Original Research

Standard MRI May Not Predict Specific Acute Anterior Cruciate Ligament Rupture Characteristics

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Background: There has been renewed interest in the concept of anterior cruciate ligament (ACL) suture repair (ACLSR). Morphologic characteristics of the ruptured ACL remnant play a role in deciding whether a patient is eligible for ACLSR. However, no classification of these characteristics of ACL rupture on magnetic resonance imaging (MRI) scans has yet been compared with intraoperative findings in the context of ACLSR.

Purpose: To investigate the value of using preoperative MRI to predict specific characteristics of acute complete ACL rupture.

Study Design: Cohort study (diagnostic); Level of evidence, 2.

Methods: A total of 25 patients were included. Two radiologists classified ACL rupture location and pattern on preoperative 1.5-T MRI scans with a standard sequence; the results were compared with the corresponding findings at arthroscopy conducted by a single surgeon. The agreement between the MRI and surgical findings was calculated using Cohen κ values. Furthermore, the reliability coefficients of the MRI classifications within and between radiologists were calculated.

Results: The agreement between MRI classification and arthroscopic findings for ACL rupture location was slight (Cohen κ, 0.016 [radiologist 1] and 0.087 [radiologist 2]), and for ACL rupture pattern, this was poor to slight (Cohen κ, <0 and 0.074). The intraobserver reliability of MRI classification for ACL rupture location was moderate for radiologist 1 and slight for radiologist 2 (Cohen κ, 0.526 and 0.061, respectively), and for ACL rupture pattern, this was slight for radiologist 1 and 2 (Cohen κ, 0.051 and 0.093, respectively). The interobserver reliability of MRI classification for ACL rupture location and pattern was slight between radiologists (Cohen κ, 0.172 and 0.040, respectively).

Conclusion: In the current study, we found poor to slight agreement between MRI classification and arthroscopic findings of specific ACL rupture characteristics. In addition, the intra- and interobserver reliability for MRI classification of the ACL rupture characteristics was slight to moderate.

Keywords: ACL; biologic healing enhancement; biology of ligament; ACL reconstruction; ACL suture repair; dynamic intraligamentary stabilization; MRI

There has been renewed interest in the concept of anterior cruciate ligament (ACL) suture repair (ACLSR) rather than ACL reconstruction (ACLR) using a tendon graft. Several promising short-term results for modern augmented and nonaugmented arthroscopic ACLSR techniques have been published.[10] Although an ideal surgical technique and insight in ideal ACL rupture characteristics aimed at optimizing the outcomes have not been established, the ACL rupture location, the ACL rupture pattern, and disruption of the synovial sheath have been reported to influence the outcomes of ACLSR.[2,6,10,13,21,30] It has been shown that when these morphologic characteristics are assessed at the time of surgery, a substantial number of ruptured ACLs are deemed unrepairable, and instead these patients undergo ACLR.[29] However, the timing at which ACLSR and ACLR are performed is different. Typically, dynamic augmented ACLSR is performed within 3 weeks after injury, whereas

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Final revision submitted August 31, 2020; accepted November 3, 2020.

The authors declared that there are no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from METC Twente.

The Orthopaedic Journal of Sports Medicine, 9(3), 2325967121992472
DOI: 10.1177/2325967121992472

ACLR can be performed at a later time, after the criteria for recovery of knee function have been met.[8,10,15-17,35]

Preoperative assessment of these characteristics of ACL rupture using magnetic resonance imaging (MRI) may be useful in the decision making regarding ACLSR for complete ACL rupture. In general, the value of using MRI to diagnose partial or complete ACL tears as well as to locate a partial ACL tear in the anteromedial or posterolateral bundle has been established, and MRI findings have been compared with those at the time of surgery.[5,23] However, there is paucity of literature comparing preoperative MRI findings and surgical findings regarding specific characteristics of complete ACL rupture that are relevant to ACLSR (ie, ACL rupture location, ACL rupture pattern, and disruption of the synovial sheath).[18,31]

In a 2019 randomized controlled trial (RCT), Hoogeslag et al[9] reported no inferiority for dynamic augmented ACLSR as compared with ACLR in terms of subjective patient-reported outcomes. In all patients, characteristics of acute complete ACL rupture were classified at the time of surgery.[8,9] However, these were not yet compared with the characteristics of ACL rupture on the corresponding preoperative MRI scans. Therefore, the purpose of this study was to investigate the value of using preoperative MRI to predict morphologic characteristics of acute complete ACL rupture in patients who participated in the RCT. Our hypotheses were that (1) MRI would be accurate for classifying specific characteristics of ACL rupture as compared with findings at time of surgery and (2) classification of specific characteristics of ACL rupture on MRI scans would be reliable within and between radiologists.

