The Segond Fracture: A Bony Injury of the Anterolateral Ligament of the Knee

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Purpose: The purpose of this study was to investigate the relation of the Segond fracture with the anterolateral ligament (ALL) of the knee. Methods: To identify the soft-tissue structure causative for the Segond fracture, a study was set up to compare anatomic details of the tibial insertion of the recently characterized ALL in cadaveric knees (n = 30) with radiologic data obtained from patients (n = 29) with a possible Segond fracture based on an imaging protocol search. The spatial relation of the ALL footprint with well-identifiable anatomic landmarks at the lateral aspect of the knee was determined, and this was repeated for the Segond fracture bed. Results: In all of the included cadaveric knees, a well-defined ALL was found as a distinct ligamentous structure connecting the lateral femoral epicondyle with the anterolateral proximal tibia. The mean distance of the center of the tibial ALL footprint to the center of the Gerdy tubercle (GT-ALL distance) measured 22.0 ± 4.0 mm. The imaging database search identified 26 patients diagnosed with a Segond fracture. The mean GT-Segond distance measured 22.4 ± 2.6 mm. The observed difference of 0.4 mm (95% confidence interval, −1.5 to 2.2 mm) between the GT-ALL distance and GT-Segond distance was neither statistically significant (P = .70) nor clinically relevant. Conclusions: The results of this study confirmed the hypothesis that the ALL inserts in the region on the proximal tibia from where Segond fractures consistently avulse, thus suggesting that the Segond fracture is actually a bony avulsion of the ALL. Clinical Relevance: Although the Segond fracture remains a useful radiographic clue for indirect detection of anterior cruciate ligament injuries, the Segond fracture should be considered a frank ligamentous avulsion itself.

Already in 1879, years before the discovery of radiographs, the French surgeon Paul Segond described a remarkably constant avulsion fracture pattern at the proximal tibia as a result of forced internal rotation applied to cadaveric human knees. The eponymous Segond fracture was reported to occur in the tibial region “definitely posterior and above the tibial tubercle.” At this anatomic location, Segond furthermore designated the existence of “a pearly, resistant, fibrous band which invariably showed extreme amounts of tension during forced internal rotation [of the knee]” (Fig 1).

Later on, in 1936, Milch was the first author to report the radiologic aspect of this enigmatic lesion showing “striking uniformity” in 3 of his patients. Rather by accident, Milch had stumbled on the experimental work of Segond and explained his radiologic findings as an “avulsion of the illotibial band at its insertion behind Gerdy’s tubercle.” The Segond fracture then became largely neglected in the orthopaedic literature until Woods et al. correlated the Segond fracture with the presence of significant knee instability in 1979, exactly 100 years after the first description of the fracture by Segond. In 4 acute cases with a positive “lateral capsular sign” (i.e., Segond fracture) on radiography, a concomitant rupture of the anterior cruciate ligament (ACL) was shown. This report, together with the work of Goldman et al. and Hess et al., has founded the current pathognomonic association of Segond fractures with ACL tears at least in the adult population.
Strikingly, although the fracture described by Segond has gained worldwide recognition in standard orthopaedic textbooks as a diagnostic clue for ACL injury, the clinical relevance of the Segond fracture itself has never been fully recognized to date. As a consequence, the anatomic structure responsible for the avulsion of this bony flake from the lateral tibial plateau has been poorly studied. Although Segond briefly mentioned a “pearly, resistant, fibrous band,” later literature remains unclear on the precise anatomic substrate potentially causing this enigmatic avulsion fracture (Fig 1).

Recently, the precise anatomic details of the newly described anterolateral ligament (ALL) of the human knee have been provided. In brief, the ALL was identified as a distinct ligamentous structure originating on the lateral femoral epicondyle and inserting on the anterolateral tibia, showing firm attachments to the body of the lateral meniscus along its oblique course at the lateral aspect of the knee. The purpose of this study was to investigate the relation of the Segond fracture with the ALL of the knee. We hypothesized that the tibial ALL insertion in cadaveric knees would match the constant location from where Segond fractures seemingly avulse on knee magnetic resonance imaging (MRI) of clinical Segond fracture cases.

