Three-dimensional Magnetic Resonance Imaging of the Anterolateral Ligament of the Knee: An Evaluation of Intact and ACL Deficient Knees from the XXXXXXX.

Abstract

Purpose: ~~To characterize the normal anterolateral ligament (ALL) and the spectrum of ALL injury in anterior cruciate ligament (ACL) deficient knees on early and delayed three dimensional magnetic resonance imaging (3D-MRI).~~The aim of this study was to determine the visualisation rate of the ALL in uninjured and ACL deficient knees when using 3D-MRI. In addition, it was sought to characterize the spectrum of ALL injury in acute and chronically ACL deficient knees, and also to determine the inter and intra-observer reliability of a 3D-MRI classification of ALL injury.

Methods: 100 knees underwent 3D-MRI (60 with ACL rupture and 40 non-injured knees). The ALL was evaluated ~~based on previous studies regarding this structure and on known structural parameters. Evaluation was performed~~ by two blinded orthopaedic surgeons. The ALL was classified as Type A: continuous, clearly defined low-signal band, Type B: with warping, thinning, or iso-signal changes, Type C: without clear continuity. Comparison between acute (<1 month) and chronically ACL injured knees was evaluated as well as intra and inter-observer reliability.

Results: Complete visualisation of the full path of the ALL was achieved in all non-injured knees. In the ACL injured group, 24 acutely injured knees were imaged: 87.5% showed evidence of injury (3 knees were normal/Type A (12.5%), 18 Type B (75.0%), and 3 Type C (12.5%)). 36 knees chronically ACL injured knees were imaged: 55.6% showed evidence of injury (16 Type A (44.4%), 18 Type B (50.0%), and 2 Type C (5.6%)). The difference in the rate of injury between the two groups was significant (p = 0.03). Multivariate analysis demonstrated that the delay from ACL injury to MRI was the only factor (negatively) associated with the rate of injury to the ALL. Inter- and intra-observer reliability of the classification of ALL type were good (kappa 0.86 and 0.93 respectively).

Conclusion: 3D-MRI allows full visualisation of the ALL in all knees. The rate of injury to the ALL in acutely ACL injured knees identified on 3D-MRI is higher than previous reports using standard MRI techniques. This rate is significantly higher than the rate of injury to the ALL identified in chronically ACL injured knees.

Level of Evidence: IV, Diagnostic, case control study

Introduction

Recent study has demonstrated that combined anterior cruciate ligament (ACL) and anterolateral ligament (ALL) reconstruction is associated with significantly reduced graft rupture rates at medium term follow-up when compared to isolated ACL reconstruction in young patients participating in pivoting sports.[1] However, the precise indications for combined ACL and ALL reconstruction are not yet clearly defined. Biomechanical studies have shown that isolated ACL reconstruction does not restore normal knee kinematics in the presence of anterolateral injury.[2] ~~Even though the healing potential of the ALL is still not known, it can be suggested~~ It may therefore be the case that the patients most likely to benefit from the addition of an extra-articular procedure are those that have demonstrable injury to the ALL on pre-operative imaging.

The ability of magnetic resonance imaging (MRI) to reliably delineate the anatomy of the ALL in injured and normal knees is controversial. Very broad ranges of visualisation of the ALL are reported (full visualisation 11-100%[3,4], partial visualisation 11.5 – 48.5%[5,6], and non-visualisation 0-49%)[3,4]. Despite this apparent lack of reliability, ALL tears have been demonstrated in 32.6-78.7% of ACL injured knees when using MRI.[7,8] Unfortunately, there are no published studies comparing imaging and open exploration. However, it appears that MRI may lack sensitivity as Ferretti et al reported a much higher rate (approximately 90%) of injury to the anterolateral structures at open surgical exploration of ACL injured knees than the aforementioned imaging studies.[9]

The variation in rates of successful identification of the ALL on MRI prevent a high level of confidence in current imaging of this structure. The main limiting factor appears to be the same issue that has confounded anatomical studies. Namely a difficulty in clearly delineating the complex and tightly confluent structural anatomy around the lateral femoral epicondyle.[10,11,12] This is further compounded by the partial volume effect which occurs when portions of several objects are averaged together in an imaging slice. This results in an impaired spatial resolution and erroneous signal intensity. Three-dimensional MRI (3D-MRI) is a technique that provides 3D data that enables the reconstruction of two-dimensional images in any section and the creation of thin-slice images within a short time. It therefore potentially enables delicate structures such as the ALL to be more clearly visualized.[13] Yokosawa et al. reported a 47% rate of visualization of the ALL with conventional 2D-MRI (T2W, slice thickness 4mm) in 32 healthy knees compared to 100% when using 3D-MRI (T2W-SPACE, slice thickness 1mm).[13] Similarly, Klontzas et al reported that when using 2D images the ALL could not be visualised on any of the sagittal sequences. In contrast it could be visualised in all cases when using 3D MRI. [14] The utility of 3D MRI in the evaluation of other extra-articular knee ligaments has also been reported. Ahn et al stated that the results of their imaging study suggested that tears of the individual structures of the posterolateral corner were better defined with 3D rather than 2D images.[15]

