Anatomical, Biomechanical and Radiological Characteristics of Anterolateral Ligament

Anterolateral Ligamanın Anatomik, Biyomekanik ve Radyolojik Özellikleri

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Abstract
Anterior cruciate ligament (ACL) ruptures in the knee joint are one of the most frequent injuries; however, problems with obtaining natural dynamic knee function with current surgical reconstruction methods are frequently reported. The aim of anatomic ACL reconstruction is to restore the anatomy and the kinematics of the knee. The failure to provide full rotational stability in ACL injured knees, strengthened the idea that procedures such as extra-articular tenodesis reconstructions, which aim to strengthen the structures in the lateral region of the knee, should be added to ACL reconstruction operations. Anatomically, these clinical observations arouse the interest in conducting studies which aim to examine the structural content of the anterolateral part of the knee and its stabilizing contributions. As a result, some research has been done, which can be called the rediscovery of the anterolateral ligament (ALL) including its detailed examinations. In addition, the close relationship between ACL ruptures and ALL injuries and the association of residual anterolateral rotational instability in pivot shift test have led to an increase in the interest of the anatomic and structural features of ALL. ALL was first mentioned by Segond in 1879 in the study where he described the extension of the iliotibial band (ITB) during internal rotation. Segond described this structure as a pearl-like, fibrous band. But the study, which aroused the main interest in ALL anatomy, was made by Claes et al., and at that time, many written and visual media reported "A new connection was found in the knee".

Keywords: Anterolateral ligament, Knee anatomy, Pivot shift

Öz
Diz ekleminde ön çapraz bağ (ÖÇB) yırtıkları en sık görülen yaralanmalarındandır ancak halen güncel cerrahi rekonstrüksiyon yöntemleri ile doğal dinamik diz fonksiyonunu elde etme ile ilgili sorunlar sıklıkla bildirilmektedir. Anatomik ÖÇB rekonstrüksiyonunun amacı dizin normal anatomi ve kinematiğini tekrar sağlamaktır. ÖÇB yaralanmalı dizlerde tam rotasyonel stabiliteyi sağlamadaki başarısızlıklar, dizin lateral bölgesindeki yapıların güçlendirilmesi amacını taşıyan eklem-dışı tenodez rekonstrüksiyonları gibi prosedürlerin, ÖÇB rekonstrüksiyonu ameliyatlarına eklenmesi gerekliliği fikrini güçlendirmiştir. Anatomik olarak, bu klinik gözlemler dizin anterolateral bölgesindeki yapıların yapısal içerik ve stabilize edici katkılarının değerlendirilmesi amaçlarını taşıyan çalışmaların yapılmasına olan ilgiyi uyandırmıştır. Bunun sonucunda anterolateral ligament (ALL) gibi bir yapının yeniden keşfi olarak adlandırılabilecek ayrıntılı incelemelerini içeren araştırmalar yapılmıştır. Ayrıca, ÖÇB yırtıkları ile ALL yaralanmalarının yakın ilişkisi ve pivot shift testinde rezidüel anterolateral rotasyonel instabilitenin birlikteliği, ALL'in anatomik ve yapısal özelliklerine olan ilginin artmasına da sebep olmuştur. ALL ilk kez Segond tarafından 1879 yılında, İliotibial bandın (ITB) iç rotasyon sırasında gerilmesini tanımladığı çalışmada belirtilmiştir. Bu yapıyı Segond, inci benzeri, fibröz bir bant olarak tanımlamıştır. Ama ALL anatomisine esas ilginin artmasını sağlayan çalışma Claes ve ark., tarafından yapılmış ve o dönemde bir çok yazılı ve görsel basında ''Dizde yeni bir bağ bulundu'' şeklinde haberler yer almıştır.

