The Segond's Fracture

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Andrea Ferretti, Edoardo Gaj, and Daniele Mazza

Avulsion fracture involving the proximal tibia just distal to the lateral plateau was first described in 1879 by a French surgeon, Paul Segond, after performing cadaveric experiments [1]. The author described a resistant, pearly, fibrous band in the lateral compartment of the knee, whose traction resulted in a cortical avulsion of the lateral proximal tibia. This injury was named Segond's fracture, and several studies have demonstrated an association of this fracture with anterior cruciate ligament (ACL) tears, meniscal tears, damage to structures of the posterolateral corner and other avulsion injuries [2]. Currently, it might seem strange, almost bizarre, how Segond's fracture, which was described well before the discovery of X-rays by Wilhelm Roentgen in 1896, has become popular as an indirect radiological sign of an ACL injury over time (Fig. 5.1). Today, although Segond's fracture can be associated with other knee injuries, if it is present, the ACL should be considered torn until proven otherwise.

The precise pathogenesis of Segond's fracture has been the subject of debate, partially due to the complexity of the anterolateral capsuloligamentous anatomy. Paul Segond demonstrated that internal rotation and varus stress applied to the knee causes tension on the lateral joint capsule at its midpoint; he believed that a resistant band of tissue produces an avulsion fracture of the lateral tibial plateau posterior to the insertion of the iliotibial tract on Gerdy's tubercle.

In a recent descriptive study [3] on the pattern and prevalence of injuries of the lateral capsule occurring along with acute ACL tears, Ferretti et al. found that among the overall 90% prevalence of injuries involving the anterolateral complex, Segond's fracture occurs in approximately 10% of cases. In a more extended experience related to more than 200 cases of acute ACL tears, the true prevalence of Segond's fractures decreased to approximately 8% [4]. Based on these findings, it was postulated that this avulsion fracture represents the tip of the iceberg of anterolateral

A. Ferretti (✉) · E. Gaj · D. Mazza
Orthopaedic Unit, Sant'Andrea University Hospital, La Sapienza University, Rome, Italy

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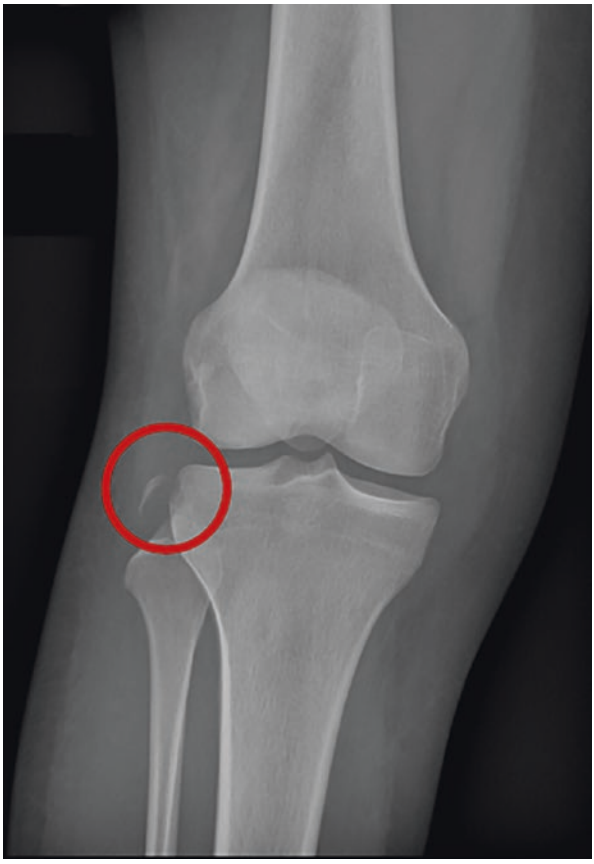


Fig. 5.1 Segond's fracture on X-rays

capsule and ligament lesions, occurring along with ACL tears and possibly affecting the rotational stability of the knee.

Moreover, Claes et al. [5], as a result of their study on the anterolateral ligament (ALL), whose insertion lies on the proximal tibia, where Segond's fracture consistently avulses, suggested that Segond's fracture is actually a bony avulsion of the ALL. A similar finding was provided by John Feagin in his textbook "The Crucial Ligaments" (see Chap. 2, Fig. 2.3) [6].

5.1 Biomechanics

Many anatomical and biomechanical studies have focused on the anterolateral capsule and ALL [7–10]. Meanwhile, their roles as the secondary restraints of the ACL in controlling tibial internal rotation and the pivot shift phenomenon are still debated. Surprisingly, all previous studies that focused on the anatomy and function of soft tissues, including ligaments and capsules, whose dissection was performed by various authors, have reported conflicting results [11–13]. In 2017, we published

the first and, to our knowledge, the only biomechanical study on the effect of an experimentally reproduced Segond's fracture on knee stability in an ACL-deficient knee [14].

The biomechanical cadaver study was conducted on entire fresh frozen cadavers following the same protocol used for evaluating the effect of sequential tearing of the ACL and ALL on anteroposterior (AP) translation, combined external and internal rotation (axial tibial rotation), the Lachman test and pivot shift test, with the aid of navigation [15]. The navigation system was equipped with dedicated software that could perform accurate static and real-time dynamic measurements by means of wires strongly fixed to the bone. All tests and navigation processes were performed by the same experienced surgeon. Three different conditions were tested: an intact knee, an ACL-deficient knee and a knee with an ACL injury with Segond's fracture (Fig. 5.2).

