Correlation between Magnetic Resonance Imaging and Surgical Exploration of the Anterolateral Structures of the Acutely Anterior Cruciate Ligament Injured Knee

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Abstract

Background: Combined Anterior Cruciate Ligament (ACL) and Anterolateral ligament (ALL) reconstruction is associated with improved clinical outcomes compared to isolated intra-articular reconstruction but the indications are not precisely defined. It may be the case that patients with proven anterolateral injury on pre-operative imaging are most likely to benefit but the accuracy of MRI is not known.

Hypothesis/Purpose: To evaluate the correlation between MRI findings and intra-operative anterolateral compartment exploration in acute ACL injured knees. The study hypothesis was that a positive correlation would be identified between imaging and surgical findings for injuries to the ALL/capsule and the iliotibial band and that pre-operative MRI would be associated with high sensitivity, specificity and accuracy for these parameters.

Study Design: Case Series

Methods: Between January 2016 to May 2016 patients presenting with an acute ACL injury were considered for study eligibility. A sample size calculation determined the numbers enrolled. Included patients underwent 1.5T MRI and this was evaluated by three investigators who attributed a Ferretti grade of injury to the anterolateral structures. At the time of ACL reconstruction, a lateral exploration was undertaken and macroscopic injuries were

identified, classified and repaired. An evaluation of correlation between MRI and surgical exploration findings was performed.

Results: 26 patients participated in the study. 96% had an ALL/capsule injury. The sensitivity, specificity and accuracy of MRI in the evaluation of ALL/capsule injury, when using surgical exploration as a gold standard were 88%, 100% and 88.5% respectively. For evaluation of iliotibial band injury these values were 62.5%, 40% and 50%. The percentage agreement between MRI and surgical findings for ALL/capsule injury was 88% but only 65% for the ITB. The sensitivity and specificity of MRI for complete or partial tear of ALL and capsule were 78.6 and 41.7 respectively. The k test for correlation between surgical and MRI findigs was 0.27 for ITB abnormalities, 0.47 for ALL/capsule abnormalities, 0.23 for ALL/capsule determination of partial or complete tear and 0.49 for ALL/capsule determination of anterior or posterior tear. The overall percentage agreement between MRI and the classification based on surgical findings was only 53% and the Altman classification of kappa was fair. This suggests that whilst the classification is useful for description of surgical findings the grade cannot be reliably established from MRI, at least with the parameters used in the current study

Conclusion: Surgical exploration demonstrates that injuries occur to the anterolateral structures in almost all acute ACL injured knees. Pre-operative MRI is highly sensitive, specific and accurate, for detection of abnormalities of the ALL/capsule and shows a high percentage of agreement with surgical findings. In contrast MRI has low sensitivity, specificity, and accuracy for the diagnosis of ITB injury. The agreement between MRI and surgical exploration with respect to ITB abnormality and determination of whether ALL/capsular tears were partial or complete was only fair.

Key terms: Anterolateral Ligament; Anterior Cruciate Ligament, magnetic resonance imaging, Iliotibial band

What is known about the subject: The recently renewed interest in extra-articular procedures has led to them being carried out frequently in clinical practice. However, the indications are not precisely defined. It is known that isolated ACL reconstruction in knees with an anterolateral injury results in failure to restore normal knee kinematics. This suggests that those patients who have an imaging proven anterolateral injury may be most likely to benefit from such a procedure. However, the sensitivity, specificity and accuracy of MRI in diagnosing anterolateral injury has not been studied to the knowledge of the authors

What this study adds to existing knowledge: To our knowledge this is the first study that has correlated MRI findings of anterolateral injury in the acute ACL-injured knee with intra-operative lateral exploration findings. This has allowed determination of the sensitivity, specificity, and accuracy of MRI for injury to the anterolateral structures. The high percentage agreement suggests that MRI is a useful modality for evaluation of injury to the anterolateral ligament and capsule

Introduction:

Lateral extra-articular procedures have recently been popularized due to the increasing evidence that they improve the outcomes of ACL reconstruction. Recent studies have demonstrated that anterolateral ligament (ALL) reconstruction performed at the time of anterior cruciate ligament (ACL) reconstruction is associated with a significant reduction in

