ilio-tibial tract and femur. This particular structure has not been studied in any prior imaging-based published research.

The purpose of this study was to identify the KF complex, focusing on the CS on routine magnetic resonance imaging (MRI) of the knee, to measure the distances of the insertion from the lateral joint line, and identify injuries to these structures associated with ACL injury.

MATERIAL AND METHODS

A retrospective study was performed on 150 MRIs of the knee with acute ACL injury after taking approval from the institutional review board.

Patient cohort

A total of 150 MRIs of the knee with acute ACL injury were retrospectively reviewed. Out of these 150 MRIs, nine patients had multi-ligamentous injuries, two had a history of prior ACL repair with reinjury, and five had displaced proximal tibial/fibular or distal femoral fractures. These cases were excluded from the final cohort.

Imaging

All the scans were performed on a 1.5-tesla scanner, using a 15-channel dedicated knee coil. Routine MRI protocol included axial, coronal, and sagittal proton density images (TR 3160 ms, TE 21 ms, field of view 150 ms), axial proton density fat-saturated images (TR 3160 ms, TE 21 ms, field of view 150 ms), T2 turbo spin echo fat-saturated coronal images, T1 coronal images (TR 500 ms, TE 9 ms, field of view 140 ms), and sagittal gradient echo images. The slice thickness was 3 mm with an inter-slice gap of 0.5 mm.

Radiological anatomy

The proximal bundle of the Kaplan fibers courses in a nearly transverse orientation from the ITB to the lateral femur. The distal bundle has a near oblique course, coursing from proximal lateral to distal medial, attaching on a lateral femoral ridge. The lateral geniculate artery courses are inferior to this bundle. The CS is another fiber tract identified as attaching distal to the lateral geniculate artery on the LG tubercle of the femur, with its fibers blending with the LG. On coronal images, these fibers course anteriorly and inferiorly along the ilio-tibial tract, correlating with the “retrograde fiber tract” described by Lobenhoffer *et al.*[3] [Figure 1].

Image analysis

All scans were independently reviewed by a fellowship-trained musculoskeletal radiologist. The proximal and distal KFs and the CS were assessed on coronal, sagittal, and axial non-fat saturated PD images to define their radiological anatomy. The axial plane was found to be most suitable for the identification of these fibers. The sagittal and coronal images helped assess the fiber orientation. Identification of the superior lateral geniculate artery coursing just below the insertion of the distal KF added to the diagnostic confidence, and this was best assessed on sagittal images [Figure 2].

To assess the distance of insertion of these fibers from the lateral joint line, a straight line was drawn along the lateral tibiofemoral joint cartilage on coronal images. The site of insertion of these fibers was measured on the coronal plane using multiple series viewing and cross-reference lines [Figure 2]. Fat-saturated proton density and T2 images were then used to identify tearing or edema around the fibers.

Normal fibers (hypointense in signal) were graded as 1, and edema around the fibers with maintained continuity was graded as 2 [Figure 3]. Differentiating partial from complete tears is not always possible on MRI, as also established by Berthold *et al.*[4] Thus, partial or complete injuries were collectively identified and graded as 3 [Figure 4]. Coexisting injuries within the knee joint were documented, including the pattern of bone marrow edema, if present. Before data analysis, all cases with multi ligamentous injury of the knee or fracture around the knee joint were excluded to prevent confounding, giving a final sample size of 134 patients.

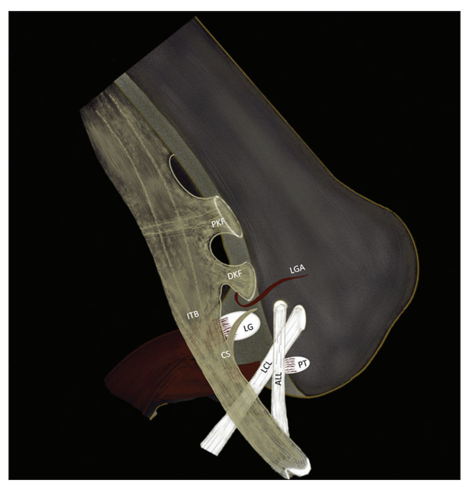

Figure 1: Diagrammatic representation of the anterolateral knee depicting the Kaplan fiber (KF) complex – proximal (PKF) and distal (DKF) KFs, condylar strap (CS), ilio-tibial band (ITB), superior lateral geniculate artery (LGA) traversing between the distal KF and CS. The anterolateral ligament (ALL), lateral collateral ligament (LCL), lateral gastrocnemius tendon (LG), and popliteus tendon (PT) are also depicted.

