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Assessment of Anterolateral Complex Injuries by Magnetic Resonance Imaging in Patients with Acute Rupture of the Anterior Cruciate Ligament

ABSTRACT

Purpose. To assess anterolateral complex (ALC) injuries in patients with acute anterior cruciate ligament (ACL) rupture on magnetic resonance imaging (MRI).

Methods. Patients with acute ACL rupture who underwent ACL surgery between 2015 and 2017 and had an MRI within 6 weeks of the initial trauma were included. Two radiologists assessed MR images retrospectively for the status of the ALC, including the iliotibial band (ITB), Kaplan fibers, and anterolateral ligament (ALL), as follows: Grade 0: normal, Grade 1: periligamentous edema, Grade 2: partial, and Grade 3: complete tear. The findings were analysed using a Friedman test and weighted-kappa (κ) values .

Results. Sixty-nine MRI scans were reviewed. Fifty-one % of 69 patients had associated injury of the ITB (Grade 1, n=31; Grade 2, n=4), 33% had associated injury of the Kaplan fibers (Grade 1, n=21; Grade 2, n=2), and 57% had associated injury of the ALL (Grade 1, n=12; Grade 2, n=22; Grade 3, n=5). There was a significant difference in the frequency and grading between ITB, Kaplan fiber and ALL injuries ($P \leq .032$). Inter-reader agreement for assessing the ALC on MRI was almost perfect ($\kappa \geq 0.922$).

Conclusion. Based on MRI analysis, ALL injuries were found with varying degrees of severity and intensity with noted injuries to associated surrounding fibers in patients with acute ACL rupture.

Level of evidence IV Case Series

INTRODUCTION

Recent descriptions of the anterolateral ligament (ALL)[1,2] have reignited interest in the anterolateral extra-articular structures and their potential role in controlling rotational laxity of the anterior cruciate ligament (ACL)-deficient knee.[3-5] In general, three layers are described from superficial to deep, namely, (1) the superficial iliotibial band (ITB) and the iliopatellar band, (2) the deep ITB (including the Kaplan fibers and capsulo-osseous layer), and (3) the anterolateral capsule and ALL.[6-8] The deep ITB lies posterior to the superficial ITB. [9,10] Proximally, the Kaplan fibers connect the superficial ITB with the distal femoral metaphysis and condyle, and traverse in close proximity to the superior genicular artery. [10-13] The capsulo-osseous layer of the ITB originates in the investing fascia of the lateral gastrocnemius and merges distally with the superficial ITB to insert on the lateral tibial tuberosity slightly posterior and proximal to Gerdy's tubercle. [9,10] The ALL is considered a distinct ligamentous structure[2], existing within Layer 3 according to Seebacher et al..[14] The ALL originates posterior and proximal to the lateral femoral epicondyle, and inserts onto the anterolateral aspect of the tibia midway between the fibular head and Gerdy's tubercle.[2, 15-17] Most authors refer to the anterolateral structures collectively as the "anterolateral complex" (ALC). [6-8]

Magnetic resonance imaging (MRI) is invaluable for evaluating normal anatomy and injuries to the lateral knee compartment [18]. . Thus, the purpose of this study was to assess ALC injuries in patients with acute ACL rupture on MRI. It was hypothesized that both ITB and ALL injuries would be associated with acute ACL rupture and injury and hemorrhaging would frequently be seen in the lateral supracondylar area on MR images of patients with rotatory knee trauma because Kaplan fibers exist in close proximity to branches of the superior genicular artery. [6,13]

MATERIALS AND METHODS

The study was approved by our Institutional Review Board and patient consent was not required. Patients who underwent ACL surgery at our institution between June 1, 2015, and February 15, 2017, were identified retrospectively. Inclusion criteria were acute ACL rupture for which MRI was obtained within 6 weeks of the initial trauma and subsequent ACL surgery within 90 days after the MRI. Exclusion criteria were patients with previous knee surgery, signs of arthritis, a history of previous knee infection, or patients with MRI studies subject to artifact limiting the quality of the examination.

