Knee Surgery, Sports Traumatology, Arthroscopy
https://doi.org/10.1007/s00167-021-06789-0

KNEE

The posterior cruciate ligament inclination angle is higher in anterior cruciate ligament insufficiency

Julio Cesar Gali[1] · Tyago Araujo Almeida[2] · Daniela Cristina de Moraes Miguel[3] · Samir Alexandre Nassar[3] · Julio Cesar Gali Filho[4] · Nicholas P. Drain[5] · Freddie F. Fu[5]

Received: 7 August 2021 / Accepted: 25 October 2021

Abstract

Purpose Magnetic resonance imaging (MRI) is the gold standard image examination for anterior cruciate ligament (ACL) lesion diagnosis. Our hypothesis was that measuring the posterior cruciate ligament inclination angle (PCLIA) using MRI images may be an auxiliary tool to aid the recognition of ACL insufficiency. The purpose of this study was to compare the PCLIA measurement in MRIs of individuals with and without ACL injury.

Methods The PCLIA was measured by two radiologists in 65 knee MRIs of patients with intact ACL (control group) and in 65 knee MRIs of people with ACL injury (study group). In both groups, the posterior cruciate ligament was intact. The control group was included 35 men (53.8%) and 30 women (46.1%). The patients' average age was 38.7 years (range 15–75; SD ± 14.8 years). In this group, 31 (47.6%) MRIs were from right knees and 34 (52.3%) were from left knees. The study group consisted of 45 men (69.2%) and 20 women (30.7%). The patients' average age was 36.8 years (range 14–55; SD ± 10.3 years). In this group, 33 (50.7%) were right knees and 32 (49.2%) were left knees. PCLIA was formed by the intersection of two lines drawn in MRI sagittal images. The first passed tangentially to the articular surface of the tibial condyle and the second was drawn over the fraction of the ligament that originated where the first crossed the PCL, outlined proximally.

Results The average PCLIA was 44.2 ± 3.8° in the control group and 78.9 ± 8.6° in the study group. Statistical analyses showed that the PCLIA was higher in the group with ACL injury ($p < 0.05$).

Conclusion

The PCLIA was significantly higher in individuals with ACL injuries. The measurement of this angle using MRI images may allow for detection of ACL insufficiency and thus assist in an individualized and precise approach to the treatment of injuries to the ACL.

Clinical relevance PCLIA may be a way to detect ACL insufficiency and thus help surgeons to decide which patient might need ACL reconstruction.

Level of evidence III.

Keywords Anterior cruciate ligament · Insufficiency · Magnetic resonance imaging · Posterior cruciate ligament

✉ Julio Cesar Gali
jcgali@pucsp.br

Tyago Araujo Almeida
araujotyago@hotmail.com

Daniela Cristina de Moraes Miguel
danielacristina1984@yahoo.com.br

Samir Alexandre Nassar
drsamirnassar@centromedicosorocaba.com.br

Julio Cesar Gali Filho
julioc41@hotmail.com

Nicholas P. Drain
drainn@upmc.edu

Freddie F. Fu
ffu@upmc.edu

[1] Department of Surgery, Faculty of Medical Science and Health, Catholic University of Sao Paulo, Rua Joubert Wey, 290, Sorocaba, SP 18030-070, Brazil

[2] Santa Lucinda Hospital, Sorocaba, SP, Brazil

[3] Centro Médico Sorocaba, Sorocaba, SP, Brazil

[4] Núcleo de Ortopedia e Traumatologia do Esporte, Sorocaba, SP, Brazil

[5] Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA, USA

Published online: 17 November 2021

Introduction

The diagnosis of an anterior cruciate ligament (ACL) injury may be made by clinical examination and has been shown to have comparable accuracy, specificity, sensitivity, and predictive value to magnetic resonance imaging, MRI [1, 13, 15]. The ACL is composed of a group of fibers. Consequently, an injury may result in damage to only a portion of these fibers, characterizing a partial ACL tear (pACL). The diagnosis and frequency of pACL tears has increased and the range of injuries varies considerably [24]. Regarding clinical examination, a high-grade Lachman test, anterior drawer test, or pivot shift test correlate with increased probability of complete ACL tear [8]. Higher grades of both Lachman and pivot shift test are associated with a greater likelihood of complete ACL tears, compared to pACL tears [4].

pACL injuries are more difficult to diagnose than complete tears using MRI [14]. Van Dyck et al. reported that many pACL tears may be indistinguishable on MRI from either a complete tear or mucoid ligament degeneration [22]. According to Shu et al., preoperative MRI showed 11 partial thickness tears (32.4%), however, arthroscopic evaluation revealed 20 partial thickness tears (58.8%) in the same study population [18]. In contrast, Zhao et al. reported an accuracy of MRI diagnosed pACL tears of 94.7% [26].

