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Original Article

The meniscotibial ligament does exist: An anatomic and histological description

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ABSTRACT

Purpose: To describe the anatomical and histological characteristics of the human MTL (meniscotibial ligament) that keeps the meniscus stable and are rarely discussed.

Study design: Descriptive laboratory study.

Methods: In total, six fresh-frozen adult cadaver knees were dissected, and the dissection protocol were designed by two experienced anatomy professors. The anatomical morphology of MTL was observed. The main anatomical specimens included meniscus, tibial plateau, MTL. The osteotome was used to excise the portion of the tibial plateau, which could obtain the complex including partial meniscus, MTL, and a tibial fragment. A histopathologic study was performed by two experienced pathologists.

Results: Macroscopically, the MTL could be divided into two parts: medial meniscotibial ligament (MMTL)and lateral meniscotibial ligament (LMTL). The MMTL is distributed continuously, whereas the LMTL is discontinuous on the tibial plateau. The average length from the tibial attachment of the LMTL to the articular surface was 19 ± 1.0mm (mean ± SD). The average length from the tibial attachment of the MMTL to the articular surface was 10 ± 1.2 mm (mean ± SD). Microscopy of the MTL showed that the MTL is a ligamentous tissue, composed of a network of oriented collagenous fibers.

Conclusions: In all knees, the MTL was inserted on the outer edge of the meniscus, attaching to the tibia below the level of articular cartilage, which was key to maintaining the rotational stability of knee and the meniscus in the physiological position on the tibial plateau. Histological analysis of this ligament demonstrated that the MTL is a veritable ligamentous structure, which is made up of collagen type I–expressing fibroblasts.

Clinical relevance: This article contributes to the understanding of the anatomical and histological characteristics of the MTL. It is beneficial to promote the development of relevant surgical techniques for the MTL lesion.

1. Introduction

The Meniscus is wedge-shaped, located between femoral and tibial condyles in the knee joint, which has many important biological functions, including load transmission, shock absorption, stability, nutrition, joint lubrication, and so on.[1,2] Some studies have confirmed the importance of the menisci for joint protection and prevention of early osteoarthritis (OA).[3,4] Due to its wedge-shaped structure, the meniscus tends to move outwards during normal loading. To avoid this tendency, the meniscus attaches closely to the tibia via loose connective tissue (i.e., MTL). Recently, the MTL has been extensively studied.[5–11] As an important meniscal stabilizer, this ligament firmly attaches the medial meniscus (MM) and lateral meniscus (LM) to the tibial plateau, stabilizing and permitting the meniscus move within a reasonable range on the tibial plateau.[6,9,12,13] The posterior MTL (pMTL) is sometimes called as coronary ligament, which is located in the posterior horn of the meniscus.[14] In addition, the coronary ligament on the medial meniscus has been extensively studied,[13,15] which is closely related to the lesion of

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the posterior horn of the medial meniscus (PHMM). Moreover, there are some studies that demonstrated the biomechanical importance of the portion of the MTL.[10,13,16–18] By some biomechanical study, Peltier et al.[13] has proved that the MTL is particularly associated with increased rotatory instability of the knee, as the PHMM is stabilized posteriorly by some fibers of the MTL.[15] In clinical practice, Mariani et al.[19] reported that the fixation of the MM showed a reduction in the rotatory and anteroposterior laxity of the knee, which further speculated that the abnormal meniscal movement is likely due to the pMTL insufficiency. Even though some parts of the MTL have already been described, the study has not yet revealed specific details of the anatomical measurements about the MTL and its histological analysis, and especially not analyzing the anatomical characteristics of the MTL on the whole. Therefore, the propose of this study was to describe the overall anatomy of the MTL, establish its anatomic points of attachment relative to other anatomic structures in the region, carry out the measurements of this ligament, and perform a histological analysis to verify that the MTL is a true ligament, which could be of great significance for the improvements of surgical techniques in the treatment of MTL and related meniscal injuries in the future.

