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Variation in the shape of the tibial insertion site of the anterior cruciate ligament: classification is required

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Abstract
Purpose To propose a classification system for the shape of the tibial insertion site (TIS) of the anterior cruciate ligament (ACL) and to demonstrate the intra- and inter-rater agreement of this system. Due to variation in shape and size, different surgical approaches may be feasible to improve reconstruction of the TIS.
Methods One hundred patients with a mean age of 26 ± 11 years were included. The ACL was cut arthroscopically at the base of the tibial insertion site. Arthroscopic images were taken from the lateral and medial portal. Images were de-identified and duplicated. Two blinded observers classified the tibial insertion site according to a classification system.
Results The tibial insertion site was classified as type I (elliptical) in 51 knees (51 %), type II (triangular) in 33 knees (33 %) and type III (C-shaped) in 16 knees (16 %). There was good agreement between raters when viewing the insertion site from the lateral portal ($\kappa = 0.65$) as well as from the medial portal ($\kappa = 0.66$). Intra-rater reliability was good to excellent. Agreement in the description of the insertion site between the medial and lateral portals was good for rater 1 and good for rater 2 ($\kappa = 0.74$ and 0.77, respectively).
Conclusion There is variation in the shape of the ACL TIS. The classification system is a repeatable and reliable tool to summarize the shape of the TIS using three common patterns. For clinical relevance, different shapes may require different types of reconstruction to ensure proper footprint restoration. Consideration of the individual TIS shape is required to prevent iatrogenic damage of adjacent structures like the menisci.
Level of evidence III.

Keywords ACL · Anterior cruciate ligament · Insertion site · Tibial insertion site · Classification · C-shape · Triangular · Elliptical · Shape · Variation

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Introduction

The anterior cruciate ligament (ACL) is composed of the anteromedial (AM) and the posterolateral (PL) bundle that insert on the anterior portion of the tibia [1, 2]. Knowledge of the anatomy of the ACL and its adjacent bony morphology is important for surgical planning of proper graft type, size, and positioning.

The position of the tibial insertion site (TIS) on the tibial plateau was shown to be consistent among different ages and gender [20]. It has been shown to be bordered by Parsons' knob, the inter-condylar ridge, the anterior horn of the lateral meniscus, and the medial and lateral tubercles [23]. Weak correlations between size of the TIS and height, weight, and body mass index of patients have been reported [10]. Good correlation exists between size of the TIS and the tibia plateau [9]. However, the exact shape of the TIS was not considered.

Recent studies have sparked discussion about the shape of the TIS. While the TIS was described as "C"-shaped in almost all cases [18], other studies have demonstrated variation in the shape of the TIS that is dependent on factors

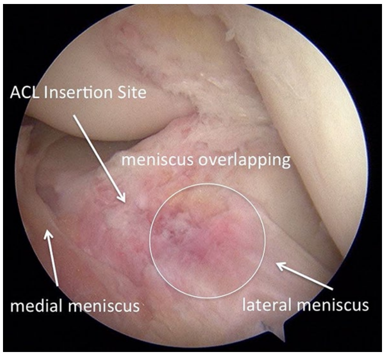

Fig. 1 Overlapping of the lateral meniscus and the tibial insertion site (TIS) of the anterior cruciate ligament (ACL) in a left knee

such as overlapping of the lateral meniscus [10, 21, 27] (Fig. 1). Degeneration can also influence the appearance of the TIS, but does not change its original shape.

Considering variation in shape and size of the TIS, accurate replacement of the ACL becomes even more important. Studies have attempted this by describing characteristics of the TIS using predefined reconstructions of computed tomography scans [11]. Individualized ACL reconstruction concepts have been developed using pre-operative and intra-operative measurements to account for the anatomy of the ACL and bony landmarks. These considerations have optimized restoration of the native ACL and normal kinematics [24].

It is well known that in cases of posteriorly placed tibial graft, increased anterior–posterior laxity might be present, whereas a too anteriorly placed graft can lead to impingement, lengthening of the graft and lack of extension [6, 16, 28]. Additionally, restoring the shape of the TIS has been of great interest coupled with the shape of the graft to replace the ACL [17].

