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High prevalence of all complex Segond avulsion using ultrasound imaging

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Abstract
Purpose The aim of this study was to determine the prevalence of a Segond avulsion fractures in acute ACL tears with ultrasound and to investigate whether other injuries can predict the avulsion.
Materials and methods One hundred thirty-eight ultrasound analyses of acute knee trauma were collected and scored for diagnosed injuries. The reports of patients with an ACL tear ($N = 87$) were evaluated to determine possible increased prevalence of Segond avulsion fracture with ultrasound. The associations between the diagnosed injuries and presence of a Segond avulsion were scored. The sports carried out at the time of injury were evaluated as possible prognostic factor.
Results In 25/87 (29%) of the patients with an ACL tear, a Segond avulsion was observed in ultrasound. Lateral femoral condyle (LFC) impaction showed the strongest individual association with a Segond avulsion and was the best predicting variable. LFC impaction, sustained during low-risk pivoting sport, shows a stronger association with a Segond avulsion, as compared to LFC impaction sustained during high-risk pivoting sports.
Conclusion Ultrasound shows a higher prevalence of Segond avulsions as literature shows with MRI or radiography. LFC impaction is the best variable in predicting this type of avulsion. Ultrasound examination should be considered, if this fracture was not diagnosed with MRI or radiographic analysis.
Level of evidence IV.

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Keywords Anterior cruciate ligament · Ultrasound · Segond avulsion · Knee imaging

Introduction

Anterolateral rotatory instability (ALRI), as a result of ACL injury, could possibly lead to reduced function and degeneration of the knee caused by meniscal or chondral damage, especially if it is not diagnosed and left untreated [23]. Beside the pronounced influence of the ACL, many other structures and anatomical characteristics affect the stability of the knee and cause rotatory instability when damaged. Important structures with similar stabilizing functions backing up the ACL during internal and valgus rotations are located at the anterolateral side of the knee [18, 22].

Many research groups [4, 6, 8, 15, 20, 25] have tried to identify these anterolateral capsular and extracapsular structures, described as the anterolateral ligament (ALL). The quantitative descriptions of the ALL positioning by Claes et al. [6] are often cited in the literature. The tibia insertion was found in the middle of the line connecting Gerdy's tubercle and the tip of the fibular head. The origin was located on the lateral femoral epicondyle, posterior to the socket from which the lateral collateral ligament (LCL) originated, and proximal and posterior to the insertion of the popliteus tendon [6] (Fig. 1). This structure is part of the anterolateral complex and has an additional contribution to resist forces during internal rotation of the knee joint [7]. Ferretti et al. [11] and Sonnery Cottet et al. [23] notified the importance of multiple structures involved in the tibia attachment of the ALL (complex).

A preliminary survey with limited numbers showed Segond fractures (Fig. 2), which were not diagnosed by MRI or radiographic imaging. These findings initiated

