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RESEARCH ARTICLE

A proposal for a new classification of the fibular (lateral) collateral ligament based on morphological variations

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ABSTRACT

Background: The fibular collateral ligament (FCL) is subject to varus forces at all knee flexion angles and is also resistant to external rotation near extension. It originates on the lateral epicondyle of the femur and inserts on the lateral surface of the head of the fibula.

However, its anatomical characteristics are inconsistent. Recent publications have focused on morphological variations concerning mainly femoral and fibular attachments, as well as morphometric measurements. Less attention has been paid to the morphology of the FCL and its relationship to the antero-lateral ligament (ALL).

Question/purposes: The aim of this paper is therefore to introduce the first complete classification of the FCL that includes all important aspects of morphological variability.

Methods: Classical anatomical dissection was performed on 111 lower limbs (25 isolated and 86 paired) fixed in 10% formalin solution. The lateral compartment of the knee was investigated in detail.

Results: The fibular collateral ligament was present in all specimens. The FCL originated most commonly (72.1% of cases) from the lateral femoral epicondyle, and the inserted on the lateral surface of the head of the fibula (Type I). In addition, bifurcated (Type IIa — 12.6%) and trifurcated (Type IIb — 0.9%) ligaments were also found with two and three distal bands, respectively. A double FCL was also found (Type III — 6.3%), as was fusion of the FCL and ALL (Type IV — 8.1%).

Conclusion: The FCL is characterized by high morphological variability. Knowledge of these variants is essential for surgeries performed in this region concerning the FCL and the ALL.

Clinical relevance: Distinguishing FCL from the FCL-ALL Complex is necessary when planning surgical procedures.

1. Introduction

The development of sophisticated treatment methods has resulted in detailed anatomical studies of the knee joint. Recently, much attention has been paid to the antero-lateral ligament (ALL), resulting in considerably less interest in the variability of the fibular collateral ligament (FCL) and the association between these two structures. The FCL is located on the postero-lateral corner of the knee joint (Chappell et al., 2014; Meister et al., 2000; Recondo et al., 2000). It attaches to the lateral epicondyle of the femur, then runs down postero-laterally, and inserts on the lateral surface of the head of the fibula. The FCL does not fuse with the articular capsule, being separated by a layer of adipose tissue (Chappell et al., 2014; Crespo et al., 2015; Olewnik et al., 2018c; Pomajzl et al., 2015).

The main role of the FCL is to resist varus forces at all knee flexion angles; however it tends to resist tension when at an angle between 0°–30°, and counters external rotation when near to full extension (Espregueira-Mendes and Vieira Da Silva, 2006; Gollehon et al., 1987; Grood et al., 1988; LaPrade et al., 2004; Moulton et al., 2015). Thus, it is subjected to the greatest force during the stance phase of the gait (Chappell et al., 2014; Espregueira-Mendes and Vieira Da Silva, 2006; Kim et al., 2013). The injury of the FCL develops as a results of various types of stress and hyperextension. It is most often injured after a direct hit to the medial side of the knee, although a lesion can develop after a strong strike to the lateral part of the foot or a non-contact injury in this same pattern of movement (Chappell et al., 2014; Espregueira-Mendes and Vieira Da Silva, 2006; Moulton et al., 2015). Although tennis players or gymnasts are most vulnera-

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ble to FCL rupture, the risk of FCL injury is increased in any sporting discipline in which the athlete is exposed to varying strains on the fully-extended knee (Majewski et al., 2006). An important aspect of FCL injuries is that they seldom occur as isolated incidents. It commonly co-occurs with damage to other ligaments at the knee joint region, such as the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL) and other postero-lateral corner (PCL) structures (Moatshe et al., 2016). An injury affecting all the above structures is known as a multi-ligament knee injury and usually requires a huge amount of force such as a high-impact sporting collision. Various treatment methods (rehabilitation, repair or reconstruction) have been developed for treating the FCL depending on the place and degree of injury. In recent years, the rapid development of physiotherapy has facilitated faster and non-invasive recovery of patients after FCL damage (after strain or partial tear). In these cases, good results are obtained after immobilizing the limb for two to four weeks, followed by the use of quadriceps strengthening exercises aimed at increasing the rotational stability of the posterolateral knee corner. Primary repair is indicated for acute bony avulsions of the femoral or fibular attachment; however, it is not recommended for midsubstance tears and chronic lateral knee instability secondary to FCL injury. In this clinical setting, reconstruction is a preferable method (Moatshe et al., 2016; Moulton et al., 2015).

Few publications examine the morphological variability of the FCL, with previous publications mainly addressing the variations of the femoral attachment and morphometric measurements. Moreover, data on the relationship between the FCL and the anterolateral ligament (ALL) are confusing. Therefore, the aim of this study is to characterize the morphological variation of the FCL and to create the first classification of this ligament. Additionally, we want to highlight the complex relation between the FCL and ALL. This knowledge will help this structure to be correctly recognized in future anatomical studies and should prove to be helpful during surgical procedures.

2. Materials and methods

One hundred and eleven lower limbs fixed in 10% formalin solution (25 isolated and 86 paired, 58 left and 53 right knee joint) were obtained from adult Caucasian cadavers. The mean age of the cadavers was 49 years (35–88 years). Limbs that showed signs of scarring or the transition of osteoarthritis were not included into the study. Consent for the study was given by the Local Bioethics Commission (agreement no RNN/297/17/KE).

A dissection of the knee region was performed using traditional techniques according to a strictly specified protocol (Olewnik et al., 2018a, 2018b, 2018c; Olewnik et al., 2017a, 2017b). Dissection began with the creation of a large rectangulate cutaneous flapwise lateral region of the knee joint and the removal of skin and subcutaneous tissue. The iliotibial band and the short head of the biceps femoris were then visualized, the structures were cleared of subcutaneous fat. The iliotibial band was then cut transversely at approximately 6 cm — proximal to the lateral epicondyle of the femur and then carefully released from its tibial insertion. Then the iliotibial band was completely separated and removed, after which the superficial lamina of the capsule was visualized. The next step was to isolate the FCL, which was palpated with the knee in various positions. The lamina encompassing the FCL was then carefully incised posteriorly and parallel to the FCL, following this, the ALL was separated (Claes et al., 2013; Olewnik et al., 2018c). After dissection, the following morphological features of the FCL were assessed:

- The types of FCL (i.e. location and types of origin and insertion).
- Morphometric measurements of the FCL.
- Relationship between FCL and ALL.