ACL graft rupture rates, and improved return to sport compared to isolated intra-articular reconstruction[10,26]. Systematic reviews have also shown that patients who undergo an extra-articular procedure have a significantly lower pivot shift index than those undergoing ACL reconstruction only[23,25]. However, it is important to note that lateral extra-articular procedures were widely abandoned in the 1980's due to concerns about high re-operation rates and complications. Contemporary study has demonstrated that combined ACL and ALL reconstruction appears to be a safe procedure. Thaunat[30] et al reported that the reoperation rate after combined ACL and ALL reconstruction in a large series of patients (n=548), with a minimum follow-up of two years, was broadly comparable to reoperation rates after isolated ACL reconstruction. In addition, they reported that the high rates of knee stiffness and reoperation reported in historical series of nonanatomic, lateral extra-articular tenodesis were not observed in their series.

Despite these significantly improved clinical outcomes, the precise indications for the addition of an extra-articular procedure remain undefined. It is perhaps the case that those patients who have a demonstrable anterolateral injury on pre-operative imaging may be most likely to benefit but this has not been proven to date.

Biomechanical studies have shown that when an anterolateral injury exists, normal knee kinematics are only restored when an extra-articular procedure is performed at the time of ACLR because isolated intra-articular reconstruction fails to restore IR control[9,18,22]. It is therefore important to note that anterolateral injury has been reported to occur in up to 90% of acute ACL injured knees[8,15,20,29]. The ability to identify these injuries on pre-operative imaging may help to determine which patients are more likely to benefit from a combined ACL reconstruction and extra-articular procedure. Several authors have therefore reported rates of identification of ALL injury on MRI[4,6,12,13,17,31].

However, the rate of reported injury shows broad variation which raises concerns about its reliability. To the knowledge of the authors, the sensitivity and specificity of MRI for determining injury to the anterolateral structures has not been previously reported. This is because published studies have not compared MRI findings with a lateral extra-articular exploration. The only studies that correlated MRI with anatomy were performed in cadavers with no anterolateral reported injuries[2,11,12].

Thus, the aim of this study was to evaluate the correlation between MRI findings and intra-operative anterolateral compartment exploration in acute ACL injured knees. The study hypothesis was that a positive correlation would be identified between imaging and surgical findings for injuries to the ALL/capsule and the iliotibial band and that pre-operative MRI would be associated with high sensitivity and specificity for these parameters.

METHODS

Ethical approval was granted for this study by the Institutional Research Board. All patients gave valid consent to participate. The sample size was derived from Bujang and Adnan[1] who reported minimum numbers required for determining sensitivities and specificities in diagnostic studies. The sample size was determined to be n=22, based on a prevalence of injury to the ALL of 90% in acutely ACL-injured knees (assumed from Ferretti at al)[8], a null hypothesis sensitivity of 50%, alternate hypothesis 80%, power 80% and a p value of <0.05.

Between January 2016 and May 2016, patients presenting to the emergency department with a history of acute knee injury and physical examination findings consistent with ACL injury were prospectively considered for study enrollment. Patients were excluded if they had a previous history of either ipsilateral or contralateral knee injury/surgery or infection, multi-ligament injury or inability to undergo MRI.

All patients underwent clinical assessment and a standard acute knee examination. This included an evaluation of the ACL with Lachman and pivot shift tests, and also relevant physical examination tests to exclude concomitant injuries.

After clinical evaluation, patients were referred for magnetic resonance imaging of the injured knee. MRI scans were performed on a 1.5T device (*Siemens Maestro Sonata, gradient 40mT, software syngo A35)* with the following parameters (Table 1).