For optimal diagnosis of ACL injury, a full clinical evaluation, including physical examination and imaging is necessary. With regard to imaging, determining the posterior cruciate ligament of inclination angle (PCLIA) may provide valuable information to aid the diagnostic accuracy of ACL injury using MRI. When there is incompetence of the ACL, there is potential for tibial anteriorization and consequent PCL deformation. Alterations in the PCL as a sign of an ACL injury on MRI have already been described [10, 17, 21, 23, 25]. It has been sought to improve the possible deficiencies found in the existing literature by conducting a research study with an adequate sample size, and with simple and easily reproducible measures of PCL changes in the context of ACL injury, as measured on MRI. The objective of our study was to verify whether there was a difference in PCLIA measured with MRI in patients with ACL injury compared to those with an intact ligament to determine its utility in ACL insufficiency diagnoses and in guiding treatment choice. Our hypothesis was that PCLIA, measured by MRI, was higher in patients with ACL injuries.

Table 1 Distribution of patients by gender

Group	Frequency of researched gender		Total
	Female	Male	
Study	20 (15.3%)	45 (34.6%)	65 (50%)
Control	30 (23%)	35 (26.9%)	65 (50%)
Total	50 (38.4%)	80 (61.5%)	130 (100%)

Table 2 Distribution of patients by laterality

Group	Laterality		Total
	Right	Left	
Study	33 (25.3%)	32 (24.6%)	65 (50%)
Control	31 (23.8%)	34 (26.1%)	65 (50%)
Total	64 (49.2%)	66 (50.7%)	130 (100%)

Materials and methods

Research approval was obtained from the Ethics Committee of our institution under the Number CAAE: 33438720.0.0000.5373. One hundred and thirty 3 T MRIs of knees from 130 patients were used for analysis. Of these, 65 were from individuals who had an intact ACL on MRI scans, constituting the control group, and 65 MRIs from individuals with injured ACLs, which constituted the study group. The sample size was calculated to detect a difference of 15° in the PCLIA values between the control and study groups at the 5% significance level.

The ACL was considered intact when viewed as a continuous group of fibers with low signal intensity, precise limits, taut between its femoral and tibial insertion sites, and directed at a more acute angle than the roof of the intercondylar fossa [7]. On the other hand, the ACL was characterized as injured if there was fiber discontinuity, malalignment, and even nonvisualization of the ligament in chronic cases [6]. In our study, the diagnosis of whether the ACL was injured or intact was certain.

In the control group, 35 individuals were male (53.8%) and 30 were female (46.1%). The mean age of these patients was 38.7 years, with a standard deviation (SD) of ± 14.8, ranging from 15 to 75 of years age. In this cohort, 31 knees were right (47.6%) and 34 (52.3%) were left. The study group consisted of 45 males (69.2%) and 20 females (30.7%). In this cohort, 33 (50.7%) were right knees and 32 (49.2%) were left (Tables 1, 2). The mean age of these patients was 36.8 ± 10.3 years, ranging from 14 to 55 years of age. The frequency of patients in each group, according to age groups grouped into decades, is shown in Table 3 and Fig. 1.

Table 3 Distribution of patients in age groups

Age range in decades and percentages								
Group	10–20	21–30	31–40	41–50	51–60	61–60	+70	Total
Study	4 (6.1)	13 (20.0)	22 (33.8)	21 (32.3)	5 (7.6)	–	–	65 (99.9)
Control	7 (10.7)	13 (20.0)	20 (30.7)	13 (20.0)	4 (6.1)	6(9.23)	2 (3.0)	65 (99.9)

