexion, recent studies have reported that a good prognosis is obtained by combining medial patellofemoral ligament (MPFL) and MPTL reconstruction[11-14]. Additionally, it has been demonstrated that combined MPTL and MPFL reconstruction could be used in recurrent patellar dislocation to achieve better stability[15,16]. To perform these reconstructions with new techniques, it is necessary to the define the detailed morphology of both the patellar and tibial insertion sites of the MPTL. Particularly, the importance of the tibial position during MPTL reconstruction was indicated by Beck et al. Because a change in the tibial position could cause significant changes in patellofemoral kinematics[9,17,18]. However, few studies have evaluated the detailed characteristic features of the MPTL insertion sites and the positional relationships between these sites and their associated landmarks.

The aim of the present study was to provide an accurate description of the anatomical findings of the MPTL, particularly its insertion sites and related landmarks on three-dimensional (3D) computed tomography (CT) images. Our hypothesis was that the characteristics of the patellar and tibial insertion sites of the MPTL and the associated landmarks could be identified and that they are consistent.

II. Materials and Methods

Eighteen nonpaired human cadaveric left knees (11 males and 7 females), with no severe macroscopic degenerative or traumatic changes, were used in the present study. The average age at the time of death was 79.3 years (range: 68–89 years). All cadavers were fixed in 10% formalin and preserved in 50% alcohol for 6 months. All cadavers were donated to our institute for educational and research purposes, and informed consent for donation was obtained from each donor and their family prior to death. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee, and with the 1964 Declaration of Helsinki and its later amendments or comparable standards. This cadaveric study was approved by the Ethical Committee of Iwate Medical University. Written informed consent was obtained from the families of the donors included in this study.

Specimen dissection was begun by excising the knee from the distal femur and the proximal tibia and fibula and removing the skin and soft tissues on the medial side of the knee; the vastus medialis muscle was removed. After the articular capsule was exposed, using a lateral parapatellar approach, the quadriceps tendon was cut to reflect the patella and patellar tendon medially. The capsule and infrapatellar pad was removed from the intraarticular side by careful dissection. The MPFL and MPTL were located superficial to the medial joint capsule in an extraarticular layer. Therefore, these ligaments could be released from the articular capsule.

The sites at which the MPTL was firmly

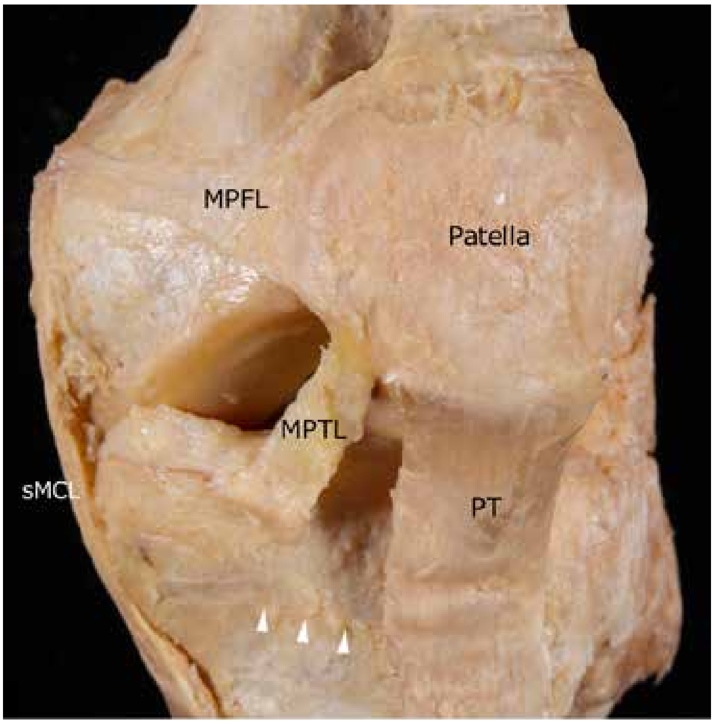

Fig. 1. Photograph of the dissected cadaver left knee showing the MPTL, MPFL, PT, patella, patella and sMCL. White triangles indicate the area where the superior margin of the sartorius muscle was attached.
MPTL, medial patellotibial ligament; MPFL, medial patellofemoral ligament; PT, patellor tendon; sMCL, superficial medial collateral ligament