METHODS

Patients

This cohort study compared characteristics of ACL rupture classified at the time of surgery with those classified on preoperative MRI scans. Patients were selected from the 2019 RCT of Hoogeslag et al.[9] In the RCT, during the study period of January 2015 to March 2016, a total of 48 patients with acute complete ACL rupture were randomized to undergo either dynamic augmented ACLSR within 3 weeks after injury (n = 24) or ACLR after meeting criteria for recovery of knee function (n = 24).[9,16,17] In addition, 3 patients underwent dynamic augmented ACLSR before the RCT to reduce the learning curve effect of the surgical technique during the study. See Hoogeslag et al[9] for the RCT procedures and outcomes.

All 27 patients who underwent ACLSR had surgery within 3 weeks after injury, with a median 14 days (interquartile range [IQR], 12-17). In contrast, all 24 patients who underwent ACLR had surgery >3 weeks after injury, with a median 47 days (IQR, 42-71). Given that morphologic changes of ruptured ACL remnants are known to occur as soon as 3 weeks after injury and this could interfere with the comparability of MRI findings versus those at the time of surgery, only patients who underwent ACLSR (n = 27) were included in the present study.[4,9] Patients included in the RCT who underwent MRI of the injured knee elsewhere were excluded from the present study.

ACL Rupture Classification at the Time of Surgery

All surgical procedures started with standard arthroscopy of the knee, with joint lavage for hemarthrosis. Afterward, ACL rupture characteristics were classified by location (proximal, middle, or distal third), pattern (not lacerated or lacerated into 2 parts or >2 parts), and integrity of the synovial sheath (completely, ≥50%, or <50% intact), as described by Henle et al[8] (Figure 1).

The described characteristics of ACL rupture were assessed by visual inspection, probing of the ligament remnants, and tensioning of the ligament remnants using a grasper. One surgeon (R.A.G.H.) with considerable experience in ACL surgery performed all the surgical procedures and ACL rupture classifications, and the findings were documented in an operative report form. The surgeon was not blinded to the preoperative MRI scans during the surgical procedure. However, classification of specific characteristics of ACL rupture on MRI scans was performed at a later time, in the context of the present study; as such, this did not influence classification at the time of surgery.

MRI Scan and ACL Rupture Classification

All MRI of the included patients was performed using a 1.5-T MRI scanner (MAGNETOM Avanto fit; Siemens) according to a standardized protocol for the knee (Table 1). All examinations were performed with the patients in the supine position and their knees in extension and without sedation or anesthesia. The knee was supported by a pillow and secured by an extremity coil (Tx/Rx 15-Channel Knee Coil; Siemens).

All MRI scans were assessed using JiveX DICOM Viewer software (Visus Technology). The same classification system that was used during assessment at the time of surgery was used for MRI assessment of the ACL rupture characteristics (Figure 2).[8] To determine the ACL rupture location on the MRI scan, first the central point of the femoral ACL attachment was determined in the transverse plane, which was then correlated with the sagittal and coronal planes using a localizer. The same procedure was followed to determine the center of the ACL attachment on the tibia. Finally, the distance between these points was measured and divided into 3 equal parts, representing the proximal, middle, and distal thirds of the native ACL, and the assessed ACL rupture location was accordingly classified. The ACL rupture pattern was classified on the basis of the severity of the laceration seen, using all scan directions. The integrity of the synovial sheath was not radiologically classified, as this is assessable only via MRI using specific sequences and/or contrast and these data were not available.[11] The radiologists were blinded to the surgical findings.