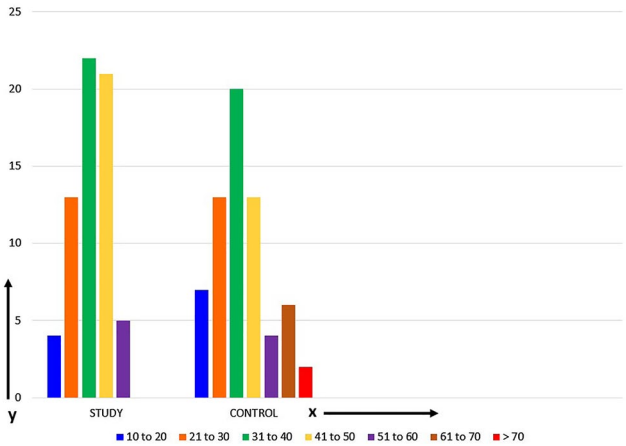

Fig. 1 Distribution of patients according to age groups grouped into decades. *x-axis* age groups, *y-axis* number of patients

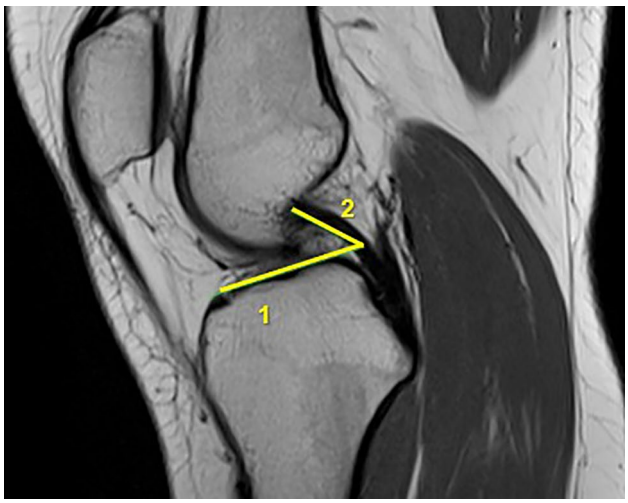

Fig. 2 T1 MRI image illustrating posterior cruciate ligament inclination angle (PCLIA). Line 1 was passed tangentially to the articular surface of the tibial condyle and line 2 was drawn over the fraction of the ligament that originated where the first crossed the PCL, delineated in the proximal direction

Two radiologists (DCMM and SAN) independently measured the PCLIA in 130 MRIs of the knees of patients in both the control and study groups using the Carestream PAC software version 12.1.5.7014. The PCLIA measurements were performed twice by each examiner, on different days, and the reported angle for each examiner was the average of the two measurements taken. It was determined that an average of the two radiologists' measurements would be reported if results demonstrated high inter-rater agreement.

The angle was defined by the intersection of two lines drawn on the sagittal MRI images where the PCL was best visualized. The first line passed tangentially to the articular surface of the tibial condyle and the second line was drawn over the portion of the ligament that originated where the first line crossed the PCL, delineated in the proximal direction (Fig. 2). This was done directly on computer images and the software provided angle measurements in degrees with two decimal points. We reported angles to one decimal point. Subsequently, PCLIA values were statistically analyzed to determine whether there was a significant difference between the control and study groups and to assess agreement between the observers' measurements.

Statistical analysis

Sample size calculation revealed that a number of 65 MRIs of patients with an intact ACL and 65 scans with the ligament injured was significant to detect a difference of 15° in PCLIA between control and study groups with a significance level of 5%. Power analysis of our research was checked on Welch's *T* test, with a 95% confidence interval. It has been chosen to use non-parametric tests and data normality was assessed using the Shapiro–Wilk and Kolmogorov–Smirnov tests, with 95% confidence. Wilcoxon's non-parametric test was used to determine whether the measurements taken by the two radiologists were significantly different, that is, whether the difference between them could be considered equal to zero. The non-parametric Mann–Whitney *U* test was used to check whether the mean PCLIA in the RMS of patients with ACL injury was equal to that of patients with intact ACL.

To reach the cut-off point for the PCLIA measurements, a confidence interval of 95% of the mean was applied. This was obtained by adding and subtracting twice the SD of the mean of the PCLIA values obtained in each group. The lower and upper limits of these ranges were considered the cut-off points for the study and control groups, respectively. If the PCLIA value obtained in the MRI of a patient in the study group was lower than the cut-off point, it was considered a false negative (FN) and if the PCLIA value found in the MRI of a person in the control group was higher than the cut-off point, it was considered a false positive (FP).