Methods

To identify the soft-tissue structure causative for the Segond fracture, a study was set up to compare anatomic details of the tibial insertion of the recently characterized ALL in cadaveric knees (n = 30) with radiologic data obtained from patients (n = 29) with a possible Segond fracture based on an imaging protocol search. The spatial relation of the ALL footprint with well-identifiable anatomic landmarks at the lateral aspect of the knee was determined, and this was repeated for the Segond fracture bed.

Anatomy

The characteristics of the tibial insertion of the ALL were investigated in 30 unpaired, formalin-fixed, human cadavers obtained by the Body Donation Program of the University of Leuven, Leuven, Belgium (17 men and 13 women; mean age at death, 81 years). Specimens with a gross deformity at the knee, signs of osteoarthritis of the lateral tibiofemoral compartment, or a damaged ACL during dissection were excluded from the study.

The precise dissection technique has been described previously. In brief, dissection was started by creating a large rectangular cutaneous flap, centered on the lateral aspect of the flexed knee. The iliotibial band (ITB), the extensor apparatus, and the short head of the biceps femoris, as well as the tendon, were cleared from subcutaneous fat tissue. Then, the ITB was cut transversely at approximately 6 cm proximal to the lateral femoral epicondyle. The ITB was carefully released to its tibial attachment on the Gerdy tubercle, thus sharply cutting the so-called Kaplan fibers attaching to the lateral intermuscular septum, as well as the lateral retinaculum. Indeed, according to Seebacher et al., the ITB forms the most superficial distinct tissue layer (layer I) on the lateral aspect of the knee, only attached to the deeper layer (layer II) anteriorly at the lateral patellar retinaculum. With the ITB reflected, the “superficial lamina of the capsule” was visualized. The lateral collateral ligament (LCL) was palpated with the knee in slight varus, and the lamina encompassing the LCL was then carefully incised posteriorly and parallel to the LCL. With the knee flexed to 60°, an internal torque was subsequently applied on the foot, thereby revealing taut, distinct fibers running from the region of the lateral femoral epicondyle to the proximal tibia posterior to the Gerdy tubercle. These fibers could be clearly delineated from the slack and thin joint capsule (layer III) lying anteriorly (Fig 2). Subsequently, careful
isolation of all visible fibers of this ligamentous structure was performed at its insertional zone at the proximal tibia, posterior and proximal from the Gerdy tubercle, along its course upward to the lateral femur. Care was taken not to damage intersecting fibers with the proximal LCL. Furthermore, the lateral meniscus, the lateral inferior geniculate artery, the LCL, and the popliteus tendon were isolated.

The insertion sites of the LCL and ALL were delineated using small metal pins. Afterward, a digital caliper with an accuracy of 0.01 mm (Mit500196-20; Mitutoyo, Kawasaki, Japan) was used to measure the dimensions of the isolated ALL and its relation to nearby anatomic structures: The depth of the lateral “tibial synovial recessus” (i.e., the distance between the cartilage surface and the insertional fold of the ALL at the proximal tibia), and the distance of the center of the ALL insertion to both the fibular LCL insertion and the Gerdy tubercle (i.e., GT-ALL distance) were recorded, with the latter forming the primary outcome measure of this part of the study. The ligament was then detached from its tibial insertion, and the width of the tibial ALL footprint was measured after marking its edges with the digital caliper. A calibrated flexible ruler was fixed at the femoral metaphysis, and standardized digital photographs were obtained from a lateral and anterior point of view.

