Internal Structural Connections in the Popliteal Muscle Tendon Complex and Their Clinical Significance

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Research article

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Abstract

Background: The popliteal muscle-tendon complex (PMTC) belongs to the deep structure of the posterolateral complex (PLC) of human knee, which plays an important role in the posterolateral stability of the knee joint. At present, the anatomical relationship between the popliteal muscle and its adjacent structures remains controversial, especially the posterior cruciate ligament (PCL) and popliteal muscle. The revelation of anatomical connection between the popliteus muscle and its deep structures could provide an anatomical basis for the reconstruction of the PLC injury.

Methods: To observe and analyze the relationship between popliteal muscle and the PCL, posterior meniscofemoral ligament (PMFL), lateral meniscus and articular capsule (AC). The dissection of 7 cases of adult human knee joint fixed with formalin, and 9 cases of sagittal P45 plastinated section of the knee joint were involved in this study.

Results: For the popliteal muscle, the anatomical dissection showed that at the posterior edge of the platform of the lateral condyle of the tibia, at the tendon-muscle transition, from medial to lateral, separately sent out: dense connective tissue to connect with the PCL, dense fiber bundles to connect with the PMFL, and dense connective tissue band to connect the lateral meniscus. Meanwhile, the results of the P45 section revealed that the popliteal muscle fascia ran superiorly over the posterior edge of the tibialintercondylar eminence, and turned forward to be integrated into the PCL. Laterally, near the posterior edge of the lateral tibial plateau, the popliteal tendon penetrates through the articular capsule, where two dense fiberous bundles were given off upwards by the popliteal tendon: one was the ventral fiber bundle, which ran superiorly over the posterior edge of the tibial plateau and then moved forwards to connect with the lateral meniscus; the dorsal fibers bundle ascended directly and participated in the AC.

Conclusion: Popliteus muscle was connected with PCL, AC, lateral meniscus, and PMFL via the dense connective tissues near its tendon-muscle transition.

Background

The posterolateral complex (PLC), previously known as the “dark side of the knee”, has been subject of innumerous studies lately. Broadly speaking, ‘posterolateral complex (PLC)’ was used to refer to the general term for all ligaments, tendons, and articular capsules, including the proximal tibiofibular joint, in the lateral posterior aspect of the human knee joint in previous studies[1]. Traditionally, PLC has subscribed to the belief that it has the effect of preventing external rotation of the knee joint, varus, and posterior instability of the knee joint [2, 3]. Furthermore, the ‘PLC’ is narrowly defined as the structure of the lateral collateral ligament (LCL), popliteal tendon (PT), popliteofibular ligament (PFL), fabellolateral ligament (FFL), arcuate ligament (AL), and posterior-lateral capsule in the knee joint[1]. The popliteal muscle-tendon complex (PMTC) belongs to the deep structure of the PLC [4], which was a functional complex of the posterior lateral structure of the knee joint, playing a role in preventing external rotation of the tibia, and to counteract the effect of move backward and varus of the tibia [5]. Without timely and
scientific diagnosis and treatment after PLC injury, it could cause posterolateral instability, degeneration of articular cartilage and meniscus, and even chronic joint pain[6, 7]. Previous literature on popliteus muscle (PM) has emphasized the importance of the primary posterolateral stabilizer of the knee joint [8], especially in the posterior cruciate ligament (PCL) deficient knee joint[9–11]. Up to now, several studies have acclaimed the boundance of anterior cruciate ligament defects (acute or chronic) and PM system lesions[12, 13]. Some studies have shown the triangular stability structure formed by the three ligaments of LCL, PT, and PFL is the main stable structure of the posterolateral in the knee joint [6, 14]. So far, there were numerous studies focusing on PM [15–17] but few described the precise anatomy [18]. According to the previous publications, the existence of accessory proximal popliteus muscle attachments remains unclear [19]. And these collectively resulted into the variosity of the relationship between the posterior cruciate ligament and popliteus muscle with different authors [18, 19]. Consequently, the long-term uncertainty of the PM attachment might made the actual function of the PM questionable[18, 20].