Table 4 Mean evaluators' measurements and evaluators' average value in the control and study groups

Group	Evaluator 1		Evaluator 2		Evaluators' average value	
	Average	SD	Average	SD	Average	SD
Study	78.7	9.8	79.3	7.5	79.0	7.4
Control	44.2	4.1	45.0	3.6	44.5	3.4

SD standard deviation

The sensitivity of the evaluators' measurements was calculated by dividing the number of true positive (TP) measurements by the sum of the TP and FN measurements, and the specificity was determined by the ratio between the true negative (TN) measurements and the sum of the FP and TN measurements. The accuracy of the evaluators' measurements was estimated by dividing the number of correct assessments by total assessments {(TN + TP)/(TN + TP + FN + FP)}.

Results

The power of our data was 0.9946. The statistical and *p* value results were − 1.471 and 0.141, respectively, so we did not reject the null hypothesis that the difference in the results of the two evaluators was equal to zero, with 95% confidence. The study and control groups consisted of subjects between the ages of 21 and 50 years old in 86.1% and 70.7%, respectively, of each group's total.

The mean PCLIA between groups was significantly different, with a mean angle of 79.0 ± 7.4° in patients with ACL injuries (study group) compared to mean an angle of 44.5 ± 3.4° in patients with an intact ACL (control group) ($p < 0.05$). The evaluators' average measurements for each group are shown in Table 4. The Mann–Whitney test revealed good inter-rater agreement, with evaluators' measurements relatively equal ($p < 0.001$), thus allowing analysis using the average of the two measurements. The frequency of PCLIA measurements in patients in the control and study groups can be seen in Fig. 3.

The 95% confidence interval for the average PCLIA angle in the study group ranged from 64.2° to 93.8°. In the control group, 95% confidence interval ranged from 33.7° to 51.3°. The mean PCLIA, lower and upper cut-off points, as well as minimum and maximum PCLIA values are displayed in Table 5. Thus, PCLIA measurements above 64.2 were indicative of ACL injury and below 51.3 suggested an intact ACL. No patient in the study group had a PCLIA lower than 64.2, while two patients in the control group had a PCLIA higher than 51.3.

Among all measurements, there were no FN results whereas two measurements made by examiner 1 in the control group were higher than the cut-off point representing two FP results. Consequently, the sensitivity of measurements of evaluators 1 and 2 was 100%, and the specificity for the measurements of evaluators 1 and 2 was 97% and 100%, respectively, and the accuracy of the evaluators' measurements was 99.2%.

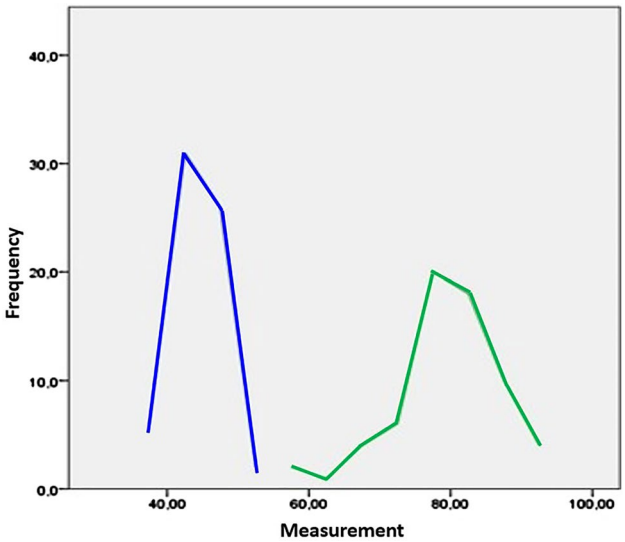

Fig. 3 Frequency of PCLIA measurements in control and study groups. *Blue* control group, *green* study group

Table 5 PCLIA average value and cut-off lower and upper limits with 95% confidence interval

Group	PCLIA average	Cut-off LL	Cut-off UL	Min value	Max value
Study	79.0 ± 7.4	64.2	93.8	48.0	97.9
Control	44.5 ± 3.4	37.7	51.3	33.7	52.3

LL lower limit, *UL* upper limit

Discussion

The most important finding of this study was a higher PCLIA in individuals with ACL injury compared to those with an intact ACL. The larger proportion of subjects aged 21–50 found in the study group suggests that ACL injuries

are more common in younger, likely more active, individuals. This finding supplements the homogeneity of baseline characteristics found between groups. Regarding gender, there was a higher percentage of males in the study group compared to the control group (69.2% vs. 53.8%), although female athletes have been reported to be at greater risk of ACL injury than male athletes in contact and fixed-object high-impact rotational landing sports [11].