Anahtar Kelimeler: Anterolateral ligament, Diz anatomisi, Pivot shift

Introduction

Anterolateral Ligament

Anterior cruciate ligament (ACL) injury is one of the most frequent orthopedic problems managed generally with ACL reconstruction (1). Although the main target is to restore normal anatomy and perfect knee kinematics, the surgical procedures frequently fail to restore rotational stability. To overcome that rotational instability, some surgeons recommended extra-articular augmentation surgeries (2-3). It was reported that 30-40% positive pivot shift test was noticed after ACL reconstructions (4). Initially, cartilage or meniscal problems were believed to be the reason; some research has focused on the importance of lateral anatomical structures (5). After being re-popularized by Claes et al in 2014, numerous articles were published about anterolateral ligament (ALL), which is one of those anatomical structures (6).

Since first described by Segond as pearly, resistant fibrous band in 1879, many other articles were written about that ligament with different names (7). Segond also noticed that anterolateral proximal avulsion fracture of tibia is pathognomonic for ACL ruptures (7,8). Hughston et al. in 1976, Müller et al. in 1982, Terry et al. in 1993, Campos et al. in 2001, Vieria et al. in 2007 and Vincent et al. in 2012 published their articles about that anatomical structure (9-13). Different authors also named that anatomical structure with various terms like lateral capsular ligament, anterior oblique band, mid-lateral capsular ligament, mid-third lateral capsular ligament and retrograde tract fibers (9-13). Using different names for the same structure has also led to confusion for

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understanding the nature of the ligament. Most recently, Vieria was the first researcher to use the term anterolateral ligament (12). Although Claes et al.'s anatomical description of the ALL was the second of the most recent about the topic, because of the strong social media network of this group, it was popularized as ''a new ligament discovered in the knee''.

Anterolateral Complex Structures and Pivot Shift Phenomenon

Anterolateral ligament, superficial, deep and capsulo-osseous layer of iliotibial band (ITB), middle 1/3 lateral capsular ligament and posterior root of lateral meniscus are the main restraints against internal rotation of tibia (14). According to biomechanical studies, the three layers of ITB are the primary checkrein of limiting internal rotation (1). Clinically, the excessive internal rotation of the knee can be assessed by pivot shift test which was first described by Galway et al. in 1972 (15). This test is described as forward subluxation of the lateral tibial plateau on the femoral condyle in extension and spontaneous reduction in flexion. Currently, pivot shift is the most specific and sensitive clinical test for ACL injury diagnosis, and it is also accepted as pathognomonic. Unfortunately, most of the patients experience a residual pivot shift with different grades after ACL reconstruction (16). Although this residual pivot shift phenomenon can be attributed to misdiagnosis or mistreatment of the injured secondary stabilizers of the knee (eg, lateral meniscus post root, meniscectomy), many surgeons reported this phenomenon in the isolated ACL injured patients after reconstruction (16). Biomechanical studies about pivot shift suggest that the primary reducer of the subluxated knee is ITB (16). In fact, none of the individuals who have experienced ACL injury has also had associated ITB injury (16). This clinical reality has forced researchers to refocus on further investigations about anterolateral complex of the knee.

What We Know about Anterolateral Ligament?

Although there are numerous anatomical studies about the existence and structure of ALL by different authors, Claes et al. described anatomical characteristics of ALL extensively (6,8-13). Claes also documented the relationship between ALL and Segond fracture (6). In order to identify ALL accurately in cadavers, the technique which was described by Daggett can be used (17). ALL lies on the third layer, with joint capsule at the anterolateral region of the knee. To identify ALL using Daggett's technique, initially reflecting of ITB until its insertion at Gerdy's tubercle has to be performed. Internal rotation of the tibia during dissection is strongly advised for proper visualization of ALL. After reflecting biceps femoris, meticulous dissection must be carried out for the identification of ALL from adjacent tissues like ITB, lateral collateral ligament (LCL), capsule and biceps femoris (17).

