



MAGNETIC RESONANCE IMAGING EVALUATION OF ANTEROLATERAL LIGAMENT INJURIES AND ASSOCIATED LESIONS IN ACUTE ANTERIOR CRUCIATE LIGAMENT TEARS

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ABSTRACT – Objective: The first aim of our study was to investigate the appearance of the injured Anterolateral Ligament (ALL) on magnetic resonance imaging (MRI) performed in acute anterior cruciate ligament (ACL) injuries and provide data about the inter- and intra-rater agreement in assessing the ALL status. The second aim was to describe the incidence of associated injuries in acute ACL-injured knees and provide data regarding the inter- and intra-rater agreement in identifying these.

Patients and Methods: Patients with ACL lesions who underwent MRI within 10 days from the injury were included. Images were evaluated by an orthopedic surgeon and a musculoskeletal (MSK) radiologist. Inter- and intra-observer reliabilities were determined for MRI parameters of the anterolateral ligament (ALL) and associated injuries by using the kappa (κ) test.

Results: A total of 100 patients were evaluated. ALL abnormalities were observed in 93% of the cases. Inter-observer reliability was substantial to almost perfect concerning ALL signal, femoral and tibial bone bruises, femoral notch sign and meniscal tears ($\kappa = 0.6-1$); moderate agreement was observed for lateral meniscus tears ($\kappa = 0.56$) and Segond fractures ($\kappa = 0.45$). Intra-observer reliability of the orthopedic surgeon was substantial to almost perfect for all the criteria evaluated ($\kappa = 0.6-1$). Intra-observer reliability of the MSK radiologist was substantial to almost perfect for ALL injuries and bone bruises ($\kappa = 0.6-1$); there was a moderate agreement for meniscal tears and Segond fractures ($\kappa = 0.41-0.6$), except for Lateral Meniscus Posterior Horn Root Tears ($\kappa = 0.21$).

Conclusions: MRI can represent an instrument of high reliability and reproducibility in the diagnosis of ALL tears and associated lesions in patients with acute ACL ruptures.

KEYWORDS: Knee, Ligaments, anterior cruciate ligament, Anterolateral ligament, Bone bruise, Segond fracture, Lateral Meniscus Posterior Horn Root Tears, Femoral notch sign.



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INTRODUCTION

The anterolateral ligament (ALL) has recently received renewed interest after its detailed anatomical description by Claes et al¹ in 2013. Numerous studies¹⁻³ have described its anatomy and the biomechanical role as an anterolateral knee stabilizer. Anatomical studies⁴⁻⁸ have shown the ALL origin posterior and proximal to the lateral epicondyle, a meniscal insertion between its anterior horn and body and a tibial insertion on the anterolateral edge of the tibia between Gerdy's tubercle and the tip of the fibular head, around 5-10 mm below the lateral plateau.

Several biomechanical and clinical studies⁹⁻¹² have recently shown that the ALL plays a role as a stabilizer of internal rotation. Moreover, other studies^{12,13} have found a high incidence of ALL lesions concomitant with anterior cruciate ligament tears and suggested that injuries to the ALL can result in residual anterolateral rotatory instability and poor outcomes, if not addressed at the time of ACL reconstruction (ACLR). For this reason, many authors^{14,15} have recently suggested indications for ALL reconstruction or lateral extra-articular tenodesis (LET) in cases of high-grade pivot shift, associated Segond fracture, chronic ACL lesions, high level of sporting activity, patients involved in pivoting sports, lateral femoral notch sign (FNS), young age females and ACL revisions.

Imaging studies^{4,6,8,16-18} for ALL assessment to allow a more precise preoperative planning are also growing in interest. Numerous studies in literature have also recently evaluated the efficacy of magnetic resonance imaging (MRI) and ultrasound (US) to characterize the ALL in both healthy and injured knees with conflicting results.

One of the primary concerns in the diagnosis of ALL lesions is the efficacy of MRI, with a percentage of identification ranging from 10% to 90%^{8,19-25}. However, MRI is routinely used to assess other injuries associated with the ACL, particularly bone bruises, meniscal tears, chondral tears and the FNS. All these abnormalities are consequences of the injury mechanism that leads to an ACL tear, which is usually a rotation and translation phenomenon similar to the pivot shift (pivot shift-like injury)^{26,27}.