The PMTC has complex and variable anatomy; nevertheless, anatomical reconstruction requires exact anatomic knowledge of these structures. P45 sheet plastination technique is capable to display the boundary of soft tissue and the shape of fibers in a wide range of high definition in situ, which plays an important role in determining the anatomical relationship between adjacent structures. Therefore, this study was performed to explore the detailed structures of the PM using gross anatomy and the P45 plastination technique, which could be helpful for reconstruction of the PLC.

**Methods**

**Study sample**

A total of 16 formalin-fixed adult knee joint specimens were collected. Gross anatomy was performed in 7 cases, and the sagittal P45 plastinated section was made in 9 cases. All the specimens were from the cadaver after the teaching of the Anatomy Department of Medical University. The continuous sagittal sections of knee joints were prepared by Dalian Hoffen Biotechnology Co., Ltd., using the P45 plastination technique. None of the specimens showed signs of tumor, congenital malformation, fracture, severe osteoarthritis, and other related diseases.

**Ethical approval**

This study was approved by the ethics committee of the Body and Organs Donation Center of Dalian Medical University. The research involved 16 knee specimens of Chinese adults in middle-aged from the Body and Organs Donation Center. Written informed consent was obtained from the donors involved in this study prior to death in accordance with the regulation of the ethics committee.

**P45 sheet plastination technique [21]:**

**1.Slice:** The specimens were frozen at -70 °C for two weeks, embedded in the embedding box by polyurethane, frozen again at -70 °C for two days, and sliced with a high-speed band saw with a thickness of 3 mm.
2. Bleaching: The slices were rinsed overnight in cold water and soaked in 5% hydrogen peroxide overnight.

3. Dehydration: After slice bleaching, the slices were pre-cooled, then dehydrated in 85% acetone at -25 °C for five days, then in 93% acetone at -15 °C for five days, then degreased at room temperature, and finally in 100% acetone.

4. Vacuum impregnation: The slice was taken out from the acetone bath, clamped with a double glass plate to make the slice infiltration mold, and then the die was filled with Hoffen polyester P45 (Dalian Hoffen Biotechnology Co., Ltd., Dalian, China). The mold filled with the infiltration and embedding material was placed vertically in the vacuum cabinet for impregnation at room temperature. The pressure was slowly reduced to 20, 10, 5, and 0 mmHg according to the bubble size and release rate. The pressure 0 mmHg was kept until the bubbling stops. The impregnation duration was more than 8 hours.

5. Curing: After releasing the vacuum, the bubbles were checked and removed out from the plate. Clamp the top of the mold with a clip and move it to solidify. Solidify in a hot water bath and place upright in a 40 °C water bath for three days. After curing, the slice was removed from the bathtub and cooled on the shelf to room temperature. The slices were removed from the glass plate and covered adequately with bonded plastic film to provide protection.

6. Photography and Observation: The slices containing PM were selected. The slices were observed by laying them on the X-ray reading lamp, and photos were taken with a Canon 7D camera (Canon Inc., Tokyo, Japan) camera. The fiber connections between PM and PCL, lateral meniscus et al. were observed and analyzed, and the results were recorded.

Anatomical dissection

In the popliteal fossa, the superficial structures was removed layer by layer to expose the PM. Identify the AC of the knee joint and PM. Along the surface of the PM, part of the AC was removed, and the knee joint was opened. The PCL, PMFL, and the lateral meniscus were exposed. The connection relationship between the PM and them was observed. The PM was amputated at the back of the tibial plateau, and the PM was lifted to observe its connection with the PCL and lateral meniscus along the articular surface of the tibial plateau. Close to the posterolateral side of the lateral condyle of the femur, cut off the popliteal tendon together with the lateral meniscus and lift them medially to observe the connection between the popliteal tendon and the lateral meniscus. The results of anatomical observation were recorded with a Canon 7D camera (Canon Inc., Tokyo, Japan).

Result

P45 observation results

In this study, totally 9 numbers knee joints were made into continuous P45 sections of the PM. 7 cases demonstrated the connection between the PM and the PCL. The connection between the PM and lateral
AC was found in 8 cases. And the connection between the PM and lateral meniscus was found in 8 cases. Impressively, the connections between the PM and the PCL, the lateral meniscus, and the AC were observed concurrently in 5 cases.

