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SCIENTIFIC ARTICLE

Segond fracture: an MR evaluation of 146 patients with emphasis on the avulsed bone fragment and what attaches to it

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Abstract
Objective To re-evaluate the Segond fragment emphasizing those structures that attach to the fragment in patients with reported acute/subacute anterior cruciate ligament (ACL) injuries, and to clarify the nomenclature used to describe these structures.
Materials and methods A search of databases of knee MR examinations over 4.5 years with reported ACL tears yielded 19,726 studies. Using strict exclusion criteria, a total of 146 MR studies with acute/subacute ACL tears were re-assessed with respect to the Segond fragment's size, shape, orientation, location, displacement, attaching soft tissue structures, and associated osseous and/or soft tissue injuries.
Results Segond fractures were present in 1.25 % of reported acute/subacute ACL tears. The fragment measured 11.9 × 7.3 × 3.27 mm, being thin, ovoid, vertically oriented, situated anterolaterally along the proximal tibial epiphysis, posterior to Gerdy's tubercle and inferior to the lateral tibial plateau, and displaced up to 6 mm laterally. The attached structures were the meniscotibial component of the mid-third lateral capsular ligament (mt-MTLCL) in 58.9 %, both the mt-MTLCL and the posterior fibers of the ITB (pf-ITB) in 35.6 %, and the pf-ITB in 5.48 % of cases. In no case was there an additional attaching structure that did not meet criteria for the mt-MTLCL or the pf-ITB.
Conclusion The mt-MTLCL most commonly attaches to the Segond fragment, but the pf-ITB can also attach to this fragment. In no case was there an additional attaching structure that did not meet criteria for the mt-MTLCL or the pf-ITB.

Keywords Segond fracture · Meniscotibial component of the mid-third lateral capsular ligament · Posterior fibers of the iliotibial band · Anterior cruciate ligament tear · MRI

Introduction

Since its initial description in 1879 by Dr P. Segond [1]—its namesake—the Segond fracture has become accepted as a potential indicator of anterolateral rotatory instability (ALRI) of the knee and of the likelihood of severe ligamentous injury, most typically the anterior cruciate ligament (ACL) [2–8]. The resulting small avulsed bone fragment derived from the lateral tibial plateau is thought to be related to varus and internal rotational forces [1, 2, 6] that result in tension upon the posterior fibers of the iliotibial band (pf-ITB) and what was originally considered to be a capsular ligament along the lateral aspect of the knee [9].

Subsequently, in part related to the complex anatomy of the static and dynamic stabilizers along the lateral aspect of the knee, the nomenclature applied to those structures attached to and possibly responsible for the Segond fracture fragment has been inconsistent, with reference to the anterior oblique band of the fibular collateral ligament (AOB-FCL) [2, 10], the capsulo-osseous layer of the iliotibial band (ITB) [11], the short external lateral ligament [12], and, more recently, the anterolateral ligament (ALL) of the knee [11, 13–18]. In some earlier reports, reference to the lateral capsular ligament (LCL) [5, 9, 19, 20] has been absent entirely. In our comprehensive review of the terminology pertaining to these attaching structures (Tables 1, 2 and 3), we found most anatomical and

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Table 1 Literature review of anatomical studies of the mid-third lateral capsular ligament (*MTLCL*) and other structures attaching to the Segond fracture fragment

Reference	Study design	Structure(s) attaching to the Segond fracture fragment	MTLCL nomenclature	MTLCL: proximal attachment	MTLCL: distal attachment
Lateral capsular ligament					
Seebacher et al. [26]	Cadavers	LCL	LCL is the middle portion of the joint capsule and is composed of two laminae	–	Defined anteriorly by the ITB and posteriorly by the FCL
Patella et al. [27]	Cadavers, isometric studies	LCL	LCL is composed of two bundles: superficial and deep	Proximal insertion 1.5 cm anterior and superior (superficial bundle) or anterior and inferior (deep bundle) along the inferior portion of the linea aspera and under the FCL at the level of the lateral epicondyle	1.5 cm posterior to (superficial bundle) or on Gerdy's tubercle (deep bundle) in the lateral plateau of the articular edge
Capsulo-osseous layer of the ITB					
Terry et al. [11]	Cadavers	Capsulo-osseous layer of the ITB (thought to be equivalent to the ALL of the knee)		Lateral investing fascia of the gastrocnemius tendon and medial investing fascia of the short head of the biceps femoris muscle	Lateral tibial tuberosity just posterior and proximal to Gerdy's tubercle
			MTLCL (distinct from the ALL)	Anterior and proximal to the lateral femoral epicondyle	In the tibia distal to the articular cartilage and just posterior to Gerdy's tubercle
Vieira et al. [14]	Cadavers	Capsulo-osseous layer of the ITB (acts as a true ALL)	Capsulo-osseous layer of the ITB	Supra-epicondylar region of femur bordering the lateral edge of the lateral epicondyle	Lateral to Gerdy's tubercle
Anterolateral ligament					
Vincent et al. [17]	Cadavers, histology	ALL	ALL	Lateral femoral condyle, closely associated with and blending with the fibers of the popliteus tendon (versus Claes et al.)	Proximal anterolateral tibia 5 mm from the articular cartilage, posterior to a line drawn vertically from the posterior border of Gerdy's tubercle to the joint line
Claes et al. [28]	Cadavers	ALL	ALL is a distinct ligamentous structure	Proximal and posterior to the popliteus tendon insertion at the lateral femoral epicondyle; distinct from the popliteus tendon (versus Vincent et al.). Most posterior fibers of the proximal ALL blend with the proximal part of the FCL in the majority of the dissected knees	*Meniscal attachment:* strong connection between the ALL and the periphery of the middle third of the body of the lateral meniscus with the lateral inferior geniculate artery and vein situated in between the lateral meniscal rim and the ALL at the level of the joint line. *Distal attachment:* proximal tibia, clearly situated posterior to Gerdy's tubercle, with no connecting fibers to the ITB
Helito et al. [29]	Cadavers, histology	ALL	ALL is a capsular thickening composed of dense connective tissue	Anterior to the origin of the FCL; proximal to the FCL in 2 cases, distal to the FCL in 3 cases, and at the same level as the FCL in 1 case	*Meniscal attachment:* peripheral portion of the transition between the anterior cornu and the body. *Distal attachment:* between Gerdy's tubercle and the fibular head
Helito et al. [24]	Cadavers, histology	ALL	ALL is the structure originally described by Segond	Anterior and distal to the attachment of the FCL; halfway between the FCL and the popliteus tendon, but closer to the FCL (contrary to studies by Vincent et al. [17])	Between Gerdy's tubercle and the fibular head, but closer to the latter than the former (contrary to studies by Vincent et al. [17])