Thus, the main objective of this study was to investigate the appearance of the injured ALL on MRI performed a maximum of 10 days after ACL injury and to provide data about the interrater agreement in assessing this ligament status. The second aim was to describe the MRI incidence of associated ALL injuries (FNS, bone bruises, meniscal and chondral tears) in acute ACL-injured knees and provide data regarding the interrater agreement in identifying and categorizing these injuries.

PATIENTS AND METHODS

Patient Population

All subjects provided written informed consent for inclusion before they participated in the study. A retrospective analysis of prospectively collected data for consecutive patients who were admitted with a history of acute knee trauma from January 2018 to October 2018 at S. Andrea Hospital in Rome, was performed. Patients who were diagnosed with acute ACL injury were included in the study. Exclusion criteria: patients who sustained concomitant fractures (with the exception of Segond fractures) or had multiligamentous injuries that required surgery in addition to ACLR; patients with a history of previous surgery on the examined knee, or knee osteoarthritis.

MRI Assessment

All MRIs were performed within 10 days of the trauma. The MRI examinations were all performed with 1.5-mm slice thickness in the supine position on a 1.5 T system (Aera, Espreo, or Avanto; Siemens Medical Solutions, Erlangen, Germany). The analysis was performed on a picture archiving and communication system workstation (Centricity RA 1000, GE Healthcare, Chicago, IL, USA). An orthopaedic surgeon and a musculoskeletal radiologist assessed the examinations twice with an interval of at least 2 weeks, in a randomized order and blinded from the readings of the other reader.

Before starting the study, the examiners reviewed 15 MRI scans to agree on the appearance of the ALL, its injuries and the classifications of the associated articular lesions.

According to Monaco et al²⁸, the ALL was evaluated on coronal images, with the axial and sagittal planes used for anatomic orientation. The regular ALL was defined as the low signal band originating from the posterior-proximal region of the lateral epicondyle of the femur and crossing the proximal sur-

face of the lateral collateral ligament, deep to the iliotibial band (ITB), to its tibial insertion between the Gerdy tubercle and the fibular apex. By T2-weighted scans, the readers assessed the ALL's signal (regular or increased), thickness (regular or increased), fibers appearance (continuous or interrupted) (Figure 1),



Figure 1. Anterolateral Ligament tear: Coronal T2 weighted MRI. The circle indicates abnormality of the inferior lateral genicular vessels (usually 2 circular areas of hyperintensity).

Segond fractures, and inferior lateral genicular artery (ILGA) appearance (Figure 2).

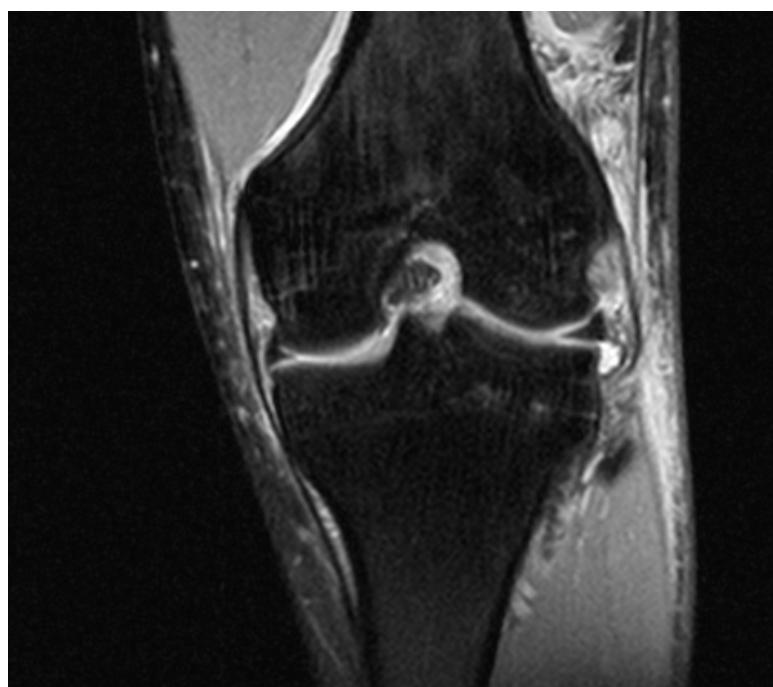


Figure 2. Asymmetry of the Genicular vessels: Coronal T2 weighted MRI. The circle indicates abnormality of the inferior lateral genicular vessels (usually 2 circular areas of hyperintensity).