	Sagittal PD	Sagittal T2 FATSAT	Coronal T2 FATSAT	Coronal T1	Axial T2 FATSAT
Field of view (FOV)	180 mm	180mm	180mm	180mm	180mm
Repetition time (TR)	2800	3950	2950	3110	2940
Echo time (TE)	33	30	30	33	33
Thickness (mm)	3 mm	3mm	3mm	3mm	3mm
Spacing (mm)	2 mm	2 mm	1.5mm	1.5mm	2mm

Table 1. Parameters used in the MRI sequences. (*Siemens Maestro Sonata, gradient 40mT, software syngo A35)*

MRI scans were evaluated by three blinded observers (two musculoskeletal radiologists, with 15 years (main evaluator) and 8 years of experience respectively, and one orthopedic surgeon with 10 years of experience of interpreting MRI scans of the knee in daily practice). The ALL was evaluated using coronal images, with the axial and sagittal planes used mainly for anatomical orientation. 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), deep to the iliotibial band, to its tibial insertion between Gerdy's tubercle and the fibular head. The fibers were considered abnormal when they presented irregular contours, a wavy aspect, or areas of discontinuity. Joint capsule lesions were defined by thickening and increased signal in T2-weighted sequences, as well as the presence of periarticular fluid. For the purposes of this study the ALL/anterolateral capsule were considered as a single unit. When the ALL and/or capsule were found to be abnormal the injuries were also sub-classified. If a full thickness injury could be observed they were classified as complete tears, otherwise they were classified as incomplete. In addition, the observers also reported whether there was extension of the capsular tear (anterior or anterior/posterior). The presence and absence of iliotibial tract (ITT) lesions was also determined and recorded using the criteria established by Mansour et al.[19] The iliotibial tract was considered abnormal when thickening, signal change in its fibers, or edema of adjacent planes were present, even if observed in a discrete manner. MRI evaluators were then asked to attribute a Ferretti grade of injury (Table 2) to the anterolateral structures[8].

Following MRI evaluation, in line with the standard of care for acute ACL ruptures at our institution, all patients underwent ACL reconstruction within 10 days from injury. A concomitant exploration of the lateral compartment was performed as part of the study protocol. All procedures were performed by the senior author who has more than 25 years of experience in this field. The lateral compartment was exposed in all cases regardless of the degree of pivot shift (evaluated under general anaesthesia prior to surgery). This was performed prior to ACL reconstruction. The lateral compartment was approached by a hockey stick incision. After elevation of skin flaps, the fascia lata was exposed and evaluated for evidence of macroscopic injury. It was then incised, in line with its fibers, to expose the

anterolateral compartment. When a lesion was found it was repaired by 3-4 parallel stitches with square knots (No. 2 Vicryl; Ethicon) with the knee at 90 of flexion and neutral rotation.

At each step of the lateral exploration, a written record was made of the presence or absence of injury to the anterolateral structures of the knee, including hemorrhage, incomplete capsular tear, ALL/capsule complete tears, and fractures. Both positive and negative findings were documented in every case by intra-operative photographs throughout the dissection.

Macroscopic tears of the ALL/capsule were classified as suggested by Ferretti et al (Table 2):

Type I	multilevel rupture in which individual layers are torn at different levels with macroscopic hemorrhage involving the area of the anterolateral ligament (ALL) and extended to the anterolateral capsule only (incomplete tear of anterolateral capsule)
Type II	multilevel rupture in which individual layers are torn at different levels with macroscopic hemorrhage extended from the area of the ALL and capsule to the posterolateral capsule (incomplete tear of anterolateral and posterolateral capsule)
Type III	complete transverse tear involving the area of the ALL near its insertion to the lateral tibial plateau, always distal to the lateral meniscus (complete tear of anterolateral capsule)
Type IV	corresponding to bony avulsion (Segond fracture)

Table 2. Classification of injuries of anterolateral complex as described by Ferretti et al.[8]

Following the lateral exploration, all of the identified ALL/capsular injuries underwent repair. ACL reconstruction was performed in a standardized manner with a doubled semitendinosus and gracilis tendon graft with an outside-in technique.

Statistical analysis

All calculations were made using SPSS software (Version 20.0, SPSS Inc., Chicago, IL). Cohens Kappa was used to determine inter- and intra-observer reliability between all MRI evaluators

and also to determine correlation between MRI and surgical findings. The latter was performed using the main evaluators assessment. Strength of agreement was evaluated according to the criteria of Altman. The sensitivity, specificity and accuracy of MRI in evaluating injuries to the anterolateral structures were calculated using surgical exploration findings as the gold standard.