Radiology
A computerized search was performed of all imaging protocols produced by our institution’s department of radiology from January 1, 2006, until February 1, 2012. From all radiographs, computed tomography (CT) scans, MRI scans, and ultrasound examinations performed in this period, only protocols containing the term “Segond” were reviewed. All the corresponding radiographic images were manually checked for the existence of an avulsion fracture in the region of the lateral proximal tibia, and images were excluded if no typical Segond fracture was apparent. Images not containing a clear calibration scale were excluded as well. Patient charts were reviewed to identify the time between injury and radiologic diagnosis of the Segond fracture; both hospital charts and medical imaging scans of these patients were studied to determine the status of the ACL. The plain radiographs were evaluated for the size, shape, orientation, and degree of displacement of the Segond fracture fragment and for radiographic evidence of associated osseous and soft-tissue injuries. When available, the magnetic resonance (MR) and/or CT images of these knees were subsequently analyzed with particular interest in the characteristics of both the avulsed bony fragment and the corresponding fracture bed on the proximal tibia. Furthermore, measurement of the absolute distance between the center of the ITB insertion on the tibia (middle of the Gerdy tubercle) and the center of the bony bed of the proximolateral tibia from where the Segond fragment had avulsed (i.e., GT-Segond distance) was obtained. To measure this distance, the “position curser” tool of the AGFA PACS software package (Agfa Healthcare, Mortsel, Belgium) was used to transpose the correct location of the Gerdy tubercle and the fracture socket from the coronal images to the calibrated axial slides (Fig 3). Subsequently, the absolute distance in millimeters between the 2 points on the axial view was recorded, and this GT-Segond distance was then studied as the primary outcome measure of this part of the study. Furthermore, the depth of the “lateral tibial synovial recess” was measured using the same criteria as in the anatomy part of the study (i.e., the distance between the lateral edge of the tibial cartilage surface and the insertional fold of the ALL at the proximal tibia). Finally, the maximum width of the fractured “Segond bony fragment” was measured. The individual measurements were performed and repeated twice by 2 observers.

Statistics
A 2-sided 95% confidence interval for the difference in distances between the anatomy and radiology parts of the study was constructed based on a t distribution, allowing unequal variances (Satterthwaite approximation). An F test was used to compare the variability between both groups. All analyses were performed using SAS software, version 9.2, of the SAS System for Windows (SAS Institute, Cary, NY). Given the observed normal distribution of the difference between the GT-ALL and GT-Segond distances with an SD of 2.51 mm, the post hoc power analysis showed that if the true difference in the GT-ALL and GT-Segond mean values is 2.3 mm (i.e., 20% of the total mean tibial footprint width of the ALL), this study...
will be able to reject the null hypothesis that the population means of the GT-ALL and GT-Segond measurements are equal with a power of 0.843. The type I error probability associated with this test of this null hypothesis was set at \( \alpha = 0.05 \).

## Results

### Anatomy

In all 29 cadaveric knees, a well-defined ALL was found as a distinct ligamentous structure connecting the lateral femoral epicondyle with the anterolateral proximal tibia. The mean depth of the lateral recess measured 6.5 ± 1.5 mm. The mean width of the tibial footprint of the ALL equaled 11.3 ± 2.8 mm. The mean distance of the center of the tibial ALL footprint to the center of the Gerdy tubercle (GT-ALL distance) measured 22.0 ± 4.0 mm, whereas the distance between the center of the ALL footprint and the insertion of the LCL on the fibular head averaged 21.3 ± 4.1 mm.

### Radiology

The database search identified 26 patients (20 male and 6 female patients; mean age, 35 years) diagnosed with a Segond fracture on plain radiographs. Review of the respective hospital charts of the patients showed
that the diagnosis of a Segond fracture was made at a mean of 7.6 days after the sustained knee injury, with 17 patients (65%) being diagnosed with a Segond fracture on the same day on which the knee injury occurred. In 5 patients the status of the ACL could not be determined because only CT images were available for analysis. An accompanying ACL injury was diagnosed in 95% of the remaining patients, of whom 2 (10%) showed an intercondylar eminence fracture. Furthermore, most patients underwent MRI (n = 19) of the injured knee at our institution, some of whom also underwent CT scanning (n = 7). Thus a total of 19 Segond fractures were available for calibrated MRI measurements of the previously mentioned distances.

The mean depth of the lateral recess on imaging measured 6.0 ± 1.1 mm. The mean width of the fractured tibial bone fragment equaled 14.5 ± 2.5 mm. The mean distance of the center of the Segond fracture bed on the tibia to the center of the Gerdy tubercle (GT-Segond distance) measured 22.4 ± 2.6 mm.

**Statistical Analysis**

The mean GT-ALL distance obtained during dissections equaled 22.0 mm (SD, 4.0 mm), whereas the mean GT-Segond distance measured on MRI was 22.4 mm (SD, 2.6 mm). This difference of 0.4 mm (95% confidence interval, −1.5 to 2.2 mm) between the 2 distances was neither statistically significant (P = .70) nor clinically relevant. The depth of the lateral tibial recess obtained during dissection and on MRI also corresponded well. Table 1 summarizes the most important results.