Table 1 (continued)

Reference	Study design	Structure(s) attaching to the Segond fracture fragment	MTLCL nomenclature	MTLCL: proximal attachment	MTLCL: distal attachment
Stijak et al. [30]	Cadavers	ALL	ALL is not always morphologically different from the joint capsule. AOB-FCL and capsulo-osseous layer of the ITB can functionally be equated to the ALL	Lateral epicondyle of the femur, clearly differentiated from the FCL posteriorly	Midway between Gerdy's tubercle and the head of the fibula with the fibers being a continuation of the ITB. Some fibers of the ITB with the same insertions and direction as the ALL were found, but are located at a much more superficial layer than the ALL
Dodds et al. [31]	Cadavers, biomechanical studies	ALL	ALL is separate from the capsule of the knee	Proximal and slightly posterior to both the lateral epicondyle and the femoral attachment of the FCL; distinct from the FCL	Distal to the anterolateral rim of the plateau midway between the head of the fibula and Gerdy's tubercle
Lutz et al. [25]	Cadavers, biomechanical studies	ALL	ALL is the anterior part of a "triangular anterolateral capsular complex," reviving the notion of the MTLCL	Highly variable femoral insertion with convergence of its fibers with those of the FCL on the lateral epicondyle	Below the joint space with the center of insertion located posterior to the center of the subcondylar tubercle and anterior to the top of the fibular head
Daggett et al. [23]	Surgical dissection	ALL	ALL	Organized, parallel fibers originating in close proximity to the lateral epicondyle overlapping the FCL at this portion	In the tibia between Gerdy's tubercle and the fibular head

LCL lateral capsular ligament, *ITB* iliotibial band, *ALL* anterolateral ligament, *AOB-FCL* anterior oblique band of the fibular collateral ligament, *FCL* fibular collateral ligament

imaging descriptions of the ALL to bear a striking resemblance to the original description of the LCL [9]. Prior investigations have acknowledged the ALL as Paul Segond's original description of a "pearly, resistant, fibrous band at the anterolateral aspect of the knee" [21–24], previously called the mid-third lateral capsular ligament (MTLCL) by Hughston et al. [5, 25]—we agree with these investigations. Contrary to some studies that still consider the ALL to be entirely distinct from the LCL [11], we believe the anterolateral ligament is the latest attempt at renaming the MTLCL.

In this investigation, we provide the results of a retrospective analysis of the Segond fracture fragment based on magnetic resonance (MR) examinations in the largest number of reported cases of the Segond injury, and clarify the nomenclature used to describe the structure(s) that attach to this bone fragment.

Materials and methods

This study complied with HIPAA guidelines and Institutional Review Board approval, along with an exemption status for informed consent.

Patients

The central databases of two affiliated hospitals at our institution were queried for MR examinations meeting the following criteria: the examination was performed between 1 October 2010 and 31 May 2015, and a report of this examination contained the term ACL tear. A total of 19,726 studies were identified. This number was then refined by excluding those examinations whose reports contained the term old, chronic, or remote ACL tear; examinations where the elapsed time from injury to imaging exceeded 6 months [41]; previous or recurrent ACL tear; ACL reconstruction and graft tear; and/or equivocal or indeterminate findings of an ACL tear, yielding 11,636 studies with reports indicating the presence of an acute/subacute ACL tear. This cohort was further refined by excluding cases in which the report:

1. Did not contain the finding of a Segond fracture (an avulsion fracture along the lateral aspect of the lateral tibial plateau) and/or
2. Indicated the presence of a soft tissue Segond injury

or in which initial study analysis showed:

1. Imaging evidence of a non-acute/subacute ACL tear (lack of bone contusions manifest as decreased signal on T1-weighted images with corresponding increased signal on T2-weighted images and/or increased intraligamentous

Table 2 Literature review of imaging studies of the MTLCL and other structures attaching to the Segond fracture fragment

Reference	Study design	Structure(s) attaching to the Segond fracture fragment	MTLCL nomenclature	MTLCL: proximal attachment	MTLCL: distal attachment
AOB-FCL					
Irvine et al. [10]	CT, radiographs	AOB-FCL	–	–	–
LCL					
Dietz et al. [3]	Radiographs	Fused LCL laminae	LCL	–	–
Hess et al. [32]	Radiographs	LCL	LCL or the medial part of the lateral capsule	–	–
MTLCL					
Laprade et al. [33]	MRI	MTLCL or specifically, the mt-MTLCL	MTLCL is a thickening of the lateral capsule of the knee	Region of the lateral epicondyle	*Meniscal attachment:* capsular connection. *Distal attachment:* lateral articular cartilage margin between the posterior border of Gerdy's tubercle and the anterior edge of the popliteal hiatus (the antero-inferior popliteomeniscal fascicle)
Claes et al. [16]	MRI	ALL	ALL	Lateral femoral epicondyle, with some ALL fibers blending into the proximal part of the FCL	Proximal aspect of the anterolateral tibia well posterior to Gerdy's tubercle, thus forming a capsulo-ligamentous insertional fold
Taneja et al. [34]	MRI	ALL	ALL thought to be the same as the short lateral ligament, MTLCL, capsulo-osseous layer of the ITB, and the LCL	Origin near the FCL; specific point of the femoral attachment and the presence of a meniscal insertion site were not clearly identified	Located in the tibia, approximately 5.7 mm from the cartilaginous surface of the lateral plateau
Porrino et al. [18]	MRI	ITB, ALL	ALL	Deep to the ITB and anterior to the FCL; inseparable from the adjacent capsule	More distinct meniscotibial component that blends into the proximal tibia, below the level of the tibial plateau and midway between the Gerdy's tubercle and the fibular head; inseparable from the posterior ITB
ALL					
Helito et al. [35, 36]	MRI	ALL	ALL	Close to the anterior limit of the origin of the FCL, with an inferior path that was practically vertical and superficial to the popliteus tendon, with bifurcation less than 0.5 cm from the corpus of the lateral meniscus	*Meniscal attachment:* antero-inferior oblique path from the bifurcation toward the anterior corpus–cornu transition of the meniscus. *Distal attachment:* posterior to Gerdy's tubercle in proximity to the ITB