Morphometry of ALL

According to the analysis of cadaveric studies, it is accepted that femoral origin of ALL is generally found posterior and proximal to the lateral epicondyle. It predominantly lies anterior to LCL, but in some articles it was also mentioned as posterior to LCL, too (6, 9-15). The femoral origin directly adheres to the bone and has a mean diameter of 11.85 mm. The ALL runs distally nearly parallel to LCL. It was also shown that, when it reaches the joint line, some fibers of the ALL are attached to lateral meniscus and also to the capsule. Distal insertion of ALL is more constant than femoral origin (6). Tibial insertion of ALL is located in proximal tibia with a width of 11 mm, approximately 21 mm posterior to Gerdy tubercle and 4-10 mm below the joint line (Figure-1). The length (34-59 mm) and thickness (male: 2 mm, female: 1 mm) of ALL vary with gender. And it is also accepted that tibial attachment lies between Gerdy's tubercle and the fibular head (1, 6, 18).

Figure 1: ALL runs distally anterior to LCL. (Black star indicates femoral origin of LCL, and black arrow femoral origin of ALL, red arrow indicates Gerdy's tubercle, blue arrow tibial insertion of ALL and yellow arrow indicates fibular head)

Radiological Anatomy

As the popularity of the ALL reconstruction has increased, the importance of radiological landmarks has become a point of interest. For minimally invasive procedures, the knowledge of these landmarks is essential for graft positioning. During the surgery, fluoroscopic views of these landmarks are crucial for proper tunnel positioning. There are four well designed studies which analyzed radiographic landmarks of ALL (19-22). As mentioned above, radiological landmarks of femoral origin of ALL vary like its anatomical landmarks. On the lateral view, Helito et al. recommended Blumensaat's line as a reference point. According to his radiological study, the femoral attachment is at approximately halfway along Blumensaat's line from the anterior edge of the femoral condyle (19).

Kennedy et al. used femoral quadrant system and found that the femoral origin of ALL is the point between the intersection of femur and Blumensaat's line. The femoral attachment was identified in the postero-inferior quadrant, 8,4 mm proximal and posterior to the lateral epicondyle center (20). Rezansoff et al. described the ALL origin as being along the posterior femoral cortical line, positioned between Blumensaat's line and a line taken from the posterior condylar articular edge parallel to Blumensaat's line (21). Heckmann et al. located the ALL origin at a distance of around 37% from the posterior edge of the femoral condyle, measured along Blumensaat's line (22). According to ALL Expert Group, Kennedy method is favoured rather than the others (18).

For tibial insertion, on a lateral view, Kennedy and Helito recommended slightly posterior to the center of the tibial plateau (19-20). According to Rezansoff, this tibial landmark was located more posteriorly (21). On the contrary of other authors, Heckmann recommended anterior to the center of plateau (22).

According to the consensus of ALL Expert Group, tibial insertion should be close to the center of the proximal tibial plateau on the lateral view and approximately 7 mm below the tibial joint line on the frontal view (18).

Biomechanics

The biomechanical studies of ALL are focused on the native and reconstructed kinematics. According to Claes et al., greater pivot shift can be experienced with both ALL and double bundle ACL deficient knee (6). Isolated ALL or one bundle (anteromedial or posterolateral) deficiency may produce grade 1 pivot shift whereas combined ruptures of ACL and ALL produce grade 3 pivot shift in cadaver models (23-24).

After the recent studies about biomechanics of ALL, its role is now well defined in overall lateral knee stability. The tensile strength test (20 mm/min) has documented mean ultimate load values of 189 Newton and stiffness of 31 N/mm. This test data is important for proper graft choice of ALL reconstruction clinically (18). Otherwise, strong and thick grafts may cause over-compression at the lateral compartment of the knee, which may cause premature lateral compartment arthritis.

In vitro robotic assessments of the ALL in the setting of an ACL injury have defined the ALL as a significant lateral knee stabilizer (24). Specifically, the ALL has been demonstrated to act as a secondary stabilizer during internal rotation torque and simulated pivot-shift test in the ACL-deficient state (25).