The aim of this study was to determine the visualisation rate of the ALL in uninjured and ACL deficient knees when using 3D-MRI. In addition, it was sought to characterize the spectrum of ALL injury in both acute and chronically ACL deficient knees, and also to determine the inter and intra-observer reliability of a 3D-MRI classification of ALL injury. The hypothesis of this study was that 3D-MRI would allow full visualisation of the ALL in all non-injured knees and good inter and intra-observer reliability (kappa 0.61-0.8)[16] of the determination of injury in ACL deficient knees.

Patients and Methods

The study received institutional review board approval and all participants gave valid consent to participate. No financial incentives were provided.

Patient recruitment to the study was performed between May 2015 to June 2016. Enrolled patients were allocated to either the "injured knee" or "non-injured knee" groups. All patients with ACL rupture (confirmed by MRI and clinical examination) who had instability during their daily activities or sport, and had been scheduled for ACL reconstruction, were screened for study eligibility. Patients were only excluded if they had concomitant multi-ligament injury, advanced osteoarthritis, or had undergone previous ipsilateral knee ligament surgery. All patients in this group underwent pre-operative assessment that included Lysholm score, IKDC evaluation and side-to-side laxity difference (KT1000) evaluation.

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For the "non-injured" knee group, consecutive patients were invited to participate in the study if they were undergoing knee MRI for indications other than clinical diagnoses of ACL and/or meniscal tear. In addition, members of staff from the primary institution were invited to volunteer to participate in the "non-injured" knee group if they were asymptomatic and had no previous history of knee pathology.

Three Dimensional 3.0 T-MRI Scanner Evaluation

Three-dimensional imaging was carried out with a small, 4-channel flex coil, 3.0T MRI scanner (Magnetom Trio, Siemens, Erlangen, Germany) following sampling perfection with application of optimized contrasts using a different flip angle evolution (SPACE) protocol. The imaging conditions used were proton density-weighted (PDW) SPACE imaging, with repetition time (TR) 1000ms, echo time (TE) 37ms, flip angle (FA) variable, number of excitations (NEX) 1.4, matrix 320 × 300, bandwidth (BW) 539 Hz, field of view (FOV) 156 mm^2, slice thickness 0.5 mm, and a scan time of 3 minutes 38 seconds.

The section passing through the centre of the lateral epicondyle of the femur and the midpoint of a line joining the posterior margin of Gerdy's tubercle on the lateral condyle of the tibia with the anterior margin of the fibula head was used as the reference section. Coronal cross-sectional images were reconstructed for a total of 50–60 slices, with a slice thickness of 0.5 mm in front of and behind this plane. The knee was positioned and supported in 30 degrees of flexion for the duration of the scan.

Imaging Evaluation

The assessment of images was performed by two independent orthopaedic surgeons (X and Y) who had greater than 12 years of experience in interpreting MR imaging of the knee in their daily practice. Both also performed a detailed review of the literature in order to gain a thorough understanding of MRI evaluation of the ALL. In the "non-injured" knee group, images were assessed in order to characterise the normal ALL on 3D MRI. The key characteristics recorded were the rate of full visualisation of the ALL, the precise location of the femoral origin and the ability to differentiate the femoral origin from adjacent structures.

For assessment of the "injured knee" group, the evaluators were blinded to physical examination findings and the history of acute or chronic injury~~patients were in the early or late imaging groups~~. The images were evaluated on the basis of the classification system described below and these assessments were performed twice, with a period of 2 weeks between test and retest evaluations. Intra-and inter observer reliability was determined.

ALL Classification

The ALL was defined as the low signal band originating from the region of the lateral epicondyle of the femur, crossing the proximal surface of the lateral collateral ligament (LCL), and reaching the middle third of the lateral tibial plateau (Fig 1.). In order to describe the spectrum of injury, the appearance of the ALL was categorised (Fig 2.) as follows: Type A; ligaments visualized as a continuous, clearly defined low-signal band, Type B; those that exhibited warping, thinning, or iso-signal changes, and Type C; those without clear continuity.

Statistical analyses

All calculations were made using SPSS software (Version 20.0, SPSS Inc., Chicago, IL). The Chi^2 test and Fisher's exact test were used to compare proportions and the Kruskall-Wallis test was used to compare medians. Bivariate and multivariate analyses were performed in order to determine whether any of the demographic or injury descriptive variables were significantly associated with the ALL classification grade~~Bivariate and multivariate analyses were conducted to test associations between the classification type of the ALL and potentially important factors~~. For all variables, results with a p value of <0.05 were considered statistically significant. Inter- and intra-observer agreement were evaluated using the Kappa test with a 95% confidence interval.