The asymmetry of the genicular vessels was considered when a single circular finding was present (usually 2 circular areas of hyperintensity are observed, corresponding to the two vessels) or when the disappearance of one or both of the corresponding areas was observed²⁹. Segond fracture was detected as a signal hyperintensity at tibial ALL's insertion or hypointense partial detachment (Figure 3)³⁰.



Figure 3. Segond fracture: Coronal T2 weighted MRI. The circle indicates the Segond Fracture.

Furthermore, associated lesions were evaluated. The bone contusions were defined as absent (none/minimal) or present (moderate or severe)³¹, and their location was assessed (medial/lateral tibial plateau, medial/lateral femoral condyle). The presence of FNS was detected on sagittal MRI images, highlighted as a depression greater than 2 mm or a low signal sulcus of the surface of the femoral condyle, an indicator of an osteochondral lesion (Figure 4).



Figure 4. Femoral Notch Sign: Sagittal T2 weighted MRI. The circle indicates a depression suggestive for the Femoral Notch Sign.

Eventually, meniscal tears, particularly lateral meniscus posterior horn radial tears (LMPHRT) and medial meniscus posterior horn-capsular (Ramp) lesions were detected.

The Ramp lesions are better detectable on FAT-SAT T2-weighted sagittal scans³². A hyperintense streak or crack of effusion between the posterior horn of the medial meniscus and the capsular margin, an alteration of the signal at the periphery of the posterior horn and a bone-bruise of the posterior medial tibial plateau can be seen (Figure 5).



Figure 5. RAMP lesion: Sagittal T2 weighted MRI. The circle indicates the Ramp Lesion with an effusion between the posterior horn of the medial meniscus and the capsular margin.

The LMPHRTs were highlighted on T2-weighted and FAT-SAT T2-weighted sequences on the coronal and sagittal planes³³. LMPHRT and root were identified, according to Asai et al³⁴, thanks to the presence of two signs: the cleft sign (a vertical linear defect between the lateral femoral condyle and the intercondylar eminence on the coronal images), and the truncated triangle sign (an abrupt interruption of the regular triangular meniscal contour at its apex on the sagittal T2 images) (Figure 6).



Figure 6. Lateral meniscus posterior horn root tear: T2 weighted MRIs. **a**, Coronal, the circle indicates the Cleft Sign with a vertical linear defect between the lateral femoral condyle and the intercondylar eminence. **b**, Sagittal, the circle indicates the Truncated Triangle Sign, as an abrupt interruption of the regular triangular meniscal contour at its apex.

Statistical Analysis

The scoring results for all observers were calculated using SPSS Statistics for MacOS v. 25 (IBM Corp., Armonk, NY, USA). Cohen's kappa coefficient was used to determine the degree of intra-observer and inter-observer agreement.

The kappa values were interpreted according to Landis and Koch³⁵, i.e., $\kappa < 0.00$ corresponds to poor agreement, $\kappa = 0.00-0.20$ to a slight agreement, $\kappa = 0.21-0.40$ to fair agreement, $\kappa = 0.41-0.60$ to moderate agreement, $\kappa = 0.61-0.80$ to substantial agreement, and $\kappa = 0.81-1.00$ to almost perfect agreement.

The lesions were dichotomized to construct 2 - 2 tables to facilitate calculations. The inter-observer value was calculated in the second examination series. No adjustment for multiple testing was made.

RESULTS

One hundred patients were eligible for inclusion in this study. The selected patients had a mean age of 28.3 ± 9.8 (mean \pm SD) years. There were 74 males (74%) and 26 females (26%). The demographic data of the study groups are displayed in Table 1.

Table 1. Demographic data of patients.

Total		
Age	n	100
	Mean (SD)	28.3 (9.8)
	Median (Q1; Q3)	27 (21; 33)
	Min; Max	13; 68
Gender	n	100
	Female	26 (26%)
	Male	74 (74%)

The left side was affected in 60% of cases (60 patients) and the right side in 40% (40 patients). The observers' mean records are displayed in Table 2. ALL abnormalities were found in 93% of MRIs; the most frequent were signal changes, found in 91% of cases; thickness variations were found in 69% of cases; fiber injuries in 39% of cases; ILGA abnormalities in 43% of cases. It can be observed that the most frequently encountered lesions were the femoral and tibial bone bruises (in 90% and 93% of the cases, respectively).