An electronic digital caliper was used for all measurements (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was carried out twice by three researchers with an accuracy of up to 0.1 mm. The statistical analysis was performed using Statistica 12 software (StatSoft Polska, Cracow, Poland). A p-value below 0.05 was considered significant. The results are presented as mean and standard deviation, as well as the minimum and maximum values, unless otherwise stated. The Chi^2 test was used to compare the difference in the occurrence of the FCL between sexes and body sides. Continuous data was checked for normality of distribution with the Shapiro–Wilk test. As the distribution was not normal, the Mann–Whitney test was used to compare obtained measurements between sexes and body sides. The Kruskal Wallis ANOVA with dedicated *post hoc* test was used to compare the measurements between FCL types.

3. Results

Fibular collateral ligament was present in all specimens.

1. According to the morphology of the FCL four types was distinguished:

- Type I, occurring a single band that originates on the lateral epicondyle of the femur, proximally and posteriorly to the popliteus tendon. It runs in a straight line distally, and its insertion is on the lateral surface of the head of the fibula distal and anterior to the fibular styloid process. It was observed in 80 cases (72.1%) — Figs. 1, 6a.
- Type II, occurring as a multiband. This category can be divided into two subtypes: bifurcated (Type a) and trifurcated (Type b)
  - Type a is bifurcated, with two distal bands, where the first inserts to the head of the fibula and runs along a similar course as Type I. The second inserts to the deep fascia of the leg posterior to Gerdy's tubercle, and its course is anterior to the first band. It was present in 14 limbs (12.6%). — Figs. 2, 6b.
  - Type b is trifurcated, with three distal bands. The main band (first) inserts to the lateral surface of the fibula and runs in a similar way to Type I. The rear band (second) inserts to the styloid process of the fibula, posterior and proximal to the main band. The front band (third) inserts to the deep fascia of the leg, posterior to Gerdy's tubercle and anterior to the first band. This type was present in only one case (0.9%) — Figs. 3, 6c.
- Type III is a double FCL. The first FCL originates on the lateral epicondyle of the femur and inserts on the lateral surface of the head of the fibula, while the second FCL originated on the lateral epicondyle of the femur, posterior and distal to the first FCL, and inserts to the deep fascia of the leg posterior and proximal to the first FCL. This type was recognized in seven cases (6.3%) — Figs. 4, 6d.
- Type IV (complex) represented the ALL starting from the FCL. The ALL inserted to the tibia, posteriorly to Gerdy's tubercle. It course is anteriorly and superficially to the FCL. The FCL inserted to the lateral surface of head of the fibula. This arrangement was observed in nine cases (8.1%) — Figs. 5, 6e.

The classification system was created only based on macroscopic morphology of the FCL (sites of origin/insertion and course) and ALL in the case of Type IV (complex FCL-ALL).

The length of the FCL was the only morphological parameter that differed between ligament type: it was significantly longer for type IV than for V (Fig. 7, Table 1). Detailed data concerning the morphology of each type is presented in Supplementary materials. Distribution of types among genders and body sides is presented

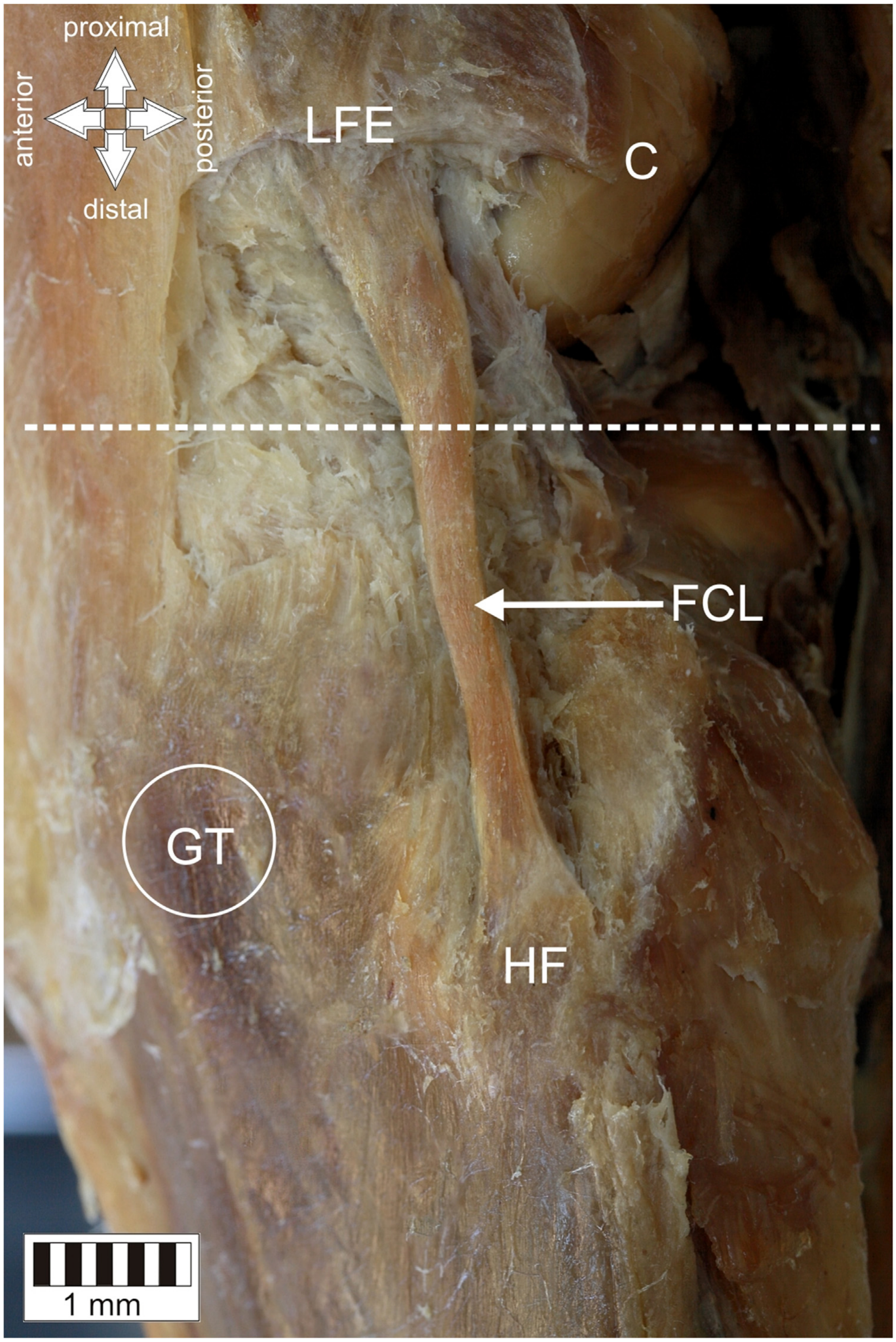

Fig. 1. Type I of the fibular collateral ligament. Lateral view of the left knee. *FCL* fibular collateral ligament; *C* condyle of the femur; *LFE* lateral epicondyle of the femur; *GT* Gerdy's tubercle; *HF* head of the fibula. A white dotted line indicates a knee joint line.