No classification system to date has been published to account for individual differences. The purpose of this study is to propose a classification system for the shape of the TIS and to demonstrate its intra- and inter-rater agreement. Due to variation in shape and size, different surgical approaches may be feasible to improve reconstruction of the TIS. The classification system can help to establish treatment algorithm based on individuals anatomy.

Materials and methods

A total of 100 successive cases performed by the same senior surgeon were included to determine the shape of the TIS according to the classification system. All revision cases were excluded. Included patients had a mean age of 26 ± 11 years. The ACL was cut arthroscopically at the TIS. Measurements of the length and width of the entire TIS were taken from the medial portal using a customized ruler as previously described [10]. Arthroscopic images were taken from the lateral and medial portals. Each image was standardized to contain the entire TIS as well as the anterior horn of the medial and lateral meniscus (Fig. 2). The images were de-identified and duplicated. Two blinded observers classified the TIS according to a classification system (Fig. 3). The classification system is based on preliminary findings of common shapes of the ACL midsubstance obtained by Faro Laser Scan. The system distinguishes between three types of TIS: type 1 is elliptical, type II is triangular, and type III is C-shaped.

The study was conducted according to the guidelines of the local IRB (University of Pittsburgh IRB PRO12020619).

Statistical analysis

Prior to conduction of this study, a sample size analysis was performed revealing that a sample size of 82 patients was sufficient to achieve a confidence level of 95 % with

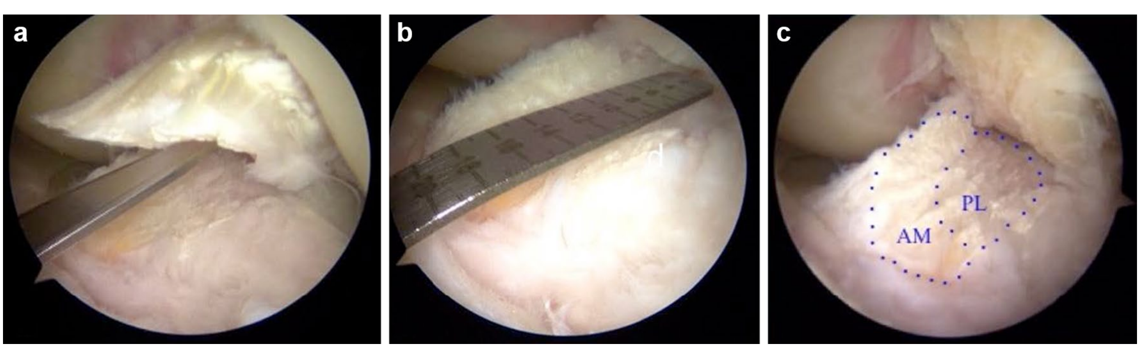

Fig. 2 Cutting of the anterior cruciate ligament (ACL) stump next to its tibial insertion site (TIS) (**a**). Measurements of the TIS after cutting of the ACL stump (**b**). Image of the TIS with marked anteromedial (AM) and posterolateral (PL) bundle areas taken from the lateral portal (**c**)

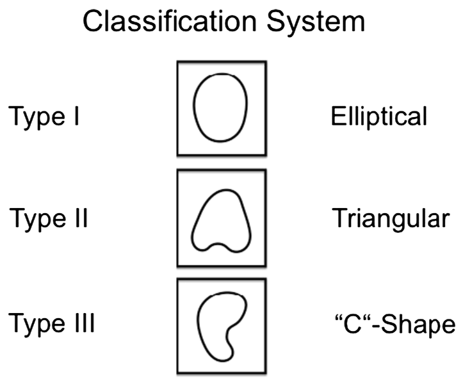

Fig. 3 Classification system for the tibial insertion site of the anterior cruciate ligament