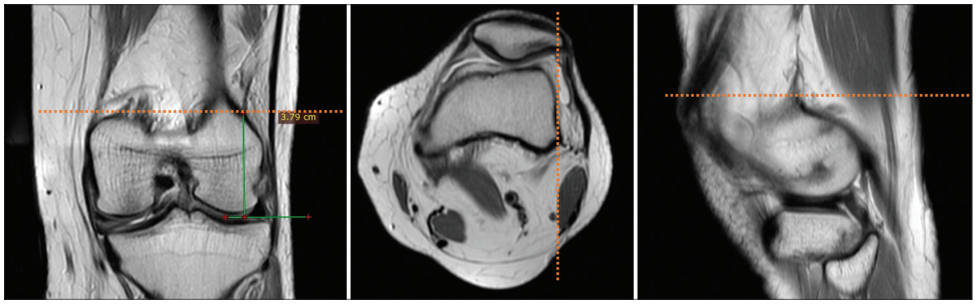

Figure 2: Coronal, axial, and sagittal proton density images in multiple series viewing with cross-reference lines to identify and measure the distance of insertion of the distal Kaplan fiber bundle from the lateral joint line.

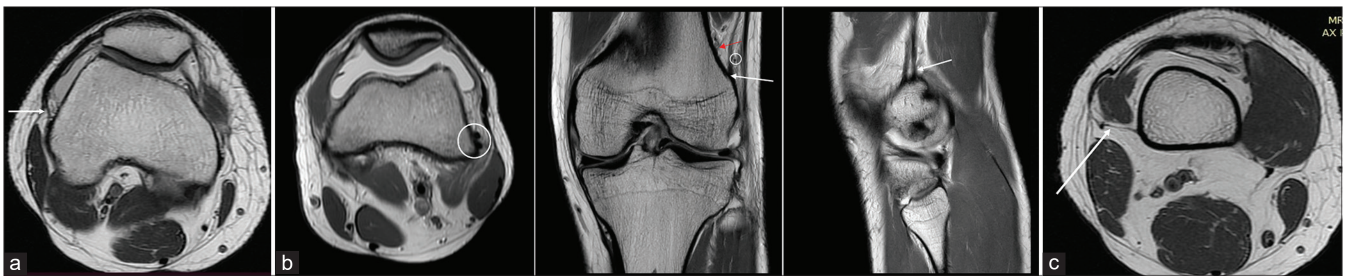

Figure 3: Radiological anatomy of the Kaplan fiber (KF) complex. (a) Axial proton density image demonstrating a thin hypointense condylar strap (CS) (white arrow) extending from the ilio-tibial band to the lateral gastrocnemius tubercle. (b) Axial, coronal, and sagittal proton density images demonstrating variant anatomy of a normal distal KF (white arrow). The fiber bundle is split, oriented from posterior-laterally to anterior-medially with a broad attachment on the lateral epicondylar ridge. The lateral geniculate artery is encircled and the proximal fiber bundle can be seen on the center coronal image (red arrow). This patient did not have a CS, likely representing a biological variant. (c) Axial T1 image demonstrating a transversely oriented proximal KF (white arrow).

Reference standard

Existing literature was extensively reviewed to identify the parameters used to assess injury to these fibers since their identification is at present limited to anatomical studies. Published literature on the radiological identification of KFs and anatomical identification of the CS served as the reference standard.

Statistical analysis

For data analysis, SPSS version 26 software (SPSS Inc, Chicago, Illinois, USA) was used. Continuous variables (demographic data) are presented as mean ± SD and categorical variables as percentages and/or numbers. For analysis of the association between KF/CS injury, meniscal injury, and bone marrow edema (categorical variables), Chi-square or Fisher exact tests were employed. $P < 0.05$ was considered statistically significant throughout the analysis.

RESULTS

The age range of the patient population was 16–42 years. Out of the 134 knees, 78.4% ($n = 105$) were males. There were a total of 70.1% ($n = 94$) of right knees and 29.9% ($n = 40$) of left knees. All MRIs were performed within 3 months of the initial injury. Contact sports accounted for 46% of total cases while a road traffic accident was the initial injury in 42% of cases.