2. Materials and methods

For the present study, six nonpaired fresh-frozen cadaveric knees without prior injury, a history of infection, a surgical history, or gross anatomic abnormalities were used in this study. The cadaveric knees were stored at −20 °C and utilized in this study were donated to our anatomy laboratory for the purpose of medical research. The specimen preparation was performed in a standardized protocol. The knees were removed from the refrigerator (set at - 20 °C) the day before the dissection (i.e., 24 hours) and placed at room temperature while wrapped in saline solution gauze. All specimen dissection work was performed in the same day, which avoided the need for refreezing or preservation with additional chemical substances that could change or damage the natural structural characteristics of the cadaveric knee specimens. All cadaveric knees always followed the same anatomic dissection protocol: Firstly, a lateral parapatellar arthrotomy was performed on each specimen to check for intraarticular lesion including lateral and medial meniscal defect and no significant macroscopic osteoarthritic changes of the medial and lateral condyle of the femur and the tibial plateau. Secondly the femoral and tibial diaphysis was disconnected 20 cm from the joint line. The soft tissue such as the skin on the surface of the knee joint was carefully dissected until the fascia could be exposed. Then, by extending the parapatellar incision, the surgeon further removed the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL). Subsequently, the fibular collateral ligament (FCL), medial collateral ligament (MCL), meniscofibular ligament (MFL), LM, MM and patellar tendon (PT) were marked at the femoral level to separate the femur to expose the LM and MM and its surrounding connection to facilitate anatomical measurement of the MTL. In addition, the patellar bone was removed, and the PT was cut distally. After the anatomy of the knee, we described the morphology, distribution of the MTL and its relationship with the surrounding tissues that were observed for anatomic determination. To prevent mistakes in anatomical measurements, all measurements were performed independently by 2 sports medicine surgeons involved in the dissection under the guidance of anatomy professors. These cadaveric knees were measured by using an electronic caliper (Fig. 1)

After all anatomical measurements were completed, samples from the 6 knees were obtained to carry out a histopathologic study. Using osteotomes, we excised the bone block of the medial tibial plateau to obtain the complex including the meniscal segment, MTL, and tibial fragment. The complex was fixed in 10 % buffered formalin at room temperature for more than one day and decalcified in a solution containing formic acid, formaldehyde and PBS buffer in a ratio of 1:1:8. The complex was embedded in paraffin, solidified in cassettes on ice. Then, 6 μm-thickness sections were sliced and stained with Hematoxylin and eosin (H&E) and toluidine blue (TB). The sections of the complex were treated by an immunohistochemistry procedure with the labelling of the COL-2 antibody and picrosirius red (PR) staining to distinguish COL-1 and COL-3. PR staining sections were observed by polarized light. Three experienced histologists reviewed all the sections and explained the results regarding histological findings.

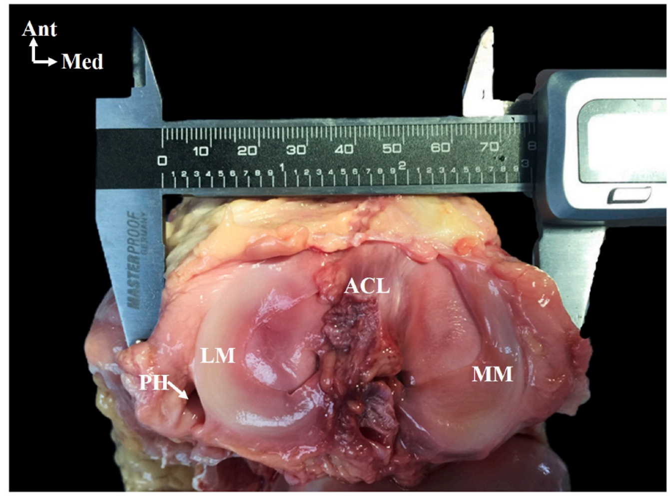

Fig. 1. Anatomic dissection of a left knee. An axial view shows an example of a measurement of the width of the knee using an electronic caliper. LM, lateral meniscus; MM, medial meniscus; ACL, anterior collateral ligament; PH, Popliteal hiatus.

3. Result

3.1. Anatomic measurements

Results are reported as averages standard ± deviations. In relation to the length measurement of the MTL as follows: the average length of the meniscotibial attachment to the posteroinferior aspect of the lateral meniscus was 20.3 ± 2.2 mm, and the average length of the midbody of LMTL was 16.0 ± 1.4 mm. The average length of the anterior portion of the LMTL was 18.0 ± 1.8 mm. The gross measurements of the MMTL are as follows: the mean lengths of the anterior portion, midbody and posterior portion are 11.0 ± 2.2 mm, 11.2 ± 2.1 mm and 10.0 ± 1.8 mm, respectively. The dimensions of the portions of the MTL are presented in Table 1.