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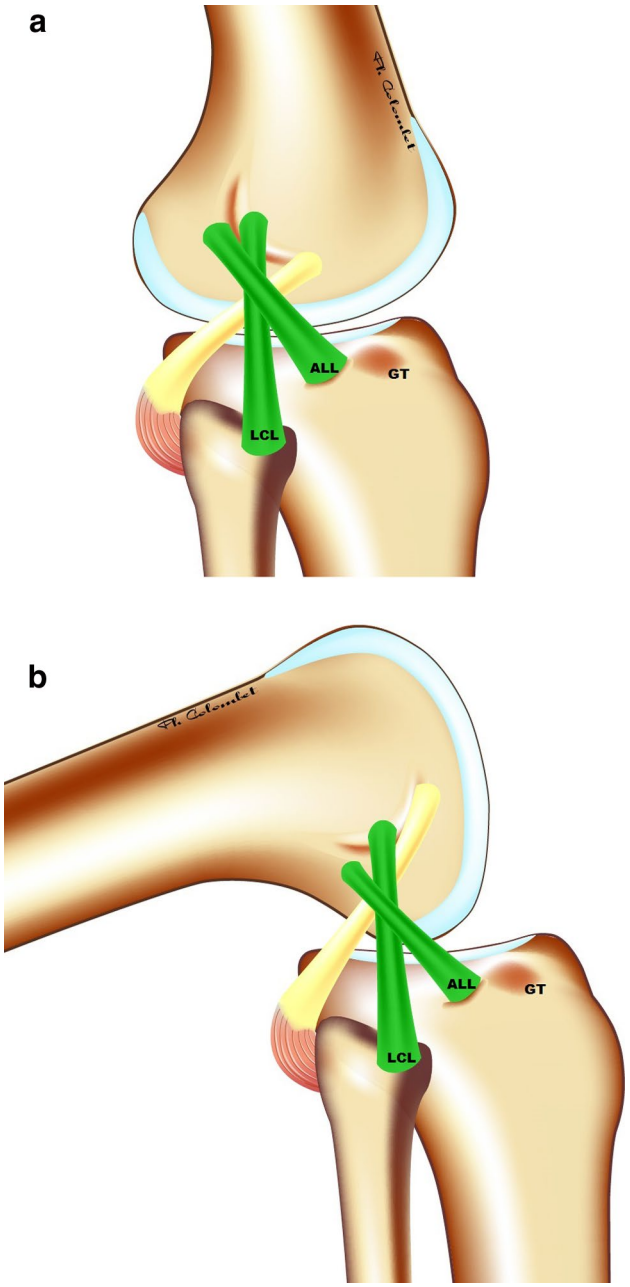

Fig. 1 Anatomical representation of the ALL and its related anatomical landmarks on the lateral side of the knee in full extension (**a**) and in 90° of flexion (**b**). *ALL* anterolateral ligament, *LCL* lateral collateral ligament, *GT* Gerdy's tubercle

the research programme. Herbst et al. [16] reported lateral femur condyle (LFC) impaction (Figs. 3, 4) as a predicting sign for the diagnosis of an acute ACL injury. We hypothesized that the LFC impaction can be used as a predicting factor for Segond avulsion.

The aims of the present study were to:

1. Determine the prevalence of Segond fractures diagnosed with ultrasound in patients with ACL injury. The additional value of ultrasound was investigated in the imaging of combined knee injuries.
2. Check single or combined types of traumatic knee lesions for prediction of the presence of a Segond fracture by evaluating the associated injuries.
3. Evaluate the sport performed at the time of knee trauma with and without Segond fracture, and relate traumatic lesions with high- or low-risk sport participation.

Materials and methods

Subjects and equipment

Approval for the study was obtained by the Medical Ethical Committee of Maastricht University Medical Center (METC 15-4-067). Ultrasound knee examination reports of acute knee injuries in 134 patients (57 females and 77 males) aged between 16 and 66 years ($\mu_x = 30.6$; $\sigma = 13.0$), derived from ICONE's medical database, have been studied. All ultrasounds were performed over a period of 3 years on patients with acute knee injuries (within 4 weeks after injury) using a Philips IU22 ultrasound system.

Ultrasound investigation

Ultrasound investigation is performed in supine, supine flexion and prone positions.

Peripheral structures including medial collateral and lateral tractus, iliotibial band, ALL complex and Segond avulsion can be visualized (Fig. 2). Medial collateral ligament (MCL) rupture is classified as normal or ruptured. The MCL rupture is most frequently located at the proximal insertion. In case of avulsion fractures, ultrasound measurements were performed in millimetres to record the size of the fracture. In flexion and extension, the ACL is scanned dynamically, showing the tensioning of the ACL. In maximum flexion, the tibia tends to come forward, and in ultrasound scanning of an intact ACL we see full tensioning of fibres. In case of a partial lesion, reduction in tensioning of fibres is recorded. Total laxity can be observed in full lesions in which there are no remaining fibres present. In flexion of 90°, the lateral femur condyle is checked for impaction notch fracture using the suggested classification of Herbst et al. [16], with a threshold of minimal 1.5 mm impaction.