mt-MTLCL meniscotibial portion of the MTLCL

Table 3 Literature review of combined anatomical and imaging studies of the MTLCL and other structures attaching to the Segond fracture fragment

Reference	Study design	Structure(s) attaching to the Segond fracture fragment	MTLCL nomenclature	MTLCL: proximal attachment	MTLCL: distal attachment
LCL					
Johnson [9]	Cadavers, radiographs, dynamic studies	LCL "complex" with vertical and horizontal components	LCL	Extension of the expansions to the FCL, with reflection into the lateral head of the gastrocnemius	Strong ligamentous structure with a reflection into the biceps femoris tendon. Attachment site at Gerdy's tubercle is distinct from the attachment site of the ITB
Campos et al. [2]	Cadavers, MRI, radiographs	ITB, LCL, AOB-FCL	LCL	–	–
Dombrowski et al. [37]	Cadavers, MRI, histology	LCL	LCL	Anterior to the origin of the FCL at the lateral femur	Proximal lateral tibia in the central third, posterior to Gerdy's tubercle, on average 6 mm caudal to the subchondral plate
ALL					
Claes et al. [15]	Cadavers, radiographs	ALL	ALL	Proximal and posterior to the popliteus tendon insertion at the lateral femoral epicondyle; distinct from the popliteus tendon (versus Vincent et al.)	Proximal tibia, posterior to Gerdy's tubercle, with no connecting fibers to the ITB
Caterine et al. [38]	Cadavers, MRI, histology	ALL	ALL	Lateral femoral epicondyle anterior and distal to the FCL	In the lateral tibia midway between Gerdy's tubercle and the fibular head
De Maeseneer et al. [13]	Cadavers, MRI	ITB, ALL	ALL	Anterosuperior margin of the FCL	Area on the tibia below the joint line and anterior to the fibular head, superior to the extension of the anterior arm of the biceps femoris to the tibia
Kennedy et al. [39]	Cadavers, radiographs	ALL	ALL	Posterior and proximal to the FCL	Midway between the center of Gerdy's tubercle and the anterior margin of the fibular head
Van Dyck et al. [22]	Arthroscopy, MRI	ALL	ALL	Lateral femoral epicondyle	Anterolateral tibia
Coquart et al. [21]	Cadavers, MRI	ALL	ALL	Lateral femoral epicondyle, anterior or anterodistal to the femoral origin of FCL and not always clearly distinguishable from it	Lateral tibial plateau between Gerdy's tubercle and the fibular head with the fibers close to the posterior fibers of the ITB; no connecting fibers with the popliteus tendon
Macchi et al. [40]	Cadavers, MRI	ALL	ALL	Lateral femoral epicondyle	Middle third (46 %) or inferior third (14 %) of the lateral meniscus; distally in the lateral aspect of the proximal tibia

signal with or without ACL fiber disruption [41]) in those cases without an available date of injury
2. A soft tissue Segond injury (high signal intensity, disruption with proximal retraction, or thickening and redundancy of the normal low signal conjoined tibial attachment of the anterior arm of the short head of the biceps femoris muscle and the mt-MTLCL [33]) without an osseous Segond fracture
3. Equivocal findings for a Segond fragment on MR imaging (MRI) and without an accompanying conventional radiograph
4. Suboptimal or incomplete examinations (e.g., images from <0.3T strength magnets [we excluded studies performed in <0.3T strength magnets because although recent literature has deemed 1.0 to 1.5T strength magnets adequate for assessing the lateral ligamentous structures of the knee [21, 42], information regarding the adequacy of magnets with strengths less than 1 T is lacking], significant MR artifact limiting evaluation of the lateral supporting structures, or studies without imaging in the coronal plane)

A total of 146 studies in 146 patients were ultimately included in our study cohort (Fig. 1)—sixty-five cases of which had corresponding radiographs.

Image analysis

MR examinations were performed on scanners ranging from 1 to 3T strength magnets. Most of these examinations consisted of the following sequences: T1-weighted (400–700/9.1–29 ms), proton density (PD)-weighted with and without fat suppression (1,985–5,600/10–53.4 ms), and T2-weighted with and without fat suppression (1,983–6,300/69.06–100 ms) in various (i.e., axial, sagittal, and coronal) planes.