3.2. Morphologic results

The MTL was clearly identified in the dissections of all 6 specimens, which was inserted on the outer edge of the medial and lateral meniscus. The MTL origins from the inferior periphery of the meniscus and

Table 1
Mean Dimensions of the meniscotibial Ligament (n = 6)[a].

Structure	Mean ± SD, mm
MMTL	
Anterior portion	11.0 ± 2.2
Midbody	11.2 ± 2.1
Posterior portion	10.0 ± 1.8
LMTL	
Anterior portion	18.0 ± 1.8
Midbody	16.0 ± 1.4
Posterior portion	20.3 ± 2.2

[a] The length of the MTL was measured to include the parts from the outer edge of meniscus to the articular cartilage edge of the tibial plateau.

attached to the tibia below the level of articular cartilage. According the meniscal attachment, the MTL is further divided into two portions, the MMTL and the LMTL. In general, it is also well-known that the meniscus can be divided into three parts, anterior horn, meniscal body, and posterior horn. On the basis of the classification above, the MTL can also be divided into three parts, as follows: anterior MTL (aMTL), posterior MTL (pMTL) and the midbody of MTL (midMTL). It is observed that MMTL is uniformly and continuously distributed on the MM (Fig. 2), nonetheless the LMTL was deficient in the region where the PT runs obliquely upwards (Fig. 3A). LMTL has no tight connection with the FCL. In addition, there was a lack of ligamentous.

Attachments to the inferior outer edge of the posterolateral aspect of lateral meniscus, in which only a weak synovial-like connection was observed. Some studies defined it as popliteomeniscal fascicle (PMFs).[11] This gap was defined as the popliteal hiatus, as an interruption of the continuity between the external border of the LM and the joint capsule where the PT runs in the anterolateral direction.[20] (Fig. 3B) In addition, the popliteal hiatus could be referred to as the boundary, the anterior margin as the midbody of the LMTL, and the posterior margin as the posterior portion of the LMTL. The mean length of each portion of the LMTL is significantly longer than that of the MMTL. There were a lot of loose connective tissues on the outside of the MTL, especially around the MMTL adjacent to the infrapatellar fat pad. However, we further cut the meniscal roots to access an internal view of the structures, observing that the internal surface of the MTL is smooth, lacking loose connective tissues (Fig. 2). Finally, the osteotome was used to excise the portion of the tibial plateau, which could obtain the complex including the meniscal segment, MTL, and a tibial fragment. (Fig. 4).

3.3. Histopathologic results

When dissections were completed, the samples were sent to our pathology laboratory for a histopathologic study of the MTL (Fig. 5). These sections were stained by H&E, toluidine blue (TB). H&E and TB staining of the specimen showed that there were a well-defined collagen structure and cell distribution in the MTL. In addition, there are more vascular structures in the bony insertion of.

MTL and the junction between the MTL and the meniscus. Combined with the results of immunohistochemistry procedure with the labelling of the COL-2 antibody and picrosirius red (PR) staining, it was further

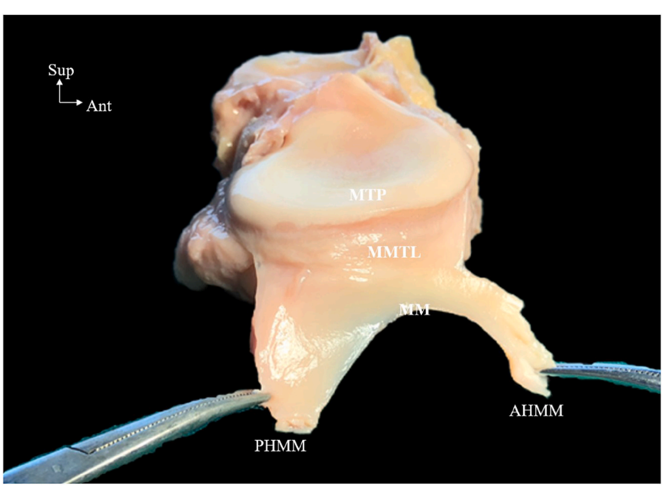

Fig. 2. Anatomic dissection of a left knee. The meniscal roots are sectioned, and the MM is flipped and tensioned to show the complex including entire MMTL, MM and tibia from an inner side. It shows the continuous distribution of MMTL between the medial meniscus and the medial tibial plateau. MM, medial meniscus; MMTL, medial meniscotibial ligament; MTP, medial tibial plateau; PHMM, posterior horn of the medial meniscus; AHMM, anterior horn of the medial meniscus.

speculated that the MTL is an actual ligamentous structure, which is characteristic of collagen type I–expressing fibroblasts that compose this ligament (Figs. 6 and 7).