Ultrasound measurements are 5–10 times enlarged on the screen, which makes a more precise submillimeter measurement possible (Fig. 3). Accuracy for

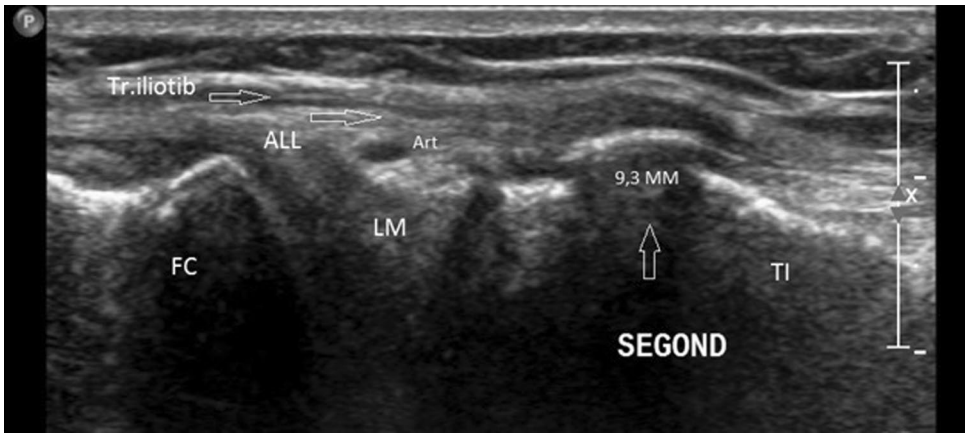

Fig. 2 Ultrasound image scanned from lateral side, left femoral condyle (FC) middle lateral meniscus (LM) right tibia (TI) a Segond avulsion (9.3 mm) diagnosed with ultrasound on the lateral side of the knee after acute knee trauma. Between the lateral meniscus and the ALL complex the lateral genicular artery is found (Art). The iliotibial band aponeurosis is covering the Segond avulsion

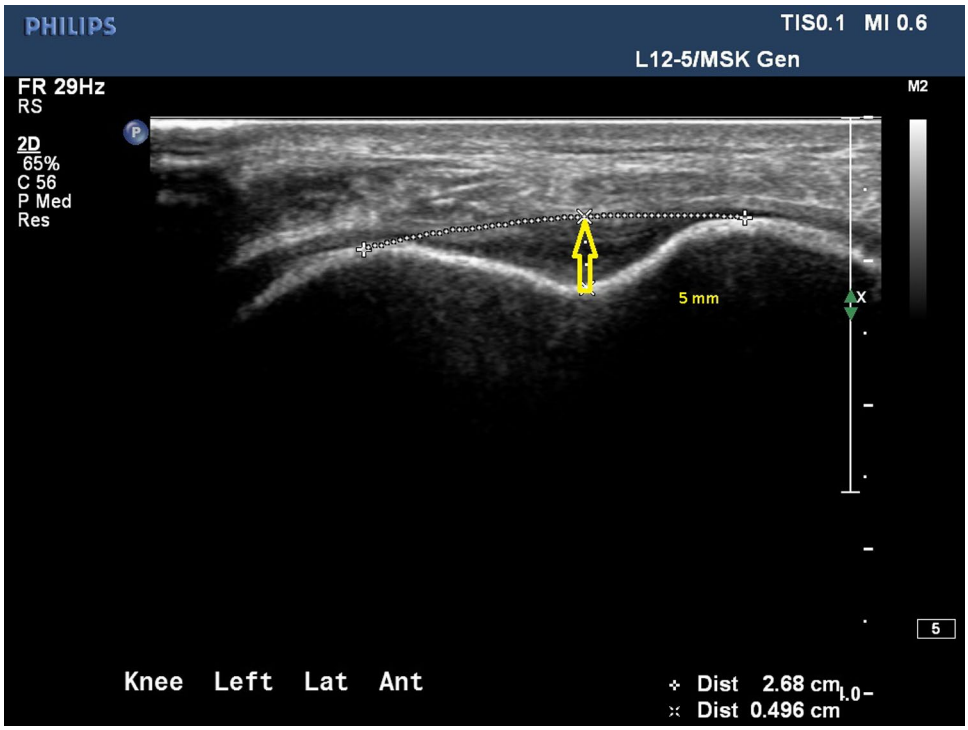

Fig. 3 Left femoral condyle scanned in flexion 100° next to the patella tendon, impaction fracture with ultrasound measurements. LFC impaction (*arrow*) scanned with ultrasound from the lateral side of the knee with ultrasound measurements in mm