In the sagittal P45 section of the knee joint through the long axis of the PCL, an overall picture of the PCL and PM was shown sagittally (Figure 1). The PCL was observed from the inner surface of the medial femoral condyle to the caudal intercondylar area of the tibia, slightly curved shape. The PM extended distally onto the dorsal surface of the tibia. Behind the intercondylar eminences, the upper edge of the PM was located at level of the posterior edge of the tibial plateau. And its fascia bypassed the posterior edge of the tibial plateau, went on forward to the deep surface of the AC, and participated in the formation of the PCL.

And in other sagittal P45 sections of the knee joint through the middle part of the lateral condyles of femur, the articular surface of the lateral condyles of the femur and the lateral part of the tibial plateau were observed (Figure 2). The popliteal tendon penetrated the articular capsule and sent two dense fiber bundles upwards: one, the ventral fiber bundle bypassed the posterior edge of the tibial plateau and moved forward to connect with the lateral meniscus; the other, the dorsal fibers ascended directly into the articular capsule.

Anatomic observation results

Among the 7 gross anatomical specimens in this study, the connection between PM and PCL was found in 6 cases, the connection between PM and PMFL was found in 5 cases, and the connection between PM and lateral meniscus and AC was found in 5 cases. It was noted that the connections between PM and PMFL, PCL, lateral meniscus, and articular capsule could be found simultaneously in 5 cases.

The dissection results showed that the PM attached to the proximal tibia and tilted upwards from medial to lateral of the lateral condyle of the femur at the bottom of the popliteal fossa, participating in the formation of the lower part of the popliteal fossa (Figure 3). At the level of the posterior edge of the platform of the lateral condyle of the tibia, the PM obliquely inserted into the articular capsule. At the tendon-muscle transition, there was a series of dense connective tissue connections, from medial to lateral, between the PM and PCL, between the PM and the meniscus end of PMFL, and between the PM and lateral meniscus (Figure 4). Inside of the tendon-muscle transition of the PM, and the PM penetrates to the inner surface of the articular capsule (Figure 5). When the PM was lifted over, it was noted that a thick connective tissue band between the popliteal tendon and the PCL(Figure 5), as well as the lateral meniscus ( Figure 5, Figure 6).

Discussion

The PMTC was a primary stabilizer of the knee involved in both static and dynamic stabilization, providing external rotation stability, and with small but important primary stabilization roles in the case of internal rotation, varus angulation, and anterior translation [22, 23]. Despite its important function, it was
believed that the anatomic descriptions of the PMTC are controversial due to its complex and variable anatomy [24]. Previous researches shows that PT was the key structure of the PMTC [22, 25]. In agreement with previous literature, the present study has found that the complexity of the anatomy of PMTC was due largely to the variable alignment of this structures. According to our findings, the popliteus muscle (PM) also plays a significantly role in this complexity.

The PM originated at the posterior tibia and ended at the lateral femoral condyle. When the PM transversed the articular capsule at the level of the posterior edge of the tibial plateau, the dense muscular fascia originated from the PM, which inserted into the PCL and became part of the PCL. In addition, the tendon-muscle junction gave off a series of dense fibrous bundles to connect with the PCL, the PMFL, the lateral meniscus, and the articular capsule. In accordance with the present results, this study has important similarities and yet differences compared to previous reports.