RESULTS

Twenty-six patients met the eligibility criteria and were enrolled to the study. Table 3 reports the demographic details and patient characteristics of the study population

Age (Range)	26.7±7.1(17-46) years
Gender **Male** **Female**	 21 5
BMI (range)	20.6±1.3(19-23.5)
Time to surgery (range)	4.3±2.2(1-10) days
Pre-operative pivot-shift test (evaluated under general anaesthesia) **Grade 0** **Grade 1**	- 5 16

Grade 2 **Grade 3**	5

Table 3. Demographics and patient characteristics of the study population

Results of MRI evaluation: The ITB was considered normal in 15/26 (57.7%) cases and abnormal in 11/26 (42.3%) cases. The ALL/ anterolateral capsule was considered normal in 4/26 (15.4%) cases and abnormal in 22/26 (84.6%) cases. Tears of the ALL and capsule were considered complete in 15/22 (68.2%) cases and incomplete in 7/22 (31.8%) cases. Extension of the capsular tear was observed to be anterior in 11/22 (50.0%) cases and anterior/posterior in 11/22 (50.0%). The inter- and intraobserver correlation indices are reported in table 4

Kappa Coefficient	ALL / capsule lesion (presence or not)	ALL / capsule lesion (complete or incomplete)	Capsular tear extension (anterior/posterior)	ITB tear (presence or not)
inter-observer	1	0.64	0.47	0.64
intra-observer 1	1	0.66	0.58	0.69
intra-observer 2	1	0.60	0.82	0.61
intra-observer 3	1	0.75	0.82	0,8

Table 4: The inter- and intraobserver correlation indices

Surgical evaluation: at surgical evaluation, the ITB was considered normal in 18/26 (69.2%) cases and abnormal in 8/26 (30.8%) cases. The ALL and capsule were considered normal in 1/26 (3.8%) cases and abnormal in 25/26 (96.2%) cases. The ALL and capsular tear was considered complete in 10/25 (40.0%) cases and incomplete in 15/25 (60.0%) cases. Extension

of the capsular tear was observed to be anterior in 11/25 (44.0%) cases and anterior-posterior in 14/25 (56.0%).

The sensitivity, specificity, positive predictive value, negative predictive value and accuracy of MRI for parameters of injury to the anterolateral structures of the acutely ACL-injured knee, when using surgical exploration as a gold standard are reported in Table 4.

Table 5: Sensitivity, Specificity, PPV – Positive Predictive Value, NPV – Negative Predictive Value and Accuracy of MRI for parameters of injury to the anterolateral structures of the acutely ACL-injured knee, when using surgical exploration as a gold standard

	Sensitivity	Specificity	PPV	NPV	Accuracy
ITB Abnormality	62.5	40.0	45.5	57.1	50.0
95% CI	24.49 to 91.48	12.16 to 73.76	28.49 to 63.54	29.2 to 81.17	26.02 to 73.98
ALL/Capsule Abnormality	88.0	100.0	100.0	25.0	88.5
95% CI	68.8 to 97.4	2.5 to 100	n/a	10.34 to 49.07	69.85 to 97.55
ALL/Capsule complete/partial tear	78.6	41.7	61.1	62.5	61.5
95% CI	49.2 to 95.34	15.17 to 72.33	47.53 to 73.16	33.29 to 84.77	40.57 to 79.77
ALL/Capsule anterior/posterior	75.0	64.3	54.6	81.8	68.2
95% CI	34.91 to 96.81	35.14 to 87.24	34.83 to 72.93	56.02 to 94.08	45.13 to 86.14

The K test for correlation between surgical and MRI findings is reported in Table 5 along with the strength of agreement according to Altman 1991.