Forty-five patients underwent knee MRI on a 3T system (Magnetom Prisma Tim, Siemens, Erlangen, Germany) and 24 patients on a 1.5T system (Magnetom Symphony Tim, Siemens, Erlangen, Germany). A routine MRI protocol was used, including axial and coronal T2-weighted (WI) fat-saturated (FS) turbo-spin-echo (TSE); coronal T1-WI TSE; and sagittal proton-density (PD)-WI TSE sequences. All images were acquired with a 160 mm field-of-view (FOV), 3 mm slice thickness (ST) and 10% interslice gap.

Two independent radiologists (with 20 and 5 years of experience in musculoskeletal radiology, respectively) assessed all MRI studies to identify ALC injuries. Associated injuries of the collateral ligaments and bone contusions on MRI were assessed by consensus and the final decision was determined by the more experienced radiologist.

On MRI, the ALC was assessed using the following criteria: The ITB was normal if a broad band of low signal could be followed over the anterolateral knee and inserting onto Gerdy's tubercle. [19] The proximal and distal Kaplan fibers were assessed approximately 68 and 48 mm proximal to the femoral condyle, respectively, with the distal fiber bundles in close proximity to branches of the superior genicular artery.[13] The Kaplan fibers were normal if low-signal-intensity fibers were seen attaching to the femur (Fig 1). The normal ALL was defined as the low-signal band originating from the region of the lateral femoral epicondyle and inserting onto the middle third of the lateral tibial plateau al.[20] . All injuries were graded, as follows: Grade 1: mild periligamentous edema with identifiable, continuous low-signal-intensity fibers;Grade 2: partial disruption or irregular contour with ligamentous edema; and Grade 3: complete disruption. Segond fractures[21] were noted and considered Grade 3 injuries.

The medial and lateral collateral ligaments were graded on MRI according to Schweitzer et al.[22] The location and grading of bone contusions was performed according to Brittberg et al.[23]

The ITB, Kaplan fiber, and ALL injuries were summarized using frequencies and were mutually compared using a Friedman test with post-hoc Bonferroni-corrected pairwise tests. Weighted-kappa (κ)-values.[24] were measured to assess inter-reader agreement of the grading of an ALC abnormality on MRI The effect of different factors (gender, type of injury or sports activity, concomitant injuries) on the outcomes was assessed by Fisher's exact test with Bonferroni-Holm correction for multiple testing. Meniscal injuries were confirmed by arthroscopy, and collateral ligament and osseous injuries were diagnosed with MRI. Analysis was performed in R software (Version 3.3.2.; R Foundation for Statistical Computing, Vienna, Austria) and SPSS 21. Statistical significance was set at $P < .05$.

RESULTS

In total, 76 patients met the inclusion criteria. The ALL could not be assessed reliably on MRI in 7 of the 76 patients, *i.e.*, three patients with MRI studies of poor quality, two patients with degenerative osteoarthritis affecting imaging of the knee's lateral compartment, and two patients without identifiable ALL in the absence of edema, who were excluded from the study. Thus, we identified a group of 69 patients (43 male and 26 female; age range:18-54 years, mean age: 29 years; right knee, n =49) as the patient population of this study. The knee injuries had been sustained playing soccer (n=25), skiing (n =18), in a fall (n=9), in a road traffic accident (bike, n=4; motor vehicle, n=2; pedestrian hit by a vehicle, n=1) , playing basketball (n = 5), during gymnastics (n= 3) and in other situations (n=2).

On MRI, thirty-five of the 69 patients (51%) had associated injuries of the ITB, 23 (33%) had associated injuries of the Kaplan fibers, and 39 (57%) had associated injuries of the ALL. (including 2patients with a Segond fracture). The findings are summarized in Tables 1-3. Nineteen (86%) of the 22 patients with a Grade 2 ALL injury and three (60%) of the 5 patients with a Grade 3 ALL injury had normal ITB and Kaplan fibers (Figs 2 and 3). There was a significant difference in the frequency and grading between ITB, Kaplan fiber and ALL injuries ($P \leq .032$). Inter-reader agreement for grading of an ALC abnormality on MRI was almost perfect ($\kappa \geq 0.922$). We found no statistically significant association between the type of knee injury or sports activity and injury to the structures of the ALC ($P \geq .094$), nor were there any gender-specific differences in the grading of ALC injuries ($P = 1$).