Results

Between May 2015 and January 2016, 100 patients met the eligibility criteria and were enrolled to the study ("injured knee" group; n=60, "non-injured" knee group; n=40). The demographics of patients in the injured knee group (including age, gender and time between injury and imaging) are presented in Table 1. ~~Other than the time elapsed from injury to imaging, t~~There were no significant differences between the two groups with respect to ~~concomitant injury and~~ pre-operative scores and the incidence of concomitant injuries. ~~In this~~The injured cohort group included 24 acutely ACL injured knees that underwent 3D-MRI within one month of the date of injury ~~and were defined as the early imaging group~~ (mean time to scan from date of injury = 5.3 days, range 0 – 28 days). The remaining ~~, and the other~~ 36 knees in the injured cohort group were chronically ACL injured and were imaged ~~beyond~~ later than 1 month from the date of injury (mean time to scan from date of injury = 45.3 months, range 1– 240 months).

"Non-Injured" Knee Group

In the non-injured group, 10 healthy volunteers were imaged and the remaining 30 knees underwent MRI for knee pain unrelated to sports or trauma (plica synovialis n=4, tumour n=3, bursitis n=2, without obvious lesion n=21). The mean age of patients in this group was 29.1 years (range 13-50 years). There were 25 male and 15 female participants

The visualization rate of the full length of the ALL was 100%. In 13/40 knees (32.5%) the ALL could clearly be seen originating proximal and posterior to the lateral epicondyle and in 12 knees (30.0%) the ALL was identified as originating distal and anterior to the origin of the LCL, close to the center of the lateral epicondyle. Both types were visualized simultaneously in 15 knees (37.5%), which was the most common variation (Figure 3). In 11 knees (27.5%), the border of ALL and iliotibial band (ITB) or the border of ALL and LCL were indistinct.

"Injured Knee" Group

Table 1 reports the demographic and clinical data of patients in the injured knee group. This demonstrates that the ~~early and delayed imaging groups~~acute and chronically ACL injured knee groups were broadly comparable with no significant differences in demographic data, Lysholm score, IKDC, side-to-side laxity difference or type of concomitant meniscal pathology.

The ALL was also visualised in all ACL injured knees. However, there were differences in the spectrum of ALL injury seen in the two subgroups. In the ~~early imaging group~~acute ACL injured group (n=24), 87.5% (21 knees) showed evidence of injury (Type B=18, and Type C=3) to the ALL. In the ~~delayed imaging~~chronically ACL injured group (n=36), only 55.6% (20 knees) showed evidence of injury (Type B=18, and Type C=2). This difference between the two groups was significant ($p = 0.02$). Both the inter-rater reliability ($\kappa = 0.86$) and the intra-rater reliability ($\kappa = 0.93$) of the 3D-MRI classification system were good (Table 2).

Multivariate analysis demonstrated that the delay from injury to MRI was associated with the rate of identification of abnormalities of the ALL. Early imaging was associated with an increased rate of identification of Types B and C ALL on 3D-MRI (OR= 0.19; CI 95%: 0.04-0.73). Other factors such as pre-operative side-to-side laxity difference, age and the presence of concomitant medial meniscal tears were not found to be associated with the rate of identification of abnormalities of the ALL (Table 4)

Discussion

The main finding of this study is that 3D MRI was able to comprehensively evaluate the full length of the ALL in all knees and that the classification system used to grade injuries had good inter- and intra-observer reliability. In contrast, previous studies using standard MRI techniques have not been able to reliably demonstrate the ALL and rates of complete evaluation have varied between 11-100%.[3,4] The main advantage of 3D-MRI is in allowing rapid acquisition of a large amount of data, in particular permitting reduced slice thickness.[13] This is particularly useful for imaging of the ALL, which is a thin structure and subject to partial volume effect due to its close proximity to the LCL, popliteus, anterolateral capsule and ITB. It is therefore unsurprising that in contrast to reports from previous authors (using standard MRI techniques)[3,5,6,11,12,17], the ALL could be identified in all knees in this study. This suggests that 3D MRI should be considered the gold standard for MR imaging evaluation of the ALL.

The failure of reliable evaluation of the ALL with standard MRI techniques has been disappointing, especially given the promising findings from early cadaveric studies. Specifically, Caterine et al[18] and Helito et al[19] were able to identify the full course of the ALL using 1.5T MRI in anatomical specimens and subjectively and objectively correlate imaging findings with dissection. It is important to note that both cadaveric studies used MRI protocols with thin slices (0.4mm and 0.6-1.5mm, respectively). In contrast, in clinical practice, a typical knee scan is performed using slice thicknesses of 3mm. Although the use of thinner slices reduces the partial volume effect, the scan duration increases significantly and therefore the use of 3mm slices is a widely accepted standard for imaging that provides high sensitivity and specificity for imaging of intra- and extra-articular structures in the acutely injured knee. However, because the ALL is a thin structure (thickness 1.4+/-0.6mm)[18], it should be expected that clinical studies using more typical slice thicknesses (particularly if an interslice gap is present) have failed to show full visualisation reliably. In previous clinical MRI series the following slice thicknesses and rates of complete visualisation have been reported: 2.5mm (Helito 71%)[11], 3mm (Devitt 20%)[20] , and 3.5mm (Macchi 54%[17], Coquart 82%)[5].