inserted into the patella, fascia, and tendon or the termini at which MPTL fibers could be macroscopically traced were defined as the patellar insertion of the MPTL. After identification of the MPTL, gross observation of the MPTL and other related structures was performed. The length of the MPTL and the width of the central part of the MPTL were determined by measurements with a scale ruler. Then, the insertion sites on the patellar and tibial sides of the MPTL, as well as the patellar attachments of the MPFL and patellar tendon (PT) were each marked by drilling with a 1.0-mm diameter K-wire.

The knees were scanned using a 16-row multi-slice CT scanner (ECLOS; Hitachi Medical Corporation, Tokyo, Japan). Axial plane images with a 0.5-mm slice thickness were obtained and saved as Digital Imaging and Communications in Medicine data. All digital imaging data were uploaded to dedicated software (Mimics version 22.0; Materialise NV, Leuven, Belgium), and accurate 3D models of the specimens, including each segment of the bone, tendon, and muscle, were created. The data from the 3D models were uploaded to advanced analysis software (3-matic, version 15.0; Materialise NV).

The 3D images were analyzed with a focus on the patellar and tibial insertions of the MPTL and related structures. On the patellar side, the insertion sites of the MPTL, MPFL, and PT were marked and colored. The centers of the insertion sites were defined automatically using the software. Similarly, the MPTL insertions on the tibial

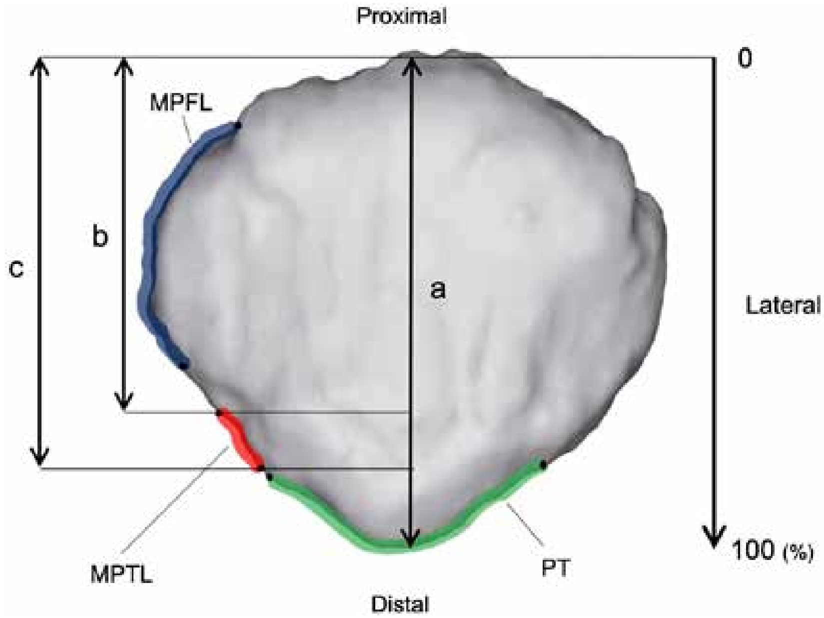

Fig. 2. This figure shows the relationship between the MPTL, MPFL and PT insertion sites on left patella. The ratio of the vertical distance from the superior pole of the patella to the superior edge of the MPTL in relation to the total patellar height is b/a and that of the distal edge is c/a. The red, blue and green lines show the MPTL, MPFL and PT insertion sites, respectively.
MPTL, medial patellotibial ligament; MPFL, medial patellofemoral ligament; PT, patellor tendon.

Table 1. The ratio of the vertical distance from the superior pole of the patella to the superior and distal edges of the MPTL and MPFL in relation to the total patellar height.