Twenty-six tears of the medial and 31 tears of the lateral meniscus were diagnosed by arthroscopy. Of 27 patients with Grade 2 or 3 ALL injury, 11 patients had a medial meniscal tear ($P = 1$) and 17 patients had a lateral meniscal tear ($P = .468$).

Fifty-three patients had an MCL injury (Grade 1 (n=12), Grade 2 (n=31), and Grade 3 (n=10)) and 36 patients had an injury of the LCL on MRI (Grade 1 (n=31) and Grade 2 (n=5) (Fig 4). Significant associations were found between ITB and LCL injuries ($P < .0001$), ALL and LCL injuries ($P < .0001$), and ALL and MCL injuries ($P = .016$).

The location and grading of bone contusions on MRI is summarized in Table 4. There was a significant association of bone contusions at the lateral ($P \leq .0003$) and medial ($P \leq .024$) knee compartment and ALL injuries. With the only exception for bone contusion at the lateral tibia and ITB injuries ($P = .002$), no significant association was found between bone contusions and injuries to the ITB ($P \geq .136$) or Kaplan fibers ($P \geq .625$). Patients involved in a traffic accident had more frequent and more intense bone contusions ($P \leq .039$) .

DISCUSSION

The most important finding of the present study is that ALL injuries with varying degrees of severity and intensity can be seen on MRI in patients with acute ACL rupture and, the degree of injury to the ALL is more commonly greater than the degree of injury to the ITB and Kaplan fibers. In our study, frank tears of the ALL (Grade 2 or 3) were seen in 39% of our patients with acute ACL rupture, whereas tears of the ITB and Kaplan fibers were seen in only 6% and 3% of the patients, respectively. In none of our patients with acute knee injury needing ACL surgery was a high-grade injury or gross hematoma seen in the lateral supracondylar area on clinical MR images.

MRI is the preferred modality for imaging the knee to show pathology and guide treatment.[18] However, conventional MRI has limitations to assess the complex anatomy of the anterolateral structures[25]. Conventional protocols typically consist of 2D TSE sequences because of their excellent tissue contrast and fast acquisition times.[18] However, these sequences have relatively thick slices, resulting in volume averaging artifacts and preventing multiplanar reformats.[25] These factors have led to a wide range of reported ALL detection rates on MRI, varying between 21% and 100%. [26-29] We could identify the ALL on MRI in 91% of our patients, and ALL tears were found in 39% of them. According to a systematic review by Puzzitiello et al.[30], these results are well within the range of previously reported ALL detection and injury rates on MRI in patients with ACL rupture, ranging between 76% to 100% and 10% to 62%, respectively. Most of the studies included in this review only included patients who were imaged after acute trauma and they found marginally higher ALL detection rates on MRI, probably related to the capsular distension associated with the acute ACL rupture[30]. In addition, our study identified the distal femoral ITB on MRI in patients with acute ACL rupture. In all of our cases, firm and distinct (Kaplan) fiber bundles could be seen, connecting the superficial ITB to the distal femoral metaphysis and condyle, and crossing in close proximity to the branches of the superior genicular artery. Although the majority of our patients with combined ACL and ALL injury showed normal appearance of the Kaplan fibers on MRI, future studies are needed, including novel 3D high-resolution imaging sequences to characterize the individual ALC components better.[31,32]

Similar to a previous study by Helito et al.,[33] we found ALL injuries to be significantly associated with collateral ligament injuries and bone contusions, but there was no association with meniscal injuries. Furthermore, our study results demonstrate that a higher-energy injury (e.g. traffic accident) leads to more extensive bone contusion and a higher frequency of associated lesions, which is consistent with results from previous studies[34-36].