Concerning intra-observer variability, a substantial agreement to an almost perfect agreement was noted for both observers: the first and second observers achieved mean κ -values of 0.84 and 0.67, respectively, ranging from substantial to almost perfect agreement.

An inter-observer agreement, demonstrated by κ -values, ranged from 0.45 for Segond fractures (fair agreement) to 0.86 for FNS (almost perfect agreement).

Assessment of the intra- and inter-observer agreements are represented in Table 3.

DISCUSSION

The study found that the Anterolateral Ligament (ALL) was clearly visualized in MRI in most cases of acute Anterior Cruciate Ligament (ACL) ruptured knees with a high prevalence of injuries. Signal abnormalities were found in 91% of cases, thickness affected 69% of cases, fiber injuries were detected in 39%, and ILGA asymmetries in 43% of cases. Associated intraarticular lesions, such as meniscal tears, Ramp lesions, LMPHRT, bone bruising, and FNS were frequently found alongside ALL injuries. In this study, a high sensitivity of MRI was observed, identifying lesions of ALL in up to 91% of patients, with an excellent reproducibility confirmed by a high intra-observer ($\kappa = 0.73-0.8$) and inter-observer ($\kappa = 0.8$)

Table 2. Prevalence of MRI injuries.

Lesion type	Patients, n (%)
ALL	
Signal	91 (91%)
Thickness	69 (69%)
Fibers	39 (39%)
ILGA	43 (43%)
FNS	
Yes	59 (59%)
No	41 (41%)
Bone Bruise	
Femoral	90 (90%)
Tibial	93 (93%)
Meniscal Tear	
None	29 (29%)
Yes	71 (71%)
Isolated Medial Meniscus	13 (13%)
Isolated Lateral Meniscus	29 (29%)
Both	29 (29%)
LMPHRT	
Yes	41 (41%)
No	59 (59%)
Ramp Lesion	
Yes	35 (35%)
No	65 (65%)
Segond Fracture	
Yes	7 (7%)
No	93 (93%)

ALL, anterolateral ligament; FNS, femoral notch sign; ILGA, inferior lateral geniculate artery; LMPHRT, lateral meniscus posterior horn root tear.

agreement. For the other parameters, inter-observer agreement ranged from moderate ($\kappa = 0.45$) to almost perfect ($\kappa = 1$), and intra-observer agreement ranged from fair ($\kappa = 0.21$) to almost perfect ($\kappa = 1$).

To date, the diagnostic procedure in the event of an ACL rupture can no longer ignore the evaluation and identification of associated structures tears as those analyzed in the current paper, due to their biomechanical function. Impairment of these leads to increased anteroposterior and rotational instability, which probably cannot be corrected with an isolated ACL reconstruction¹⁵.

It is particularly important to systematically search for lesions of the ALL on MRI because of the clinical implications they may have. MRI ALL abnormalities in patients with ACL injuries have a significant association with pivot shift test results in patients under anesthesia³⁶. At present, a remarkable variability can be seen in MRI in the identification rate of ALL lesions. Recently, Ferretti et al²⁹ have used the MRI of the uninjured side as a comparison to detect ALL lesions in acutely ACL-injured knees; they found that, when using the healthy side as a comparison, the percentage of ALL injury is up to 88.2% with an inter- and intra-observer agreement ranging from 0.81 to 1. Cavaignac et al¹⁸, in an MRI study of 30 knees, found the tibial portion of the ALL to be injured in 100% of cases. The variability of protocols used for MRI scans, radiologic signs, and time from injury to MRI results in high variability of ALL lesions on MRI, ranging from 10.8% to 78.8%^{8,11,18,19,22,25,30,37-39}. This study's high prevalence of ALL abnormalities may be due to the acute setting in which the MRI was performed, prior to the reparative process involving ALL. In fact, it has been suggested⁴⁰ that rates are lower in chronic ACL-injured knees, indicating that some ALL injuries heal. Saithna et al⁴¹, have recently explored the rate and duration of the healing process of ALL injuries following anterior cruciate ligament reconstruction ACLR using serial 3 T, 3D-MRI scans.