The ratio of the vertical distance (%)	Proximal edge (b/a)	Distal edge (c/a)
MPTL	70 ± 3.3 (65–76)	84 ± 3.5 (80–89)
MPFL	14 ± 6.6 (7–21)	63 ± 5.7 (54–73)

Data are presented as the mean ± standard deviation (range).
MPTL, medial patellotibial ligament; MPFL, medial patellofemoral ligament

side were marked. The accuracy of the length measurements was within < 0.1 mm for all measurements. When comparing the accuracy of the 3D images with the optical scans, the average error was 0.65 ± 0.31 mm or approximately one-third of the pixel size. The tolerance and margin of error for the CT measurements (according to the manufacturer) were both ± 0.39 mm. The distribution of each variable was checked for normality using the Kolmogorov–Smirnov test, and all statistical data were analyzed using SPSS v. 22.0 (IBM Corporation, Armonk, NY, USA).

The distance between the centers on the patellar and tibial sides of each insertion was measured to determine the length of the MPTL. The width at each MPTL insertion was also determined. To directly investigate the range of MPTL insertion sites on the patella, the ratios of the vertical distance

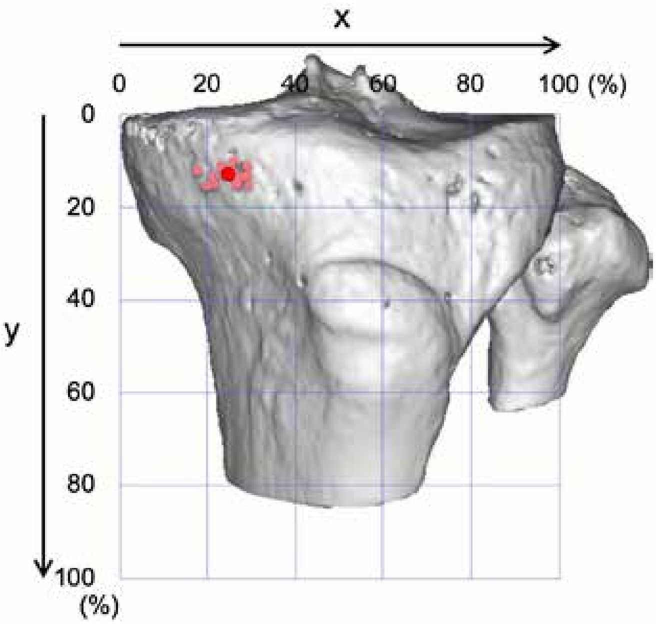

Fig. 3. This image shows the frontal view of left proximal tibia with an overlaying grid; the centers of the MPTL insertions were shown as a coordinate (red dots).

Table 2. Locations and coordinates in a true frontal view in 3-D images.

	Medial-Lateral ratio (x)	Proximal-Distal ratio (y)
The center of the MPTL insertion on the tibia (%)	25 ± 3.5 (18-29)	13 ± 1.7 (10-16)

Data are presented as the mean ± standard deviation (range).
3D, three dimensional; MPTL, medial patellotibial ligament.

from the superior pole of the patella to the superior and distal edge of the MPTL in relation to the total patellar height were calculated. These measurements were then made on the tibial side. The frontal image of the tibia was defined in accordance with the method of Tajima et al. [19], and a line was drawn at both ends of the tibial anterior edge as a reference line (100%). The x-axis was the upper of the square, the y-axis was the furthest left perpendicular line on the squares, and the origin of the coordinate axes was the point of intersection of the highest line and the proximal perpendicular lines. The coordinates of the center of the tibial insertion of the MPTL were mapped on squares in the true frontal view. These images were projected onto a two-dimensional view, and a true frontal view was created. An original coordinate plane was created to standardize and ensure the reproducibility of the knee size and to guide the fluoroscope during surgery. In addition, the direct distances between the center of the MPTL insertion site and the related structures were measured on the 3D images.