**Discussion**

The results of this study confirmed the hypothesis that anatomic data on the tibial ALL insertion site would match the constant anatomic location on the proximal tibia from where Segond fractures do avulse.

In 1879, years before the discovery of radiographs, the French surgeon Paul Segond tried to resolve the cause of bloody knee effusions that were often seen after a twisting knee injury. While subjecting cadaveric knees to forced rotational loads, he noticed the occurrence of a curiously consistent avulsion fracture at the lateral tibial rim, in communication with the knee joint and thus plausibly causing the observed hemorrhosis. In 1936 the Segond fracture was recognized on radiographs in the first clinical cases presented by Milch. Only in the late 1970s was the clinical importance of this remarkably constant knee fracture emphasized. Indebted to the work of Dr. Jack Hughston, the first correlation of the Segond fracture with the presence of significant knee instability was shown by Woods et al. in 1979. In all of the 4 acute cases with a positive “lateral capsular sign” on radiographs, a concomitant rupture of the ACL was shown. This study, together with the work of Goldman et al. and Hess et al. (9 and 14 cases, respectively), has established the widely recognized pathognomonic association between Segond fractures and ACL ruptures. Although the current literature is clearly lacking series with a large cohort analysis, some studies do suggest that a Segond fracture might occur in 9% to 12% of all ACL injuries.

The Segond fracture is generally described as an avulsion-type fracture, indicating the detachment of a bone fragment by the pull of a ligament or tendon from its insertion point. However, although Segond himself briefly reported on the existence of a “pearly, resistant, fibrous band” attached to his eponymous fracture, later literature has remained unclear on what structure actually causes the avulsion. The “iliotibial band,” the “(menisco)lateral portion of the) middle one-third of the lateral capsular ligament,” the “anterior (oblique) band of the lateral collateral ligament,” and the “anterior arm of the short head of the biceps femoris” have all been named as the potential anatomic culprit. Yet, vague descriptions and the obvious lack of detailed illustrations or photographs of these anatomic structures have led to much confusion about the presumed anatomy and function of Segond’s enigmatic “pearly, fibrous band.” Likewise, the Segond fracture is nowadays merely considered a pathognomonic radiographic feature for a ruptured ACL, and the clinical relevance of the Segond fracture itself has only been poorly investigated. Johnson noted, for instance, that the occurrence of a bony Segond fracture attached to an intact “lateral capsular ligament” suggested a “strength beyond that previously attributed to this ligament.” Furthermore, he suggested a link between a lesion to this “lateral capsular ligament” and the occurrence of a certain knee instability pattern, what he called the

**Table 1. Summary of Measured Distances Both in Cadavers and on MRI Images**

<table>
<thead>
<tr>
<th>Distance to Gerdy Tubercle (mm)</th>
<th>Distance to Fibular Head (LCL Insertion) (mm)</th>
<th>Width of ALL Footprint/Segond Fracture Fragment (mm)</th>
<th>Depth of Lateral Tibial Recess (mm)</th>
<th>Width of ALL (n = 29)</th>
<th>Depth of Lateral Tibial Recess (mm)</th>
<th>Width of ALL (n = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL (n = 29) 19</td>
<td>22.4 ± 2.6</td>
<td>21.3 ± 4.1</td>
<td>14.5 ± 2.5</td>
<td>6.0 ± 1.1</td>
<td>6.5 ± 1.5</td>
<td></td>
</tr>
<tr>
<td>Segond (n = 19)</td>
<td>22.0 ± 4.0</td>
<td>NA</td>
<td>11.3 ± 2.8</td>
<td>6.0 ± 1.1</td>
<td>6.5 ± 1.5</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: Data are given as mean ± SD.
NA, not applicable.
*Distances for ALL measurements in cadaveric knees (Anatomy part of study).
Measurements derived from MRI images of patients with Segond fractures (Radiology part of study).
“lateral pivot shift.” More recently, Campos et al.\textsuperscript{15} suggested that fibers of the ITB and the so-called anterior oblique band are important factors in the pathogenesis of the Segond fracture.