In addition to the broad reported ranges of complete visualisation, rates of partial (11.5-48%) and non-visualisation (0-49%) also show considerable variation.[3,5,6,11,12,17] In a study of 113 knees with acute ACL injury (53 knees imaged with 1.5T and 48 knees with 3T), Helito et al found that the rate of non-visualisation when using 1.5T (17%) was more than twice that of those undergoing imaging with 3T (8%).[21] Although, this was not statistically significant, likely due to small sample size, it is logical that using a stronger magnet would improve spatial resolution and reduce the non-visualisation rate arising from a partial volume effect.

Reliable identification of the ALL has also been complicated by a lack of consensus in the literature regarding its anatomy[22,23,24,25] with some authors reporting a proximal and posterior [23,25,26,27,28] origin in relation to the lateral epicondyle and others anterior and distal.[21,22,29,30] This variability in femoral origin was also demonstrated in the current study, but simultaneous visualisation of both types was also seen in 37.5% of patients. ~~To the authors knowledge this has not previously been described in any imaging study.~~ This finding is and proximal origin) and deep parts (central lateral epicondylar origin, or distal, or proximal/posterior) of the ALL in a cadaveric dissection study. The authors considered that both structures were ligamentous, on the basis of the presence of dense and well-organised collagen fibres and a similar number of fibroblasts per mm^2 as the adult ACL.[31] Other authors have also noted similar intra-specimen variations in femoral origin in anatomical studies.[17,19,28,32] In addition, it has previously been highlighted that there seems to be agreement in all published series that the femoral origin is less easily seen on imaging and also at dissection.[12]

On standard MR imaging, due to the partial volume effect, it can be difficult to clearly delineate the ALL from the LCL/ITB.[4] Helito et al reported that in some situations, when it is possible to visualise a clear differentiation between these structures, the ALL is already anterior to the LCL on its path to the tibia and this can be misconstrued as an anterior/distal origin.[33] In any case, this difficulty in clearly delineating the femoral origin when using standard imaging protocols, is one of the main reasons to consider using 3D-MRI. Porrino et al., in 53 knees, identified the ALL with MRI in all patients but described the femoral origin as inseparable from the adjacent LCL and difficult to discern.[4] Caterine et al. also reported the ability to visualize the ALL in all patients but described the proximal origin as "not clearly visible" in many patients.[18] Other studies have more explicitly reported the rate of visualization of the femoral origin (Kosy et al. 57%[12], Helito et al. 89.7%[11]). It was hypothesized that the use of 3D-MRI in the current study would allow clear visualization of the femoral origin in all cases. However, there were a small percentage of cases (11%) where the femoral origin could not be clearly differentiated from the LCL or ITB and this was attributed to the tight confluence of these structures at the lateral epicondyle rather than a pathological abnormality as this was studied in the "non-injured knee" group

The rate of identification of injury to the ALL in acute (87.5%) and chronically (55.6%) ACL injured knees was significantly different (p=0.02). A possible explanation for this difference may be that the ALL has some intrinsic potential for healing, akin to that of the medial collateral ligament, though longitudinal studies are required to evaluate this theory. An alternative possible explanation for the difference in rates of injury in the early and delayedacute and chronically ACL injured groups is that the presence of effusion in acutely knees may improve the ability to visualise the ALL and certainly this has been suggested by previous authors.[3,8,21] In fact, Helito et al, injected 40ml of saline into cadaveric knees in order to help with identification at MRI.[19] Despite that, there are no comparative studies to demonstrate that this is a proven advantage and in contrast, Hartigan et al suggested that because the ALL is extracapsular, a capsular distension may actually make visualisation more difficult.[10]