III. Results

1. Macroscopic findings

Although the medial retinaculum was

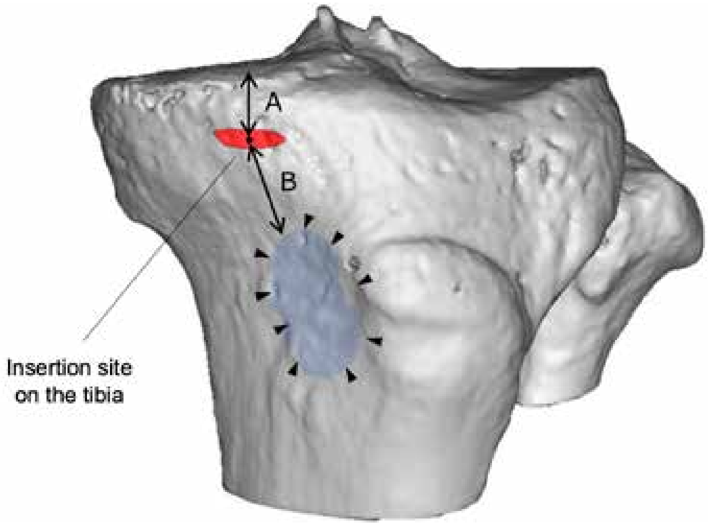

Fig. 4. This image shows the medial oblique view of left knee. The red area indicates the MPTL insertion site. Arrowheads show the medial aspect of the tibial tuberosity groove. The linear distance between the center of the MPTL insertion site and the tibial anterior edge (A) and that of the proximal medial aspect of the tibial tuberosity groove (B) were measured using dedicated software.

Table 3. 3D measurement of the length from the MPTL insertion site on the tibial side to the osseous landmarks.

Distance	Proximal-Distal ratio (y)
From the center of the MPTL insertion site on the tibia (mm)	
To the tibial anterior edge (A)	16.2 ± 2.5 (11.3–18.3)
To the proximal aspect of the tibial tuberosity groove (B)	21.4 ± 2.9 (18.4–28.1)

Data are presented as the mean ± standard deviation (range).
3D, three-dimensional; MPTL, medial patellotibial ligament.

conjoined to superficial fibers of the MPTL, it could be identified by tracing the fibers. The patellar insertion was attached to the deep layer of the medial retinaculum and was observed directly inserting into the medial inferior edge of the patella. The insertion site of the MPTL on the patella was located midway between the insertions of the MPFL and PT. The MPTL ran from the patellar insertion medioinferiorly in contact with the capsule to the tibial insertion, which was just proximal to the sartorius attachment, medioproximal to the tibial tuberosity (Fig. 1). Macroscopic measurements showed that the length of the MPTL was 44.5 ± 3.1 mm and the width was 9.5 ± 1.3 mm at the center of the MPTL.

2. 3D analysis of the MPTL insertion sites

The distance between the center points of the MPTL insertions on the patellar and tibial sides was measured, and the length was 40.4 ± 3.8 mm. The width of the MPTL at each attachment point was 10.6 ± 1.2 mm on the patellar side and 10.2 ± 1.0 mm on the tibial side. The positional relationships between the MPTL, MPFL, and PT insertion sites on the patella were observed in the 3D images (Fig. 2). The height of the MPTL insertion site in relation to the total patellar height was shown as a percentage. The proximal end was 70%, and the distal end was 84%. These data are summarized in Table 1.

On the frontal view in the 3D image, the average centers of the MPTL insertion sites on the tibia were x = 25% and y = 13% (Fig. 3).

Geometric data regarding these locations are shown in Table 2. The MPTL insertion site on the tibia was measured as the distance from the tibial anterior edge and the distance from the proximal medial aspect of the tibial tuberosity groove. The groove is the site where the pes anserinus attaches and was clearly identified as an osseous landmark in all knees. The MPTL insertion site on the tibia was located 16.2 ± 2.5 mm distal to the tibial anterior edge and 21.4 ± 2.9 mm proximal to the proximal medial aspect of the tibial tuberosity groove, and the positional relationships were constant (Fig. 4). These data are summarized in Table 3.