Based on previous reports[19], in 42 knee joints, there was a connection between the PM and lateral meniscus, posterolateral articular capsule, posterior cruciate ligament. This was similar to the results. However, for posterior cruciate ligament, a total of 13 cases (P45 section 7 cases, 78%, gross anatomy 6 cases, 86%) were found to have a dense connection between the PT and the PCL, the total rate was 81% in this study. This was different from the findings by Feipel et al[19] and Chuncharunee et al[18], their results were 5% and 0%. The knee joint is the largest and most complex joint of the musculoskeletal system. Hence, it is difficult to determine the boundary of soft tissue by the method of gross anatomy. However, the adjacent relationship between organizations could be revealed on the premise of retaining the original organizational structure by the P45 sheet plastination technique, because of the characteristics of its high-definition soft tissue display. The anatomical structure observed using P45 sheet plastination technique could make us more targeted in the process of gross anatomy. This reason might be responsible for the significant difference in the gross anatomical results of this study and previous studies[18, 19]. Therefore, through the combined method of P45 and gross anatomy, we identified that there were dense connections in the PMTC. Meanwhile, it was found for the first time that two kinds of ventral and dorsal fiber bundles were sent out during the popliteal tendon penetrated the articular capsule. One connected the lateral meniscus anteriorly and the other ascended and blended into the articular capsule. Demonstrated by P45 sheets, the fiber connection between popliteal muscle and posterior cruciate ligament was firstly described. The relationship between the PM and lateral meniscus enriched previous observation of Chuncharunee et al. [18], by revealing the details of the connection between the PM and lateral meniscus in the sagittal plane.

PLC injury is often associated with complex injury of the knee, clinically, concomitant injuries of posterolateral corner structures with a cruciate injury lead to an increased incidence of ACL and PCL reconstruction failures [5]. Thus, the operation should take one not only to reconstruct the cruciate ligament but also to reconstruct the PLC [26, 27]. Nowadays, anatomical reconstruction of the PLC is commonly performed in chronic PLC injuries. However, the guidelines for PLC reconstruction remain unclear, and several surgical techniques for PLC reconstruction have been suggested, such as open techniques with a large lateral incision and extensive soft tissue dissection, or arthroscopic assisted
Despite there are still many differences in the treatment of PLC injury, it is difficult to formulate a unified treatment strategy due to PMTC complex and variable anatomy [25, 29]. Many investigations using laboratory, radiographic, and surgical studies to define the anatomy and function of PMTC [25, 29, 30], aimed at better understand this complex area. These studies have found that the PT, which functions as the fifth major ligament of the knee, is the key structures of the PMTC [22]. The complexity of the anatomy of PMTC is due largely to the variable alignment of these structures [23, 24]. In this study, there were dense connections between the PM and the posterior cruciate ligament, the PMFL, the lateral meniscus, and the lateral articular capsule, in which dense fiber connections were concentrated in the tendon-muscle migration where the PT penetrates the AC. Whether this anatomical structure plays an important role in maintaining the stability of the knee joint could be addressed in further study, and yet the existence of this connection should be paid a clinical attention.

In particular, there are studies indicating that those higher rates of cruciate graft failure were due to increased force transmitted through the cruciate ligaments if a concomitant posterolateral corner injury was not fixed alongside the cruciate injury [31]. Thus, hopefully, the anatomy about dense connections between the PM and the posterior cruciate ligament, could contribute to the resolution of the related clinical issues.

**Limitations**

In future research, it is necessary to carry out in vivo mechanical experiments on PMTC to discuss the mechanical interactions between each part. In addition, multiple samples are needed in the future.

**Conclusion**

In the PMTC, the PM connected the PCL via dual fibers including the popliteal fascia and dense fibrous bundle. And at meantime a series of compact fibrous band-like connections were between the PM and the PMFL, the PT and the lateral meniscus, and also between the PT and the AC, among the PT penetrated the articular capsule.

**Abbreviations**

Posterolateral complex: PLC, popliteal muscle-tendon complex: PMTC, posterior cruciate ligament: PCL, articular capsule: AC, posterior menisci of emoral ligament: PMFL.

**Declarations**

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Author Contributions

S-B. Y, H-J. S, conceived and designed the experiments. W-B. J, S-Z. S, T-W. S, WT, and FX, data acquisition. W-B. J, CL, drafted the manuscript. S-B. Y, H-J. S, critical revision of the manuscript. All authors were involved in data interpretation.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the ethics committee of the Body and Organs Donation Center of Dalian Medical University. The research involved 16 knee specimens of Chinese adults in middle-aged from the Body and Organs Donation Center. Written informed consent was obtained from the donors involved in this study prior to death in accordance with the regulation of the ethics committee.

Consent for publication

Not applicable.

Competing interests

The authors declare no conflicts of interest associated with this study.

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