Table 1
Length of the FCL according to different classifications.

	Type I (n = 80)	Type II a (n = 14)	Type II b (n = 1)	Type III (n = 7)	Type IV (n = 9)
FCL length — distance between origin and insertion in neutral position: mean (±SD)	48.37 (8.76)	49.78 (8.07)	50.14 (–)	59.55 (6.55)	46.65 (4.12)

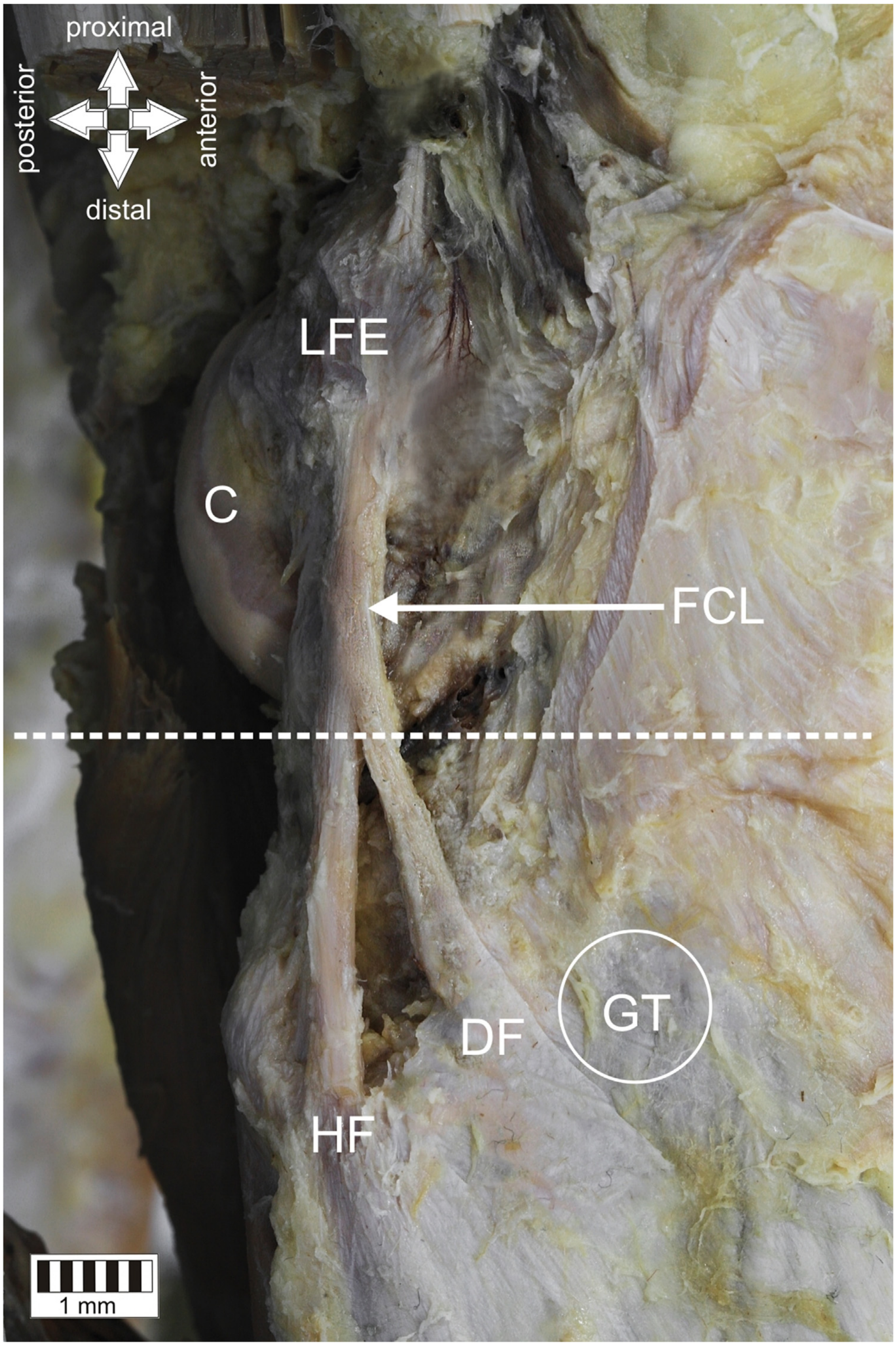

Fig. 2. Type II a of the fibular collateral ligament. Lateral view of the right knee. *FCL* fibular collateral ligament; *LFE* lateral epicondyle of the femur; *GT* Gerdy's tubercle; *HF* head of the fibula; *DF* deep fascia of the leg; *C* condyle of the femur. A white dotted line indicates a knee joint line.

in Table 1. When comparing the result according to body side and gender, only the thickness of the FCL differed. The FCL was thicker in men in all three points: origin (p = 0.0361; middle p = 0.0067; insertion p = 0.0021).

2. Comparison of the difference between type II a of FCL and the FCL-ALL complex.

The ALL-FCL complex is characterized by its origin from the FCL. The course of the ALL is superficial compared to the main FCL band (Figs. 8a, 9a), while **Type II a (bifurcated)** FCL is characterized by the "antero-medial" approach and runs at the same altitude (Figs. 8b, 9b). The fibers which create the ALL band are faintly combined with main FCL band along the initial part of their shared course (when viewed from the point of divergence) and can be easily separated in this site. In the case of a bifurcated FCL, this situation was not observed, because both of its bands are strongly linked with each other. The differences are shown in Fig. 8 in the place of the red circle. The insertion of both "accessory" bands is located in the deep fascia of the leg.