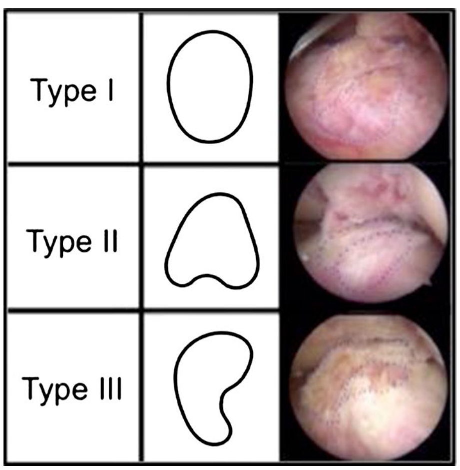

Fig. 4 Intra-operative appearance of the TIS and assignments based on the classification system (all left knees)

a margin of error of 10 %. Intra- and inter-rater reliability was calculated using the Kappa coefficient. Cohen's Kappa coefficient was also used to determine the relationship between the images taken from the lateral and medial portals.

Table 1 Intra-rater reliability using Cohen's kappa coefficient

	Medial portal	Lateral portal
Rater 1	0.73, $p < 0.001$	0.71, $p < 0.001$
Rater 2	0.81, $p < 0.001$	0.84, $p < 0.001$

Results

According to rater I, the TIS was classified as type I (elliptical) in 51 knees (51 %), type II (triangular) in 33 knees (33 %) and type III (C-shaped) in 16 knees (16 %). Figure 4 shows the variable intra-operative appearances of the TIS. Fatty degeneration was observed in 26 out of 100 patients (26 %) (Fig. 5).

There was good agreement between raters when viewing the TIS from the lateral portal ($\kappa = 0.65$) as well as from the medial portal ($\kappa = 0.66$). The intra-rater reliability was good to excellent (Table 1). Agreement in the description of the TIS between the medial and lateral portals was good for rater 1 and good for rater 2 ($\kappa = 0.74$ and 0.77, respectively).

Intra-operative measurements of the TIS resulted in a total mean length of 16.1 mm (±2.6 mm) and a total mean width of 9.6 mm (±1.5 mm). The mean length of the AM bundle TIS was 9.0 (±1.0 mm) with a mean width of 9.1 mm (±1.3 mm). The mean length of the PL bundle TIS was 7.2 (±1.1 mm) with a mean width of 7.1 mm (±1.4 mm).

Discussion

The most important finding of the present study was that the shape of the TIS varies and can be summarized using three common patterns.

In orthopaedics, the ACL is one of the most described and discussed areas in the human body. However, there is still disagreement on its anatomy [18, 19]. A deep understanding of the basic science, kinematics and anatomy is

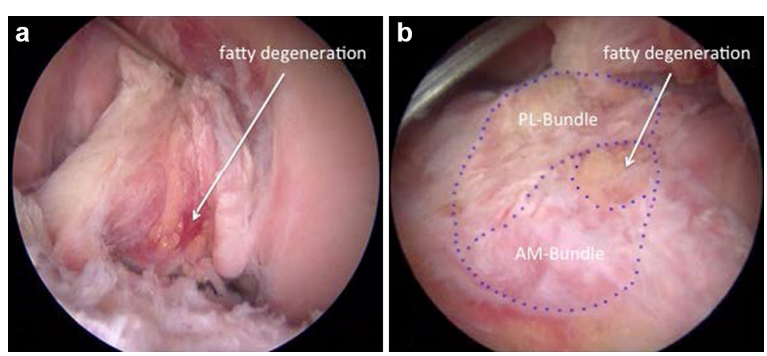

Fig. 5 Fatty degeneration of the anterior cruciate ligament (ACL) in a left knee. ACL stump after cutting (**a**). Tibial insertion site after cutting of the ACL (**b**)

key to evaluating the pathologic and morphologic changes in the ACL and its insertion site. A common theme of variation in shape and overall size, which has been studied more closely, has been observed. This is illustrated by Kopf et al. [10] who performed a cross sectional study of 137 patients and evaluated the size of the femoral insertion site and TIS that had been marked with electrocautery and measured with an arthroscopic ruler. They concluded that there is a large variation in size of the TIS. The AM bundle and the PL bundle can be more or less prominent, and in some cases, an intermediate bundle can be present [17, 22, 27].