Static measurements of anterior tibial translation (ATT) and axial tibial rotation (ATR) at 30° of flexion were performed in all three conditions. All measurements were recorded under a manual maximum force applied by the same surgeon who made every effort to apply a similar load to the knee to minimize intra-observer variability.

Dynamic measurements of ATT and ATR during the pivot shift test were also performed under the same three conditions. ATT was expressed in millimetres and ATR was expressed in degrees, and a diagram showing the curve of ATT and ATR during the test was visualized and saved as a screenshot at the end of each procedure step. All data were collected and statistically analysed by a single researcher.

As shown in Tables 5.1, 5.2, 5.3 and 5.4, an isolated complete tear of the ACL had a significant effect only on ATT and only a mild effect, if any, on the rotational stability of the knee; the addition of a reproduced Segond's fracture had a significant effect on ATR in both static and dynamic conditions during the execution of the pivot shift test. Therefore, from a biomechanical point of view, a Segond's fracture has the same effect as a severe injury on the ALL, both of which usually occur along with an ACL tear.

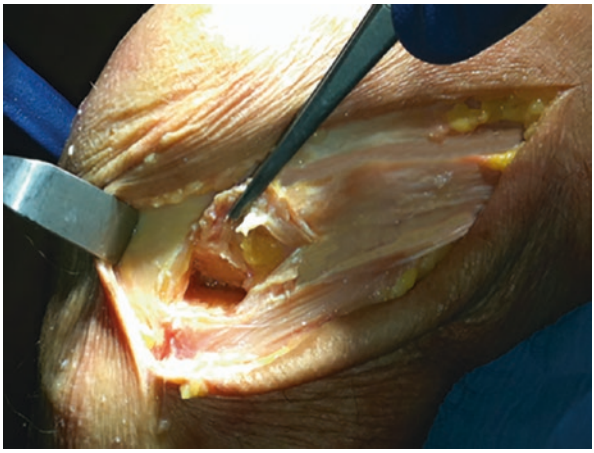


Fig. 5.2 Segond's fracture as reproduced on a cadaver model

Table 5.1 Anterior tibial translation during pivot shift (Dynamic measurements)

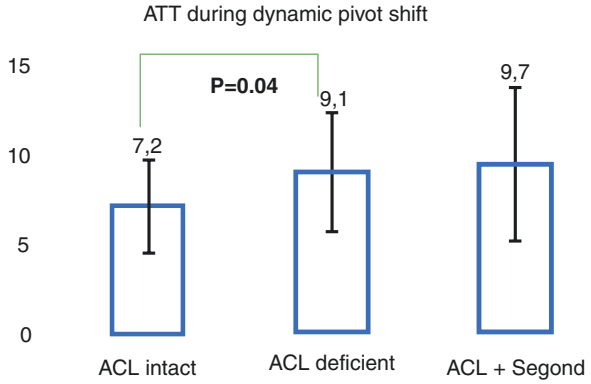


Table 5.2 Axial tibial rotation (Internal+External tibial rotation) during pivot shift (Dynamic measurements)

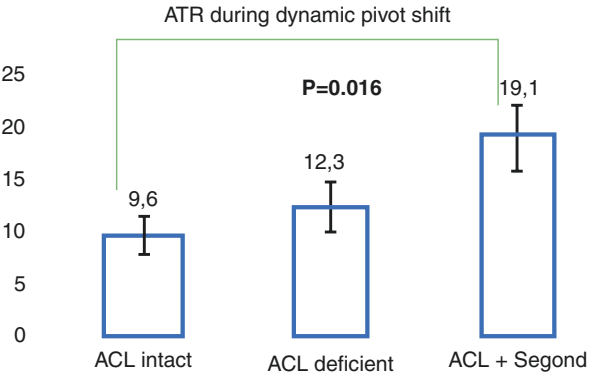


Table 5.3 Anterior tibial translation (ATT) during pivot shift (Static measurements)

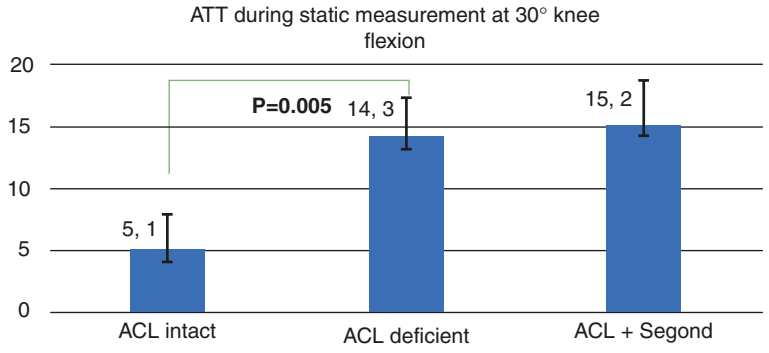
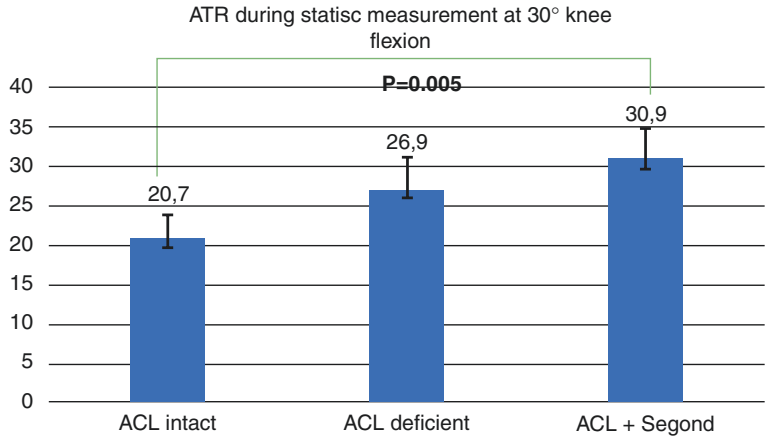