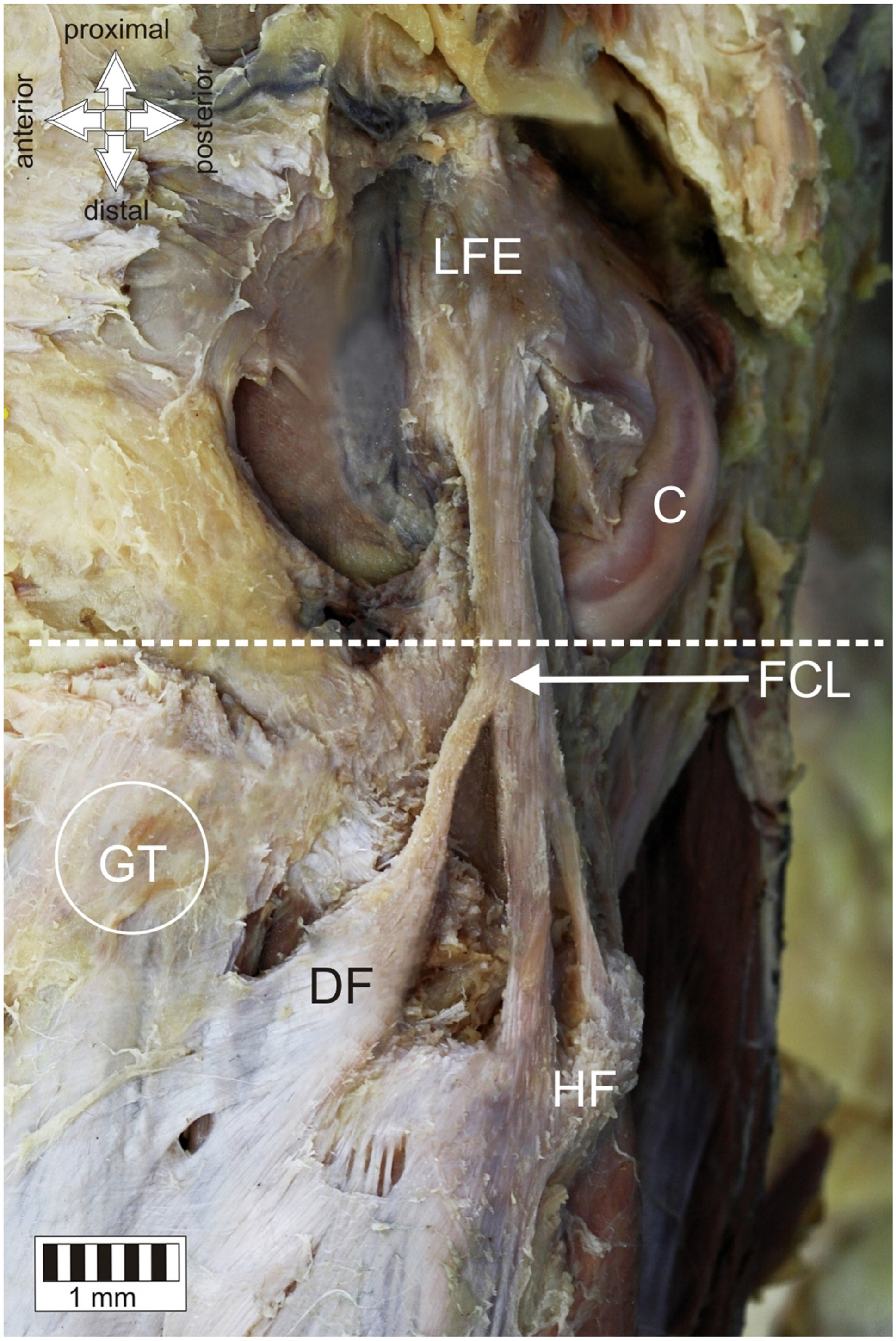

Fig. 3. Type II b of the fibular collateral ligament. Lateral view of the left knee. *FCL* fibular collateral ligament; *LFE* lateral epicondyle of the femur; *GT* Gerdy's tubercle; *HF* head of the fibula; *DF* deep fascia of the leg; *C* condyle of the femur. A white dotted line indicates a knee joint line.

4. Discussion

The greatest value of the present work is that it presents possibly the first such systematic classification of the FCL. In addition, it also attempts to distinguish the FCL-ALL complex from the bifurcated FCL. Following trends in orthopedic surgery, such a categorization may be helpful for planning procedures, and would allow further research on the biomechanics and functions of particular types of FCL.

The most common FCL variations described in the literature concern different locations of femoral attachment (Brinkman et al., 2005; Espregueira-Mendes and Vieira Da Silva, 2006; LaPrade et al., 2003; Meister et al., 2000; Otake et al., 2007; Terry and LaPrade, 1996). Meister et al. (2000) describe an origin on a fovea immediately posterior to the apex of the lateral epicondyle, while Terry and LaPrade (1996), LaPrade et al. (2003), and Brinkman et al. (2005) and Chappell et al. (2014) describe an origin on the posterior and more proximal aspect of the lateral epicondyle. In addition, a different type located directly on the apex of the lateral femoral epicondyle