Devitt, et al. showed no significant difference in the ability to fully visualise the ALL in the ACL injured and ACL intact knees but the overall percentage of full visualisation was very low in both groups.[20] The rate of MRI identified ALL injury in ACL injured knees in previous studies varies between 32.6 to 78.7%.[7,8,21] In the current study, the rate of injury to the ALL in the early imaging group was 87.5% and this is consistent with the rate reported by Ferretti et al, at surgical exploration of the anterolateral structures at the time of ACL reconstruction.[9] The current study is the first to show concordance between the clinically reported rate of ALL injury and MR imaging findings. Almost all previous MRI studies have shown a much lower rate of injury with the only exception being Claes et al at 78.7%.[7] In contrast, Helito et al, identified a rate of ALL injury in knees with an acutely (<3 weeks) ruptured ACL at a rate of only 32.6%, the remaining patients either had a normal ALL (54.4%) or it was considered not adequately visualized (12.8%).[21] Helito et al reported that the rate of failure to characterize the ALL was twice as high in those patients who underwent MRI with 1.5T compared to 3.0T and this may also be an explanation as to why the incidence of ALL injury identified is much lower than in the current study. It is also important to note that although some authors have reported high rates of visualisation of the ALL with standard imaging techniques, this does not necessarily equate to the ability to reliably diagnose an injury to the ALL. An example of this is the study by Hartigan, et al. who reported 100% visualisation of the ALL but poor inter-observer reliability regarding determination of whether the structure was injured or not (Kappa statistics: femoral insertion 0.14, tibial insertion 0.31, meniscal attachment 0.15).[10]

Further reasons for previous studies demonstrating a much lower rate of ALL injury in ACL ruptured knees than in the current study is that many authors have excluded patients with evidence of injury to the lateral side of knee (including lateral meniscal tears).[4,6,11,17] However, significant associations with ALL injury and injuries to the LCL, popliteus, IT band, bone contusions and lateral meniscal tears have been previously demonstrated[8,34,35] and on that basis excluding these patients would likely falsely lower the incidence of ALL injury. Although multiligament injuries were excluded in the current study, other types of lateral sided injuries were not excluded. Other considerations that may also have led to the large variations seen between previous studies includes differences in imaging protocols, experience in evaluation of the ALL, and knee position during imaging. Further work should aim to establish standardised protocols for MR imaging.

Recent study has drawn some comparison between MRI and ultrasound scan (USS) evaluation of the ALL. ~~Bilfeld~~ Cavaignac et al, reported that ultrasound was able to visualise the ALL in all normal knees and that the rate of abnormalities detected in injured knees was higher than detected with MRI. This was attributed to the higher spatial resolution of ultrasound and the fact that it is a dynamic investigation during which the ALL can be placed under tension. However, the MRI sequences were performed in a strict coronal plane and it was highlighted that the use of 3DMRI may have increased the rate of detection of injuries. One of the disadvantages of USS is that it is highly operator dependent but further study is required to determine whether one modality has a significant advantage over the other. It is interesting to note that Cavaignac et al demonstrated that there was a significant association with USS proven ALL abnormality and high grade pivot shift but only a trend towards this with standard 2D MRI~~In addition, the authors reported that in ACL injured knees there was a strong correlation between both standard MRI and ultrasound with respect to the pathological appearance of the ALL~~.[36] ~~Future study should also aim to compare ultrasound, which has a higher spatial resolution than standard MRI, with 3D-MRI.~~

Limitations

The main limitations of this study are that the MRI findings were not correlated with surgical exploration of the anterolateral structures or with the grade of pivot shift and that no specific 3DMRI protocol exists for evaluation of the ALL. This means that the possibility that the higher rate of injury detection being a result of false positive diagnoses cannot be excluded, although this seems unlikely due to the high inter-observer reliability. Therefore, the findings of this study cannot be extrapolated to demonstrating that all 3DMRI abnormalities of the ALL are clinically important. Additional limitations include the number of patients enrolled to the study (n=100), but this is larger than many of the previous studies on the same topic. However, it does mean that the population size may be too small to determine a reliable estimate of the rate of injury to the ALL. An additional~~A final~~ limitation is that there was no longitudinal component to this study. ~~This means that~~As a result even ~~al~~though a difference in the rate of ALL injury in acute and chronically ACL injured knees has been demonstrated, further study will be required to determine the pathophysiology behind these findings. Furthermore, the influence of including injuries that were several years old (and more likely to have developed secondary restraint lesions) on the rate of identified ALL injury in the chronic group cannot be determined in the current study.

Conclusion

3D-MRI allows full visualisation of the ALL in all normal knees. The rate of injury to the ALL in acutely ACL injured knees identified on 3D-MRI is higher than previous reports using standard MRI techniques. This rate is significantly higher than the rate of injury to the ALL identified in chronically ACL injured knees.