Table 5.4 Axial tibial rotation (Internal+External tibial rotation) (Static measurements)



Recently, Mullins et al. performed a cadaver study [16] investigating the bone density of various entheses of the proximal tibia using a micro-CT scan to perform "virtual biopsies", to measure the bone trabecular volume fraction ("bone volume divided by the total volume" (BV/TV)). The subentheseal trabecular properties at Segond's site were compared with other entheses across the tibial plateau and fibular head, and it was hypothesized that a lower trabecular bone structure at Segond's site would explain its propensity for avulsion. A reduced mineral content (BV/TV), which correlates with tensile and torsional strength, was detected in the anterolateral aspect of the tibia exactly where Segond's fracture usually occurs, possibly resulting in a weaker bone. Based on their results, the authors postulated that the high prevalence of Segond's fracture was due to a reduced mineral content, actually questioning the existence of the ALL, postulating that according to Frost's Mechanostat hypothesis, the insertion of a ligament would correspond to a stronger and more resistant site.

However, to better understand the mechanism and biomechanics of a Segond's fracture, additional factors should be reasonably considered.

In fact, in their study, the authors compared virtual biopsies of several entheses of various ligaments and tendons with different biomechanical properties. Therefore, it was not surprising that the entheses themselves showed different properties. In particular, the ultimate failure load and the stiffness of the ALL were much lower than those of all other ligaments and tendons whose bony insertion was evaluated [17–19]. Compared with the ACL, Lateral Collateral Ligament (LCL) and iliotibial band (ITB), the biomechanical properties of the ALL are more than ten times lower [20, 21], not to mention the difference with the patellar tendon [22]. Therefore, we should not be surprised if a similar difference was found in

their sites of insertion. Moreover, the ALL is only a secondary restraint of internal rotation, with the ACL being the first restraint [23]. Therefore, the ALL usually exerts tension over its insertion only as the result of an ACL tear. Compared with other, stronger entheses, ALL insertion is probably not normally exerted, with a resulting lack of the constant and adequate stimulus required for an adaptive bony reaction and hypertrophy.

In conclusion, while the study of Mullins et al. reasonably explained how a Segond's fracture, even if a rare event, is probably the most frequent avulsion fracture of the tibial plateau, it does not challenge the hypothesis of the existence of a discrete ligament (the ALL) that is strong enough to sometimes pull out its bony insertion as a result of forced internal rotation and ACL failure.

5.2 Surgical Anatomy

As Segond's fracture occurs in less than 10% of acute ACL tear, cases collecting a reliable series of cases would mean having access to hundreds of cases of truly acute ACL tears. In fact, the literature is scarce, and most of the papers are case reports or observational studies of a few randomly collected cases [24].

Between 2014 and 2020, in a consecutive series of 210 acute patients prospectively selected and admitted for early surgical treatment, 17 were diagnosed as having a Segond's fracture. In addition to X-rays, MRI and/or CT scans confirmed the anterolateral location of the bony avulsion (Figs. 5.1, 5.2, and 5.3).

Although the size of bony fragments is usually small, a few cases of exceptionally large fragments have been reported as a result of severe knee injuries of polytrauma (Figs. 5.3 and 5.4).

During preoperative evaluation under anaesthesia, the Lachman test and pivot shift test were always positive, confirming the anterolateral pattern of the instability. In contrast, the varus test at either 30° of flexion or in extension was negative in all cases.

Preliminary diagnostic arthroscopy showed a complete rupture of the ACL in all cases. Along with standard ACL reconstruction with the hamstrings, the lateral compartment was explored to detect the fracture, which was surgically inspected, accurately described, and photographically documented. With the knee flexed on the operating table, the lateral compartment was approached through a hockey stick skin incision. Below the subcutaneous tissue, the fascia lata was exposed and carefully examined: it was slightly haemorrhagic in 9 cases, only haemorrhagic in 5 cases, and haemorrhagic, attenuated and stretched in 3 cases (Fig. 5.5).

It was normally inserted on Gerdy's tibial tubercle in all cases. The deeper, capsular layer was exposed by splitting the fascia lata along its fibres: the capsule was found to be diffusely haemorrhagic and frankly stretched in all cases; the bony fragment was always detected at the proximal tibia just below the lateral meniscus, almost midway between Gerdy's tubercle and the anterior edge of the fibular head.