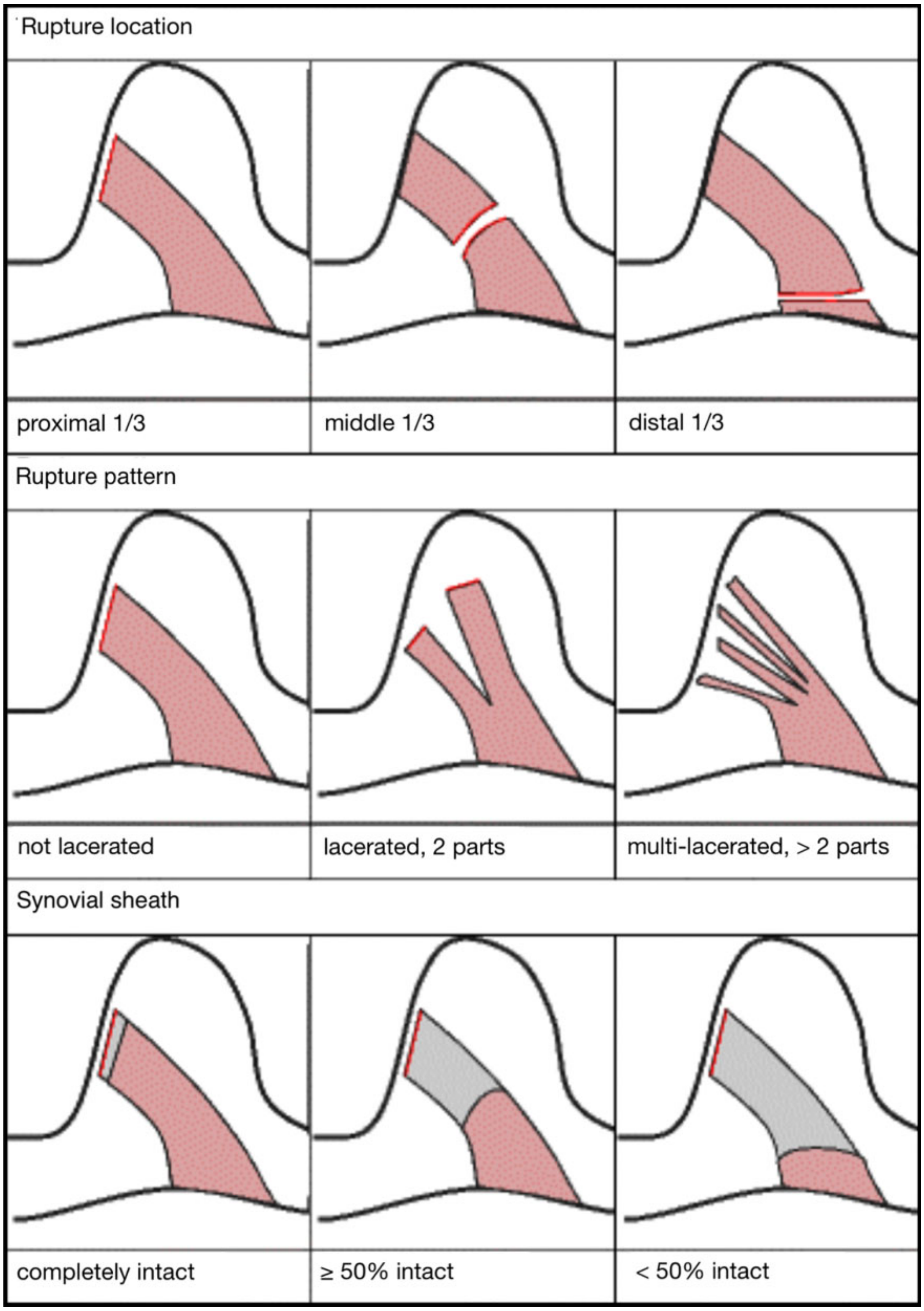

Figure 1. Classification of complete anterior cruciate ligament rupture characteristics at the time of surgery based on the rupture location, the rupture pattern, and the integrity of the synovial sheath.[8] Image from Henle et al.[8] Reproduced with permission from BMC/Springer Nature.

Data Collection

Baseline characteristics of the included patients including sex, side of injury, body mass index, age at the time of knee injury, time from injury to surgery, time from injury to the MRI scan, and time from the MRI scan to surgery were recorded. Two experienced musculoskeletal radiologists (S.M.v.R. and R.P.H.D.) separately performed the described MRI classification on 2 occasions 12 weeks apart, and their findings were documented and tabulated. The documented classifications of the ACL rupture characteristics at the time of surgery of the included patients were retrieved from the operative report form and tabulated.

TABLE 1
Sequences of the Standard Magnetic Resonance Imaging Scan Protocol for the Knee

	Turbo Spin Echo, Sagittal Oblique Scan		Turbo Spin Echo, Fat Suppressed	
Settings	T1 Weighted	Proton Density, Fat Suppressed	T2-Weighted Coronal Scan	Proton Density Transversal Scan
Repetition time, ms	520.0	3950.0	3010.0	2880.0
Echo time, ms	13.0	37.0	42.0	39.0
Flip angle, deg	180	150	150	150
Echo trains per slice, No.	99	27	13	12
Echo spacing, ms	12.8	9.34	8.46	9.68
Bandwidth, Hz/Px	130	171	191	193
Field of view, mm	180	180	165	160
Slice thickness, mm	3.0	3.0	3.0	3.0
Spacing between slices, mm	0.3	0.3	0.3	0.3
Echo train length, No.	3	10	9	10
Acquisition matrix	480, 0, 0, 358	384, 0, 0, 307	0, 320, 334, 0	0, 320, 240, 0