Two fellowship-trained musculoskeletal radiologists, with 1 (DF) and 3 (ES) years of experience, retrospectively

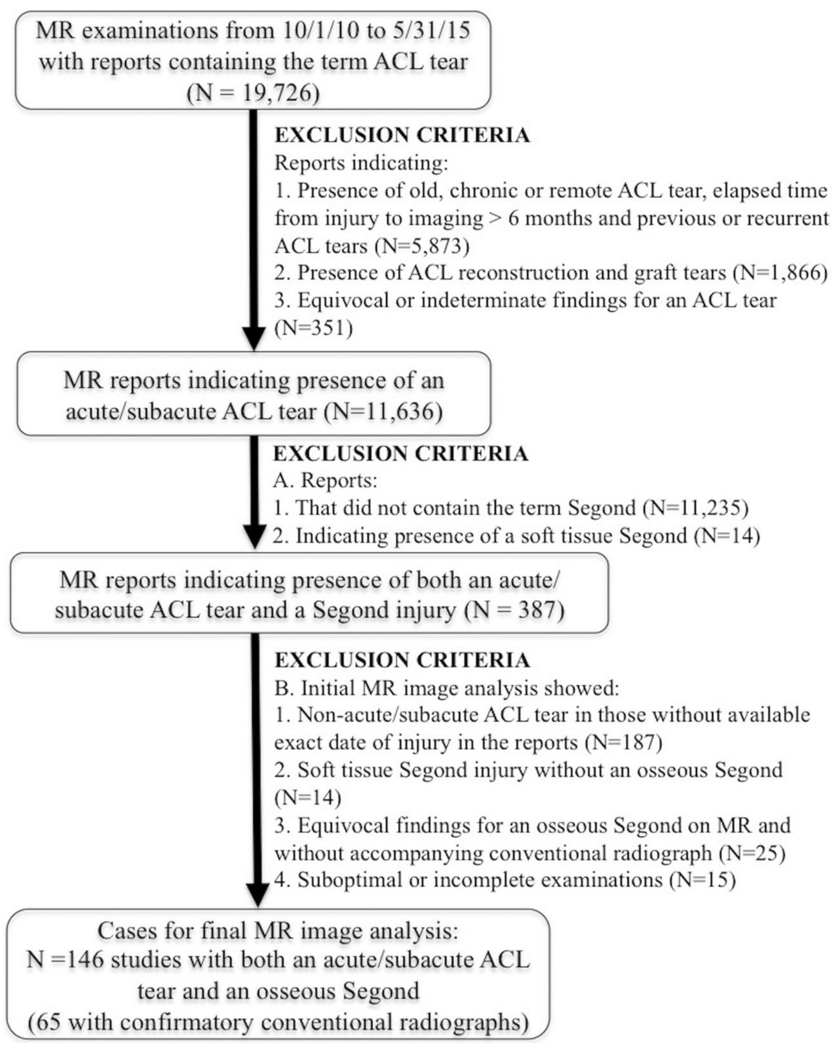

Fig. 1 Flow diagram showing the case selection process with exclusion criteria

assessed all MR examinations by consensus. Patient demographics and time elapsed between the injury and imaging study were also documented. Segond fracture fragments were evaluated for size (mm), shape, orientation, location, degree of displacement (mm), soft tissue attachments (i.e., to ligament(s) or tendon(s) and to the lateral meniscus [43]), and associated osseous and/or soft tissue injuries (i.e., meniscus, tendon, ligament, and muscle). When available, accompanying knee radiographs, which consisted of anteroposterior, oblique, lateral, and/or sunrise views, were used to further confirm the presence of a Segond fracture.

Finally, the lateral knee structures shown in Fig. 2 and Table 4 were considered to have been visualized as attaching to the Segond fracture fragment if they met the MRI criteria described. The inclusion of the structures in this list was based on previous studies that investigated and described the structures most frequently attaching to the Segond fracture fragment. Because we noted that the descriptions of the ALL and MTLCL were remarkably similar in our review of the literature [9, 13, 15–19, 24, 28, 30, 31, 33–39, 44–46], the ALL was identified by exclusion if it could not be classified as the ITB, MTLCL, FCL, or tendinous anterior arm of the SHBF.

Descriptive statistics for demographic data were calculated for the study cohort. Measures of central tendency were obtained for time elapsed since injury and fragment size. The study cohort was also divided into two groups based on magnetic strength (i.e., studies performed at <1.5 T versus studies performed at ≥1.5 T), and on the presence or absence of accompanying radiographs. Chi-squared test was used to compare these groups based on structures attaching to the Segond fragment. A *P* value less than 0.05 was considered statistically significant.

Results

Most MR examinations in our evaluation utilized a 1.5T strength magnet (67 out of 146; 45.9 %; Table 5). At least one fat-suppressed PD-weighted image in both axial and coronal planes was available for all studies. Slice thickness in 145 out of 146 (99.3 %) cases was 4 mm, whereas 1 out of 146 (0.68 %) cases had a slice thickness of 3.5 mm.

Segond fractures were described and were present in 1.25 % (*N* = 146) of those cases with reports that indicated the presence of an acute/subacute ACL tear (*N* = 11,636) and 0.74 % of all cases with reports that indicated the presence of an ACL tear (*N* = 19,726) in our population. Time elapsed from injury to imaging study ranged from 0 to 111 days, with a mean of 13.5 days (standard deviation of 18.9 days) and a median of 7 days in those studies with known dates of injuries (103 out of 146; 70.5 %). Of these 146 cases, 65 (44.5 %) had accompanying conventional radiographs and all confirmed the presence of the Segond fragment. The resulting fracture fragments were typically thin, ovoid, and vertically oriented, and measured 3.3–21 mm in anteroposterior (mean 11.9 mm, SD 3.55, median 12 mm, interquartile range [IQR] 4.15), 2–21 mm in craniocaudal (mean 7.3 mm, SD 2.76, median 7 mm, IQR 3.5), and 0.9–9 mm in transverse (mean 3.27 mm, SD 1.39, median 3 mm, IQR 2) dimensions. These fractures were usually situated anterolaterally or laterally along the proximal tibial epiphysis, up to 7 mm posterior to Gerdy's tubercle and 5.5 mm inferior to the articular surface of the lateral tibial plateau, and they were either minimally displaced or displaced up to 6 mm laterally. There were subcentimeter areas of reactive marrow edema at the tibial donor sites in 113 out of 146 cases (77.4 %). In all 146 cases, a ligamentous structure located along the lateral aspect of the knee attaching to and connecting the lateral femoral