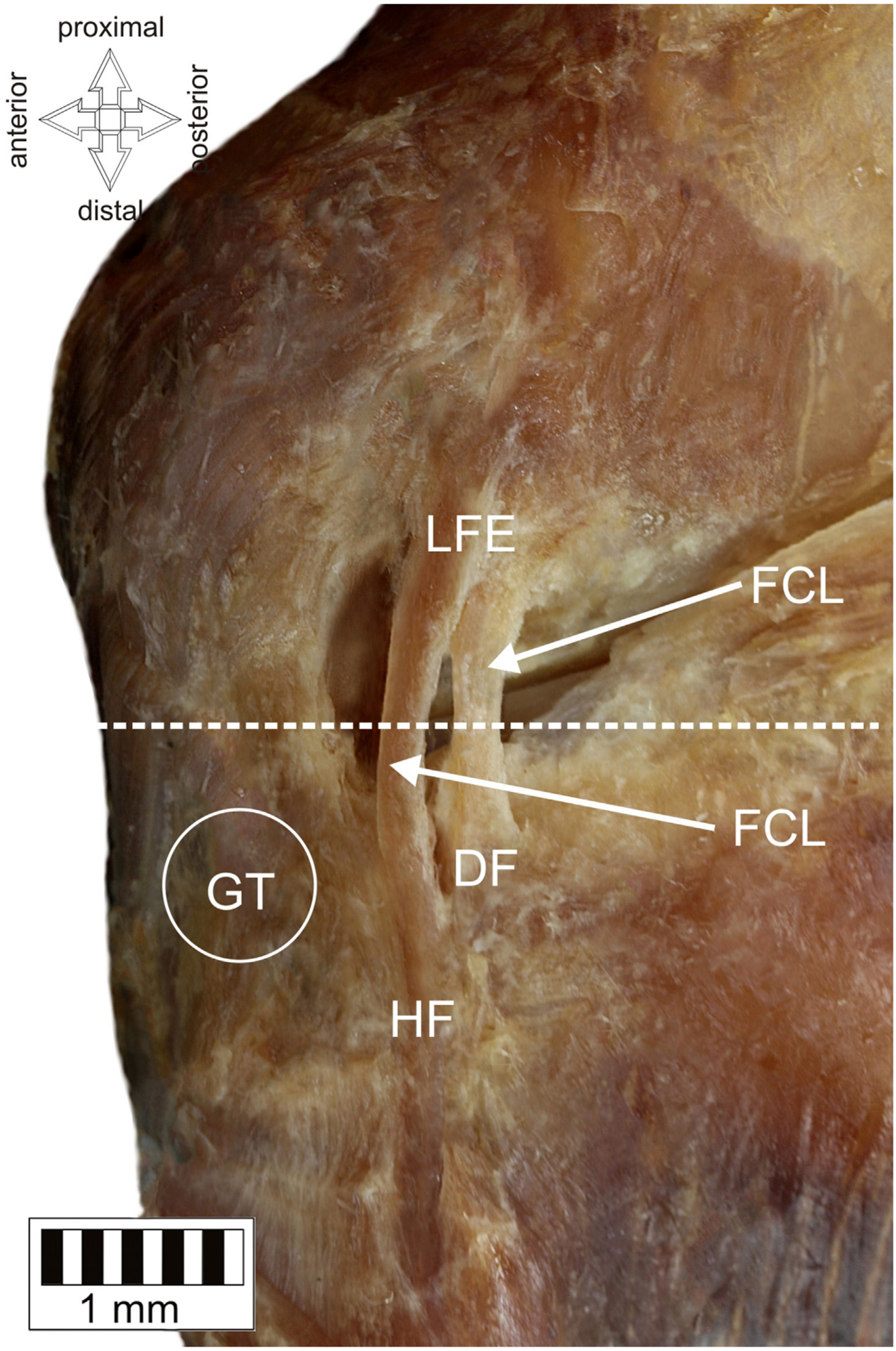

Fig. 4. Type III of the fibular collateral ligament. Double FCL. Lateral view of the left knee. *FCL* fibular collateral ligament; *LFE* lateral epicondyle of the femur; *HF* head of the fibula; *DF* deep fascia of the leg; *GT* Gerdy's tubercle. A white dotted line indicates a knee joint line.

was described by Otake et al. (2007). As for the single band, only a single insertion has been described, and it was located on the lateral aspect of the head of the fibula (Brinkman et al., 2005; Chappell et al., 2014; Espregueira-Mendes and Vieira Da Silva, 2006; LaPrade et al., 2003; Meister et al., 2000; Terry and LaPrade, 1996).

To our knowledge, only two previous studies mention additional bands of the FCL (Chappell et al., 2014; Diamantopoulos et al., 2005). Diamantopoulos et al. (2005) report an accessory band (superficial bundle) of the FCL inserted anteriorly to the fibular head on the lateral side of the tibia. In a study of 70 FCLs, Chappell et al. (2014) found only single bifurcated or trifurcated cases. In the bifurcated type, the accessory band inserted to the anterior aspect of the head of the fibula, while in trifurcated FCL, one of the distal bands inserted to the anterior aspect of the head of fibula, and the second inserted to the posterior aspect of the head of the fibula (Chappell et al., 2014).

Similar types were found in the present study; however, they differed in their distal attachments. Namely, in **the bifurcated type** (**Type II a**), the accessory band inserted to the deep fascia of the leg, while in **the trifurcated type** (**Type II b**), two additional bands