4. Discussion

The main findings of this study are that the MTL is distributed on the MM and LMC, which is essentially fibrous connective tissue, attaching meniscus to the tibia plateau, and it is histologically proved that the MTL is an actual ligamentous structure, which is characteristic of collagen type I–expressing fibroblasts that compose this ligament. In addition, Wang et al.[18] stated the MTL is located between meniscus and tibial plateau, and thicker than the meniscal attachment to capsule. Furthermore, based on the bilateral distribution, the MTL could be divided into two parts: MMTL and LMTL. In previous anatomical studies of human specimens, MTL has been identified as an exact anatomic structure in 23 %–100 % of specimens.[10,11,18,21,22] In our study, we observed that the MTL is a constantly present structure in our specimens. Furthermore, it is observed that the MMTL is uniformly and continuously distributed on the MM, but the LMTL was deficient in the region where the PT runs obliquely upwards. On the one hand, back in the 1940s, Brantigan et al. described that MM was attached to the MCL through connective tissue.[23,24] Some studies[10,25,26] about the anatomy of the MCL suggest that the MCL can be divided into two main layers: the superficial MCL (sMCL) and deep MCL (dMCL). In addition, the dMCL could be further divided into the meniscofemoral portion and the meniscotibial portion. The meniscotibial portion of the dMCL is one part of the MMTL, which is a consistently tighter and fibrous structure and connected the medial meniscus to the edge of the articular cartilage of the medial tibial plateau. Rupture of the meniscotibial portion of the dMCL leads to the destabilization of medial meniscus and meniscal extrusion. There was no macroscopic difference between the meniscotibial portion of the dMCL and the MTL on the anterior and posterior horn of the MTL. We suspect that the meniscotibial portion of the dMCL is a segment of the MMTL in nature. Certainly, this need to be further confirmed histologically. Furthermore, DePhillipo.et al.[15] described the anatomy of posterior MMTL quantitatively and qualitatively. They found that the pMTL insertion on the PHMM had a mean length of 14.0 $\pm$ 5.4 mm, which was located 5.9 $\pm$ 1.3 mm inferior to the articular cartilage edge of the medial tibial plateau. On the other hand, Masferrer, M.D et al.[27] described that the LMTL was a relatively thin tissue, and Robert F, MD et al.[28] found that the LMTL have a tibial insertion on the inferolateral aspect of the LM, from the anterior edge of the popliteal hiatus to the lateral aspect of the posteroinferior popliteomeniscal fascicle (PI-PMF).

To our knowledge, our research is the first study about the anatomy and histology of the MTL on the whole. In addition, the MTL has not been defined accurately recently, which few authors have referred to the "meniscotibial ligament." For the most part, it was only described as capsular fibers with a proximal origin in the outer edge of the meniscus and a distal insertion in the cartilage edge of the tibial plateau. This is also the first time to define the MTL anatomically and name all the portions of the MTL in terms of its distribution on the MM and LM. Moreover, we also observed an interesting presentation that the length of LMTL is significantly longer than that of MMTL. And Stein G. et al.[29] thought that the MM was attached to the capsule and the MCL more tightly than the connection between the LM and its peripheral structure, so the range of motion (ROM) of the LM is greater than that of the MM. In line with our morphologic results, it could be further speculated that the MTL may be related to the ROM of the meniscus. The greater the ROM of the meniscus, the greater the likelihood of the injury of the MTL. When it comes to the MTL injury, we find that there has been concern about this injury long ago. In 1984, El-koury et al.[30] first reported patients with MTL tears. Since then, many people have begun to study the MTL injury. Recent studies mostly focused on the injury of the posterior MTL around the PHMM.[10,19,31] When the MTL around the PHMM is injured, the special injury could belong to category of ramp lesion. Ramp