The frequency of partial injuries described in the literature varies between 10 and 47% [12, 22]. pACL injuries may present with nonspecific symptoms, such as repeated pain, swelling or instability [19]. The parameters for defining a pACL tear on MRI exams include the presence of a high-intensity signal in the ligament, which may also display a wavy course and/or focal thinning, but which maintains its continuity and orientation [3].

Jog et al. reported that in patients with pACL injury, histological examination of an intact band revealed that the integrity of the remaining material was altered, with a histological response similar to that a complete ACL tear [9]. Fayard et al. demonstrated that 39% of pACL tears in young and active patients, treated conservatively, evolved to a partial injury to a complete ACL tear [5].

A systematic review revealed that pACL tears are symptomatic and ligament laxity may progress over time, making the indications for surgical treatment of partial and complete ACL injuries similar [16] and Barton et al. showed that pACL transection in an ovine model leads to degenerative changes in the trabecular bone mineral density and alterations in structural integrity of the remaining intact ligament [2]. Stone et al. reported that the main determinant for guiding treatment of a patient with pACL tear depended on the functional competence of the ligament [20].

pACL tears may still allow for sufficient stability and the conclusion of a competent ACL if the stabilization provided by its elongated or intact fibers still has the capacity to limit mobility within physiological limits. Likewise, the ligament may be insufficient and thus deemed incompetent if this stabilizing capacity is impaired. In the case of ACL insufficiency, there is tibial anteriorization, with consequent modification of the shape of the PCL and alteration of the PCLIA. Thus, measuring this angle can aid in the diagnoses ACL injuries and improve therapeutic planning.

Schweitzer et al. reported PCL alterations resulting from ACL rupture in the MRIs of 22 patients [17]. In their study, lines adjacent and parallel to the posterior margins of the distal portions of the PCL were delineated and when a line did not cross the medullary cavity of the femur, it was considered positive. This methodology accurately predicted an ACL injury in 86.3% of patients, however, the study may have been under-powered to detect a clinically significant difference with a sample size of 22 patients.

Tung et al. evaluated the mean curvature of the PCL in the MRIs of patients undergoing knee arthroscopy, with 50 MRIs of ACL injuries and 53 MRIs of an intact ACLs. The mean curvature of the PCL in the MRIs of patients with ACL injuries was $0.40 \pm 0.12°$ and $0.27 \pm 0.06°$ in MRIs of intact ACLs ($p < 0.0001$). However, there was an overlap in the distribution of PCL curvature values between the two cohorts [21]. In contrast, our study did not have such overlap between the PCLIA measurements in each cohort.

McCauley et al. measured the angle of the PCL in the MRIs of 68 patients with arthroscopically proven ACL injuries. This angle was formed by two lines, one passing through the central portion of the tibial insertion of the ligament and the other traced across the central portion of the femoral insertion. The authors concluded that a PCL angle smaller than 105° should be considered strong evidence of an ACL tear [10]. Although this method of measurement is relatively easy to perform, evaluation of sensitivity and specificity by two evaluators revealed sensitivities of 72% and 74% and specificities of 79% and 86%. In the present study, the sensitivity of the measurements of evaluators 1 and 2 was 100%, and their specificity was 97% and 100%, respectively.

Van Dyck et al. defined a hyperbuckled PCL as one with vertical alignment of their middle and distal fibers and demonstrated 100% specificity in 61 MRIs of unstable ACL injuries, confirmed by clinical and arthroscopic examination. However, the authors did not present an objective numerical value for the degree of deformation [23]. Yoo and Lim evaluated 38 MRIs from patients, before and after ACL reconstruction. They found that in cases of chronic ACL injuries, the change in the preoperative shape of the PCL disappeared after ACL reconstruction surgery [25]. This study focused on post-operative changes and may have been under-powered with a sample size of 38 patients and the methodology performed is quite complicated and difficult to be reproduced.

Compared to other methods of measuring PCL alterations by MRI in the context of ACL injury found in the existing literature, we adopted a simple, reproducible, and quantifiable criterion that demonstrated a significant difference between injured and intact ACLs. Furthermore, our study was adequately powered to detect a clinically significant difference, and showed high sensitivity and specificity.