References

1. Sonnery-Cottet B, Saithna A, Cavalier M, et al. Anterolateral Ligament Reconstruction Is Associated With Significantly Reduced ACL Graft Rupture Rates at a Minimum Follow-up of 2 Years: A Prospective Comparative Study of 502 Patients From the SANTI Study Group. Am J Sports Med 2017;45:1547-1557.
2. Inderhaug E, Stephen JM, Williams A, Amis AA. Biomechanical Comparison of Anterolateral Procedures Combined With Anterior Cruciate Ligament Reconstruction. Am J Sports Med 2017;45:347-354.
3. Taneja AK, Miranda FC, Braga CA, Gill CM, Hartmann LG, Santos DC, Rosemberg LA. MRI features of the anterolateral ligament of the knee. Skeletal Radiol 2015;44:403-410.
4. Porrino J Jr, Maloney E, Richardson M, Mulcahy H, Ha A, Chew FS. The anterolateral ligament of the knee: MRI appearance, association with the Segond fracture, and historical perspective. Am J Roentgenol 2015;204:367-373.
5. Coquart B, Le Corroller T, Laurent PE, Ollivier M, Pradel V, Champsaur P, Guenoun D. Anterolateral ligament of the knee: myth or reality? Surg Radiol Anat 2016;38:955-962.
6. Helito CP, Demange MK, Helito PV, et al. Evaluation of the anterolateral ligament of the knee by means of magnetic resonance examination. Rev Bras Ortop 2015;50:214-219.
7. Claes S, Bartholomeeusen S, Bellemans J. High prevalence of anterolateral ligament abnormalities in magnetic resonance images of anterior cruciate ligament-injured knees. Acta Orthop Belg 2014;80:45-49.
8. Van Dyck P, Clockaerts S, Vanhoenacker FM, et al. Anterolateral ligament abnormalities in patients with acute anterior cruciate ligament rupture are associated with lateral meniscal and osseous injuries. Eur Radiol 2016;26:3383-3391.
9. Ferretti A, Monaco E, Fabbri M, Maestri B, De Carli A. Prevalence and classification of

injuries of anterolateral complex in acute anterior cruciate ligament tears. Arthroscopy 2016;33:147-154.

10. Hartigan DE, Carroll KW, Kosarek FJ, Piasecki DP, Fleischli JF, D'Alessandro DF. Visibility of anterolateral ligament tears in anterior cruciate ligament deficient knees with standard 1.5-tesla magnetic resonance imaging. Arthroscopy 2016;32:2061–2065.
11. Helito CP, Helito PV, Costa HP, et al. MRI evaluation of the anterolateral ligament of the knee: assessment in routine 1.5-T scans. Skeletal Radiol 2014;43: 1421-1427.
12. Kosy JD, Mandalia VI, Anaspure R. Characterization of the anatomy of the anterolateral ligament of the knee using magnetic resonance imaging. Skeletal Radiol 2015;44:1647-53
13. Yokosawa K, Sasaki K, Muramatsu K, Ono T, Izawa H, Hachiya Y. Visualization of anterolateral ligament of the knee using 3D reconstructed variable refocus flip angle-turbo spin echo T2 weighted image. Nihon Hoshasen Gijutsu Gakkai Zasshi 2016;72:416-23.
14. Klontzas ME, Maris TG, Zibis AH, Karantanas AH. Normal Magnetic Resonance Imaging Anatomy of the Anterolateral Knee Ligament With a T2/T1-Weighted 3-Dimensional Sequence: A Feasibility Study. Can Assoc Radiol J 2016;67:52-9.
15. Ahn SJ, Jeong YM, Lee BG, Sim JA, Choi HY, Kim JH, Lee SW. Using three-dimensional isotropic SPACE MRI to detect posterolateral corner injury of the knee. Acta Radiol. 2016 Oct;57(10):1251-60.
16. Altman, DG. Practical Statistics for Medical Research. London: Chapman & Hall, 1991
17. Macchi V, Porzionato A, Morra A, et al. The anterolateral ligament of the knee: a radiologic and histotopographic study. Surg Radiol Anat 2016;38:341-348.
18. Caterine S, Litchfield R, Johnson M, Chronik B, Getgood A. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. Knee Surg Sports Traumatol Arthrosc 2015;23:3186-3195.

19. Helito CP, Helito PV, Bonadio MB, et al. Correlation of Magnetic Resonance Imaging With Knee Anterolateral Ligament Anatomy: A Cadaveric Study. Orthop J Sports Med 2015;3:2325967115621024.
20. Devitt BM, O'Sullivan R, Feller JA, Lash N, Porter TJ, Webster KE, Whitehead TS. MRI is not reliable in diagnosing of concomitant anterolateral ligament and anterior cruciate ligament injuries of the knee. Knee Surg Sports Traumatol Arthrosc 2017;25:1345-1351.
21. Helito CP, Helito PV, Costa HP, Demange MK, Bordalo-Rodrigues M. Assessment of the Anterolateral Ligament of the Knee by Magnetic Resonance Imaging in Acute Injuries of the Anterior Cruciate Ligament. Arthroscopy 2017;33(1):140-146.
22. Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. Anatomy of the anterolateral ligament of the knee. J Anat 2013;223:321-328.
23. Dodds AL, Halewood C, Gupte CM, Williams A, Amis AA. The anterolateral ligament: anatomy, length changes and association with the Segond fracture. Bone Joint J 2014;96:325-331.
24. Helito CP, Demange MK, Bonadio MB, et al. Anatomy and histology of the knee anterolateral ligament. Orthop J Sports Med 2013;1:2325967113513546.
25. Rasmussen MT, Nitri M, Williams BT, et al. An in vitro robotic assessment of the anterolateral ligament, part 1: secondary role of the anterolateral ligament in the setting of an anterior cruciate ligament injury. Am J Sports Med 2016;44:585-592.
26. Kennedy MI, Claes S, Fuso FA, et al. The anterolateral ligament: an anatomic, radiographic, and biomechanical analysis. Am J Sports Med 2015;43:1606-1615.
27. Lutz C, Sonnery-Cottet B, Niglis L, Freychet B, Clavert P, Imbert P. Behavior of the anterolateral structures of the knee during internal rotation. Orthop Traumatol Surg Res 2015;101:523-528.
28. Daggett M, Ockuly AC, Cullen M, et al. Femoral origin of the anterolateral ligament: an