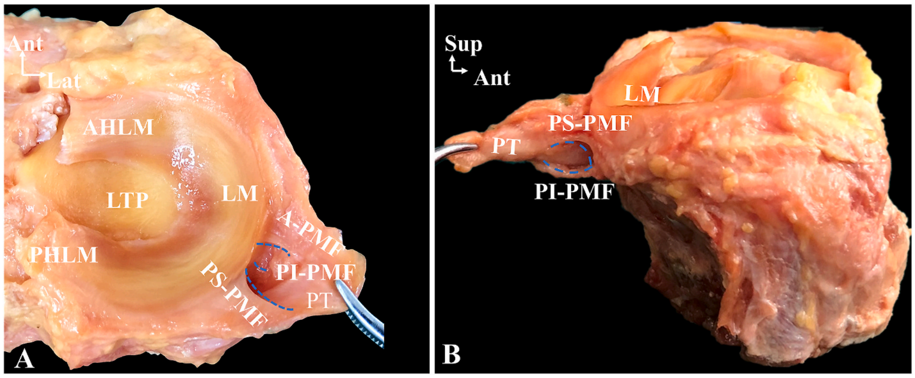

Fig. 3. Anatomic description for the popliteal hiatus. After cutting the ligaments and capsule from femoral insertion and disarticulating the femur, the postero-superior popliteomeniscal fascicle (PS-PMF) is seen, and the recess underneath can be explored with a curved clamp (A). After cutting the PS-PMF (blue dotted line) and retracting the PT, the postero-inferior popliteomeniscal fascicle (bluec dotted line) is tensioned and seen, connecting the inferior meniscal border with the medial portion of popliteus tendon. By retracting the more proximal part of the PT, the anterior popliteomeniscal fascicle (A-PMF, blue dotted line) is tensioned and appreciated connecting obliquely the lateral margin of the meniscal body and the more lateral portion of the PT (B).PS-PMF, postero-superior popliteomeniscal fascicle; PI-PMF, postero-inferior popliteomeniscal fascicle; A-PMF anterior popliteomeniscal fascicle; PT, popliteus tendon; PHLM, posterior horn of the lateral meniscus; AHLM, anterior horn of the lateral meniscus; LTP, lateral tibial plateau; LM lateral meniscus.

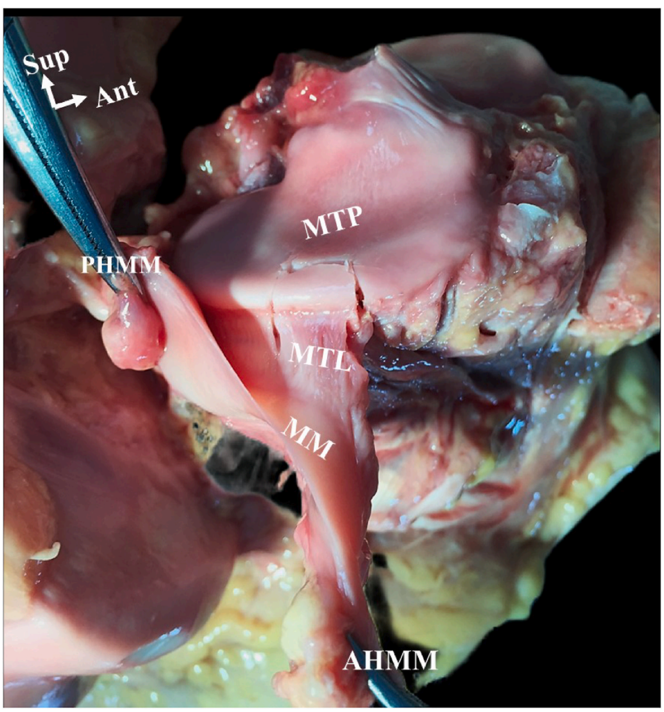

Fig. 4. Anatomic dissection of a left knee. Using osteotomes, we excised the midbody portion of the medial tibial plateau (MTP) to obtain the complex including the meniscal segment, MTL, and a tibial fragment. MM, medial meniscus; MMTL, medial meniscotibial ligament; MTP, medial tibial plateau; PHMM, posterior horn of the medial meniscus; AHMM, anterior horn of the medial meniscus.