IV. Discussion

The most important findings in the present study were the locations of the MPTL insertion sites and the related structures using both macroscopic findings and 3D images. The MPTL insertion site on the patella was located midway between the MPFL and PT insertions and was in contact with the medial side of the PT. The MPTL insertion site on the tibia was located midway between the tibial anterior edge and the proximal medial aspect of the tibial tuberosity groove in which the pes anserinus attached. These findings will improve the understanding of the anatomy of the MPTL insertion sites and may assist surgeons in performing successful procedures in reconstructions involving this ligament.

In our results, the MPTL was identified in 16 of 18 formalin-fixed knees and was a thin uniform band-like tissue appearing as a capsular ligament. According to previous studies, although MPTLs generally had a similar shape and similar attachment locations, there was a great deal of variability in their sizes [7,20,21]. We found the macroscopic length and width of the MPTL averaged 44.5 mm and 9.5 mm, respectively. Furthermore, using 3D images, the length between the centers of the insertions was 40.4 ± 3.8 mm, and the width at the insertions was 10.6 ± 1.2 mm on the patellar side and 10.2 ± 1.0 mm on the tibial side. These findings are similar to the observations of Hinckel et al. [20], who identified MPTLs in all nine examined frozen knees, and reported an MPTL length of 36 ± 6.4 mm and width of 7.1 ± 2.0 mm. Philippot et al. [7] identified MPTLs in only 11 of 23 frozen knees and reported an MPTL length of 55 ± 8.4 mm and an average width of 22 ± 4.4 mm, which was much wider than our result. LaPrade et al. [21] reported a narrower MPTL average width of 4.6 ± 8.8 mm in 22 frozen knees. However, the authors did not report the length. Previous reports have shown large differences in MPTL size, especially width because macroscopic width can be difficult to recognize and distinguish. This is because the MPTL is a thin capsular ligament and it is also in contact with the subpatellar fat pad. In particular, the width of the ligament is expected to vary greatly depending on the dissection technique because it is a thin membranous tissue that is firmly connected to the joint capsule. In this study, the sizes of the MPTLs were confirmed using both the macroscopic actual width and by measuring each insertion width on 3D images, which may be a more accurate method.

This study revealed that the MPTL insertion site on the patella was located mid-way between the MPFL and PT insertions and was in contact with the medial side of the PT. This positional relationship was consistent in all knees. Several studies have described the MPTL insertion site on the patella as a distance from the medial side of the PT or the inferior pole of the patella [1,4,6,20,22,23]. However, because their results were based on actual measurements, individual differences in the size of the patella cannot be ignored. To indicate the MPTL insertion site on the patella more clearly intraoperatively, we used the ratio of the height of the proximal and distal portions of the MPTL insertions to the height of the patella, which was not affected by individual size differences [24].

The distances between the landmarks on the tibia were accurately identified using 3D images in our study. Several studies have described the osseous and soft tissue landmarks for the MPTL insertion site on the tibia in relation to the tibial anterior edge and the medial side of the PT [4,6,23]. The distance of the MPTL insertion site from the tibial anterior edge was generally similar to that reported in previous studies. However, the distance of the MPTL insertion site from the medial side of the PT was difficult to recognize because the PT was an approximate broad shape as a landmark, relatively far from the MPTL insertion, and the direction was unclear. In the present study, the MPTL insertion on the tibia was located approximately midway between the tibial anterior edge and the proximal medial aspect of the tibial tuberosity groove, which was clearly confirmed in all knees as a landmark. We believe that our findings identified important landmarks that will be useful for intraoperative determination of the tibial site for MPTL reconstruction. The current study also identified the accurate coordinate positions of the MPTL insertion site on the tibia on the true frontal view in 3D images, which may be useful for preoperative planning using X-ray imaging and fluoroscopic intraoperative determination.

This study had several limitations. First, the cadavers that we dissected comprised mostly older donors. As most of the actual surgeries are performed on younger patients, it is possible that the degenerative changes in this case may have affected the results. Second, although accurate 3D measurements were performed, the method depended on human dissection and decisions, which might have introduced bias. Third, a comparatively small number of cadavers were investigated, and normal anatomical variation cannot be ruled out.