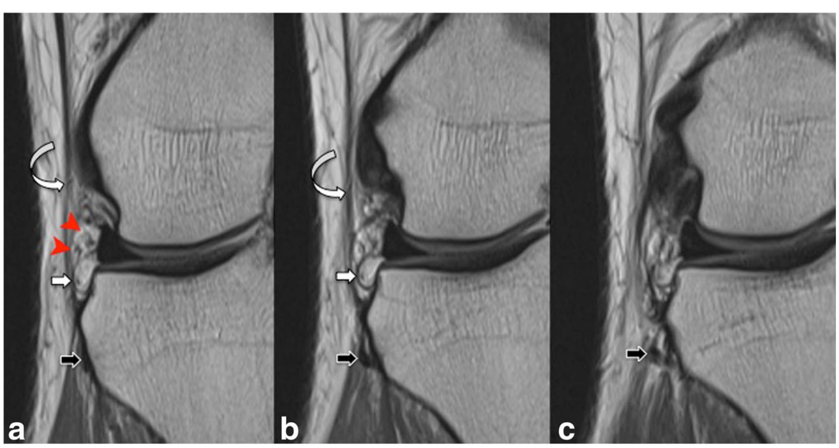

Fig. 2 **a–c** Sequential (**a** being the anterior-most coronal image) coronal proton density (PD)-weighted non-fat-suppressed images (TR 4,140 ms/TE 38 ms) with a slice thickness of 4 mm obtained on a 1.5 T magnet demonstrate the normal MR appearance of the posterior fibers of the iliotibial band (pf-ITB; *white curved arrow*), meniscotibial component of the mid-third lateral capsular ligament (mt-MTLCL; *white arrow*) located inferolateral to lateral geniculate vessels (*red arrowheads*), and the tendon of the anterior arm of the short head of the biceps femoris muscle (SHBF; *black arrow*)

Table 4 MRI criteria used in determining structures attaching to the Segond fracture fragment

Structure	MRI criteria
pf-ITB [2, 33]	Broad band of low-signal intensity with distal attachments to the lateral intermuscular septum and Gerdy's tubercle in the anterolateral tibial rim
mt-MTLCL [5, 19, 33, 43]	Low-signal intensity structure with lateral epicondylar, meniscal, and tibial attachments demonstrating a slightly antero-oblique course as it passes distally over the lateral inferior geniculate vessels to its meniscotibial attachment inferior to the lateral articular cartilage margin and along the posterior border of Gerdy's tubercle
AOB-FCL [2, 19, 33]	Low-signal intensity structure arising from the FCL in an oblique fashion, located posterior to the ITB and which may blend imperceptibly with the posterior fibers of the ITB, prior to their combined distal attachment to the lateral midportion of the tibia
Tendinous anterior arm of the short head of the biceps femoris (SHBF) muscle [33]	Thin low-signal intensity structure coursing from the fibula in an anteromedial direction toward its attachment to the posterolateral tibial tuberosity (just posterior to Gerdy's tubercle) and inferior to the mt-MTLCL attachment

pf-ITB posterior fibers of the iliotibial band, *AOB-FCL* anterior oblique band of the fibular collateral ligament, *SHBF* short head of the biceps femoris

epicondyle, the body of the lateral meniscus, and the proximolateral tibial rim just posterior to Gerdy's tubercle was visualized, fulfilling the previously reported characteristics of the MTLCL. The structures that attached to the Segond fragment were the mt-MTLCL in 58.9 % (86 out of 146; Fig. 3), both the mt-MTLCL and the pf-ITB in 35.6 % (52 out of 146; Fig. 4), and the pf-ITB in 5.48 % (8 out of 146) of cases. There was no significant difference in these results whether the examination was performed on a low- or high-field strength magnet or whether accompanying radiographs were available (Tables 6 and 7). In none of the 146 cases was there an additional structure attaching to the Segond fracture fragment that did not meet our criteria for the mt-MTLCL or pf-ITB. We did not identify any cases in which the AOB-FCL or the tendon of the anterior arm of the SHBF attached to the fracture fragment (Figs. 5 and 6).

The MTLCL was visualized in all cases, best seen in the coronal plane. Its femoral attachment was readily delineated from the adjacent proximal portions of the FCL and popliteus tendon. Alternatively, as noted in previous reports, the appearance of its meniscal attachment was variable [43], with the most commonly visualized appearance consisting of femoral and tibial attachments both arising from the meniscal component, creating a figure-of-3 configuration (69 out of 146; 47.3 %; Fig. 3).

There were several additional findings associated with the Segond fracture (Table 8): bone contusions that most frequently occurred at the posterior aspect of the lateral tibial plateau

Table 5 Summary of magnetic strengths (in Tesla) and soft tissue structures attaching to the Segond fragment

Magnetic strength (T)	mt-MTLCL only	mt-MTLCL and pf-ITB	pf-ITB only
1	16	9	2
1.16	1	0	0
1.5	67	43	6
3	2	0	0

Fig. 3 A 24-year-old man 3 days after a twisting injury while playing soccer. Coronal proton density (PD)-weighted fat-suppressed image (TR 3,440 ms/TE 26 ms) demonstrates the figure-of-3 appearance of the MTLCL with intact meniscofemoral (*white dashed arrow*) and meniscotibial (*white arrow*) components, the latter attaching to a minimally displaced Segond fracture fragment (*blue arrow*). Additional findings include a minimal bone contusion at the Segond donor site and a mild sprain of the medial collateral ligament (*black arrows*) with subtle edema in the medial femoral condyle