lesion is referred specifically to the injury of the PHMM or the detachment between the PHMM and its adjacent surrounding structures, such as meniscocapsular separations, or a rupture of the MTL.[10] Thaunat et al.[32] first classified ramp lesion into five types. According to previous studies,[10,33] Greif et al. further redefined the classification of ramp lesion, and stated that type 3 lesion could be divided into two subtypes: type 3A and type 3B. Type 3A is not associated with the MTL injury, while type 3B was closely associated with the MTL injury, involving two subtypes: the rupture of the MTL itself and the separation of its meniscal attachment from the PHMM. Similarly, type 4 lesion is also divided into two subtypes: type 4A and type 4B. Type 4B is referred to an avulsion of common insertion of the MTL and meniscocapsular ligament from meniscal attachment.[33] Recently, ramp lesions have received much attention, which may contribute to the instability of the knee.[10,13] Peltier et al.[13]confirmed that ramp lesions significantly increased tibial internal and external rotation and the forces in the ACL compared with both an untreated knee and isolated sectioning of the ACL. In addition to these studies, Patrick et al. [6]found that compared to the ramp lesion, the injury about the mid-body of the MTL has always been overlooked in recent years. By cutting the midbody of the MMTL, they created the model of MMTL disruption. And then, the cadaveric specimens were tested biomechanically in both ACL-intact and ACL-deficient state. They found that the deficiency of MMTL could cause the knee instability in multiple directions. Additionally, MMTL disruption renders ACL withstand increased strain during joint loading, which can reach more than three times normal load. Thus, early recognition and repair of MMTL injury can promote the restoration of knee stability and protection of the native or reconstructed ACL, and thus possibly reduce the incidence of ACL graft failures. There is a standardized surgical treatment for this MTL injury. George A et al.[7] utilized three anchors, one in the anterior margin of the lesion, one in the posterior margin of the lesion, and one in the midway of the lesion, respectively. These three anchors were linked to each other in an interconnected way by shuttling the suture into the adjacent anchor creating a knotless fixation, which successfully completed the reconstruction of the midbody of the MTL.

In addition to causing aforementioned injuries, the MTL injuries are often clinically associated with meniscal extrusion. The meniscus may be detached from the tibial plateau when the MTL is ruptured. Meniscal extrusion may result from this ligamentous injury, lack of tight attachment on the margin of the tibial plateau, which narrows meniscal coverage of the tibial plateau, and further leads to inappropriate distribution of pressure load in the knee. Moreover, Nobutake et al.[34] successfully created an animal model of meniscus extrusion in rats by cutting the anterior portion of the MMTL, and proved that the MTL also play a significant role in the stabilization and centralization of the meniscus. Additionally, Krych et al.[9] also demonstrated that meniscal extrusion occurred not only in the injury of the meniscal horn bony insertions but also in the injury of the MTL, finding that the MTL abnormality was identified in 65 % of patients with meniscus extrusion and minimal knee pathology. What's more, patients with a meniscal extrusion of 3 mm or more were nearly three times more likely to have associated MTL lesions than patients with a meniscal extrusion of less than 3 mm, which gives us sufficient reason to believe that meniscal extrusion is closely associated with the MTL abnormality. In a

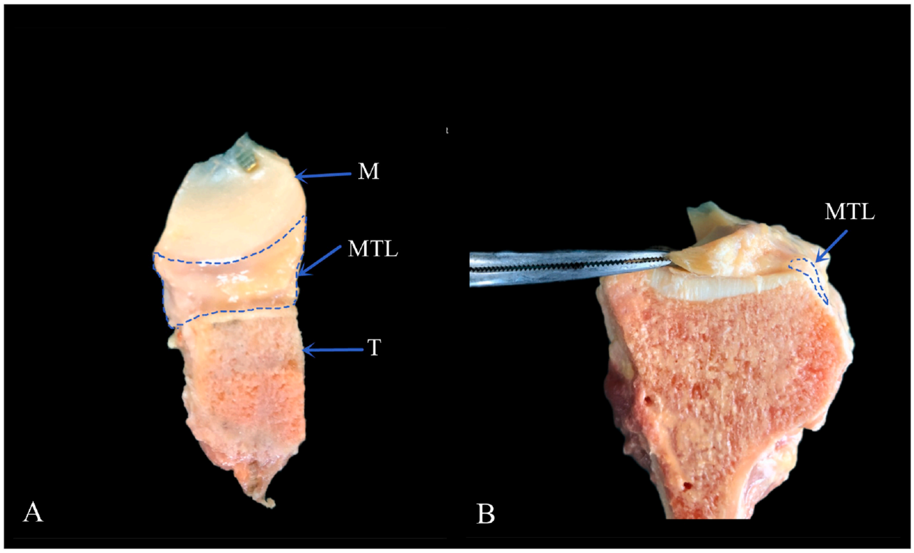

Fig. 5. The observation of the meniscus-ligament-bone complex. After cutting the bone block of the MTP, we could observe the complex that included the meniscus, MTL, and tibia. the meniscus is flipped and tensioned to show the complex (A). and the sagittal view of a cadaveric dissection of the complex (B).