The clinical relevance of the current study is that we clearly identified the landmarks associated with MPTL insertion sites both macroscopically and using 3D CT images.

The morphological characteristics of the MPTL and its insertion sites were shown to be consistent. The MPTL insertion site on the patella was located midway between the MPFL and PT insertions and was in contact with the medial side of the PT, and on the tibial side, the insertion was located midway between the tibial anterior edge and the proximal medial aspect of the tibial tuberosity groove in which the pes anserinus attached. The clinical relevance of this study is that understanding of the anatomy of the MPTL was improved, and our findings may assist surgeons performing exact anatomical reconstruction of this structure.

Acknowledgements

We thank Jane Charbonneau, DVM, from Edanz for editing a draft of this manuscript. The authors wish to thank Professors Jiro Hitomi and Tomoyuki Saino and Associate Professor Jun Kanazawa from the Department of Anatomy of Iwate Medical 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 technical assistance.

Conflict of interest : The authors have no conflict of interest to declare.

References

1) **Panagiotopoulos E, Strzelczyk P** and **Herrmann M**: 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**, 7-12, 2016.
2) **Philippot R, Boyer B, Testa R, et al.**: The role of the medial ligamentous structures on patellar tracking during knee flexion. Knee Surg Sports Traumatol Arthrosc **20**, 331-336, 2012.
3) **Terry GC**: The anatomy of the extensor mechanism. Clin Sports Med **8**, 163-177, 1989.
4) **Desio SM, Burks RT** and **Bachus KN**: Soft tissue restraints to lateral patellar translation in the human knee. Am J Sports Med **26**, 59-65, 1998.
5) **Hinckel BB, Gobbi RG, Bonadio MB, et al.**: Reconstruction of medial patellofemoral ligament using quadriceps tendon combined with reconstruction of medial patellotibial ligament using patellar tendon: initial experience. Rev Bras Ortop **51**, 75-82, 2016.
6) **Kruckeberg BM, Chahla J, Moatshe G, et al.**: Quantitative and qualitative analysis of the medial patellar ligaments: an anatomic and radiographic study. Am J Sports Med **46**, 153-162, 2018.
7) **Philippot R, Chouteau J, Wegrzyn J, et al.**: Medial patellofemoral ligament anatomy: implications for its surgical reconstruction. Knee Surg Sports Traumatol Arthrosc **17**, 475-479, 2009.
8) **Tanaka MJ, Chahla J, Farr J 2nd, et al.**: Recognition of evolving medial patellofemoral anatomy provides insight for reconstruction. Knee Surg Sports Traumatol Arthrosc **27**, 2537-2550, 2019.
9) **Beck P, Brown NA, Greis PE, et al.**: Patellofemoral contact pressures and lateral patellar translation after medial patellofemoral ligament reconstruction. Am J Sports Med **35**, 1557-1563, 2017.
10) **Gelaude F, Vander Sloten J** and **Lauwers B**: Accuracy assessment of CT-based outer surface femur meshes. Comput Aided Surg **13**, 188-199, 2008.
11) **Grannatt K, Heyworth BE, Ogunwole O, et al.**: Galeazzi semitendinosus tenodesis for patellofemoral instability in skeletally immature patients. J Pediatr Orthop **32**, 621-625, 2012.
12) **Joo SY, Park KB, Kim BR, et al.**: The 'four-in-one' procedure for habitual dislocation of the patella in children early results in patients with severe generalised ligamentous laxity and aplasis of the trochlear groove. J Bone Joint Surg Br **89**, 1645-1649, 2007.
13) **Sobhy MH, Mahran MA** and **Kamel EM**: Midterm results of combined patellofemoral and patellotibial ligaments reconstruction in recurrent patellar dislocation. Eur J Orthop Surg Traumatol **23**, 465-470, 2013.
14) **Zaffagnini S, Grassi A, Marcheggiani Muccioli GM, et al.**: Medial patellotibial ligament (MPTL) reconstruction for patellar instability. Knee Surg Sports Traumatol Arthrosc **22**, 2491-2498, 2014.
15) **Brown GD** and **Ahmad CS**: Combined medial patellofemoral ligament and medial patellotibial ligament reconstruction in skeletally immature patients. J Knee Surg **21**, 328-332, 2008.
16) **Giordano M, Falciglia F, Aulisa AG, et al.**: Patellar dislocation in skeletally immature

patients: semitendinosous and gracilis augmentation for combined medial patellofemoral and medial patellotibial ligament reconstruction. Knee Surg Sports Traumatol Arthrosc **20**, 1594-1598, 2012.