measurement of impaction is around 0.2 mm. In prone position, lesions of the menisci are found clearly visible with our current technique [19] using a Philips IU22 US equipment with a broadband linear array high-resolution probe (5–12 MHz).

Assessment

Traumatic knee lesions were recorded by our ultrasound specialist and scored for: ACL tears (total and partial), medial/lateral meniscus injuries, medial collateral ligament (MCL) injuries, LFC (lateral femur condyle) impactions and Segond avulsions. Since Segond fractures are related to ACL trauma [7], only patients with either a partial or total ACL tear were included for further analysis. To evaluate the predictive value previously enumerated knee injuries, in relation to the Segond avulsion, associations between these lesions were calculated. The association between a combined group of knee injuries and the Segond avulsion was determined to evaluate which group of variables have the most predictive value.

The type of sports activities during the trauma was assessed with the Innsbruck Knee Sports Rating Scale and examined whether this variable affected the risk of Segond fractures. Based on the demands of these sports for knee stability, they are classified into two categories: low-risk pivoting activities (e.g. running, skiing) and high-risk pivoting activities (e.g. soccer, basketball) [12].

Fig. 4 An LFC impaction (*red circle*) diagnosed with radiography in the lateral plane of the knee

Statistical analysis

All recorded data of the patients' reports were transferred to a standard Excel spreadsheet (Microsoft Corp, Redmond, Washington, USA). SPSS software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, version 21.0. Armonk, NY: IBM Corp.) was used for the statistical analysis (results were considered statistically significant at $p < 0.05$):

1. The associations between single knee injuries and Segond fractures were examined using crosstabs. Using this method, the Cramér's V was calculated as a measure of association between the independent variable and the Segond fracture.
2. A binary logistic regression was performed to assess the odds ratio and the significance of each variable. Furthermore, the associations between multiple predicting variables and the Segond avulsion were examined. To assess each variable's contribution and its significance to these group associations, a block model was built. From these outcomes, a group of variables, which all influence the prediction of the Segond avulsion, was formed. The Nagelkerke *R* square was calculated as a way to quantify the fit of this group of variables and the association with the Segond fracture.
3. In order to determine the differences in risk of having a Segond avulsion between the two types of sports categories, crosstab and binary logistic analysis was performed. The numbers in the low-risk pivoting sports category were not sufficient to perform a binary logistic regression. Therefore, only the associations of individual predicting variables for the high-risk group were evaluated. Power analysis showed a minimum required sample size of 64 cases. This calculation was performed with the prediction of three times more prevalence of Segond fracture found with ultrasound in ACL injury (18 vs. 6%).

Results

In a total of 87/138 (63%) of all the examined knees, an anterior cruciate ligament injury was recorded. Of 87, 44 (51%) had a partial ACL tear while 43/87 (49%) showed a complete ACL rupture with dynamic ultrasound examination. A Segond fracture (usually 6–9 mm) was observed in 25/87 (29%) recorded cases with an ACL tear.

A total of 18/65 (28%) of the patients that injured their ACL during high-risk pivoting sports had a Segond fracture, while 7/22 (32%) of the ACL injuries during low-risk pivoting sports were combined with a Segond fracture. Most Segond fractures in the high-risk pivoting group were sustained during soccer 10/25 (40%) and in the low-risk pivoting group during alpine skiing 7/25 (28%).

Individual associations

Of all tested variables, an LFC impaction is the most positive predictor, with the highest measured association in relation to the Segond fracture and a high level of significance: $p = 0.000$. The Cramér's V value of 0.433 indicates a strong association [14]. Other variables are given in Table 1. In Tables 2 and 3, the prevalence is divided for high- and low-risk sports injuries.