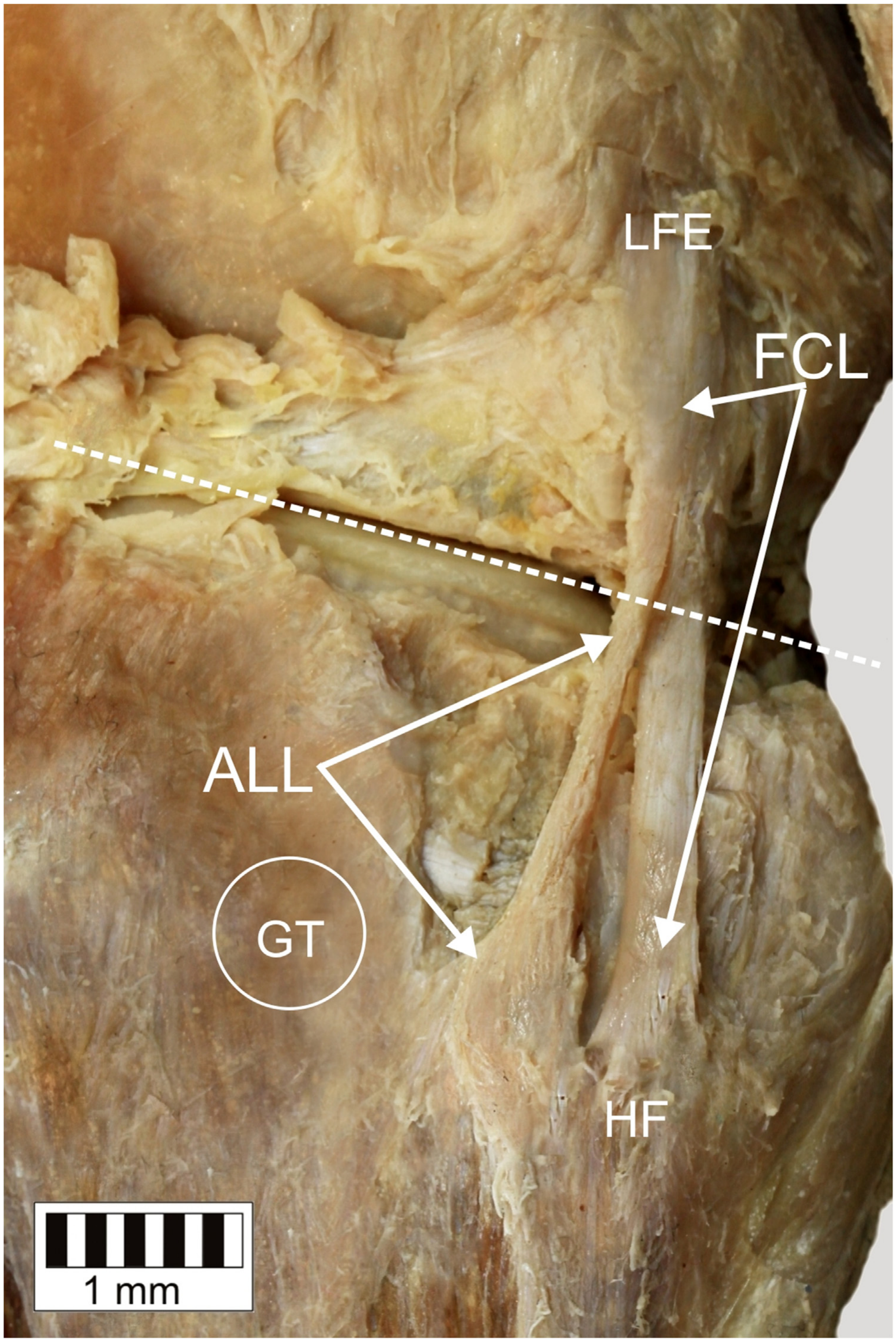

Fig. 5. Type IV of the anterolateral ligament (Complex). Lateral view of the left knee. *ALL* anterolateral ligament; *FCL* fibular collateral ligament; *GT* Gerdy's tubercle; *HF* head of the fibula; *LFE* lateral epicondyle of the femur. A white dotted line indicates a knee joint line.

inserted to the head of the fibula and the third band fused with the deep fascia of the leg. **Type II a** occurred on 14 knees (12.6%), and **Type II b** on one knee (0.9%). It is noteworthy that that we observed a double FCL (Type III) on nine knees (6.3%); interestingly, earlier publications do not report the presence of this type. There are benefits to having two ligaments: firstly, the forces acting on the ligament are evenly distributed and secondly, it is possible that one could be broken during injury, and functional potential will be retained without the need to reconstruct.

The study also attempts to distinguish Complex FCL-ALL from **bifurcated type** FCL (Fig. 7a, b). The ALL-FCL complex has been classified in both fetal (Toro-Ibarguen et al., 2017) and adult studies (Claes et al., 2013; Olewnik et al., 2018c); the present study also classifies the FCL-ALL complex in 8.1% of cases. As the FCL-ALL complex and Type IIa FCL frequently co-occur, knowledge about how to distinguish them from each other is of clear value. The FCL-ALL complex demonstrated a superficial band that arose from the main part of the FCL and inserted into the deep fascia of the leg; in their initial part of their shared course, the fibers forming the ALL band are only

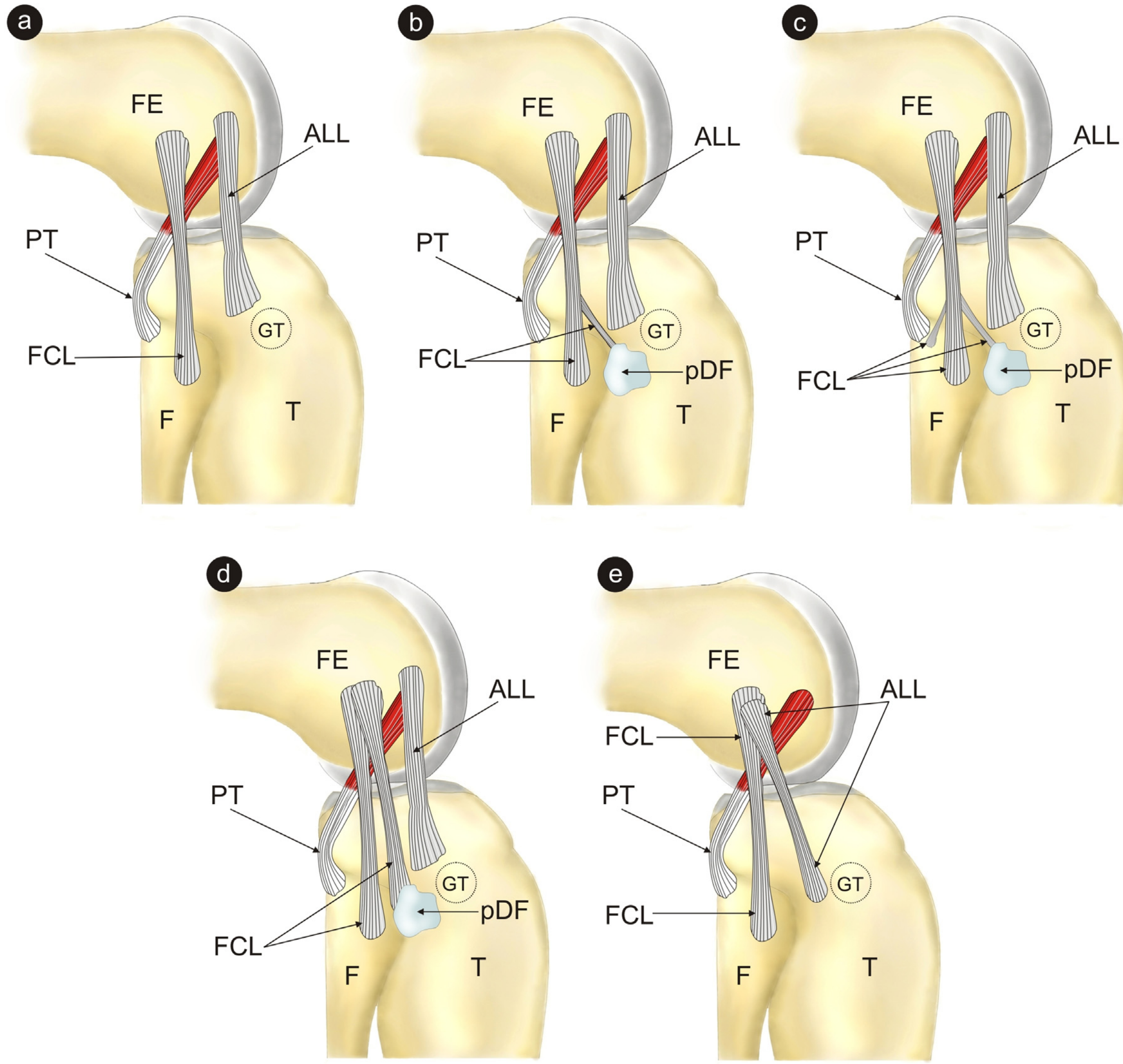

Fig. 6. Schematic drawing of the types of the fibular collateral ligament. Lateral view of the righ leg. (a) Type I (72.1%) (b) Type II a (12.6%) (c) Type II b (0.9%) (d) Type III (6.3%) (e) Type IV (8.1%). *FE* femur; *FCL* fibular collateral ligament; *ALL* anterolateral ligament; *PT* popliteus tendon; *GT* Gerdy's tubercle; *F* fibula *T* tibia; *pDF* part of the deep fascia of the leg.

faintly combined with those of the main FCL band and can be easily separated. For the **bifurcated type** FCL, the additional band arose from the FCL at the same altitude. Both, in this type and this distal attachment is located in the deep fascia of the leg. As these two types possess the same distal attachment and depart at the same height, and differ only in their division into a superficial band, it is easy to make a mistake in correct classification. Knowledge of the difference between Type IIa and FCL-ALL complex is extremely important both in terms of orthopedic and rehabilitation. To confirm our hypothesis, more advanced clinical trials should be carried out.