	Kappa	Al Class
ITB Abnormality	0.27	
ALL/Capsule Any Abnormality	0.47	Mo
ALL/Capsule: Determination of complete/partial tear	0.23	

ALL/Capsule: Determination of anterior/posterior tear extension		0.49	Mo

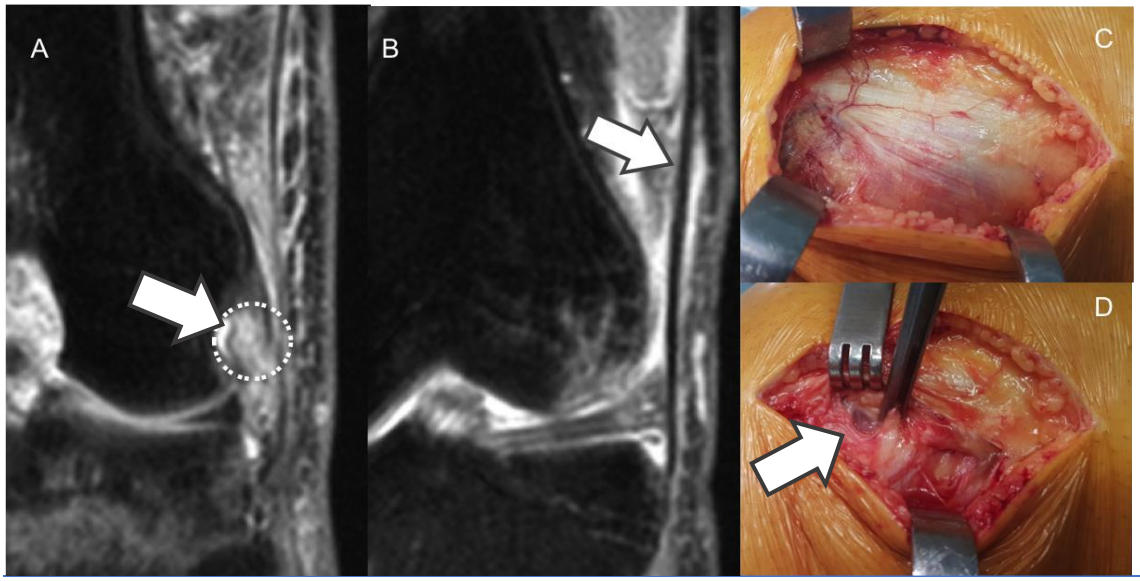

Table 6: Correlation between MRI and Surgical findings using Cohens Kappa and the Altman classification of strength of agreement and overall percentage agreement

Figure 1 A: Coronal T2 weighted MRI image. Discontinuity at the proximal (femoral) portion of the anterolateral ligament (circle) with marked regional edema. B: Coronal T2 weighted MRI image. Non-insertional iliotibial band strain (arrow) characterized by adjacent edema, with no fiber discontinuity. C: surgical exploration of the fascia lata showing edema and incomplete tear. D: surgical exploration of the capsule showing a complete tear of the anterolateral capsule and ligament (arrow; type 3 according Ferretti classification).