The present study has limitations. First, we did not correlate the results of MRI measurements on the knees of the patients investigated to the clinical or arthroscopic examination of these cases, because the diagnosis was made exclusively by MRI analysis. However, the radiologists who performed the PCLIA measurements included in this study assessed MRI images of cases where the diagnosis of damaged or intact ACL was certain. Second, the data were comprised of frankly injured and intact ACLs, and thus

excluding cases that could be diagnosed as partial injuries, so we could not assess PCLIA in pACL tears. Nevertheless, we could question the mechanical properties of the remaining ACL fibers [3]. Certainly future studies are needed further delineate the appearance and biomechanical behavior of pACL injuries, and the consequences of pACL insufficiency.

The clinical relevance of this study is that PCLIA provides useful diagnostic information for detecting ACL insufficiency in MRIs, thus aiding in the diagnosis and subsequent treatment of ACL insufficiency.

Conclusions

The PCLIA was significantly higher in patients with ACL injuries when compared to individuals with an intact ACL. The measurement of this angle using MRI images may improve diagnosis of an ACL insufficiency.

Acknowledgements We are grateful to the brilliant, fabulous and eternal Dr. Freddie Fu for the time we were able to live together and thus learn from his example as a doctor, professor and researcher. We will always miss you so much.

Author contributions JCG—conception, interpretation and drafting of the manuscript. TAA—literature search and submission to the Ethics Committee. DCMM—PCLIA measurements in patients' MRIs. SAN—PCLIA measurements in patients' MRIs. JCGF—statistical analysis and drafting of the manuscript. NPD—reviewing and editing of the manuscript. FFF—reviewing and editing of the manuscript.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Funding There was no funding source.

Ethical approval This research was approved by the Ethics Committee of the Faculty of Medical Science and Health, Catholic University of Sao Paulo, Sorocaba/SP, Brazil, under the Number CAAE: 33438720.0.0000.5373.

Informed consent Informed consent was obtained from all patients included in this research.