Table 3. Measurement of observers' agreement.

	ALL				Bone Bruise		FNS		Meniscus			Segond
	Signal	Thickness	Fibers	ILGA	Femur	Tibia			MM	LM	LMPHRT	Ramp
Inter-observer κ	.8	.72	.65	.64	1	1	.86	.77	.56	.61	.84	.45
Inter-observer % agreement rate,	94.7	86.4	78	73.6	100	100	90.6	89.2	70.8	75	93.7	55
Intra-Observer 1 κ	.73	.75	.88	.64	1	1	.86	.83	.94	.77	.78	.90
Intra-Observer 1 agreement rate, %	93.1	83.4	91.9	79.2	100	100	93.1	91.7	97.2	88.9	90.3	94.1
Intra-Observer 2 κ	.8	.77	.88	.66	1	1	.58	.57	.42	.21	.57	.58
Intra-Observer 2 agreement rate, %	86.1	79.4	93.3	75.6	100	100	75	68.1	67.2	52.5	79.2	76.1

Cohen's κ values and agreement rates are expressed by comparing operator 1 to operator 2 (Inter-observer), operator 1 at the first measurement to operator 1 at the second measurement (Intra-observer 1), and operator 2 at the first measurement to operator 2 at the second measurement (Intra-observer 2). For Cohen's κ , its value and statistical significance were calculated. Values which did not reach statistical significance ($p < 0.05$) are shown in bold. The agreement rate is expressed as a percentage.

Among the 44 patients in the study, 71.2% had preoperative ALL injuries. The authors found that 30.3% of ALL injuries fully healed by 12 months after ACLR, but none of the patients with a complete ALL tear was observed to achieve full healing. This study suggested that the healing process for ALL injuries after ACLR is generally slow, with only a small proportion of patients experiencing a full recovery.

An alteration of the ILGA was detected in 43% of cases, also with excellent inter-observer agreement ($\kappa = 0.64$), suggesting that this sign, if detected, could help in the diagnosis of ALL lesions. An overlapping variability is also evident in the identification of the Segond fractures. In multiple published studies^{19,42}, its prevalence varies from 1.8% to more than 36% of injured ALL. Following these previous studies, avulsion fractures were found in 7% of the patients examined in this study, with a moderate inter-observer agreement ($\kappa = 0.45$).

Recently, many authors⁴³⁻⁴⁶ have tried to correlate and confirm a pivot-shift-like mechanism in ACL injuries with lesions found on MRI. Several papers have reported^{18,28,29,47} an association between lateral bone bruising and abnormalities of the ALL, supporting the hypothesis of a rotational injury mechanism that leads to an ACL and ALL tear. Helito et al⁴⁸ found that only 1 out of 66 cases of ALL injury was not accompanied by a bone bruise, and that ALL injury was present for 46.5% of the time when both lateral femoral condyle (LFC) and lateral tibial plateau (LTP) bone bruises were present. Another study showed that 37.5% of acute ACL tears with LFC and LTP bone bruises were associated with an ALL injury⁸. Similarly, Lintin et al⁴⁹ found that 68 of 75 cases of ALL injury had an associated bone bruise. Their findings were supported by two studies by Lee et al³¹, who found an increased risk of ALL injury with the presence of bone bruises and an increased severity of ALL injury with the presence of bone bruise⁵⁰. However, Marot et al⁵¹ found no correlation between ALL injury and bone bruise volume. In the present study, these results were confirmed with an elevated prevalence of BB both in the tibial plateau (93%) and in the femoral condyles (90%) with the same typical distribution on the sagittal plane in the lateral portions, in association with lesions of the lateral meniscus in 58% and with perfect interrater concordance ($\kappa = 1$).

The literature shows a high prevalence of lateral meniscus injuries associated with ACL rupture⁵². Many authors considered the Lateral Meniscus (LM) injury being correlated to the ALL insertion on it^{5,31,53}. Helito et al⁷ and Caterine et al⁵, in their cadaveric studies, described the presence of an ALL-meniscal insertion. These authors assumed that meniscus could break due to the pulling of the ALL, during the pivot shift phenomenon. Meniscal ruptures, with particular reference to lesions of the posterior horn, may be caused to entrapment of the meniscus between the posterior aspect of the LTP and the LFC^{31,54}.