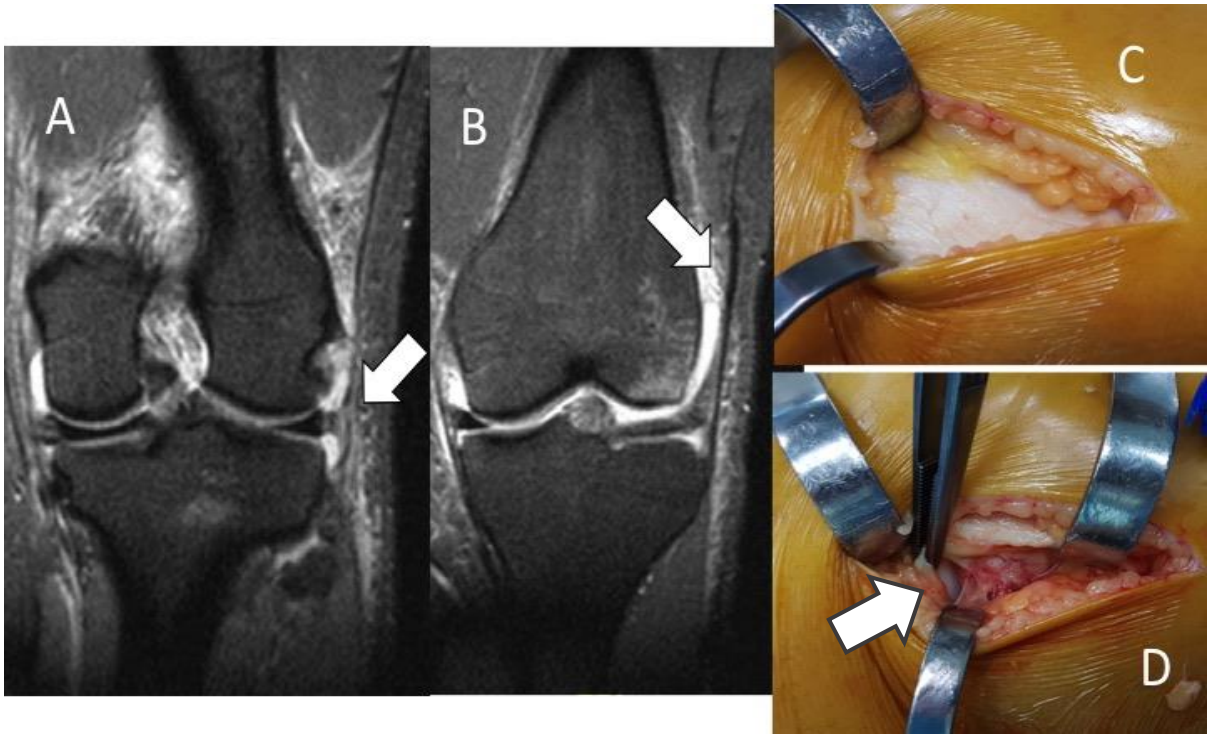

Figure 2. MRI T2 weighted images with fat saturation. **A.** Anterolateral ligament presenting abnormal signal and irregular aspect of its fibers (arrow). **B**. Iliotibial band with normal signal and thickness (arrow). **C**. surgical exploration of the fascia lata that is normal. **D**. surgical exploration of the capsule showing a complete tear of the anterolateral capsule and ligament (arrow; type 3 according Ferretti classification).

Discussion

The most important finding of this study was that when considering surgical exploration as the gold standard, MRI evaluation demonstrated high sensitivity, specificity and accuracy for detection of abnormalities of the ALL/capsule. The sensitivity and specificity for other parameters such as whether there was a complete tear or not, and anterior/posterior extension were not as high, and for evaluation of the ITB, the values were low. These findings were mirrored in the kappa correlation data for agreement between surgery and

MRI evaluations. Although there was moderate agreement between them for ALL/capsular abnormalities and determination of anterior/posterior extension of tears, the agreement between them with respect to ITB abnormality and determination of whether ALL/capsular tears were partial or complete was only fair.

To the knowledge of the authors this is the first study that has compared MRI findings with intra-operative anterolateral exploration in the acute ACL-injured knee. However, several previous cadaveric studies have compared MRI findings with laboratory exploration in normal knees. Caterine et al and Helito et al both reported that they were able to fully visualise the ALL and subjectively and objectively correlate 1.5T MRI findings with dissection in all specimens[2,12]. Subsequent authors have not demonstrated such a high degree of reliability in identification of the ALL in clinical studies, and published rates of full visualisation (11-100%)[24,28], partial visualisation (11.5-48.5%)[5,11] and non-visualisation (0-49%)[24,28] show broad variation in normal knees. Part of the reason for this discrepancy is that the aforementioned cadaveric studies used MRI protocols with very thin (0.4mm and 0.6-1.5mm) slices. This has the advantage of reducing the partial volume effect and improving spatial resolution. However, in clinical practice the increased scan duration with thinner slices is prohibitive and more typically a slice thickness of 3mm is used.

Rates of MRI identification of abnormalities of the anterolateral ligament in the ACL injured knee also demonstrate broad variation which may be influenced by factors such as magnet strength, slice thickness, experience of evaluators, and the timing of injury (acute/chronic). Rates of injury between 32.6-88% are reported, with the majority of authors reporting values around 40%, towards the lower end of the spectrum[4,7,12,13,31]. These lower values are inconsistent with the clinical findings of surgical exploration studies by Hughston[15], Terry[29],

Muller[20] and more recently by Ferretti[8] et al that demonstrated a much higher rate of injury of approximately 90%

More recent imaging studies have tended to report higher rates of ALL and capsule injury which are more in keeping with the rate previously reported at surgical exploration.