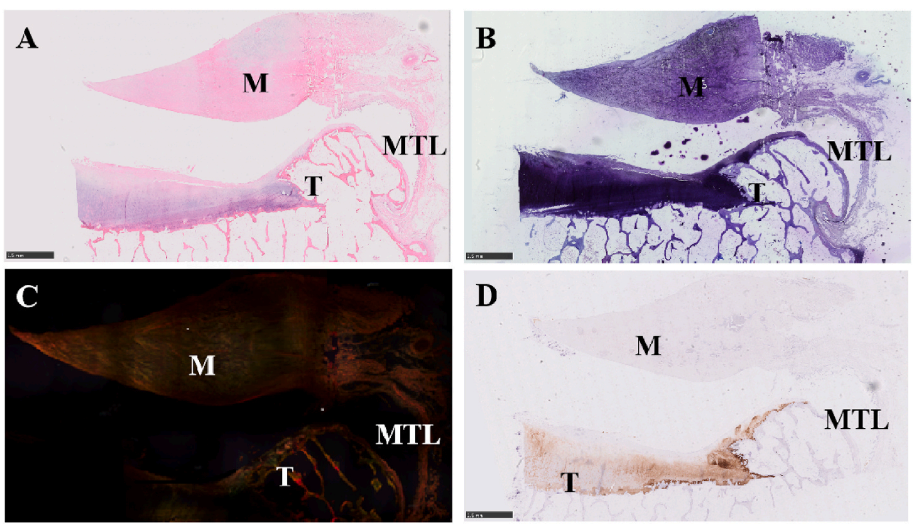

Fig. 6. Collagen structure and distribution in the MTL. (A, B) hematoxylin–eosin, and toluidine blue staining of the complex showed that there were an obvious collagen structure and cell distribution in the MTL. And more vascular structures were observed in the bony insertion of MTL and the junction between the MTL and the meniscus. (C, D) Combined with the results of immunohistochemical staining of COL-2 antibody and picrosirius red (PR) staining, it was further speculated that MTLFV is an actual ligamentous structure, which is characteristic of collagen type I–expressing fibroblasts that compose ligaments.

retrospective study, some researchers found that meniscal extrusion was related to presence of posttraumatic MTL lesion at the time of arthroscopic ACL reconstruction.[35] Furthermore, some reports found that meniscal extrusion was a significant and independent contributing factor to the development of knee OA.[36,37] Therefore, we can speculate that MTL lesions contribute to the development of OA, to a certain extent. In the future, some large animal models are needed to verify the relationship between the MTL and meniscus extrusion. In addition, a recent study suggests that the MTL also play an important role in meniscus allograft transplants (MAT).[38] There were two cohorts in this study. For frozen MAT cohort, all patients were treated by Fresh-frozen meniscal allograft with meniscocapsular sutures only. For fresh MAT cohort, all patients were treated by fresh meniscal allograft with additional MTL reconstruction and meniscocapsular sutures. Anna. et al.[38] found that the revision rate in the fresh MAT + MTL cohort was 21 %, which is lower than the overall revision rate of > 30 % reported for frozen MAT. In addition, N. B. Condron et al. [39] performed a cadaveric analysis, which demonstrated that during MAT, the additional MTL reconstruction could reduce the degree of the meniscal extrusion and improve the biomechanical environment of the knee after transplantation.

Therefore, we believe that the MTL may play a significant role in preventing meniscal extrusion, and maintaining the rotational stability of the knee. In addition, with application to clinical practice, Masferrer-Pino et al. have tried to improve surgical techniques that can verify the role that the MTL may play in preventing the native meniscus extrusion.[7,40] By reconstructing the MTL, they succeeded in limiting the degree of meniscal extrusion. Of course, more biomechanical studies would be necessary to further confirm our hypothesis. Currently, the anatomical and histological studies of this MTL are not detailed enough. In the future, we need to further determine the specific components of MTL through more accurate histological methods. The MTL function will be fully confirmed through appropriate biomechanical studies.