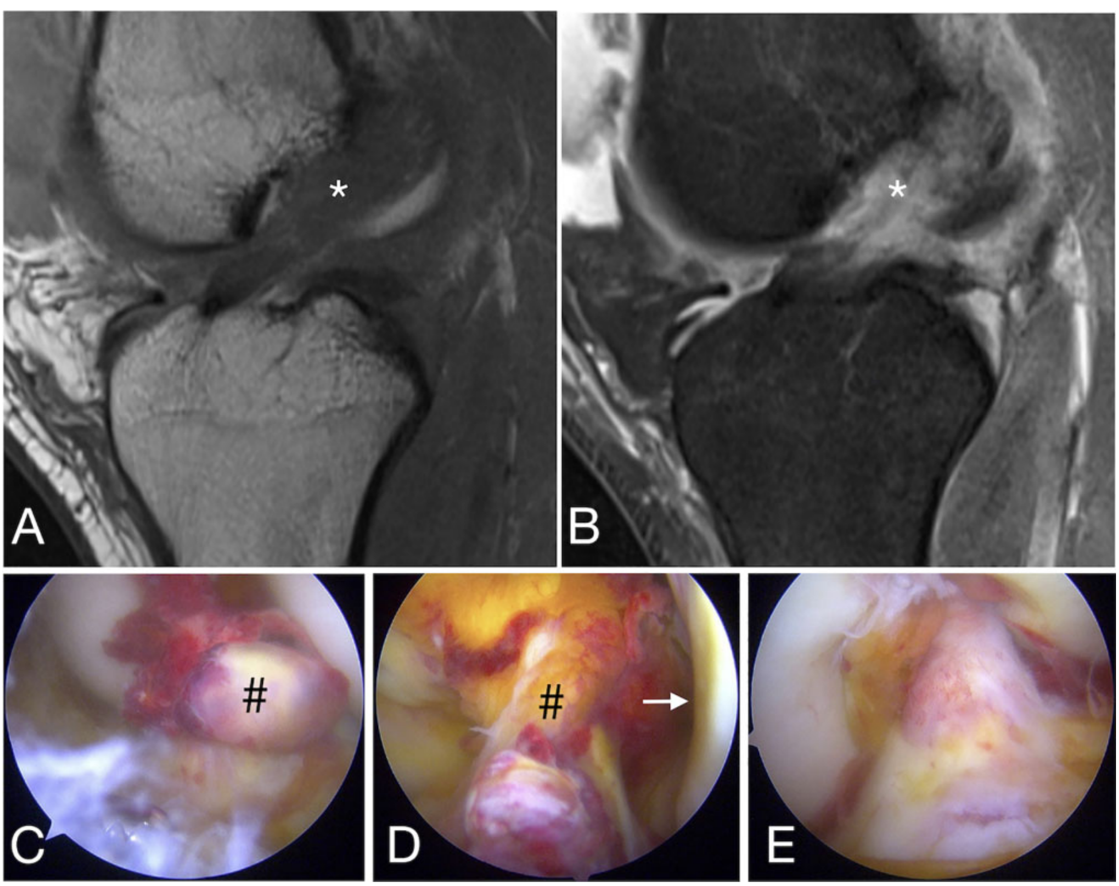

Figure 2. Preoperative magnetic resonance imaging scans and arthroscopic images at the time of surgery of the same knee. Sagittal (A) T1 and (B) T2 views of the knee show the region of the anterior cruciate ligament (ACL) rupture (*). Arthroscopic views of the same knee: (C) ACL rupture (#), (D) "empty wall sign" (arrow), and (E) after dynamic augmented ACL suture repair.

Statistical Analysis

For classification of ACL rupture location and pattern, the agreement between MRI scans and surgery was calculated using the single-measure 2-way absolute agreement intraclass correlation coefficient (Figure 3).[14] Furthermore, to calculate the intra- and interobserver reliability of MRI findings within and between radiologists, the same procedure was followed. The resulting Cohen κ values were interpreted as poor (<0.00), slight (0.00-0.20), fair (0.21-0.40),

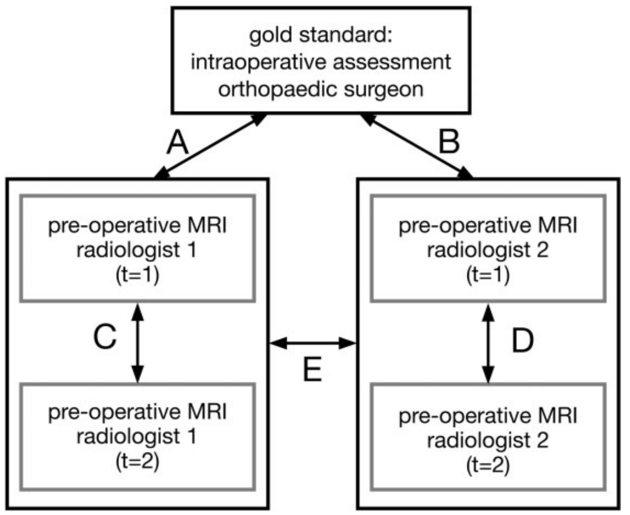

Figure 3. Overview of the collected data and statistical analysis. (A, B) Agreement of the MRI findings as compared with the findings at the time of surgery for ACL rupture location and pattern. (C, D) Intraobserver reliability within and (E) interobserver reliability between the radiologists' MRI findings for ACL rupture location and pattern. The time between the initial (t = 1) and second (t = 2) MRI assessments was 12 weeks. ACL, anterior cruciate ligament; MRI, magnetic resonance imaging.

moderate (0.41-0.60), substantial (0.61-0.80), or almost perfect (0.81-1.00) agreement, according to the guidelines outlined by Landis and Koch.[14] All statistical analyses were performed using SPSS Statistics 24 (IBM Corp).