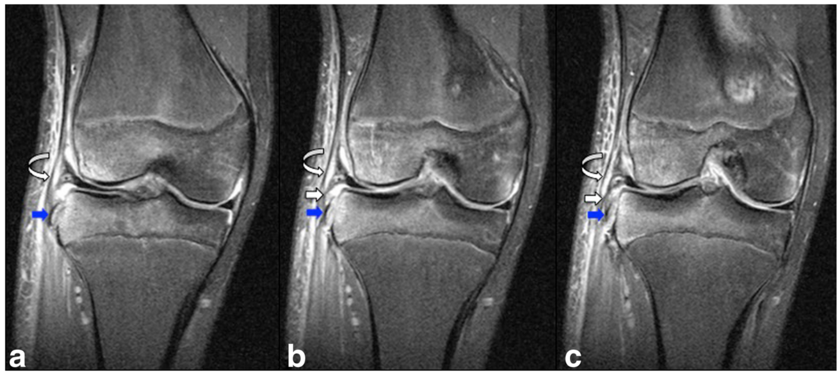

Fig. 4 A 15-year-old man with posterior and lateral knee pain following a basketball injury. Sequential coronal PD-weighted fat-suppressed images (TR 3,550 ms/TE 36 ms) demonstrate both (**a**) the pf-ITB (*white curved arrow*) and (**b** and **c**) more posteriorly, the mt-MTLCL (*white arrow*) attaching to the Segond fracture fragment (*blue arrow*)

and midportion of the lateral femoral condyle, meniscal tears, posterolateral corner injury (FCL, arcuate ligament complex, popliteofibular ligament, popliteus tendon, or biceps femoris tendon, or combinations of these), medial collateral ligament (MCL) injury, and posterior cruciate ligament (PCL) injury. Muscle injuries were also identified, most of which consisted of grade I strains (hyperintense signal on fat-suppressed images without imaging evidence of architectural distortion or structural changes in the muscle [47]), with the soleus and popliteus being the most frequently involved muscles (61 out of 146; 41.8 % and 51 out of 146; 34.9 % respectively).

Discussion

Our major stimulus to initiating a retrospective analysis of MR examinations in a large number of cases of Segond fracture was the excitement and enthusiasm that followed the initial reports of an apparently "new" ligament of the knee, the ALL [48–53]. Upon review of our imaging data and analysis of many earlier reports, it is clear to us that the ALL of the knee is not new at all, but has previously been described using inconsistent terminology that includes not only the MTLCL, but also the capsulo-osseous layer of the ITB [11], AOB-FCL [13], and short external lateral ligament [12]. Although it was only recently that studies have begun to focus uniquely on the anterolateral ligament's anatomy and biomechanics through remarkable gross and histological dissections, MR analyses, and robotic studies [13, 15, 17, 24, 28, 31, 35, 39], the descriptions of the ligament in these studies exhibit exceptionally similar features to what has already previously been termed the LCL, specifically its middle third. Although there is disagreement regarding its femoral attachment [16, 27, 28, 30, 32, 38, 39, 46], descriptions of the ligament's possible role in preventing both increased axial plane anterior tibial translation and internal tibial rotation [54], and its meniscal and tibial attachments have mostly remained consistent, with the latter attachment localized at the anterolateral margin proximal and posterior to Gerdy's tubercle or between Gerdy's tubercle and the fibular head [11, 15–18, 21, 23, 24, 27–31, 33, 35, 37–39, 44]. This definition is largely similar to Hughston et al.'s original description of the MTLCL, which "attaches proximally to the lateral epicondyle of the femur extending posteriorly as far as the FCL, and distally at the tibial joint margin, often misinterpreted as mere areolar tissue, but is technically strong and is a major lateral static support of the knee at around 30° of flexion" [5]. Contrary to some authors, who have emphasized the ligament as being an extra-capsular structure [28, 31] with a distinct role in the Segond fragment [15], others have concluded that it is a component of the joint capsule [24, 30, 32, 33] and is actually a revival of [25] or a re-introduction to the LCL [21, 38, 55]. In fact, a recent article by Porrino et al. gives credit to Hughston and colleagues for one of the original and most comprehensive studies of the ALL, and these authors also propose the use of the term, (mid-third) lateral capsular ligament [18]—we enthusiastically second that motion. In not one of our 146 cases of a Segond fracture fragment could we find a ligament attaching to the fragment that did not correspond to the

Table 6 Summary of soft tissue structures attaching to the Segond fragment classified into two groups: low (<1.5 T) versus high (≥1.5 T) magnetic field strength

	mt-MTLCL only	mt-MTLCL and pf-ITB	pf-ITB only
<1.5 T	17	9	2
≥1.5 T	69	43	6

$p = 0.8557$. This result is not significant at $p < 0.05$

Table 7 Summary of soft tissue structures attaching to the Segond fragment classified into two groups: those without conventional radiographs versus those with conventional radiographs

	mt-MTLCL only	mt-MTLCL and pf-ITB	pf-ITB only
Without conventional radiographs	48	28	5
With conventional radiographs	38	24	3

$p = 0.8960$. This result is not significant at $p < 0.05$

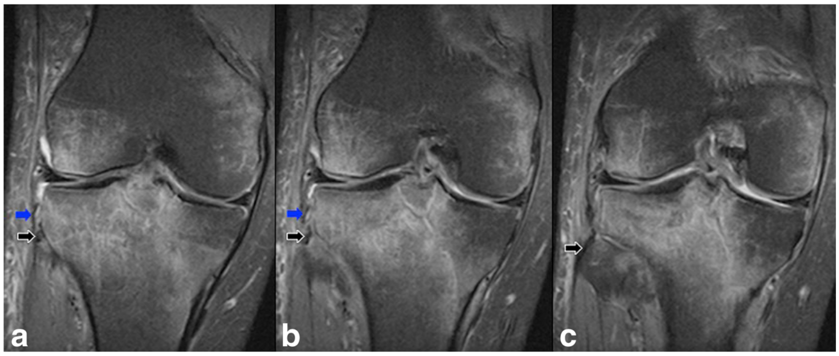

Fig. 5 A 27-year-old man 10 days after being struck by a truck. Coronal PD-weighted fat-suppressed images (TR 2,500 ms/TE 30 ms) demonstrate (**a** and **b**) an intact tendon of the anterior arm of the SHBF (*black arrow*) located inferior to the Segond fracture fragment (*blue arrow*); the posterior-most coronal image (**c**) demonstrates its insertion into the styloid process of the fibula (*black arrow*). Other findings include a fracture of the intercondylar eminence with adjacent extensive bone marrow edema and bone contusions in both femoral condyles

well-established MRI features of the mt-MTLCL or the pf-ITB [2, 5, 19, 33]. Furthermore, we could not find a single anatomical or imaging investigation of the ALL or the MTLCL in the existing literature that studied both, or provided gross distinguishing characteristics between the two.