LMPHRT had been commonly associated with anterior cruciate ligament injuries, with an incidence ranging from 4% to 52%⁵⁵⁻⁵⁷, probably caused by the rotational ACL injury mechanism^{45,58}. Lee et al³¹, analyzing 275 MRI scans in patients with acute ACL rupture, found lesions of the external meniscus in 42% of the cases with ALL displayed, with a prevalence of these significantly higher in the case of injured ALL ($p < 0.03$); moreover, they reported a correlation of LMPHRT with ALL lesions (14.8% and 6.4% in injured and healthy ALL, respectively, $p = 0.042$). In the present study, we found, in agreement with Lee, a high prevalence of lateral meniscus lesions with an excellent inter-rater concordance ($\kappa = 0.77-0.83$). This remarkable datum is due to the fact that a distinction has not been made between root lesions and proper radial lesions when referring to lesions of the posterior horn of the lateral meniscus. Moreover, as we performed the MRIs in a very acute phase, the joint effusion could lead to an overestimation of the LMPHRT.

In the present study, we also detected lesions of the medial meniscus in 42% of the cases, with excellent inter-rater concordance ($\kappa = 0.86$). Among these, we have found the Ramp lesions to be diagnosed by MRI in 35% of patients. Since Ramp lesions may remain hidden in the anterior (at 90° of flexion) or anterolateral "standard" arthroscopic approach, a preoperative suspicion for knee surgeons is needed to diagnose and treat these lesions⁵⁹, and MRI could be a useful tool. DePhillipo et al⁶⁰ detected an incidence of Ramp lesions in 16.6% of knees with ACL rupture and low sensitivity of MRI, able to identify these lesions in only 48% of the cases, compared to the gold-standard arthroscopic exploration. A significant result in our study, compared to the previous ones in literature, was a higher identification rate of Ramp lesions, resulting in 35% of injured knees, with an almost perfect inter/intra-observer concordance, demonstrated by kappa values of 0.84 and 0.78, respectively. This result should be explained because the MRIs were in the early phase after injury, and some alterations, such as an evident effusion and imbibition of the periarticular tissues due to the effusion, can be correlated to the recent injury and not only to the Ramp lesion.

Another typical lesion associated with ACL ruptures is the Lateral FNS, represented by the presence of a deep notch on the lateral femoral condyle. In the present study, we found a significantly higher percentage of the Lateral FNS compared in the previous literature, with an almost perfect inter-rater

agreement ($\kappa = 0.86$). Although various studies^{61,62} had hypothesized that this diagnostic sign could result by chronic rotational instability, more precisely the anterior subluxation of the lateral tibial plateau, causing recurrent impacts on the lateral femoral condyle, we found it in the majority of the acute cases we studied. Other studies⁶³ suggest that it may be the result of the progression of occult osteochondral lesions that occur because of traumatic valgus injuries at the time of ACL tearing, in part analogous to a Hill-Sachs injury during shoulder dislocations.

Limitations and Strengths

We are aware of possible limitations of the study as the injury criteria were established arbitrarily based on the experience of the authors and on previous studies in literature which evaluated these structures. Moreover, the number of patients is not high, and a power analysis was not performed, but the study population can be considered in line with similar studies^{31,48}. Another limitation is represented by using a 1.5 T MRI, while other recent studies in literature have highlighted a higher accuracy of the 3T scans.

On the other hand, the main strength of our study is represented by having assessed the majority of the associated lesions in ACL rupture only in patients with an acute injury, so we provided a real estimation of the lesions associated with the first trauma, without confounding factors due to possible subsequent traumas or recurrent instability.

CONCLUSIONS

MRI can represent an instrument of high reliability and reproducibility in the diagnosis of lesions of the anterolateral ligament and associated lesions in patients with acute ACL rupture.

ETHICS APPROVAL:

This study was conducted in accordance with the Declaration of Helsinki of 1975 (as revised in 2013), and the protocol was reviewed and approved by the Ethics Committee of the University of Rome La Sa-pienza (Ref. number: 5713_2018).

INFORMED CONSENT:

All subjects provided written informed consent for inclusion before they participated in the study.

CONFLICT OF INTEREST:

Edoardo Monaco and Andrea Ferretti are Arthrex paid Consultants.

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DATA AVAILABILITY:

Data are available on request.

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