Muramatsu et al.[21] with the use of 3D-MRI demonstrated that 87.5% of acute ACL-injured knees and 55.6% of chronic ACL injured knees were associated with an ALL injury. This trend towards reporting higher rates of injury may reflect increasing experience and knowledge regarding MRI evaluation of these structures and a consequently improved detection rate.

In the current study, it was hypothesised that there would be good agreement between MRI and anterolateral exploration. An attempt to reduce confounding was made by only including acute ACL injured knees and having three imaging evaluators with considerable expertise in ALL evaluation. Despite that, using the Altman classification of Cohen's kappa, none of the parameters studied showed good agreement between MRI and surgical findings. However, it is important to highlight that for the category ALL/capsule injury, the strength of agreement is lower than expected, principally because over 90% of observations were in the "abnormal" category. This skewness of data is a well-recognised cause of paradox where the kappa coefficient appears to be lower than expected based on the percentage agreement. As such the percentage agreement in this particular group (88%) is a more useful metric than the kappa coefficient, but for other parameters it is an appropriate evaluation. The Altman classification for agreement between MRI and surgical findings was moderate for anterior/posterior extension of ALL and capsular injuries but only fair for determination of whether the injury was complete or partial, and for evaluation of ITB abnormalities.

The overall percentage agreement between MRI and the Ferretti classification, based on surgical findings, was only 53% and the Altman classification of kappa was fair. This suggests

that whilst the classification is useful for description of surgical findings the grade cannot be reliably established from MRI, at least with the parameters used in the current study. The main reasons for this lack of correlation are that the percentage agreement between MRI and surgery for the parameters of complete/partial injury and anterior/posterior extension were only 61% and 57% respectively. This is reflected in the fact that MRI has a moderate sensitivity and low specify for both of these injury characteristics.

It is important to note that surgical exploration identified injury to the ITB in only 8 patients, whereas almost all patients had an injury to the ALL/capsule. More importantly, it should be specifically stated that 19/26 (73.1%) patients had an injury to the ALL/capsule with a completely normal ITB. This is somewhat in contrast to the laboratory-based concept that the ITB is the primary restraint to internal tibial rotation and the ALL a secondary restraint[16]. This important clinical finding is likely a reflection of the reliance of laboratory studies on artificially created injury patterns which do not easily replicate in-vivo mechanisms. It should also be stated that there was fair agreement with respect to kappa and a 65% agreement between surgical findings and MRI with respect to ITB abnormalities. However, the accuracy of MRI was only 50%. Where there was disagreement between MRI and surgery the most common reason (66.6%) was that MRI had suggested an ITB injury but no abnormality was identified at surgery. This is also an important finding because MRI evidence of injury to the ITB has been reported as an indication for performing a LET but the findings of the current study suggest that the accuracy of MRI for this parameter is low and that using it in this way may lead to overtreatment[27].

Limitations

The small study population could be considered a limitation given that ACL rupture is a very common injury in the sports medicine scenario. However, a sample size calculation was specifically performed in order to include an adequate number of patients to answer the research question studied. It was a deliberate decision not to include a much larger number of patients because it is not useful to access the lateral compartment in every ACL-injured knee and there is a potential associated morbidity of this additional procedure. Specifically, it is not known which patterns of anterolateral injury warrant direct surgical repair and this study did not attempt to define that. A further limitation of the study was that there is no published, validated, standardized imaging protocol for evaluation of injury to the ALL/anterolateral capsule. This may have been mitigated to some extent by the fact that the MRI evaluators in this study had considerable experience in evaluating these structures in their daily practice. However, it should be noted that evaluators were specifically instructed to identify injuries to the anterolateral structures. It is plausible that this lack of blinding of the study purpose may have influenced the rate of diagnosis of injury to these structures.

Conclusions

Surgical exploration demonstrates that injuries occur to the anterolateral structures in almost all acute ACL injured knees. Pre-operative MRI is highly sensitive, specific and accurate, for detection of abnormalities of the ALL/capsule and shows a high percentage of agreement with surgical findings. In contrast MRI has low sensitivity, specificity, and accuracy for the diagnosis of ITB injury

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