Combined associations

Of all the diagnosed knee injuries, the Segond avulsion has a high correlation to the LFC impaction. The Cramér's V is strongly significant: $p = 0.000$. Selection of the prominent insignificant variables was performed by assessing their value in the grouped variables analysis [Table 4]. In the prediction model, LFC impaction was found to be an essential contributor in predicting a Segond avulsion. The

Table 1 Prevalence of different knee injuries (i.e. LFC impaction, total ACL tear, MCL injury, medial meniscal injury and lateral meniscal injury), prevalence of a Segond fracture in case of the presence of knee injury, and the extent of association between different knee injuries and the presence of a Segond fracture (Cramér's V with *p* value) in the total population

Knee injuries	Prevalence of injury (% of total)	Prevalence of Segond fracture (% knee injury)	Cramér's V	*p* value
LFC impaction	40 (46)	20 (50)	0.433	0.000
Total ACL tear	44 (51)	18 (41)	0.272	0.011
MCL injury	26 (30)	8 (31)	0.029	n.s.
Lateral meniscal injury	33 (38)	13 (39)	0.184	n.s.
Medial meniscal injury	66 (76)	21 (39)	0.121	n.s.

n.s. not significant

Table 2 High-risk group: prevalence of different knee injuries (i.e. LFC impaction, total ACL tear, MCL injury, medial meniscal injury and lateral meniscal injury), prevalence of a Segond fracture in case of the presence of knee injury, and the extent of association between different knee injuries and the presence of a Segond fracture (Cramér's V with *p* value) in the high-risk pivoting sports subgroup

Knee injuries	Prevalence of injury (% of total)	Prevalence of Segond fracture (% knee injury)	Cramér's V	*p* value
LFC impaction	29 (45)	13 (45)	0.344	0.006
Total ACL tear	32 (49)	11 (34)	0.147	n.s.
MCL injury	17 (26)	5 (29)	0.023	n.s.
Lateral meniscal injury	28 (43)	11 (39)	0.225	n.s.
Medial meniscal injury	50 (78)	15 (30)	0.094	n.s.

n.s. not significant

Table 3 Low-risk group: prevalence of different knee injuries (i.e. LFC impaction, total ACL tear, MCL injury, medial meniscal injury and lateral meniscal injury), prevalence of a Segond fracture in case of the presence of knee injury, and the extent of association between different knee injuries and the presence of a Segond fracture (Cramér's V with *p* value) in the low-risk pivoting sports subgroup

Knee injuries	Prevalence of injury (% of total)	Prevalence of Segond fracture (% knee injury)	Cramér's V	*p* value
LFC impaction	11 (50)	7 (63)	0.683	0.01
Total ACL tear	12 (55)	7 (58)	0.624	0.03
MCL injury	9 (41)	3 (33)	0.027	n.s.
Lateral meniscal injury	5 (23)	2 (40)	0.095	n.s.
Medial meniscal injury	16 (73)	6 (38)	0.199	n.s.

n.s. not significant

Table 4 Prediction model of Segond fracture, odds ratio, *p* value, 95% confidence interval and Nagelkerke *R* square for the total patient group

Prediction model total patient population—backward selection procedure							
	B	S.E.	OR	*p* value	95% CI of OR		Nagelkerke *R* square
					Lower	Upper	
LCF impaction	2.128	0.569	8400	0.000	2754	25.624	0.255
Constant	−2.128	0.473	0.119	0.000			

Dependent variable = presence of Segond fracture

Removed: total ACL tear, MCL injury, medial meniscal injury and lateral meniscal injury

B slope, *S.E.* standard error, *OR* odds ratio, *p-value* level of significance, *CI* confidence interval

numbers for single and combined results of this new variables group are shown in Table 4.

Discussion

The most significant finding is a higher prevalence of Segond fractures identified by ultrasound compared to reported fractures in earlier studies using MRI or radiographs.