RESULTS

Of the 27 patients who underwent ACLSR, 2 had undergone preoperative MRI elsewhere before referral to our clinic and were excluded. The remaining 25 patients underwent preoperative MRI of the knee at our clinic and were included in the study. Table 2 shows the baseline characteristics of the included patients. The median time between injury and surgery—and therefore between injury and the classification of ACL rupture characteristics—was 14 days (IQR, 12-16.5; range, 9-20), and the median time between MRI and surgery was 8 days (IQR, 5-10; range, 1-15). At the time of surgery, the ACL rupture location was classified as proximal third in 84% of the cases (n = 21), middle third in 12% (n = 3), and distal third in 4% (n = 1), whereas the ACL rupture pattern was classified as not lacerated in 8% (n = 2), lacerated into 2 parts in 40% (n = 10), and multilacerated into >2 parts in 52% (n = 13).

Agreement Between MRI and Surgical Findings

Table 3 presents the agreement between the MRI classifications and the arthroscopic findings for ACL rupture location and ACL rupture pattern. The agreement for ACL rupture location was slight (Cohen κ, 0.016 [radiologist 1] and 0.087 [radiologist 2]), and the agreement for ACL rupture pattern was poor to slight (Cohen κ, <0 and 0.074, respectively).

TABLE 2
Baseline Characteristics[a]

Characteristic	Patients (N = 25)
Sex	
Male	21 (84)
Female	4 (16)
Age, y	21 (17-31)
Side of injury	
Left	10 (40)
Right	15 (60)
Body mass index	23.1 (21.4-24.5)
Time from, d	
Injury to repair	14 (12-16.5)
Injury to MRI scan	5 (1-14)
MRI scan to repair	8 (5-10)

[a]As the data were not normally distributed, they are expressed as a median (interquartile range) or frequency (percentage). MRI, magnetic resonance imaging.

TABLE 3
Agreement Between MRI Classification (Radiologists 1 and 2) and Surgical Findings of ACL Rupture Location and Pattern[a]

	Cohen κ	
	Rupture Location	Rupture Pattern
Surgeon vs radiologist 1 (n = 50)	0.016	−0.012
Surgeon vs radiologist 2 (n = 50)	0.087	0.074

[a]ACL, anterior cruciate ligament; MRI, magnetic resonance imaging.

TABLE 4
Intra- and Interobserver Reliability for MRI Classification of ACL Rupture Characteristics[a]

	Cohen κ	
	Rupture Location	Rupture Pattern
Intraobserver reliability, measurement 1 vs 2		
Radiologist 1 (n = 25)	0.526	0.051
Radiologist 2 (n = 25)	0.061	0.093
Interobserver reliability		
Radiologist 1 vs radiologist 2 (n = 50)	0.172	0.040

[a]ACL, anterior cruciate ligament; MRI, magnetic resonance imaging.

Intra- and Interobserver Reliability for MRI Classification of ACL Rupture Characteristics

Table 4 presents the intra- and interobserver reliability for MRI classification of ACL rupture location and pattern by the 2 radiologists. The intraobserver reliability for the ACL rupture location was moderate for radiologist 1 and slight for radiologist 2 (Cohen κ, 0.526 and 0.061, respectively). The intraobserver reliability for the ACL rupture pattern was slight for radiologists 1 and 2 (Cohen κ, 0.051 and 0.093, respectively). Furthermore, the interobserver reliability for the ACL rupture location and pattern was slight between the radiologists (Cohen κ, 0.172 and 0.040, respectively).

DISCUSSION

The most important finding of the present study is that the agreement was poor to slight between the MRI classification of ACL rupture characteristics and the findings at the time of surgery. In addition, intra- and interobserver reliability was slight to moderate for MRI classification of ACL rupture characteristics by the radiologists.