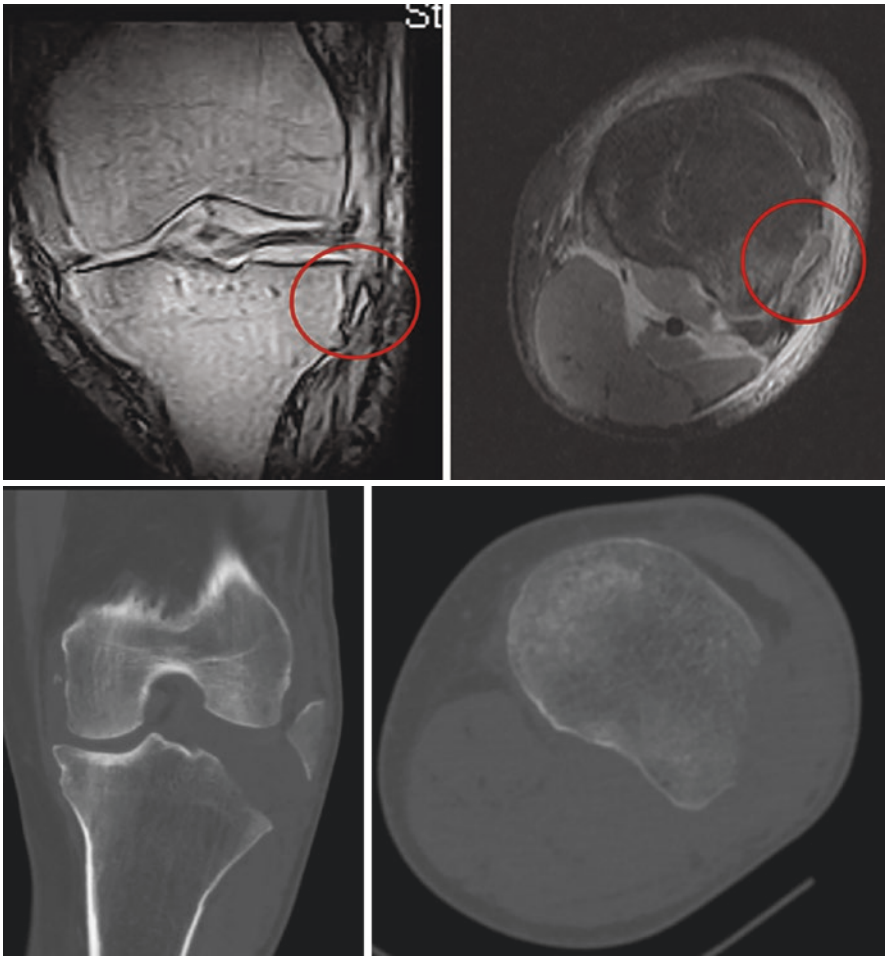


Fig. 5.3 Segond's fracture on MRI and CT in axial and coronal view

The size of the fragment was variable but always corresponded to the preoperative imaging; the ALL and the surrounding capsule were the only structures attached to the bony fragment in all cases (Fig. 5.6). In fact, the site of the fragment corresponded to the site of insertion of the ALL, as described by Claes et al. [5].

Based on our surgical findings of the largest ever-reported case series of Segond's fractures, we can reasonably state that Segond's fractures:

(1) are constantly associated with a complete rupture of the ACL resulting in anterolateral rotatory instability (ALRI)
(2) represent the avulsion of the tibial insertion of the ALL

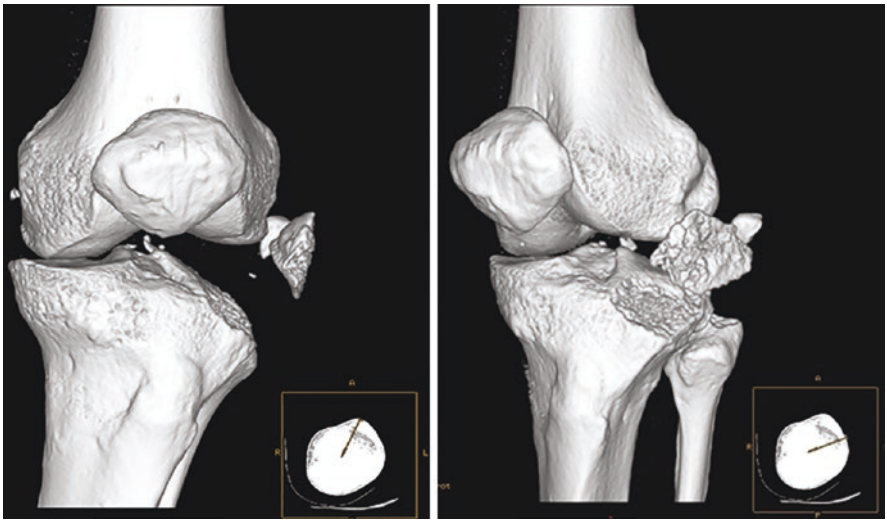


Fig. 5.4 Exceptionally large and rare Segond's fracture on CT and 3D CT

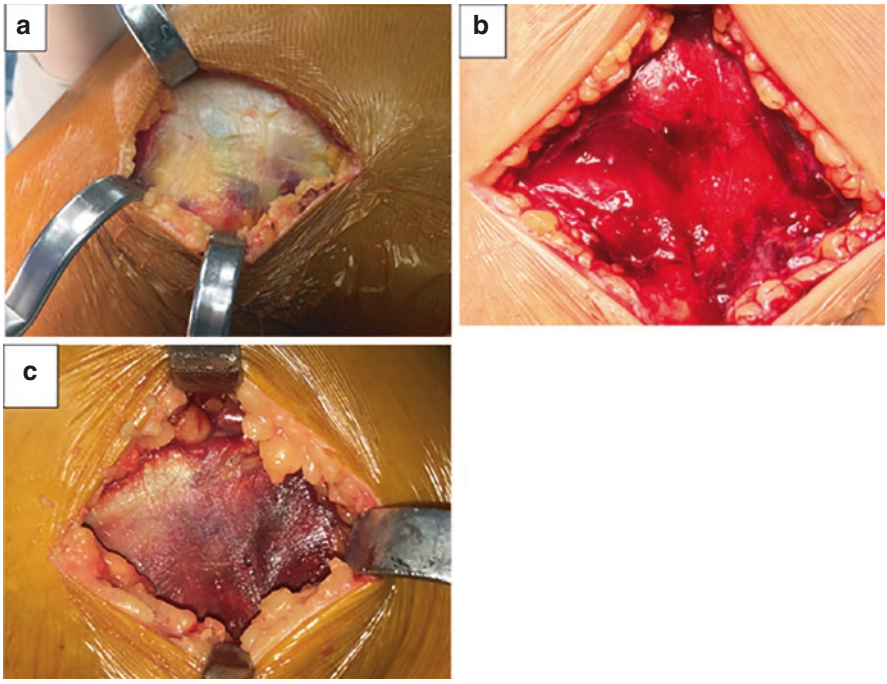


Fig. 5.5 Fascia lata as it can appear in case of Segond's fracture: (**a**) *Mildly haemorrhagic;* (**b**) *Haemorrhagic;* (**c**) *Haemorrhagic and stretched*