Additionally, the anterior horn of the lateral meniscus variably overlaps with the TIS, further illustrating the importance to develop techniques that allow for precise graft measurements to ensure anatomical placement [5, 21, 25]. Injuries to the meniscal root can cause gross instability and should be prevented to ensure good outcome and patient satisfaction. ACL anatomy can vary secondary to pathologic processes and degeneration [3, 27]. Changes in extracellular matrix composition (type X collagen, sulfated glycosaminoglycan), cellularity, alkaline phosphatase activity and mineral distribution have been reported [26]. This may influence the appearance of the TIS and should be considered if the classification system is applied to prevent misinterpretation of the bony morphology.

Different techniques of reconstruction have been developed to restore the ACL with the aim of anatomical reconstruction. Oval dilators to create oval tunnels were established to match the insertion site anatomy more closely [14]. Computer-assisted surgical systems were tested to assure accurate pre-operative planning. However, the systems require adjustment to each individual knee's anatomy [13], and the currently available evidence does not indicate that computer-assisted surgery improves outcome in knee ligament reconstruction [4]. Depending on the individual anatomy, different surgical approaches, single-bundle or double-bundle reconstruction, graft diameters and drill angles may be feasible [17]. Studies have postulated that the average anatomical single-bundle reconstruction of the ACL was able to reconstruct 70 ± 12 % of the TIS. Studies have shown that the double-bundle technique, if applied in the right setting, can restore the TIS significantly better than a single-bundle surgery [15]. However, anatomical reconstruction of the ACL does not restore the native insertion site in its entirety, and further studies are needed to illustrate the threshold of restoration needed to predict successful or poor outcome [12]. Van Eck et al. [25] described that the goal of anatomical ACL reconstruction is the functional restoration of the ACL to its native dimensions, collagen orientation and insertion sites.

This study provides the surgeon with a classification system for the TIS that can help assist the surgeon when considering graft size and preparation. Thus, the surgical approach and techniques should be modified based on the shape of the insertion site to accommodate the size and morphology that was initially present with the native anatomy. Even if each TIS is different, this study shows that a pattern is present.

The study is not without limitations. First, recent studies have shown that distortion can be present based on the angle of the arthroscope and the view given by the portals [7, 8]. In this study, a good classification was achieved, when evaluating the TIS from the lateral and medial portal. However, it is recommended to use the same portal for classification to achieve a more standardized procedure. Second, the classification system leads exclusively to an optimized restoration of the TIS. Classification of the femoral insertion site is lacking so far and should be established in the future.

In summary, this classification system may provide an avenue to optimize restoration of the tibial footprint by considering variable shapes. This can be used in the day-by-day clinical practice to establish treatment algorithms based on individual anatomy.

For clinical relevance, different shapes may require different types of reconstruction to ensure proper footprint restoration. A type III "C-shaped" TIS may be better restored using a double-bundle technique, while a type I "elliptical" TIS may be sufficiently restored by a single-bundle technique. However, thought has been given to other variables like size of the TIS, size of the notch and shape/size of the femoral insertion site as well. In addition, consideration of the individual TIS shape is required to prevent iatrogenic damage of adjacent structures like the menisci. Furthermore, optimized footprint restoration may have influence on rotary stability. Further studies are required to determine the effect of graft-TIS mismatch or match on kinematics of the human knee.

Conclusion

There is variation in the shape of the ACL TIS. The classification system is a repeatable and reliable tool to summarize the shape of the TIS using three common patterns.

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Compliance with ethical standards

Conflict of interest D.G. receives travel funding from Traumastiftung gGmbH and Richard und Annemarie Wolf-Stiftung. The Department of Orthopaedic Surgery receives funding from Smith and Nephew to support research related to ACL reconstruction. This funding is not directly related to the findings presented in this article.

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