anatomic analysis. Arthroscopy 2016;32:835-841.

29. Vincent JP, Magnussen RA, Gezmez F, et al. The anterolateral ligament of the human knee: an anatomic and histologic study. Knee Surg Sports Traumatol Arthrosc 2012;20:147-152.

30. Heckmann N, Sivasundaram L, Villacis D, et al. Radiographic landmarks for identifying the anterolateral ligament of the knee. Arthroscopy 2016;32:844-848.

31. Helito CP, do Amaral C Jr, Nakamichi YD, et al. Why Do Authors Differ With Regard to the Femoral and Meniscal Anatomic Parameters of the Knee Anterolateral Ligament?: Dissection by Layers and a Description of Its Superficial and Deep Layers. Orthop J Sports Med 2016;4:2325967116675604.

32. Runer A, Birkmaier S, Pamminger M, et al. The anterolateral ligament of the knee: a dissection study. Knee 2016;23:8-12.

33. Helito CP, Helito PVP. Magnetic Resonance Imaging Analysis of the Anterolateral Complex of the Knee. Oper Tech Orthop 2017;27:113-120.

34. Helito CP, Helito PVP, Leão RV, Demange MK, Bordalo-Rodrigues M. Anterolateral ligament abnormalities are associated with peripheral ligament and osseous injuries in acute ruptures of the anterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc 2017;25:1140-1148

35. Song GY, Zhang H, Wang QQ, Zhang J, Li Y, Feng H. Bone Contusions After Acute Noncontact Anterior Cruciate Ligament Injury Are Associated With Knee Joint Laxity, Concomitant Meniscal Lesions, and Anterolateral Ligament Abnormality. Arthroscopy 2016;32:2331-2341

36. Cavaignac E, Faruch M, Wytrykowski K, Constant O, Murgier J, Berard E, Chiron P. Ultrasonographic Evaluation of Anterolateral Ligament Injuries: Correlation With Magnetic Resonance Imaging and Pivot-Shift Testing. Arthroscopy 2017;33:1384-1390

Figure Legends

Figure 1. Coronal cross-sectional images along the course of the ALL scanned by PDW-SPACE in a 19-year-old woman (5 days after ACL injury). The ALL can be visualized clearly as the low-signal band originating proximal and posterior to the lateral epicondyle of the femur, crossing the proximal surface of the LCL, and reaching the middle third of the lateral condyle of the tibia. (1.Anterolateral ligament, 2.Lateral femoral epicondyle, 3.Lateral collateral ligament, 4.Deep layer of iliotibial band, 5.Superficial layer of iliotibial band, 6.Popliteus tendon, 7.Capsule, 8.Lateral meniscus)

Figure 2. Injury classification of the ALL in ACL deficient knees demonstrated on coronal cross sectional images (Type A: Normal ALL: Visualized as a continuous, clearly defined low-signal band, Type B: Abnormal ALL: Demonstrates warping, thinning, or iso-signal changes, Type C: Abnormal ALL: No clear continuity)

Figure 3. Visualization status of the ALL in non-injured knees demonstrated on coronal cross sectional images. The femoral origin of the ALL was observed to be proximal and posterior to the lateral epicondyle of the femur in 13/40 knees (32.5%). In 12 knees (30.0%), the femoral origin was observed to be distal and anterior to the origin of the LCL in the lateral

epicondyle of the femur. Both of these subtypes types were visualised simultaneously in 15 knees (37.5%).