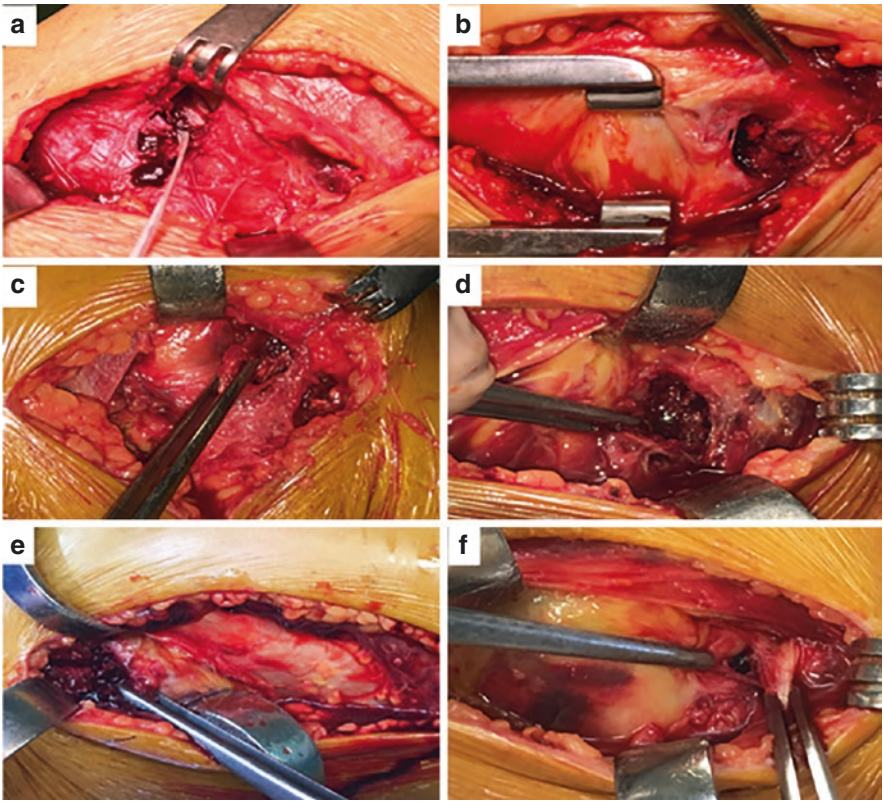


Fig. 5.6 In our series, the Segond's fracture was always identified at the tibial insertion of ALL. Detachment of fascia lata, biceps tendon or other lateral structures was never encountered. (**a**, **e** Left Knee; **b**, **c**, **d**, **f** Right Knee)

However, it must be considered that in addition to the bony injury, the ALL itself and its whole anterolateral complex also underwent severe plastic deformation, as documented by the extensive haemorrhagic infarction associated with diffuse stretching, sometimes extending to the overlying ITB.

5.3 Surgical Treatment

Among the 17 cases of Segond's fracture that were observed and surgically treated in our hospital between 2014 and 2020, twelve were reviewed at a minimum follow-up of two years and were the subjects of recently published studies [25, 26]. Despite the relatively low number of patients, this series still represents the largest of this kind.