The KFs were identified in 97.2% of the cases in at least one plane. The CS was identified in 72% of the MRI knees. There was one case where only the CS was identified and two cases where only one out of the two KF bundles was identified. The distal bundle of the KF was universally related to the lateral geniculate artery which traversed inferior to the bundle, coursing posterior to anterior.

The mean distance of the proximal KF from the lateral joint line was 59.1 ± 6.9 mm, range 46–75 mm, while the distance from the distal KF to the lateral joint line was 42.4 mm ± 5.6 mm, range 31–60 mm. The CS attached 35.6 ± 4.8 mm proximal to the lateral joint line, with a range of 26–45 mm, with its attachment corresponding to the LG tubercle.

KF and CS injury was present in 34% of cases with ACL tear, 19% of which occurred in cases with a history of contact sport. The MRI finding of the meniscal tear had a statistically significant positive correlation with KF injury ($P = 0.003$). In addition, a statistically significant positive correlation was found between a classic pivot shift impaction injury pattern

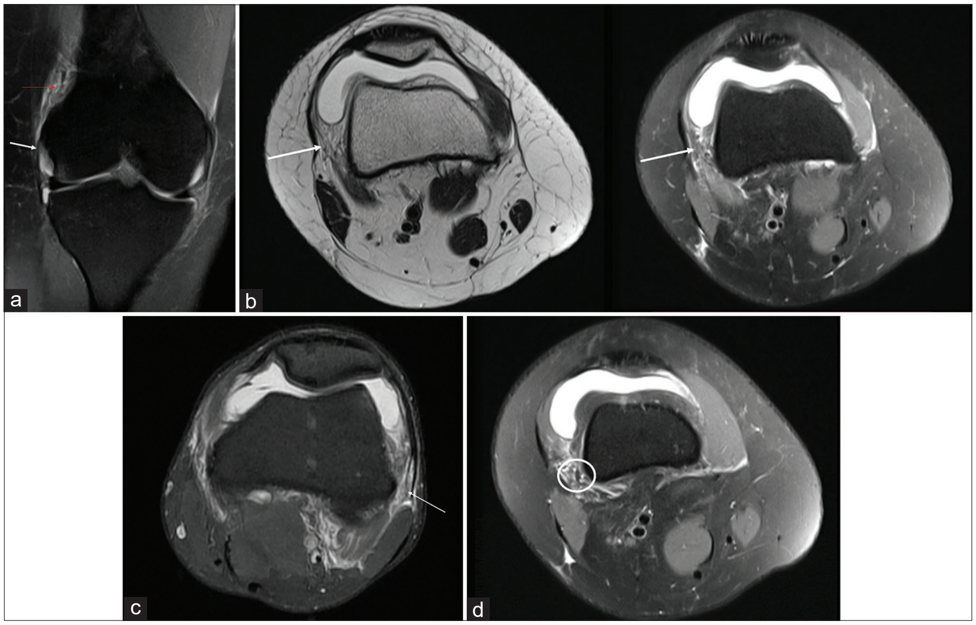

Figure 4: Pathologies of the Kaplan fiber (KF) and the condylar strap (CS). (a): Coronal proton density fat-saturated image demonstrating edema around the distal KF (red arrow) and CS (white arrow) graded as 2. (b) Axial proton density and proton density fat-saturated image demonstrating CS fiber discontinuity (white arrow) with surrounding edema suggesting at least a partial thickness tear, graded as 3. (c) Axial proton density fat-saturated image demonstrating tear of the condylar (white arrow) with surrounding edema, graded as 3. (d) Axial proton density fat-saturated image demonstrating edema around the proximal KF bundle, graded as 2.

bone marrow edema and KF injury ($P < 0.001$). There was no incidence of isolated CS injury.

DISCUSSION

Numerous historical studies have detailed the complex anatomy of the anterolateral aspect of the knee. Kaplan described the eponymous KFs in 1958, and since then many anatomical and few radiological studies focusing on the identification of these fibers and their pathology have been published.[5] Lobenhoffer *et al.* in 1987 documented the existence of three distinct fiber tracts arising from the iliotibial tract and inserted on the distal femur – the proximal and distal KFs, and a third bundle called the retrograde fiber tract.[3] Presumably, this retrograde fiber tract is the same structure that Muller had referred to as the "lig. Femoro-Tibiale laterale anterius"[6] and Terry *et al.*[7] had included in his description of the "capsulo-osseous layer." Godin *et al.*[8] also described this third strap as a distinct capsulo-osseous layer intimately related to the lateral knee capsule in close proximity to the LG tubercle. This retrograde fiber tract was recently again identified in an anatomical study and labeled as CS.[1] This terminology has been used in the present study and is the first study in the literature systematically describing this third fiber tract on imaging.