References

1. Babalola OR, Itakpe SE, Afolayan TH, Olusola-Bello MA, Egbekun EI (2021) Predictive value of clinical and magnetic resonance image findings in the diagnosis of meniscal and anterior cruciate ligament injuries. West Afr J Med 38(1):15–18
2. Barton KI, Heard BJ, Kroker A, Sevick JL, Raymond DA, Chung M, Achari Y, Martin CR, Frank CB, Boyd SK, Shrive NG, Hart DA (2021) Structural consequences of a partial anterior cruciate ligament injury on remaining joint integrity: evidence for ligament and bone changes over time in an ovine model. Am J Sports Med 49(3):637–648
3. Colombet P, Dejour D, Panisset JC, Siebold R (2010) Current concept of partial anterior cruciate ligament ruptures. Orthop Traumatol Surg Res 96(8 Suppl):S109-118
4. Ekdahl M, Acevedo M, Dominguez C, Barahona M, Hernandez R, Mujica I (2018) Knee examination under anesthesia: development of a predictive score for partial anterior cruciate ligament tears. Knee Surg Relat Res 30(3):255–260
5. Fayard JM, Sonnery-Cottet B, Vrgoc G, O'Loughlin P, de Mont Marin GD, Freychet B, Vieira TD, Thaunat M (2019) Incidence and risk factors for a partial anterior cruciate ligament tear progressing to a complete tear after nonoperative treatment in patients younger than 30 years. Orthop J Sports Med 7(7):2325967119856624
6. Griffith JF, Ng AWH (2019) Top-ten tips for imaging the ACL. Semin Musculoskelet Radiol 23(4):444–452
7. Guenoun D, Le Corroller T, Amous Z, Pauly V, Sbihi A, Champsaur P (2012) The contribution of MRI to the diagnosis of traumatic tears of the anterior cruciate ligament. Diagn Interv Imaging 93(5):331–341
8. Guenther D, Zhang C, Ferlin F, Vernacchia C, Musahl V, Irrgang JJ (2020) Fu FH (2020) Clinical examination of partial ruptures of the anterior cruciate ligament: a retrospective case–control study. Knee 27(6):1866–1873
9. Jog AV, Smith TJ, Pipitone PS, Toorkey BC, Morgan CD, Bartolozzi AR (2020) Is a partial anterior cruciate ligament tear truly partial? A clinical, arthroscopic, and histologic investigation. Arthroscopy 36(6):1706–1713
10. McCauley TR, Moses M, Kier R, Lynch JK, Barton JW, Jokl P (1994) MR diagnosis of tears of anterior cruciate ligament of the knee: importance of ancillary findings. Am J Roentgenol 162(1):115–119
11. Montalvo AM, Schneider DK, Webster KE, Yut L, Galloway MT, Heidt RS Jr, Kaeding CC, Kremcheck TE, Magnussen RA, Parikh SN, Stanfield DT, Wall EJ, Myer GD (2019) Anterior cruciate ligament injury risk in sport: a systematic review and meta-analysis of injury incidence by sex and sport classification. J Athl Train 54(5):472–482
12. Musahl V, Hoshino Y, Ahlden M, Araujo P, Irrgang JJ, Zaffagnini S, Karlsson J, Fu FH (2012) The pivot shift: a global user guide. Knee Surg Sports Traumatol Arthrosc 20:724–731
13. Navali AM, Bazavar M, Mohseni MA, Safari B, Tabrizi A (2013) Arthroscopic evaluation of the accuracy of clinical examination versus MRI in diagnosing meniscus tears and cruciate ligament ruptures. Arch Iran Med 16(4):229–232
14. Ng WH, Griffith JF, Hung EH, Paunipagar B, Law BK, Yung PS (2011) Imaging of the anterior cruciate ligament. World J Orthop 2(8):75–84
15. Orlando Júnior N, de Souza Leão MG, de Oliveira NH (2015) Diagnosis of knee injuries: comparison of the physical examination and magnetic resonance imaging with the findings from arthroscopy. Rev Bras Ortop 50(6):712–719
16. Pujol N, Colombet P, Cucurulo T, Graveleau N, Hulet C, Panisset JC, Potel JF, Servien E, Sonnery-Cottet B, Trojani C, Djian P, French Arthroscopy Society (SFA) (2012) Natural history of partial anterior cruciate ligament tears: a systematic literature review. Orthop Traumatol Surg Res 98(8 Suppl):S160–S164
17. Schweitzer ME, Cervilla V, Kursunoglu-Brahme S, Resnick D (1992) The PCL line: an indirect sign of anterior cruciate ligament injury. Clin Imaging 16(1):43–48
18. Shu HT, Wegener NR, Connors KM, Yang DS, Lockey SD, Thomas JM, Argintar EH (2021) Accuracy of magnetic resonance imaging in predicting anterior cruciate ligament tear location and tear degree. J Orthop 25:129–133
19. Siebold R, Fu FH (2008) Assessment and augmentation of symptomatic anteromedial or posterolateral bundle tears of the anterior cruciate ligament. Arthroscopy 24(11):1289–1298

20. Stone AV, Marx S, Conley CW (2021) Management of partial tears of the anterior cruciate ligament: a review of the anatomy, diagnosis, and treatment. J Am Acad Orthop Surg 29(2):60–70
21. Tung GA, Davis LM, Wiggins ME, Fadale PD (1993) Tears of the anterior cruciate ligament: primary and secondary signs at MR imaging. Radiology 188(3):661–667
22. Van Dyck P, De Smet E, Veryser J, Lambrecht V, Gielen JL, Vanhoenacker FM, Dossche L, Parizel PM (2012) Partial tear of the anterior cruciate ligament of the knee: injury patterns on MR imaging. Knee Surg Sports Traumatol Arthrosc 20(2):256–261
23. Van Dyck P, Gielen JL, Vanhoenacker FM, Wouters K, Dossche L, Parizel PM (2012) Stable or unstable tear of the anterior cruciate ligament of the knee: an MR diagnosis? Skelet Radiol 41(3):273–280
24. Yadav S, Singh S (2020) Analysis of partial bundle anterior cruciate ligament tears— diagnosis and management with ACL augmentation. J Clin Orthop Trauma 11(Suppl 3):S337–S341
25. Yoo JD, Lim HM (2012) Morphologic changes of the posterior cruciate ligament on magnetic resonance imaging before and after reconstruction of chronic anterior cruciate ligament ruptures. Knee Surg Relat Res 24(4):241–244
26. Zhao M, Zhou Y, Chang J, Hu J, Liu H, Wang S, Si D, Yuan Y, Li H (2020) The accuracy of MRI in the diagnosis of anterior cruciate ligament injury. Ann Transl Med 8(24):1657