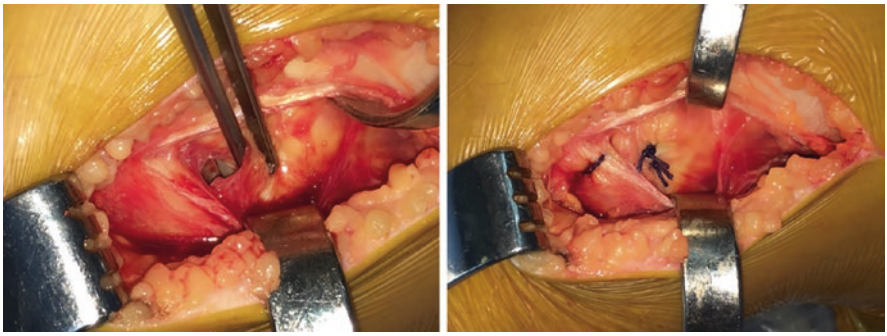


Fig. 5.7 Fixation of Segond's fracture using absorbable periosteal stitches

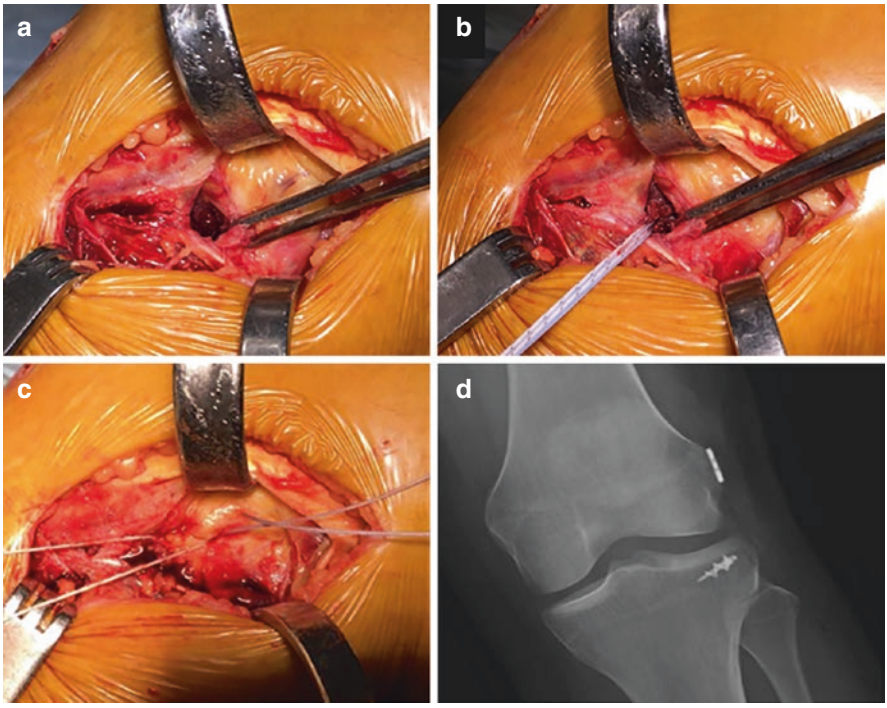


Fig. 5.8 Fixation of Segond's fracture using one suture anchor (**a**) identification of Segond's fracture (**b**) placement of the anchor suture (**c**) fixation of the bony fragment and re-tensioning of the antero-lateral capsule (**d**) post-operative x-ray after ACL reconstruction and Segond's fracture fixation

Once the bony fragment was identified, surgical repair consisted of the refixation of the fragment in its anatomical site by means of periosteal sutures in 11 cases, suture anchors in 5 cases and cancellous screws in one case where the bony fragment exceeded 2 cm in size. In all cases, the anterolateral complex was retensioned by plication using absorbable stitches (Figs. 5.7, 5.8, 5.9 and 5.10)

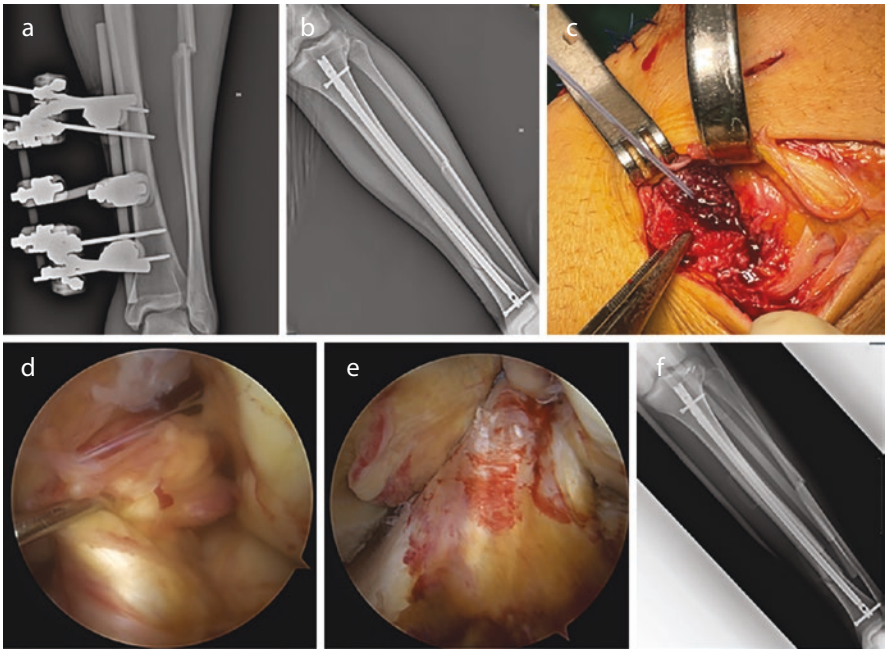


Fig. 5.9 A very unusual ski injury: open leg fracture associated with an ipsilateral ACL tear and Segond's fracture. Comprehensive one-stage treatment (fracture fixation, ACL and Segond's fracture repair). (**a**) *X-ray showing leg fracture after provisional external fixation;* (**b**) *X-ray after definitive intramedullary nailing before ACL and Segond's fracture repair;* (**c**) *Surgical finding after the first stage of the procedure (tibial fixation): Suture anchor repair of the Segond's fracture, identified as usual deep to the iliotibial tract and below the lateral meniscus;* (**d**) *Arthroscopy showing a repairable complete proximal ACL tear;* (**e**) *ACL tear as it appears after repair;* (**f**) *X-ray after comprehensive surgical treatment*

After repair and before intra-articular ACL reconstruction, the pivot shift test was repeated to verify the effect of the procedure. It was negative or only mildly positive (+––) in all cases. Therefore, the efficacy of the repair and the role of the Segond's fracture on anterolateral stability were confirmed.

As shown in Tables 5.5 and 5.6, which summarize the demographic data and preoperative and post-operative clinical findings, the results of the combined ACL reconstruction and Segond's fracture repair were excellent, with ten cases of IKDC with objective scores classified as A and two classified as B. No complications, such as infection, malunions, post-operative stiffness or arthrofibrosis, mechanical failure or rerupture of the ACL graft, were reported at a minimum follow-up of 2 years (mean: 28.6 ± 2.1 months). One patient underwent a second operation for meniscectomy. On average, the patients returned to the sport after six months. At the latest follow-up, all patients had returned to their preoperative sports activity level.