A proposed classification for the ALL highlights its variability relative to the FCL. Type I ALL is characterized by a single band and originates on the lateral femoral epicondyle, proximal and anterior to the FCL. Type II also has origins on the lateral femoral epicondyle, but emerges posterior and proximal to the FCL. Type III has a wide, fan-shaped origin on the lateral epicondyle and lateral-posterior joint capsule of the knee joint, posterior to the FCL. Type IV (double) has two bands attached to the lateral femoral epicondyle, anterior to the FCL (Olewnik et al., 2018a, 2018b, 2018c). Therefore, it is more important to consider the alignment of the ALL relative to the FCL, rather than vice versa, because the ALL is more superficial than the FCL.

The main role of the collateral ligaments, both tibial and fibular, consists of stabilizing the lower leg relative to the thigh during movement in the medial and lateral planes. More precisely, the FCL stabilizes the posterolateral corner of the knee. The fibular collateral ligament is also responsible for providing restraint against varus forces at all knee flexion angles, and is also resistant to external rotation near full extension. In addition, it resists external rotation as the knee extends (0°–30°). When the knee flexion is above 30°, the FCL loses its significance as a stabilising structure, as it is under less tension. Nearly 40° external tibial rotation is needed to tighten it when the knee is at 90° flexion. Hence the resistance of the FCL to external rotation is much lower when the knee joint is at a right angle (Sugita and Amis, 2001). The FCL also stabilizes internal tibial rotation, but its role is much less. Our present findings may act as a base for further studies examining the biomechanical aspects and functional differences between the FCL types identified herein. For example, some types can provide superior resistance to external rotation and more stability for the knee joint thanks to the additional bands.

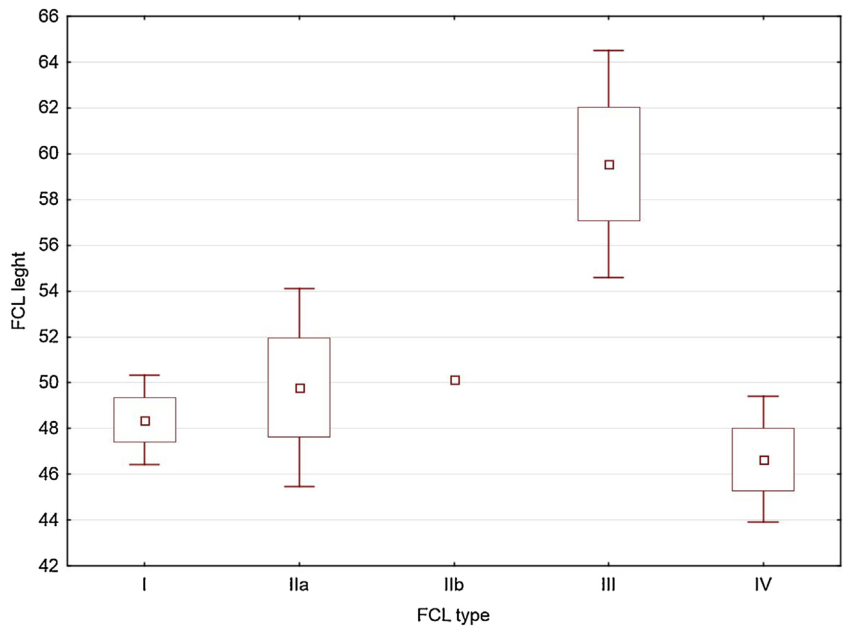

Fig. 7. Statistical diagram between anterolateral ligament length and types of the anterolateral ligament.