In general, MRI has been established as a valuable diagnostic tool for the evaluation of ACL injuries.[23] However, studies investigating this have focused on the presence of a complete or partial ACL rupture and not on the presence of the characteristics of acute complete ACL rupture that were investigated in the present study.[23] Additionally, although MRI findings to diagnose ACL rupture and to differentiate between the anteromedial and posterolateral bundle in a partial ACL tear have been compared with those at surgery, no MRI findings on characteristics of complete ACL rupture relevant to ACLSR have been compared with those at surgery.[5,18,31] van der List and DiFelice[29] retrospectively classified the characteristics of acute ACL rupture using preoperative MRI and analyzed the frequency with which either ACLSR or ACLR was performed. They reported that assessing the ACL rupture location and the quality of tissue on the preoperative MRI scans can predict whether a patient is eligible for ACLSR. Interestingly, while patients were reported to undergo ACLSR only when the length and tissue quality of the tibial ACL remnant were sufficient, some were retrospectively classified as having an ACL rupture location in the middle 25% to 75% on the preoperative MRI scan.[29] Although no direct comparison of MRI and surgical findings was performed, this implies that (at least) in these patients, the classification at the time of surgery was not correlated with the retrospective MRI classification of the ACL rupture location. In contrast, in the present study, preoperative MRI findings were compared with their corresponding surgical ones, and the results showed that the ability of the MRI findings to predict specific ACL rupture characteristics was poor to slight. This suggests that 1.5-T MRI with a standard clinical MRI sequence is currently not a feasible diagnostic tool to accurately classify the ACL rupture characteristics relevant to ACLSR.

The limited reliability coefficients within and between the radiologists for MRI assessment of ACL rupture characteristics in the present study could be explained by the following: first, as a primary sign of ACL rupture, clear gap formation is not always present on MRI scans; second, precisely locating and grading acute ACL injuries can be obscured by injury-inflicted hemorrhage and edema, which are present in the majority of cases.[32-34,36] Present primary signs of ACL rupture will not always be well defined and therefore might sometimes overlap with the defined ACL rupture location zones. In contrast, van der List et al[31] reported higher reliability coefficients for the classification of the ACL rupture location in a sample comparable with that of the present study (30 patients) with acute ACL rupture; the reliability coefficient for classification of the ACL rupture pattern, which was slight in the present study, was not analyzed.

This difference could be attributed to several reasons. First, 2 of 3 observers were already familiar with the radiologic classification system. The third observer was a radiologist who was new to the classification system, like the observers in the present study, and had a lower intraobserver reliability score than did the other 2 observers. This implies that familiarity with the classification system might improve the results.

Second, a different classification system was applied (modified Sherman), which provides more differentiation of the ACL rupture location in the proximal half as compared with the classification system applied in the present study.[27,31] As the majority of the ACL ruptures are located in the proximal half of the ACL, this might have favored the results of van der List et al.[8,31]

Third, despite being sufficient in both studies, the time between the first and second MRI assessments was 3 weeks, as opposed to 12 weeks in the present study, thereby reducing the risk of recall bias among the radiologists.

Fourth, reliability coefficients were calculated for 30 patients randomly selected from a larger group of 353 patients, who were scanned using 1.5- or 3.0-T MRI (not specified for this subgroup), as compared with 1.5 T in the present study.[31] However, field strength alone does not necessarily result in better resolution of the MRI scan. Having a smaller slice thickness (3.0 vs 3.5 mm) which increases the signal-to-noise ratio, having a small gap (0.3 mm vs no gap) which decreases interference between adjacent slices, and using a dedicated knee coil with a larger number of receiver channels (15 vs 8 channels) would have resulted in better spatial resolution in the present study.[24,28] Nevertheless, van der List et al[31] reported reliability coefficients for MRI assessment of ACL rupture location that were substantially higher than the values in the present study.

There have been some reports of excellent outcomes with augmented ACLSR for midsubstance ACL rupture with the addition of a bridging collagen scaffold, which might, at least in part, eliminate the decision making between ACLSR and ACLR on the basis of specific ACL rupture characteristics in the future.[3,6,7,10,19] However, it seems that for now the final assessment of a patient's eligibility for ACLSR should be made at the time of surgery.

Nevertheless, the value of using MRI in the classification of specific characteristics of acute complete ACL rupture might be improved in several ways as compared with the 1.5-T MRI with a standard sequence that was used in the present study. Although the capabilities of 1.5- and 3.0-T MRI scanners are not significantly different in the diagnosis of ACL rupture in general, higher field strength improves the signal-to-noise and contrast-to-noise ratios.[28] Higher field strength together with a small field of view and a dedicated knee coil with a larger number of receiver channels can optimize the spatial resolution, which may allow better visibility of the ACL rupture characteristics.[24] Additional oblique scans in the coronal and axial planes improve visualization of the ACL, and a 3-dimensional MRI sequence might provide more information on the ACL rupture characteristics.[1,12,20,22,25,26] Furthermore, it has been reported that MRI performed with the knee in flexion instead of extension improves accuracy in the diagnosis of partial and complete ACL ruptures in general. Although not investigated, this might improve the accuracy of MRI for classifying the characteristics of complete ACL rupture that were investigated in the present study.[18]

This study has some limitations that need to be addressed. First, only 1 observer assessed the classification of the ACL rupture characteristics at the time of surgery. However, in ACLR procedures, it is common practice that decisions at the time of surgery are made by just 1 orthopaedic surgeon. In addition, assessments are based not only on the arthroscopic image but also on probing the ruptured ACL remnants at the time of surgery. Although arthroscopic images were available for all the included patients, probing could not be replicated by assessing only arthroscopic images. As such, the single-surgeon classification of ACL rupture characteristics at the time of surgery can be considered the current gold standard.