In our analysis, the Segond fracture fragment measured 11.9 x 7.3 x 3.27 mm (mean anteroposterior, craniocaudal, and transverse dimensions), and was thin and ovoid, vertically oriented, and anterolaterally or laterally located along the lateral tibial plateau, but posterior to Gerdy's tubercle. The mt-MTLCL most frequently attached to the Segond fracture fragment (86 out of 146; 58.9 %). The pf-ITB also attached to this bony fragment, typically in conjunction with the mt-MTLCL (35.6 %; 52 out of 146), rather than as a solitary attachment (5.48 %; 8 out of 146). We observed no cases in which the AOB-FCL or the tendon of the anterior arm of the SHBF attached to the Segond fracture fragment. The AOB-FCL most commonly inserted close to and, at times, appeared to blend with the pf-ITB instead of directly attaching to the fracture fragment, whereas the tendinous arm of the SHBF usually inserted postero-inferior to the Segond donor site.

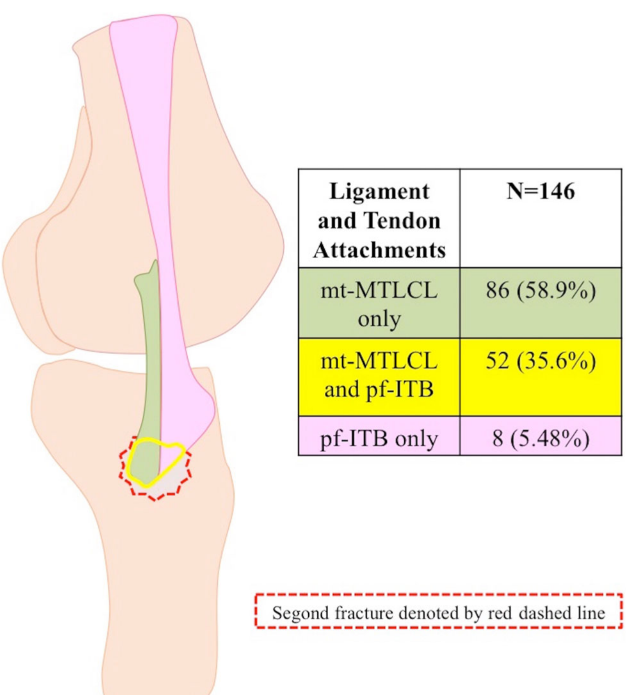

Fig. 6 Schematic diagram showing the ligament and tendon attachments of the Segond fracture fragment

Table 8 Summary of other findings associated with the Segond fracture fragment

Associated injuries	Number (%)
Osseous injuries	
Segond fractures	146
Bone contusions involving both the posterior aspect of the lateral tibial plateau and the middle aspect of the lateral femoral condyle	141 (96.6)
Soft tissue injuries	
Both medial and lateral menisci	42 (28.8)
Medial meniscus only	26 (17.8)
Lateral meniscus only	24 (16.4)
Posterolateral corner injury	
FCL	28 (19.2)
Arcuate ligament complex	35 (24.0)
Popliteofibular ligament	41 (28.1)
Popliteus tendon	32 (21.9)
Biceps femoris	32 (21.9)
MCL	71 (48.6)
PCL	16 (11.0)
Muscle injuries	
Soleus only	61 (41.8)
Popliteus only	51 (34.9)
Both soleus and popliteus	35 (24.0)
Lateral head of the gastrocnemius	9 (6.2)
Short head of the biceps femoris	5 (3.4)
Vastus lateralis	4 (2.7)
Tibialis anterior	4 (2.7)
Vastus medialis	3 (2.1)
Extensor digitorum longus	2 (1.4)
Peroneus longus	2 (1.4)
Medial head of the gastrocnemius	1 (0.68)

MCL medial collateral ligament, *PCL* posterior cruciate ligament

The Segond fracture is a cortical avulsion fracture of the lateral tibial plateau thought to be related to internal rotation and varus stress [2] resulting in tension upon the mt-MTLCL and pf-ITB. The resulting bony fragment can be difficult to detect on MRI, but it is often apparent on an anteroposterior radiograph of the knee [2, 3, 7, 8, 32], as was the case in all 65 of our cases in which corresponding radiographs were available. Although it is a seemingly innocuous-appearing lesion, it may herald the presence of a significant soft tissue injury to the ACL [2–8], meniscus [17], posterolateral corner, MCL, or PCL [7]. The presence of the fragment in ACL injuries has long been considered a possible sign of rotary instability [2]; however, recent studies have shown that although the fragment may be seen only in a minority of knees with acute ACL injuries (up to 17 %) [22, 44], the structure attaching to it, the MTLCL, can be injured in as many as 46 % of cases [22, 44], suggesting that the Segond fragment is not the only indicator of this pattern of instability. Similar to the results of a recent study by De Maeseneer et al. [13], our study showed that an associated MCL injury was not uncommon, being seen in 48.6 % of our cases. This finding would support but not confirm a valgus, rather than a pivot shift or anterolateral rotational instability (ALRI) mechanism of injury, but the finding could also reflect isolated anterior translation of the tibia.