The main finding of this study was that repair of a Segond's fracture, performed along with standard ACL reconstruction with the hamstrings, is a safe and

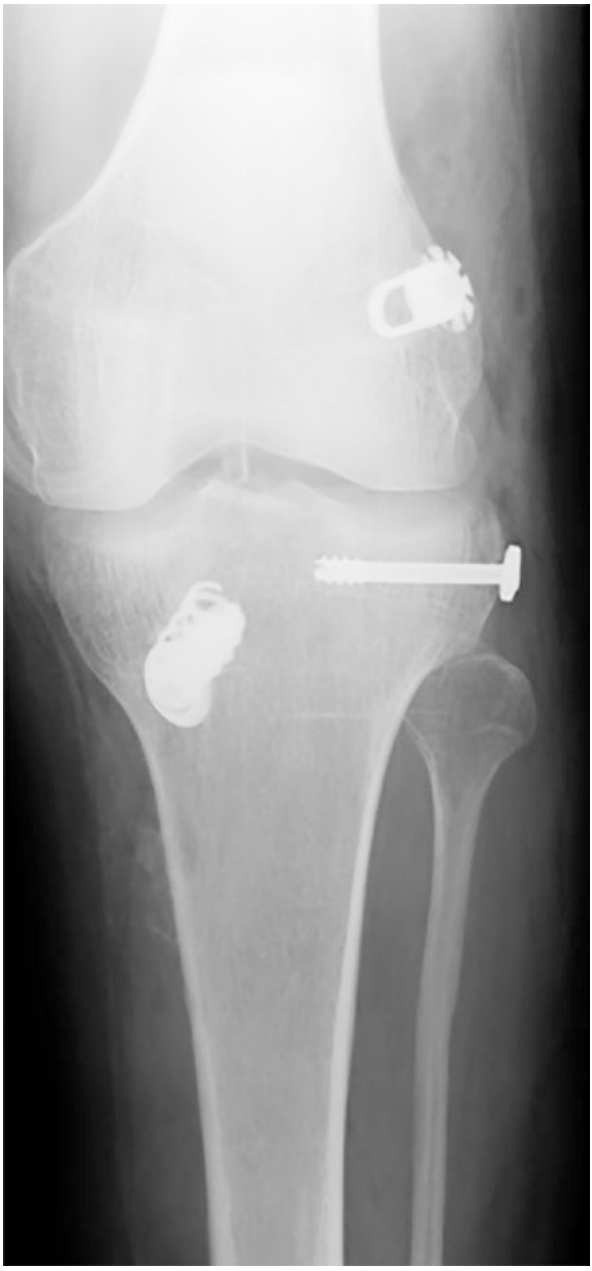


Fig. 5.10 Fixation of Segond's fracture using a screw

successful procedure resulting in the excellent recovery of knee stability and function and no major complications. Another important finding was that although a second skin incision and an open procedure are required, it does not otherwise increase morbidity. The patient post-operative course, rehabilitation and return to

Table 5.5 Demographic data

Male, n **Female, n**	10 2
Affected knee, left, n **Affected knee, right, n**	8 4
Weight, kg	58.3 ± 6.1 (range 48-71)
Age at procedure, y	26.5 ± 5.7 (range 16-45)
Interval to surgery (days)	4.5 ± 2.5 (range 2-7)
Follow-up period, m	28.6 ± 2.1 (range 24-37)
Additional procedures, n (%)	
Medial partial selective meniscectomy Lateral partial selective meniscectomy Lateral/medial selective meniscectomy	4 (33%) 1 (8%) 1 (8%)
Rerupture, n	0
Reintervention (meniscectomy), n	1

Table 5.6 Pre- and post-operative data

	Pre-operative	Post-operative	*P*
Joint Laxity (S-S), mm **<3 mm** **3–5 mm** **>5 mm**	10.2 ± 0.77 (range 9–11) 0 4 (23%) 8 (67%)	2.2 ± 0.7 (range 1–3) 11 (92%) 1 (8%) 0	**<0.05**
Lachman, n			**<0.05**
+ **++** **+++**	2 3 7	0 0 0	
Pivot shift, n			**<0.05**
+ **++** **+++**	0 0 12 (100%)	1 (8%) 0 0	
Lysholm	52.5 ± 5.1	91 ± 2.3	**<0.05**
Tegner	8.1 ± 1.1	7.1 ± 1.9	**<0.05**

the sport were identical to those occurring after isolated, standard intra-articular ACL reconstruction. Our results compare well with those of previous studies that reported that extra-articular reconstruction and/or repair, in addition to standard ACL reconstruction, has very good clinical outcomes and knee stability with a low rate of recurrence and failure [27–29].

Some authors have questioned the need to repair Segond's fractures, as their presence does not affect clinical results regardless of whether isolated ACL reconstruction is performed [30]. This finding is not surprising, as Segond's fractures do not necessarily increase the severity of anterolateral instability, possibly having the same effect as other unrecognized, misdiagnosed, and undetectable (by Xray) injuries of the ALL. If untreated, both bony and soft injuries could result in similar outcomes.

Our results confirm the importance of Segond's fractures and of the anterolateral ligament in controlling rotational stability of the knee and the pivot shift

phenomenon, supporting early speculation that an unrecognized and/or untreated injury of an extra-articular structure such as the anterolateral complex may account for some cases of persistent rotational instability after isolated ACL reconstruction.