Second, although this study included a relatively small sample size, it was large enough to reject the null hypothesis. Additionally, while important for the decision making in surgical timing and technique, there is a paucity of studies concerning the investigated topic. This study is the first to validate specific rupture characteristics of acute complete ACL rupture on preoperative MRI scans against findings at the time of surgery in the context of ACLSR.

Third, the distribution of the ACL rupture characteristics in the present study differed from that reported by Henle et al,[8] who had a much larger sample size (278 patients), and might not represent the normal distribution of the ACL rupture characteristics in the general population. In the present study, the reported frequency of a multilacerated ACL rupture pattern was higher than that reported by Henle et al. This further obscures the assessment of the ACL rupture characteristics and might have negatively affected the current results.

Fourth, the morphology of ruptured ACL remnants is known to change over time. Although MRI and surgery were not performed on the same day, the median time between MRI and surgery was 8 days (IQR, 5-10; range, 1-15). Thus, no relevant morphologic changes were expected between MRI and surgery. Furthermore, as the median time between injury and surgery was 14 days (IQR, 12-16.5; range, 9-20) and morphologic changes were reported to occur from 3 weeks on after injury, no major morphologic changes in the ACL remnants between MRI and surgery were expected from this perspective.

CONCLUSION

In the current study, we found poor to slight agreement between MRI classification and arthroscopic findings of specific ACL rupture characteristics. In addition, the intra- and interobserver reliability for MRI classification of the ACL rupture characteristics was slight to moderate.

REFERENCES

1. Araki D, Thorhauer E, Tashman S. Three-dimensional isotropic magnetic resonance imaging can provide a reliable estimate of the native anterior cruciate ligament insertion site anatomy. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(5):1311-1318.
2. Ateschrang A, Schreiner AJ, Ahmad SS, et al. Improved results of ACL primary repair in one-part tears with intact synovial coverage. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(1):37-43.
3. Buchler L, Regli D, Evangelopoulos DS, et al. Functional recovery following primary ACL repair with dynamic intraligamentary stabilization. *Knee*. 2016;23(3):549-553.
4. Chambat P. ACL tear. *Orthop Traumatol Surg Res*. 2013;99(1): S43-S52.
5. Chang MJ, Chang CB, Choi JY, Won HH, Kim TK. How useful is MRI in diagnosing isolated bundle ACL injuries? *Clin Orthop Relat Res*. 2013; 471(10):3283-3290.
6. Evangelopoulos DS, Kohl S, Schwienbacher S, Gantenbein B, Exadaktylos A, Ahmad SS. Collagen application reduces complication rates of mid-substance ACL tears treated with dynamic intraligamentary stabilization. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(8): 2414-2419.
7. Haberli J, Bieri KS, Aghayev E, Eggli S, Henle P. Dynamic intraligamentary stabilization of anterior cruciate ligament repair: hardware removal has no effect on knee laxity at 2-year follow-up. *Arch Orthop Trauma Surg*. 2019;139(5):639-644.
8. Henle P, Roder C, Perler G, Heitkemper S, Eggli S. Dynamic intraligamentary stabilization (DIS) for treatment of acute anterior cruciate ligament ruptures: case series experience of the first three years. *BMC Musculoskelet Disord*. 2015;16:27.
9. Hoogeslag RAG, Brouwer RW, Boer BC, de Vries AJ, Huis In 't Veld R. Acute anterior cruciate ligament rupture: repair or reconstruction? Two-year results of a randomized controlled clinical trial. *Am J Sports Med*. 2019;47(3):567-577.
10. Hoogeslag RAG, Brouwer RW, de Vries AJ, Boer BC, Huis In 't Veld R. Efficacy of nonaugmented, static augmented, and dynamic augmented suture repair of the ruptured anterior cruciate ligament: a systematic review of the literature. *Am J Sports Med*. 2020;48(14): 3626-3637.
11. Jaganathan S, Goyal A, Gadodia A, Rastogi S, Mittal R, Gamanagatti S. Spectrum of synovial pathologies: a pictorial assay. *Curr Probl Diagn Radiol*. 2012;41(1):30-42.
12. Kosaka M, Nakase J, Toratani T, et al. Oblique coronal and oblique sagittal MRI for diagnosis of anterior cruciate ligament tears and evaluation of anterior cruciate ligament remnant tissue. *Knee*. 2014;21(1): 54-57.
13. Krismer AM, Gousopoulos L, Kohl S, Ateschrang A, Kohlhof H, Ahmad SS. Factors influencing the success of anterior cruciate ligament repair with dynamic intraligamentary stabilisation. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(12):3923-3928.
14. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
15. Magarian EM, Fleming BC, Harrison SL, Mastrangelo AN, Badger GJ, Murray MM. Delay of 2 or 6 weeks adversely affects the functional outcome of augmented primary repair of the porcine anterior cruciate ligament. *Am J Sports Med*. 2010;38(12):2528-2534.
16. Millett PJ, Wickiewicz TL, Warren RF. Motion loss after ligament injuries to the knee, part I: causes. *Am J Sports Med*. 2001;29(5):664-675.