A radiological study assessing injury to the KF complex by Berthold *et al.*[4] found an average distance of the proximal fibers complex from the lateral joint line to be 57.6 mm and that of the distal fiber complex to be 44.9 mm on MRI. In another study, correlating MRI with anatomical dissection, Berthold *et al.*[9] identified the fibers in 100% of cases with Distance from the lateral joint line to proximal KFs 63.5 ± 7.6 mm and the distal KFs 45.3 ± 3.7 mm. They reiterated the close topography of these fibers to the superior lateral genicular artery on the anatomical dissection. Batty *et al.*[10] performed MRI on 50 patients and identified the mean distance of the distal fibers to be 50.1 mm from the lateral joint line. The fiber was consistently identified as just superior to the lateral geniculate artery on sagittal images in all cases. Sayac *et al.*[11] recently performed anatomical dissection in 21 non-paired cadaveric knees and identified the proximal and distal fibers lying approximately 49.20 ± 7.38 and 27.54 ± 7.69 mm from the lateral epicondyle. Godin *et al.*[8] measured the proximal and distal bundle insertions to the 53.6 mm and 31.4 mm proximal to the lateral epicondyle, respectively, inserting on a distinct ridge. These measurements are within the range of the measurements in our study, inferring that there is no anatomical variation in the Indian population. This is also supported by the cadaveric study done by Raghavan *et al.*[12] who noted a consistent supracondylar attachment of the KFs, either as a single or double limb, 30–40 mm from the lateral femoral epicondyle without any statistically significant difference between Caucasian and Asian groups.

Jakob *et al*.[13] first described the contribution of KF to knee pivot shift injury. There is contradictory data in the literature with regard to the significance of injury to the KFs in the clinical setting. In the present study, a statistically significant positive correlation was noted between KF/CS injury and meniscal injury, and the presence of bone marrow edema in a pivot shift impaction pattern. Fiber orientation identified in various anatomical studies suggests that the KFs play an important role in the rotatory knee stability,[8] and this is further supported by biomechanical studies.[14,15] Smith *et al*.[15] emphasized that the distal ilio-tibial band is more important than the ALL for control of pivot shift. Berthold *et al*.[9] found that 53–56% of cases initially diagnosed as isolated ACL tears had concomitant KF injury, which can contribute to persistent anterolateral rotatory instability. Marom *et al*.[16] found substantial reliability for the identification of proximal fibers and moderate reliability for the distal fibers. The associated injury was seen in the majority of their cases with acute ACL tear. In the present study, 34% of all cases had concomitant KF injury. The lower incidence of KF injury with acute ACL injury may be due to a large number of cases in this study being secondary to road traffic accidents (42%). Clinically relevant anterolateral rotatory instability persists in 15% of cases following ACL reconstruction;[17] the International ALC Consensus Group Meeting[18] has further acknowledged this by stating the need for future studies to establish indications for anterolateral reinforcement/reconstruction in patients undergoing primary ACL repair.

Godin *et al*.[8] and Wytrykowski *et al*.[19] performed biomechanical studies by externally loading the ITB in cadaveric studies. They found that both KFs are strong enough to affect the rotatory stability of the knee, with the distal fiber being stiffer than the proximal fiber. This difference is likely due to the geometric orientation of the fibers. A cadaveric biomechanical study by Smith *et al*.[15] found that ACL deficient knees return to a native biomechanical state following anterolateral reconstruction with ACL repair, and this minimally invasive anterolateral reconstruction was equivalent to the more extensive modified Lemaire reconstruction. At 0°, the distal ITB plays a more important role than the ALL in controlling anterolateral rotatory movement. Considering these biomechanical, anatomical, and clinical studies, Gali *et al*.[20] described a novel procedure for anatomical reconstruction of the KF by re-tensioning the ilio-tibial band. This was based on preceding studies which found a significant association between ITB injuries and grade of pivot shift, and not between ACL injury and grade of pivot shift,[7] thus emphasizing the role of ITB and its fibrous attachments in preventing rotatory instability.