In this study, 25/87 (29%) of all patients with acute injury of ACL, ultrasound detected a Segond avulsion. With ultrasonography, the prevalence was four times higher compared to the 3–6% diagnosed with MRI by several authors [1, 2, 5, 26] and three times higher to the 9% diagnosed with radiography, as reported by Hess et al. [17].

Ultrasound is used more frequently the past few years in imaging soft tissue injuries. It has several advantages in acute injuries with swelling and haematoma. Small bony lesions can be detected in fluid and are displaced in larger magnification. Several studies show that the ALL (complex) can be visualized by ultrasound [3, 4, 21], but the prevalence of the Segond avulsion lesion and other lesions of the ALL complex was not published up till now to the best of our knowledge. Surgical exploration and classification by Ferretti et al. in open lateral surgery indicate that many lesions on the lateral site (prevalence 90%) are difficult to diagnose with imaging. Ferretti is advocating primary repair in combination with ACL reconstruction in acute setting [11]. Sonnery Cottet is advocating combined ACL and ALL reconstruction [24].

Patients who rupture their ACL in combination with a LFC impaction are more prone to have a Segond avulsion, since a strong association has been found between these two injuries (Cramér's V = 0.433). If the LFC impaction was sustained during a high-risk pivoting sport, the predicting value gave a lower outcome of this injury in relation to a Segond avulsion (Cramér's V = 0.344). Contrary to the high-risk pivoting sport group, evaluation of the low-risk pivoting sport group showed stronger association between these injuries (Cramér's V = 0.683). In the multiple variables analysis, the LFC impaction was prominently associated with a Segond avulsion.

Insufficiencies in MRI are explained by swelling and haematoma of the knee in the acute stage. Literature reports low prevalence in MRI and radiographs in diagnosis of Segond fractures. Some reports have included detailed analysis of ALL complex lesions but without the prevalence and the analysis of false negative/false positive findings [2, 11, 15, 20]. In radiography, the quality of imaging, insufficiency of clinical information, direction of projection and the size of the fracture affect the accuracy of diagnosing osseous injuries. Considering the small size of the Segond avulsions (usually 6–9 mm) and the compact capsular structures which confine the avulsion, prevalence is expected to be higher in the ultrasound diagnosis. The strong link between ACL lesions, LFC impactions and Segond fractures suggests rotation of the knee as main cause. The pivoting of the knee, which occurs during these accidents and causes a combination of a LFC impaction and a Segond fracture, is schematically pictured in Fig. 5. The association between the valgus and internal rotational movement of the tibia and a Segond avulsion has been examined and described extensively [2, 13]. The reported associations are based on the strong relation between an ACL tear, caused by high rotational forces in the knee, and the Segond fracture. To our knowledge, no study has checked associations between any other mechanism of knee injury and