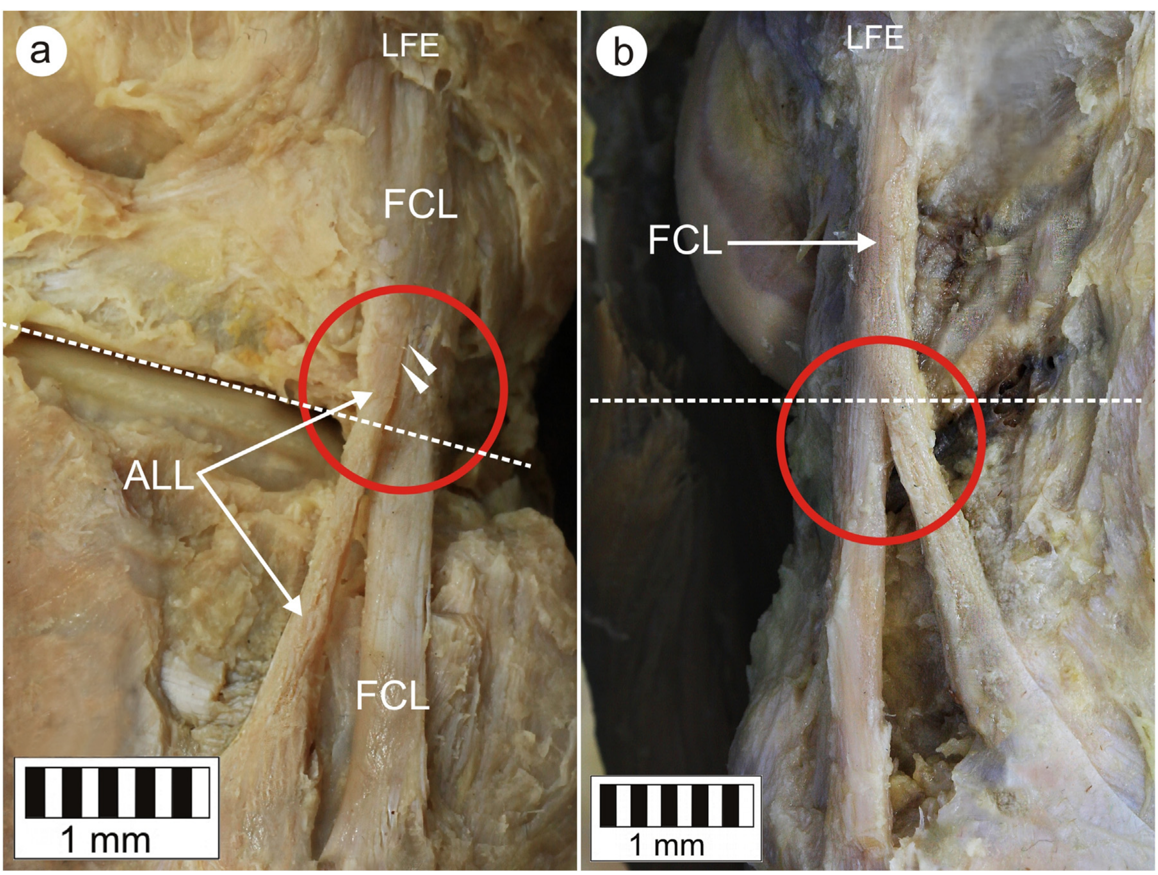

Fig. 8. Comparing Complex Type FCL-ALL with Type II a FCL. (a) Type Complex FCL – ALL. Lateral view of the left knee. *FCL* fibular collateral ligament; *ALL* anterolateral ligament. White arrowheads show a superficial band, which differentiates it from Type II FCL. (b) Type II a of the fibular collateral ligament. Lateral view of the right knee. *FCL* fibular collateral ligament.

Injuries to the lateral side of the knee are not so frequent as those to the medial side; nevertheless, they can be more disabling due to the greater forces placed on the knee during gait. Damage to both the FCL and ALL are often associated with injuries to the anterior and posterior cruciate ligament (Espregueira-Mendes and Vieira Da Silva, 2006; LaPrade et al., 2003; Moulton et al., 2015; Olewnik et al., 2018c). Correct diagnosis and treatment of FCL injuries are important because these injuries can cause functional limitations

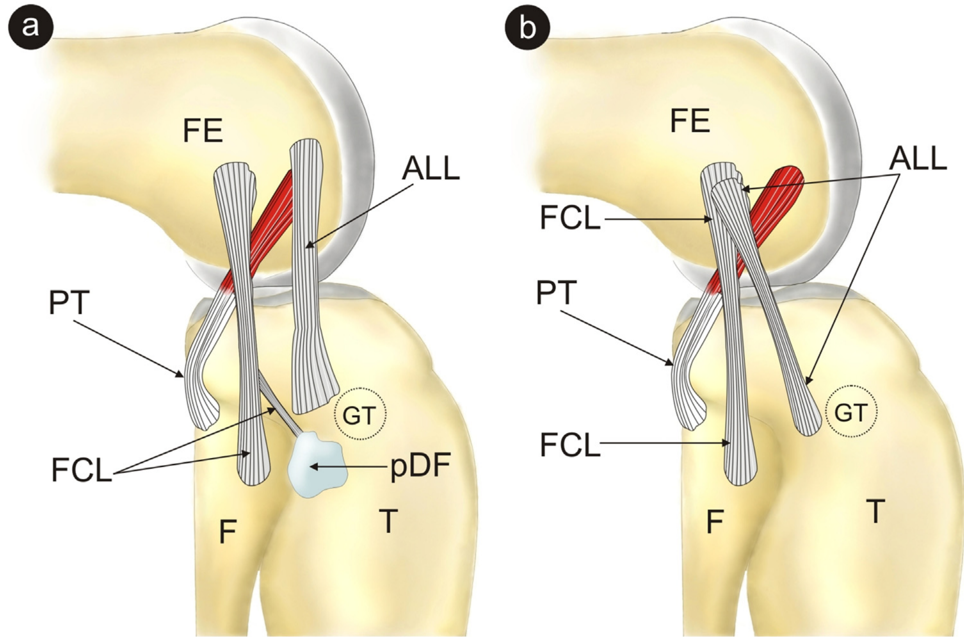

Fig. 9. Schematic drawing of comparison of the difference between type II a FCL and the FCL-ALL complex. Lateral view of the right knee. *FE* femur; *FCL* fibular collateral ligament; *ALL* anterolateral ligament; *PT* popliteus tendon; *GT* Gerdy's tubercle; *F* fibula *T* tibia; *pDF* part of the deep fascia of the leg.

and significantly increase the strain of both ACL and PCL grafts (LaPrade et al., 2004; Terry and LaPrade, 1996). Reconstruction of the FCL is performed only after full tear, and grafts are commonly harvested from the semitendinosus tendon (Moulton et al., 2015). Reconstruction of FCL may be difficult due to the morphological variability of this ligament. This study provides important information about the variability of the macroscopic morphology of the FCL and its morphological parameters. It sheds greater light on variants of the FCL and allows more appropriate treatment to be prepared for FCL injuries. What is more, an appropriate radiological examinations should be performed before planning surgical procedures. Patient rehabilitation depends on the degree of injuries, although patients most often return to physical activity within six months (1st and 2nd degree) and six to nine months after reconstruction (3rd degree).

Our study has some limitations. Its main weakness was the absence of a biomechanical and kinematics analysis of the FCL. In addition, the exact biomechanical function of each type of ligament needs to be determined. Another limitation is the lack of advanced radiological images, to determine whether or not it is possible to visualize the variation with ultrasound or MRI. Nonetheless, this study helps raise awareness of "what and where" to look for, and offers a uniform classification and terminology to act as a foundation for communication with surgeons.

5. Conclusion

The FCL is characterized by morphological variability, with additional bands occurring as bifurcation, trifurcation or double FCL. Fusion with ALL is also possible. Knowledge of these variations is essential when planning the correct reconstructive treatment after injuries of the lateral compartment of the knee joint.

Ethics approval and consent to participate

The protocol of the study was accepted by Bioethics Committee of Medical University of Lodz (resolution RNN/297/17/KE). The cadavers belong to the Department of Normal and Clinical Anatomy of the Medical University of Lodz.

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Authors' contribution

Łukasz Olewnik — project development, data collection and management, data analysis and manuscript writing. Bartosz Gonera — data collection, data analysis manuscript editing Konrad Kurtys — data collection, data analysis, manuscript editing. Michał Podgórski — data analysis, manuscript editing. Michał Polguj — data analysis, manuscript editing. Mirosław Topol — data analysis, manuscript editing. All authors have read and approved the manuscript.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.aanat.2018.10.009.

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