Table 1. Demographic and clinical data of patients included in the "Injured-knee" group

	~~Time between injury and MRI~~Chronicity of ACL Injury			
	Acute (<1 month)	Chronic (>1 month)	Total	
	n(%)	n(%)	N(%)	P*
	24 (40%)	36 (60%)	60 (100%)	
Gender				0.78
Female	9(37.5)	11(30.6)	20(33.3)	
Male	15(62.5)	25(69.4)	40(66.7)	
MRI ALL state				**0.02**
Normal (Type A)	3(12.5)	16(44.4)	19(31.7)	
Abnormal (Types B+C)	21(87.5)	20(55.6)	41(68.3)	
Meniscal state				>0.2
Patient with Meniscal tears	11(45.8)	18(50)	29(48.3)	0.96
Patient with LM tears	7(29.2)	8(22.2)	15(25)	0.76
Patients with MM tears	5(20.8)	14(38.9)	19(31.7)	0.23
KT1000				0.657
med[IQR]	4.5[4-5]	4[4-6]	4[4-6]	
Δ AP laxity (IKDC grade)				0.464
B	18(78.3)	23(65.7)	41(70.7)	
C	5(21.7)	12(34.3)	17(29.3)	
Age				0.341
med[IQR]	21.5[19.8-30.2]	28.5[20.8-40.2]	25[20-40]	
Time from injury to MRI (months)				**0.003**
med[IQR]	0.1[0-0.2]	4.5[1.5-60]	1.5[0.1-7.8]	
Lysholm				0.06
med[IQR]	70.5[43.8-82]	80[69.5-87.5]	79.5[64.2-86.2]	
IKDC				0.487
med[IQR]	60.4[46-72.4]	64.4[54-69.3]	62.6[50.6-71.3]	

Table 2: Concordance between measures (weighted kappa). An evaluation of inter- and intra-observer reliability of classification of injury to the ALL when using 3D-MRI

		95%CI	
	Estimate	Lower	Upper
Inter-observer concordance			
Weighted kappa*	0.86	0.76	0.95
Intra-observer concordance			
Weighted kappa*	0.93	0.85	1.00

* Quadratic weighting

Table 3: Bivariate analysis: Factors associated with the presence of injury to the ALL on 3D-MRI

Variables	Type of lesion A n(%) 19 (31.7%)	Type of lesion B-C n(%) 41 (68.3%)	Total N(%) 60 (100%)	P*
Sex				0.624
F	5(26.3)	15(36.6)	20(33.3)	
M	14(73.7)	26(63.4)	40(66.7)	
Side				1
L	11(57.9)	24(58.5)	35(58.3)	
R	8(42.1)	17(41.5)	25(41.7)	
Lateral Meniscus Injury				0.755
-	15(78.9)	30(73.2)	45(75)	
+	4(21.1)	11(26.8)	15(25)	
Medial Meniscus Injury				0.376
-	11(57.9)	30(73.2)	41(68.3)	
+	8(42.1)	11(26.8)	19(31.7)	
~~Delayed Imagin~~Chronicity of Injury~~g~~				**0.02**
~~No~~Acute ACL Injury	3(15.8)	21(51.2)	24(40)	
~~Yes~~Chronic ACL Injury	16(84.2)	20(48.8)	36(60)	
Any Meniscal Injury				1
-	10(52.6)	21(51.2)	31(51.7)	
+	9(47.4)	20(48.8)	29(48.3)	
KT1000				1
B	13(68.4)	28(71.8)	41(70.7)	
C	6(31.6)	11(28.2)	17(29.3)	
KT1000				0.943
A+B	13(68.4)	30(73.2)	43(71.7)	
C	6(31.6)	11(26.8)	17(28.3)	
Age				0.117
med[IQR]	28[22-42.5]	23[19-40]	25[20-40]	
mean(SD)	32.2(12.3)	28.3(11.9)	29.5(12.1)	
Time to imaging (days)				**$<10^{-3}$**

med[IQR]	5[1.8-102]	0.7[0.1-2.5]	1.5[0.1-7.8]	
mean(SD)	56.1(80.4)	13.9(42.7)	27.3(60)	
KT1000.dif				0.317
med[IQR]	5[4-6]	4[4-6]	4[4-6]	
mean(SD)	5.1(1.5)	4.8(1.9)	4.9(1.7)	
Lysholm				0.404
med[IQR]	81[67.5-86.5]	79[62-85]	79.5[64.2-86.2]	
mean(SD)	76.3(15.4)	70.1(22.5)	72(20.6)	
IKDC				0.546
med[IQR]	64.4[55.8-69.5]	62.1[46-71.3]	62.6[50.6-71.3]	
mean(SD)	62(11.1)	57.3(16.9)	58.8(15.4)	

*P=Pvalue from Fisher exact or Chi square test for categorical variables or Kruskal-Wallis test for continuous variables, Med=Median IQR=Interquartile range, SD=Standard deviation

Table 4. Multivariate analysis: factors associated with ALL lesion at MRI.

	Adjusted odds ratio (95%CI)	P
~~Delayed Imaging~~Delay between Injury and Imaging	0.19 (0.037-0.726)	**0.024**
KT1000	1.034 (0.277-4.092)	0.961
Age < 20 years	3.377 (0.72-24.928)	0.160
Presence of medial meniscus injury	0.684 (0.184-2.591)	0.569