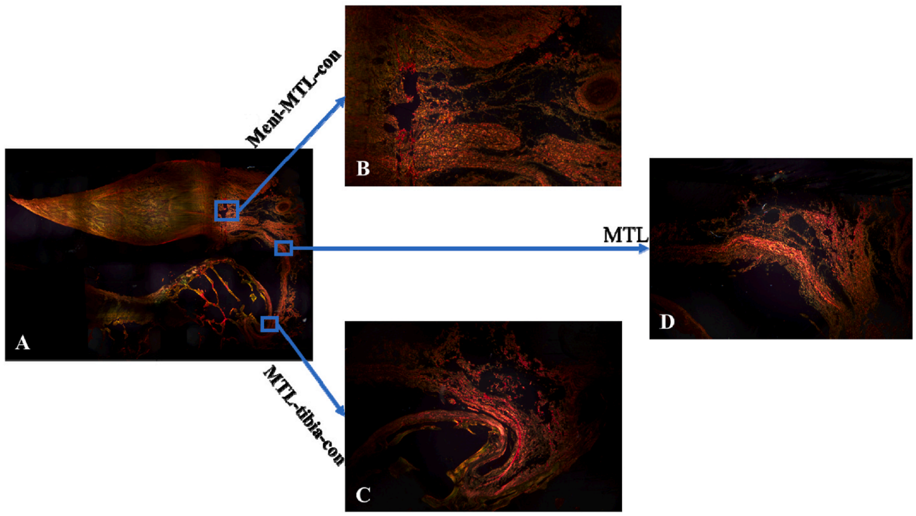

Fig. 7. The panoramic scanning of MTL histological structure by the polarization microscope. (A) Histological structure of the transition between the meniscus and MTL (B) and the transitional zone between the MTL and the tibia (C). Histological structure of the MTL (D) (picrosirius red staining).

4.1. Limitation

There are several limitations in our study. Firstly, only six cadaveric specimens were dissected, which was a relatively small sample size. Nonetheless, we believe that this sample size is sufficient to draw our conclusions. The second limitation was related to the advanced age of cadaver donors, who underwent a process of knee degenerative disease that have altered the anatomical measurements and so we only conduct qualitative evaluation of histological structure, but not quantitative evaluation for the MTL. The third limitation was the absence of a biomechanical analysis in our study. Thus, we cannot come to any firm conclusions about the biological function of the MTL.

5. Conclusion

In all knees, our research showed that the MTL was inserted on the outer edge of the meniscus, attaching to the tibia below the level of articular cartilage, which was key to maintaining the rotational stability of knee and the meniscus in the physiological position on the tibial plateau. Histological analysis of this ligament demonstrated that the MTL is a veritable ligamentous structure, which is made up of collagen type I–expressing fibroblasts.

Authorship

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Each author certifies that this material or part thereof has not been published in another journal, that it is not currently submitted elsewhere, and that it will not be submitted elsewhere until a final decision regarding publication of the manuscript in the Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology (AP-SMART) has been made.

Ethical approval

The cadaveric knees were donated to our anatomy laboratory for the purpose of medical research and the study was approved by the ethics committee of Peking University Third Hospital. (Number IRB00006761-M2021188.

Declaration of competing interest

The authors declare that no conflict of interest regarding the publication of this paper and the manuscript is approved by all authors for publication.

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Authors' contribution

Conception and design of the study: Shi-Tang Song, Xin-Jie Wang. Acquisition of data: Ji-Ying Zhang, You-Rong Chen, Yi-Fan Song. Analysis, or interpretation of data: Shi-Tang Song, Xin-Jie Wang. Drafting the work: Shi-Tang Song, Xin-Jie Wang,Jing Ye. Revising it critically for important intellectual content: Jia-Kuo Yu, Bing-Bing Xu. Final approval of the version to be published: Shi-Tang Song, Xin-Jie Wang,Jing Ye, Ji-Ying Zhang, You-Rong Chen, Yi-Fan Song, Jia-Kuo Yu, Bing-Bing Xu. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Shi-Tang Song, Xin-Jie Wang, Jing Ye,Ji-Ying Zhang, You-Rong Chen, Yi-Fan Song, Jia-Kuo Yu, Bing-Bing Xu.

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