Oshima et al. showed that, ALL reconstruction reduces the knee laxity. An important finding of this study was that, during a simulated pivot-shift test, ALL reconstruction combined with ACL reconstruction reduces internal rotation at 30°, 45° and 60° of knee flexion. This was statistically significant when compared to the ACL reconstruction with deficient ALL testing state. When the isometry of ALL was considered, it was found that ALL was tight in extension and in internal rotation at 20° whilst lax at flexion at 120° and internal rotation at 90° when femoral origin is preferred at proximal and posterior to the femoral position. The clinical reflections of these biomechanical studies are critical for optimization of femoral location (26).

Imaging of ALL

After the popular anatomical study of Claes, many radiologists were focused on demonstration of ALL with different imaging modalities. Firstly, the radiological basis of Segond fracture has been well defined in terms of its relationship with ALL. Currently, the basis of Segond fracture is an avulsion fracture of ALL, and it is the result of internal rotation of the knee and possibly varus stress. These fractures can be visualized on straight, anteroposterior (AP) radiographs of the knee (6) (Figure-2). On the lateral view, the deep lateral femoral notch sign in ACL deficient patients is an indirect pathological finding of ALL injury.

Figure 2: Segond fracture is avulsion fracture of proximal tibia and it is pathognomonic for ACL ruptures and can be seen in direct X-rays

ALL can also be visualized on coronal MRI scans with T2-weighted sequences and proton density fat-suppressed evaluation. According to MRI findings, ALL is divided into three parts due to its relationship with lateral meniscus. Femoral portion has a close relation with insertion of popliteus tendon whilst the tibial portion is just above the inferior lateral geniculate arteries. MRI studies documented that the ALL abnormalities are frequently located in the tibial part of the ligament (27). On MRI, an important indication of ALL injury is the presence of bone bruise as a result of rotational trauma which can be seen in the lateral femoral condyle and bilaterally on the posterior tibial plateau (28-29) (Figure 3A-B).

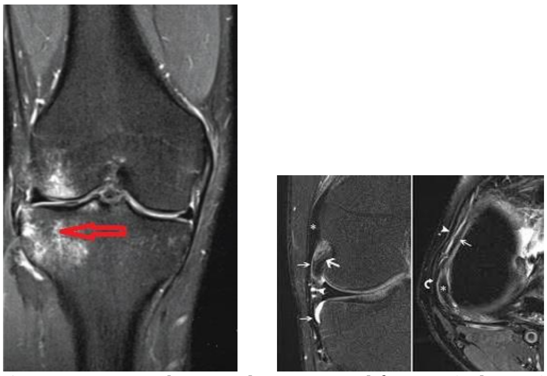

Figure 3: A- Bone bruise indicates Segond fracture (red arrow), **B-** Assessment of ALL with MRI (white arrows).

And finally, ultrasound imaging can be a helpful tool for diagnosing ALL injury directly. The distal tibial portion of the ALL can be visualized more accurately than the meniscal and femoral portion of the ligament. The discontinuity and irregularity of the ligament with abnormal echoic findings can be established with ultrasonography rapidly on bed side clinic. Radiological findings combined with clinical findings are meaningful for diagnosis of accurate ALL injury (26).

Conclusion

There is no doubt that ALL is a distinct anatomical structure at the anterolateral region of the knee, which exists in the vast majority of the studied cadavers. The histological feature of this structure is compatible with ligament distinct from joint capsule. Recently, the biomechanical basis of Segond fracture is correlating with ALL avulsion injury. However, pivot shift phenomenon is more obvious with patients who have ACL injury with Segond fracture.

Our knowledge of ALL is solely based on cadaveric studies. The literature is still lack of the clinical importance of ALL in vivo. One unanswered question is the natural history of ALL rupture. As ALL is an extra articular structure, it has a potential healing capacity. Therefore, it is still a clinical question that which patients are optimal candidates for ALL reconstruction although it is diagnosed with imaging modalities in acute phase.

Also, we do not know the alterations of pivot shift during the time. A common belief is that chronic patients have great pivot shift test, but this clinical finding has not been proven with well-designed studies.

It is clear that, to understand the instability patterns after ACL reconstruction procedures, more scientific research is needed. Further anatomical, biomechanical and radiological studies will clarify the underlying pathologies.

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