There were associated bone contusions in 96.6 % of our cases, usually located at the posterior aspect of the lateral tibial plateau and the middle aspect of the lateral femoral condyle, lending support to, but again not confirming, the pivot-shift mechanism of injury.

In keeping with previous literature, our study showed that the mt-MTLCL was the most common structure attaching to the Segond fracture fragment [3–5, 7, 8, 32]. Additionally, the pf-ITB could be seen attaching to the avulsed fragment, along with the mt-MTLCL, in approximately a third of our cases, which is compatible with earlier reports that have emphasized the reinforcement of the MTLCL by the pf-ITB via prominent interdigitating fibers [5, 9], anatomical dissections that found some distal fibers of the ALL continuing into the ITB [30], and recent biomechanical studies that revealed a pattern of failure suggestive of concomitant injury to the ITB and anterolateral capsule of the knee in most patients with a Segond fracture [13, 56]. Moreover, it is possible that other researchers noticed this "conjoint" attachment of the mt-MTLCL and pf-ITB, but were using other terms such as the ALL and capsulo-osseous layer of the ITB [11, 14]. The results of our study are most discordant with those of Dodds et al., who, in a cadaveric study, described an extracapsular structure separate from the MTLCL, using the term anterolateral ligament, concluding that this ligament was most likely to be associated with the Segond fracture as the mt-MTLCL was "…an insubstantial structure" [31]. It is possible that Dodds and associates disregarded the substantial mt-MTLCL. Furthermore, Dodds et al. and Claes et al. [28, 31] also found no connecting fibers between their so-called ALL and distal portion of the ITB [28], but retrospective analysis of the figures provided in the studies by Claes et al. and others reveals a perceptible band of tissue that appears to share a common footprint with the mt-MTLCL and that resembles features of the ITB [13, 15, 19]. Contrary to previous investigations that attributed the avulsion of the Segond fragment to singular failure of the MTLCL [15, 39, 55], recent biomechanical studies have shown that the ITB may also provide rotational control of the knee [25, 56, 57] in addition to its tensile properties largely resembling the ALL [58]. The original description of the MTLCL that consists of both the "ITB and a capsular ligament deep to it" whose injury results in ALRI [5], and Johnson's reconstructive procedure involving both osseous attachments of the ITB and LCL that provided the most stability in injured knees [9], further lend credence that both the mt-MTLCL and pf-ITB may contribute to the Segond fracture. Finally, we observed no attachment of the AOB-FCL or the tendon of the anterior arm of the SHBF to the Segond fracture fragment.

Our retrospective study has limitations. Although the number of patients we investigated is substantial, we did not obtain detailed clinical information on the specific mechanism of injury, particularly the position and movement of the leg at the time of injury, which may have aided further comprehension of the mechanisms involved in this injury. Although our main objective was the analysis of the structures attaching to the Segond fracture fragment, we accepted the fact that a Segond fracture was absent when it was not mentioned in the reports of cases of acute and subacute ACL tears (1.25 %) instead of reassessing the images themselves to be certain that no Segond fracture was present. As these elusive fractures may be missed on MRI, the true incidence of these fracture fragments in recent ACL tears was likely underestimated in our study, a possibility that is strengthened by the 3–12.5 % incidence that has been reported in the literature [3, 4, 7, 59]. Recurrent, old, remote, or chronic ACL injuries were also excluded because in addition to most of these being follow-up examinations of those already included in our cohort, the distinction between a normal ACL and a chronically torn and secondarily scarred ACL on MRI may be subtle [41]. The imaging protocols and the types and strengths of the magnet varied in our patients, but the most commonly utilized magnetic strength (1.5 T), sequence (fat-suppressed), planes (axial and coronal), and slice thickness (4 mm) are similar to those of earlier investigations that deemed these suitable for visualizing the lateral structures of the knee, particularly the LCL [2, 16, 21, 35–37, 42, 43, 60, 61]. Furthermore, when we took into consideration the varying strengths of the magnet, no statistically different results were found, as noted previously. Additionally, the presence or absence of conventional radiographs did not influence our results. Consensus, rather than independent interpretation of the images represents a minor limitation of our study, although other studies that used more than one observer in the assessment of structures attaching to the Segond fracture fragment reported inter-observer agreement to be either "significant" (=0.70) [34] or "almost perfect" (=0.843–1.000) [36]. We did not perform cadaveric studies, which could possibly have provided a better understanding of our imaging findings in relation to previous anatomical studies that described the lateral knee structures attaching to the fragment [2, 13, 28]. Such anatomical studies, when coupled with en bloc histological analysis, similar to the method of Vincent et al., would likely be valuable in further assessing the common attachment of the mt-MTLCL and pf-ITB and their contributions to the Segond fracture fragment [17]. Finally, although post-arthroscopy reports detailing the particular procedure(s) performed were available in a few cases, information regarding the structure(s) repaired, specifically those that attached to the fracture fragment, was frequently not mentioned.

In conclusion, we provide an analysis of the MRI features in the largest number of reported cases of a Segond fracture. The mt-MTLCL is the structure that most commonly attaches to the Segond fracture fragment, although the pf-ITB can also attach to this fragment, more commonly in association with the mt-MTLCL. The AOB-FCL and the tendon of the anterior arm of the SHBF do not attach to the Segond fracture fragment. We found no evidence of any additional attaching structure that could not be attributed to the mt-MTLCL or the pf-ITB. Furthermore, we believe that those previous reports indicating that the ALL is "new" are incorrect. Rather, along with others, we encourage the use of what we believe is the anterolateral ligament's former, but more appropriate name, the mid-third lateral capsular ligament, when describing important lateral supporting structures of the knee.

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Compliance with ethical standards

Grants received None.

Disclosures None.

Institutional review board statement This study complied with HIPAA guidelines and institutional review board approval, along with an exemption status for informed consent.

Conflicts of interest The authors declare that they have no conflicts of interest.

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