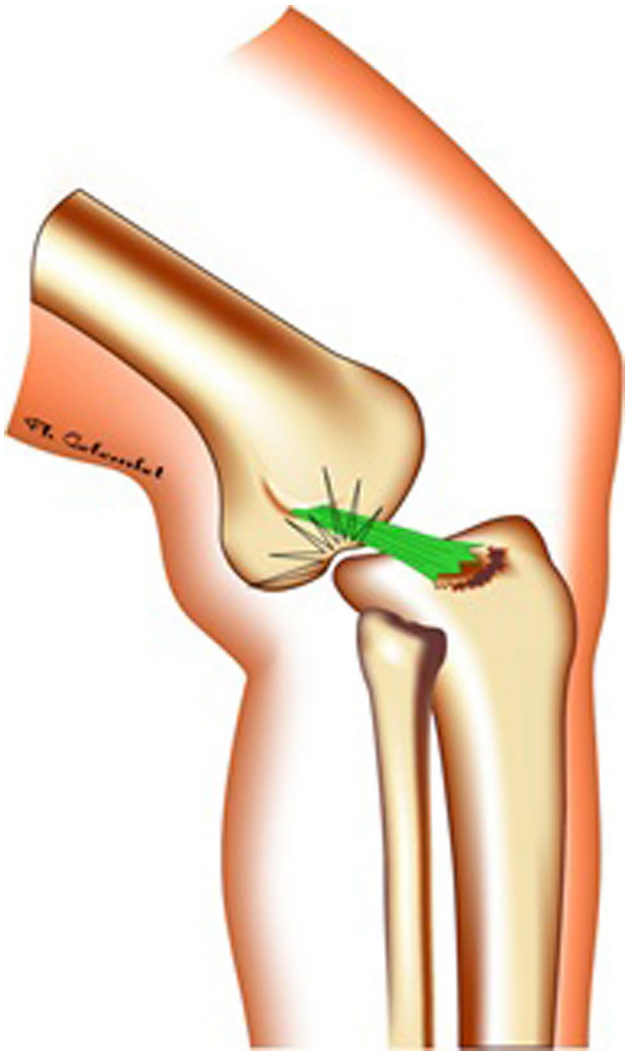

Fig. 5 A simplified representation of the relation between an LFC impaction and a Segond avulsion in high-rotational knee trauma

a Segond avulsion. Our data indicate internal rotational pivoting of the knee as the cause of these fractures, due to high associations with LFC impactions. The possible association with a MCL injury suggests association between an excessive valgus movement of the knee and a Segond avulsion in selected cases. While an internal rotation of the tibia is the main cause of a Segond fracture from an anatomical and pathogenic stand point, a combined valgus and internal rotation trauma could explain the combination of MCL and Segond avulsion lesions in selected cases.

Previous work shows that high-risk pivoting sports are positively associated with the presence of an LFC impaction [16]. This association indicates an increased rotational trauma mechanism during these sport injuries. Controversially, our study shows that in low-risk pivoting sports Segond avulsions are relatively more frequent than in high-risk pivoting sports. The possible combination with MCL injury supports this theory (Tables 2, 3). Further trauma and biomechanical analysis has to be performed to support these conclusions.

The main limitation of this study was the limited amount of examined knee reports. The test groups, once divided into the different sports categories, showed insufficient numbers to perform a binary logistic regression and to evaluate the combined associations. Furthermore, the knee trauma of all individual cases was not reported with a clear protocol. The scoring was based on the ultrasound specialist interpretation of the injuries, rather than on general pathogenic definitions. The weakness of this study is that the numbers are correlated with other patients groups reported in the literature for Segond lesions. In these reported groups, other injuries mechanisms and sports participation can produce different prevalence. A prospective study with radiographs, MRI and ultrasound used on the same knee injuries could be a next-level investigation. Future studies should focus on the intraoperative findings to confirm the imaging diagnosis and explore the possibilities to restore function and stability. Recent studies have advocated ALL reconstruction and repair [11] and found reduced ACL graft rupture rates at follow-up of 2 years [24].

Campos et al. [2] and Goldman et al. [13] reported residual laxity in the natural healing of Segond fractures. Malunion of the Segond fractures was reported by Bock et al. [1].

Segond fractures might have major consequences for knee stability due to ligamentous avulsion of the ALL complex [9, 10]. Reconstruction or refixation of the ALL is an option to restore the anterolateral stability of the knee to the pre-injury level. Although the consequences of Segond fractures may be severe, the optimal treatment is questionable. A study to look at the possibilities for and advantages of refixation of the distal ALL avulsion lesions/Segond fractures is needed.

Conclusion

The results from this study show a much higher prevalence of Segond fracture than previously reported in MRI and radiography. Dynamic ultrasound should be considered as additional imaging modality in acute knee diagnostics. To predict a Segond avulsion, an LFC impaction shows the best association with this fracture. LFC impaction fracture is a strong indicator for a Segond avulsion and should initiate ultrasound imaging after initial radiography and MRI.

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Compliance with ethical standards

Conflict of interest Author Klos, Author Konijnenberg and Author Scholtes declare that they have no conflict of interest.

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Ethical approval Approval for the study was obtained by the Medical Ethical Committee of Maastricht University Medical Center (METC 15-4-067).

Informed consent For this type of study formal consent is not required.

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