LIMITATIONS

There were several limitations to this retrospective study. First, a standard knee MRI protocol typically uses an FOV of no more than 160 mm for image quality and resolution purposes. [18,25] Therefore, the proximal Kaplan fiber attachments may be at the outer margin of the FOV on coronal MR images, which may lead to decreased signal-to-noise (SNR) ratios and less accurate image analysis in this area. Although patients with poor quality MRI were excluded from our study, further optimization of clinical knee MRI protocols is needed. Second, the MRIs were performed within 6 weeks of the initial trauma. It is possible that deep hemorrhages in the lateral supracondylar area are reabsorbed shortly after the trauma prior to the MRI exam, and thus go undetected . Third, although the details of the injuries were obtained from the patient’s medical record, it was sometimes difficult to elucidate the type of knee injury, as the data were collected retrospectively.

CONCLUSION

Based on MRI analysis, ALL injuries were found with varying degrees of severity and intensity with noted injuries to associated surrounding fibers in patients with acute ACL rupture.

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FIGURE LEGENDS

Fig 1 Left knee magnetic resonance coronal T1-w (A), axial (B) and coronal (C) fat-saturated T2-w images demonstrating the iliotibial band (large arrow), proximal and distal Kaplan fibers (small arrows), and anterolateral ligament (ellipsoid). Note close proximity of the distal Kaplan fibers to branches of the superior genicular artery (arrowhead).

Fig 2 Left knee magnetic resonance coronal fat-saturated T2-w image demonstrating anterior cruciate ligament rupture (long small arrow) and partial tear of the anterolateral ligament (ellipsoid). There is only mild edema surrounding the iliotibial band (large arrow) and the

Kaplan fiber insertion (small arrow). Note associated tear of the lateral meniscus (arrowhead) and partial tear of medial collateral ligament (double arrows).

Fig 3 Left knee magnetic resonance coronal T1-w image demonstrating a Segond fracture (ellipsoid). Kaplan fiber insertion (small arrow) is normal. Note associated avulsion fracture (large arrow) at the medial femoral condyle.

Fig 4 Right knee magnetic resonance coronal fat-saturated T2-w images (A- B) demonstrating complete tear of the anterolateral ligament (ellipsoid). Mild thickening and edema are seen at the Kaplan fiber insertion site (small arrow). Note partial tear of the medial (arrowhead) and the lateral (double arrows) collateral ligament, and extensive bone contusion at the lateral tibia.

Table 1. Distribution of ITB gradings

ITB	Nr of patients	Percent	95% confidence interval
Grade 0	34	49%	38 – 61%
Grade 1	31	45%	34 – 57%
Grade 2	4	6%	2 – 14%

Table 2. Distribution of Kaplan fiber gradings

K	Nr of patients	Percent	95% confidence interval
Grade 0	46	67%	55 – 77%
Grade 1	21	30%	21 – 42%
Grade 2	2	3%	1 – 10%

Table 3. Distribution of ALL gradings

ALL	Nr of patients	Percent	95% confidence interval
Grade 0	30	43%	32 – 55%
Grade 1	12	17%	10 – 28%
Grade 2	22	32%	22 – 44%
Grade 3	5	7%	3 – 16%

Table 4. Location and grading of bone contusions.

	Grading Bone Contusion			
Location	**0**	**1**	**2**	**3**
Anterior LFC	46	17	6	
Middle LFC	21	25	22	1
Posterior LFC	68			1
Anterior LT	68	1		
Middle LT	42	4	21	2
Posterior LT	6	15	37	11
Anterior MFC	69			
Middle MFC	32	20	17	
Posterior MFC	64	4	1	
Anterior MT	69			
Middle MT	61	6	2	
Posterior MT	36	20	12	1

LFC=lateral femoral condyle; LT=lateral tibia; MFC=medial femoral condyle; MT=medial tibia. Note: Data are number of patients