17) **Ebied AM** and **El-Kholy W**: Reconstruction of the medial patello-femoral and patello-tibial ligaments for treatment of patellar instability. Knee Surg Sports Traumatol Arthrosc **20**, 926-932, 2012.

18) **Garth WP Jr, Connor GS, Futch L, et al.**: Patellar subluxation at terminal knee extension isolated deficiency of the medial patellomeniscal ligament. J Bone Joint Surg Am **93**, 954-962, 2013.

19) **Tajima G, Nozaki M, Iriuchishima T, et al.**: Morphology of the tibial insertion of the posterior cruciate ligament. J Bone Joint Surg Am **91**, 859-866, 2009.

20) **Hinckel BB, Gobbi RG, Kaleka CC, et al.**: Medial patellotibial ligament and medial patellomeniscal ligament: anatomy, imaging, biomechanics, and clinical review. Knee Surg Sports Traumatol Arthrosc **26**, 685-696, 2018.

21) **LaPrade MD, Kallenbach SL, Aman ZS, et al.**: Biomechanical Evaluation of the Medial Stabilizers of the Patella. Am J Sports Med **46**, 1575-1582, 2018.

22) **Hinckel BB, Gobbi RG, Demange MK, et al.**: Medial Patellofemoral Ligament, Medial Patellotibial Ligament, and Medial Patellomeniscal Ligament: Anatomic, Histologic, Radiographic, and Biomechanical Study. Arthroscopy **33**, 1862-1873, 2017.

23) **Kaleka CC, Aihara LJ, Rodrigues A, et al.**: Cadaveric study of the secondary medial patellar restraints: patellotibial and patellomeniscal ligaments. Knee Surg Sports Traumatol Arthrosc **25**, 144-151, 2017.

24) **Kikuchi S, Tajima G, Yan J, et al.**: Morphology of insertion sites on patellar side of medial patellofemoral ligament. Knee Surg Sports Traumatol Arthrosc **25**, 2488-2493, 2017.

岩手医誌 75 巻，3 号（令和 5 年 8 月）109-119 頁.

3D コンピューター断層撮影を用いた内側膝蓋脛骨靱帯の挿入部位と形態的特徴の解剖学的検討

大矢康貴，田島吾郎，丸山盛貴，
菅原　敦，及川伸也，土井田稔

岩手医科大学医学部，整形外科学講座

(Received on January 13, 2023 & Accepted on February 9, 2023)

要旨

内側膝蓋脛靭帯（MPTL）再建を正確な位置で行うことの重要性が注目されている．MPTL 挿入部位の詳細な特徴や手術の基本となるランドマークの位置関係を明らかにするため，MPTL の解剖学的所見，およびその付着部とランドマークについて正確に計測を行なった．まず MPTL およびその周囲の関連構造物の肉眼的観察を行い，その後 CT 撮影した後に MPTL の長さ，MPTL と関連構造物の位置関係を画像解析した．膝蓋骨の MPTL 付着部は内側膝蓋大腿靭帯と膝蓋靭帯の付着部の中間のやや脛骨側，更には脛骨粗面の内側の鵞足が付着する脛骨結節の近位内側面の頂点との中間であることがわかった．すなわち，脛骨との付着部の骨指標として鵞足切痕が有効であることが明らかとなった．本研究で，MPTL の付着部の解剖的理解が深まり，この靭帯を含む再建術の治療成績をより向上させる重要なランドマークの情報を提示できた．