Recently, the precise anatomic details of the ALL of the human knee have been provided.\textsuperscript{8,19,20} In brief, the ALL was identified as a distinct ligamentous structure originating on the lateral femoral epicondyle and inserting on the anterolateral tibia, showing firm attachments to the body of the lateral meniscus along its oblique course at the lateral aspect of the knee. Given the course of the ALL and its presumed role in controlling internal rotation of the tibia relative to the femur, it was hypothesized that the ALL could be the anatomic culprit in Segond fractures, and the results of this study have confirmed this hypothesis.

The main finding of our series—the largest series of Segond fractures ($n = 26$) in the current literature—is the confirmation of the hypothesis that the ALL inserts precisely in the region on the proximal tibia from where Segond fractures consistently avulse. Furthermore, our series showed that the occurrence of a Segond fracture is strongly associated with a concomitant ACL injury because 95% of the patients in this study showed ACL abnormalities on medical imaging. These results are in line with the vast majority of the current literature on Segond fractures, classically mentioning correlations ranging between 75%\textsuperscript{21} and 100%\textsuperscript{4,5} in the adult population.\textsuperscript{6} The results of this study therefore underscore that the Segond fracture can be regarded as a strong indication of the presence of an intra-articular ligament injury\textsuperscript{12} but, above all, that a Segond fracture represents a frank ligamentous avulsion itself. In this view the Segond fracture should not be uniquely regarded as a useful radiographic clue for ACL injury but should be regarded as a bony injury of the ALL as well.

Given its anatomic location at the anterolateral edge of the knee, the ALL has been suggested to function as a stabilizer for internal rotation.\textsuperscript{8} Indeed, our qualitative findings in the anatomic part of this study are in line with the remarks of Segond,\textsuperscript{7} who described “invariably... extreme amounts of tension during forced internal rotation” occurring in the “pearly, fibrous band.” Although the ALL was previously found to become tense with forced internal rotation between 30° and 90° of knee flexion,\textsuperscript{8,22} further kinematic analysis is needed to formally establish a potential role for the ALL in common knee instability patterns involving excessive internal rotation such as the pivot shift.\textsuperscript{23,24} In addition, more research is needed to delineate the clinical effect of a Segond fracture on knee stability in the ACL-deficient knee and to establish an eventual role for concomitant Segond fracture treatment in these patients.

**Limitations**

This study did have its limitations. To prove the hypothesis that the Segond fracture is caused by an avulsion of the ALL, a comparison between 2 different sets of data of different origin (cadaveric knees vs imaging) was performed. However, with all the included MR images being calibrated, excellent accuracy of 2-dimensional MRI measurements (i.e., distances) on “clinical” MR images has extensively been reported in the orthopaedic literature.\textsuperscript{25-27} Given the different nature of the data sets, this study by definition delivers only indirect proof of the presumed causal link between Segond fractures and the ALL. Ideally, performing a study involving the production of a Segond fracture in cadaveric knees by a forced provocative movement with subsequent dissection of the fracture fragment and its attached soft tissues would be the only way to provide direct proof of the hypothesis. In fact, such a study would imply the exact replication of

![Fig 4](image_url)

(A) Typical Segond fracture as observed on a frontal MRI sequence of a left knee (radiology part of study). (B) Frontal view of ALL in a dissected left knee (anatomy part of study). The parallel between the location of the Segond fracture bed and the tibial ALL insertion can be easily appreciated. The yellow arrows depict the ALL on both the MR image and cadaveric dissection. (LFC, lateral femoral epicondyle; LM, lateral meniscus.)
experiments performed by Segond himself. However, because the exact provocative mechanism of a bony ALL injury is still unclear, these complex experiments were regarded as beyond the scope of this study. On the other hand, direct comparison of typical MR or CT images of a Segond fracture case with the precise anatomic findings on the ALL’s tibial insertion bears such a high degree of self-evidence (Figs 4 and 5) that the repetition of Segond’s experiments was considered redundant.

Conclusions
The results of this study confirmed the hypothesis that the ALL inserts in the region on the proximal tibia from where Segond fractures consistently avulse, thus suggesting that the Segond fracture is actually a bony avulsion of the ALL.

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References