References

1. Segond P. Recherches cliniques et experimentales sur les epanchements sanguins du genou par entorse. Paris: Progres Medical; 1879.
2. Woods GW, Stanley RF, Tullos HS. Lateral capsular sign: x-ray clue to a significant knee instability. Am J Sports Med. 1979;7:27–33.
3. Ferretti A, Monaco E, Fabbri M, et al. Prevalence and classification of injuries of anterolateral complex in acute anterior cruciate ligament tears. Arthroscopy. 2017;33(1):147–54.
4. Ferretti A, Monaco E, Gaj E, et al. A. risk factors for grade 3 pivot shift in knees with acute anterior cruciate ligament injuries: a comprehensive evaluation of the importance of osseous and soft tissue parameters from the SANTI Study Group. Am J Sports Med. 2020;48(10):2408–17.
5. Claes S, Vereecke E, Maes M, et al. Anatomy of the anterolateral ligament of the knee. J Anat. 2013;223:321–8.
6. Feagin JA. The crucial ligaments. Churchill Livingstone; 1988.
7. Amis AA. Anterolateral knee biomechanics. Knee Surg Sports Traumatol Arthrosc. 2017;25(4):1015–23.
8. Corbo G, Norris M, Getgood A, et al. The infra-meniscal fibers of the anterolateral ligament are stronger and stiffer than the supra-meniscal fibers despite similar histological characteristics. Knee Surg Sports Traumatol Arthrosc. 2017;4:1078–85.
9. Getgood A, Brown C, Lording T, Amis A, Claes S, Geeslin A, Musahl V, ALC Consensus Group, et al. The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. Knee Surg Sports Traumatol Arthrosc. 2019;27(1):166–76.
10. Inderhaug E, Stephen JM, Williams A, et al. Biomechanical comparison of anterolateral procedures combined with anterior cruciate ligament reconstruction. Am J Sports Med. 2017;45(2):347–54.
11. Caterine S, Litchfield R, Johnson M, et al. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. Knee Surg Sports Traumatol Arthrosc. 2015;23(11):3186–95.
12. Redler A, Miglietta S, Monaco E, et al. Ultrastructural assessment of the anterolateral ligament. Orthop J Sports Med. 2019;7(12):2325967119887920.
13. Stijak L, Bumbaširević M, Radonjić V, et al. Anatomic description of the anterolateral ligament of the knee. Knee Surg Sports Traumatol Arthrosc. 2016;24(7):2083–8.
14. Monaco E, Mazza D, Redler A, et al. Segond's fracture: a biomechanical cadaveric study using navigation. J Orthop Traumatol. 2017;18(4):343–8.
15. Monaco E, Fabbri M, Mazza D, et al. The effect of sequential tearing of the anterior cruciate and anterolateral ligament on anterior translation and the pivot-shift phenomenon: a cadaveric study using navigation. Arthroscopy. 2018;34(4):1009–14.
16. Mullins W, Jarvis GE, Oluboyede D, et al. The Segond fracture occurs at the site of lowest subentheseal trabecular bone volume fraction on the tibial plateau. J Anat. 2020;237(6):1040–8.
17. Helito CP, Bonadio MB, Rozas JS, et al. Biomechanical study of strength and stiffness of the knee anterolateral ligament. BMC Musculoskelet Disord. 2016;30(17):193.
18. Kennedy MI, Claes S, Fuso FA, et al. The anterolateral ligament: an anatomic, radiographic, and biomechanical analysis. Am J Sports Med. 2015;43(7):1606–15. https://doi.org/10.1177/0363546515578253.

19. Wytrykowski K, Swider P, Reina N, et al. Cadaveric study comparing the biomechanical properties of grafts used for knee anterolateral ligament reconstruction. Arthroscopy. 2016;32(11):2288–94.
20. Monaco E, Lanzetti RM, Fabbri M, et al. Anterolateral ligament reconstruction with autologous grafting: a biomechanical study. Clin Biomech (Bristol, Avon). 2017;44:99–103.
21. Sugita T, Amis AA. Anatomic and biomechanical study of the lateral collateral and popliteofibular ligaments. Am J Sports Med. 2001;29(4):466–72.
22. Cooper DE, Deng XH, Burstein AL, et al. The strength of the central third patellar tendon graft. A biomechanical study. Am J Sports Med. 1993;21(6):818–23.
23. Muller W. The knee. New York: Springer Verlag; 1983.
24. Hardy A, Ferreira FB, Hunter JC. Segond fracture after anterior cruciate ligament reconstruction. Radiol Case Rep. 2015;4(3):305.
25. Ferretti A, Monaco E, Wolf MR, et al. Surgical treatment of Segond fractures in acute anterior cruciate ligament reconstruction. Orthop J Sports Med. 2017;5(10):2325967117729997.
26. Mazza D, Monaco E, Redler A, et al. Segond fractures involve the anterolateral knee capsule but not the iliotibial band. Arthrosc Sports Med Rehabil. 2021;3(3):e639–43.
27. Ferretti A, Monaco E, Ponzo A, et al. Combined intra-articular and extra-articular reconstruction in anterior cruciate ligament-deficient knee: 25 years later. Arthroscopy. 2016;32(10):2039–47.
28. Guzzini M, Mazza D, Fabbri M, et al. Extra-articular tenodesis combined with an anterior cruciate ligament reconstruction in acute anterior cruciate ligament tear in elite female football players. Int Orthop. 2016;40(10):2091–6.
29. Redler A, Iorio R, Monaco E, et al. Revision anterior cruciate ligament reconstruction with hamstrings and extra-articular tenodesis: a mid- to long-term clinical and radiological study. Arthroscopy. 2018;34(12):3204–13.
30. Yoon KH, Kim JS, Park SY, et al. The influence of segond fracture on outcomes after anterior cruciate ligament reconstruction. Arthroscopy. 2018;34(6):1900–6.