17. Millett PJ, Wickiewicz TL, Warren RF. Motion loss after ligament injuries to the knee, part II: prevention and treatment. *Am J Sports Med*. 2001;29(6):822-828.
18. Muhle C, Ahn JM, Dieke C. Diagnosis of ACL and meniscal injuries: MR imaging of knee flexion versus extension compared to arthroscopy. *Springerplus*. 2013;2(1):213.
19. Murray MM, Fleming BC, Badger GJ, et al. Bridge-enhanced anterior cruciate ligament repair is not inferior to autograft anterior cruciate ligament reconstruction at 2 years: results of a prospective randomized clinical trial. *Am J Sports Med*. 2020;48(6):1305-1315.
20. Ng WH, Griffith JF, Hung EH, Paunipagar B, Law BK, Yung PS. Imaging of the anterior cruciate ligament. *World J Orthop*. 2011;2(8):75-84.
21. Nwachukwu BU, Patel BH, Lu Y, Allen AA, Williams RJ III. Anterior cruciate ligament repair outcomes: an updated systematic review of recent literature. *Arthroscopy*. 2019;35(7):2233-2247.
22. Pereira ER, Ryu KN, Ahn JM, Kayser F, Bielecki D, Resnick D. Evaluation of the anterior cruciate ligament of the knee: comparison between partial flexion true sagittal and extension sagittal oblique positions during MR imaging. *Clin Radiol*. 1998;53(8):574-578.
23. Phelan N, Rowland P, Galvin R, O'Byrne JM. A systematic review and meta-analysis of the diagnostic accuracy of MRI for suspected ACL and meniscal tears of the knee. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(5):1525-1539.
24. Reiser M, Semmler W, Hricad H. *Magnetic Resonance Tomography*. Springer-Verlag; 2008.
25. Scheffler SU, Maschewski K, Becker R, Asbach P. In-vivo three-dimensional MR imaging of the intact anterior cruciate ligament shows a variable insertion pattern of the femoral and tibial footprints. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(12):3667-3672.
26. Shakoor D, Guermazi A, Kijowski R, et al. Cruciate ligament injuries of the knee: a meta-analysis of the diagnostic performance of 3D MRI. *J Magn Reson Imaging*. 2019;50(5):1545-1560.
27. Sherman MF, Lieber L, Bonamo JR, Podesta L, Reiter I. The long-term followup of primary anterior cruciate ligament repair: defining a rationale for augmentation. *Am J Sports Med*. 1991;19(3):243-255.
28. Smith C, McGarvey C, Harb Z, et al. Diagnostic efficacy of 3-T MRI for knee injuries using arthroscopy as a reference standard: a meta-analysis. *AJR Am J Roentgenol*. 2016;207(2):369-377.
29. van der List JP, DiFelice GS. Preoperative magnetic resonance imaging predicts eligibility for arthroscopic primary anterior cruciate ligament repair. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(2):660-671.
30. van der List JP, DiFelice GS. Role of tear location on outcomes of open primary repair of the anterior cruciate ligament: a systematic review of historical studies. *Knee*. 2017;24(5):898-908.
31. van der List JP, Mintz DN, DiFelice GS. The location of anterior cruciate ligament tears: a prevalence study using magnetic resonance imaging. *Orthop J Sports Med*. 2017;5(6):2325967117709966.
32. Van Dyck P, De Smet E, Veryser J, et al. Partial tear of the anterior cruciate ligament of the knee: injury patterns on MR imaging. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(2):256-261.
33. Van Dyck P, Gielen JL, Vanhoenacker FM, Wouters K, Dossche L, Parizel PM. Stable or unstable tear of the anterior cruciate ligament of the knee: an MR diagnosis? *Skeletal Radiol*. 2012;41(3):273-280.
34. Van Dyck P, Vanhoenacker FM, Gielen JL, et al. Three tesla magnetic resonance imaging of the anterior cruciate ligament of the knee: can we differentiate complete from partial tears? *Skeletal Radiol*. 2011;40(6):701-707.
35. van Melick N, van Cingel RE, Brooijmans F, et al. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. *Br J Sports Med*. 2016;50(24):1506-1515.
36. Yao L, Gentili A, Petrus L, Lee JK. Partial ACL rupture: an MR diagnosis? *Skeletal Radiol*. 1995;24(4):247-251.