Watanabe *et al*.[21] found KF injury in 23.5% of cases but stated that concomitant fiber injury did not affect the pivot shift phenomena in acute ACL injuries. Contradictory to our study, Lynch *et al*.[22] did not find any significant association between KF injury and concomitantly observed injuries in conjunction with ACL tear (including meniscal injuries and bone marrow edema), concluding that identifying KF injury does not help surgeons in distinguishing higher grades of rotatory instability. Devitt *et al*.[23] found no difference in clinical or functional outcomes in patients undergoing ACL reconstruction with or without evidence of KF injury on imaging. Devitt *et al*.[24] another study found that KF injuries were uncommon, and the rate of Grade III pivot shift was low, suggesting that the role of KF in controlling anterolateral rotatory laxity in acute ACL injury in the clinical setting may be less evident as compared with the biomechanical setting. This may in part be due to a delay between MRI and clinical examination, which could affect the grade of pivot shift injury. In the same study by Devitt *et al*.,[24] the authors have mentioned an association between KF injury and lateral meniscal injury.

The present study has certain limitations. As there was a single reader, inter-reader reliability was not assessed. Cadaveric study by Godin *et al*.[8] found the CS universally. The lower rate of identification in our study may in part be due to the studies being performed on a 1.5T magnet and anatomical variations in the population. This is also supported by the study of Lobenhoffer *et al*.[3] who did not find the retrograde fiber tract in all specimens and speculated this to either be due to biological or congenital variation.

CONCLUSION

This radiological study confirms the existence of the CS by identifying it on MRI, which has previously been described only in cadaveric studies. We reiterate the positive association of KF injury with meniscal tears and bone marrow edema in patients with acute ACL tears. The radiological anatomy of KF and CS is described with femoral attachments found to be in the range of the previous cadaveric studies. All cases with KF injury had concomitant CS injury, but there was no case with isolated CS injury. Identifying injuries to these bundles may help the surgeon in identifying patients at risk for persistent instability following ACL reconstruction with or without ALL reconstruction. Future biomechanical studies focusing on CS are needed to identify its contribution to anterolateral stability.

Declaration of patient consent

Patient's consent not required as patient's identity is not disclosed or compromised.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Landreau P, Catteeuw A, Hamie F, Saithna A, Sonnery-Cottet B, Smigielski R. Anatomic study and reanalysis of the nomenclature of the anterolateral complex of the knee focusing on the distal iliotibial band: Identification and description of the condylar strap. Orthop J Sports Med 2019;7:2325967118818064.
2. Slette EL, Mikula JD, Schon JM, Marchetti DC, Kheir MM, Turnbull TL, *et al*. Biomechanical results of lateral extra-articular tenodesis procedures of the knee: A systematic review. Arthroscopy 2016;32:2592-611.
3. Lobenhoffer P, Posel P, Witt S, Piehler J, Wirth CJ. Distal femoral fixation of the iliotibial tract. Arch Orthop Trauma Surg (1978) 1987;106:285-90.
4. Berthold DP, Willinger L, Muench LN, Forkel P, Schmitt A, Woertler K, *et al*. Visualization of proximal and distal Kaplan fibers using 3-dimensional magnetic resonance imaging and anatomic dissection. Am J Sports Med 2020;48:1929-36.
5. Kaplan EB. The iliotibial tract: Clinical and morphological significance. J Bone Joint Surg Am 1958;40:817-32.
6. Müller W. Functional anatomy and clinical findings of the knee joint. Helv Chir Acta 1984;51:505-14.
7. Terry GC, Hughston JC, Norwood LA. The anatomy of the iliopatellar band and iliotibial tract. Am J Sports Med 1986;14:39-45.
8. Godin JA, Chahla J, Moatshe G, Kruckeberg BM, Muckenhirn KJ, Vap AR, *et al*. A comprehensive reanalysis of the distal iliotibial band: Quantitative anatomy, radiographic markers, and biomechanical properties. Am J Sports Med 2017;45:2595-603.
9. Berthold DP, Willinger L, LeVasseur MR, Marrero DE, Bell R, Muench LN, *et al*. High rate of initially overlooked Kaplan fiber complex injuries in patients with isolated anterior cruciate ligament injury. Am J Sports Med 2021;49:2117-24.
10. Batty L, Murgier J, O'Sullivan R, Webster KE, Feller JA, Devitt BM. The Kaplan fibers of the iliotibial band can be identified on routine knee magnetic resonance imaging. Am J Sports Med 2019;47:2895-903.
11. Sayac G, Goimard A, Klasan A, Putnis S, Bergandi F, Farizon F, *et al*. The anatomy of Kaplan fibers. Arch Orthop Trauma Surg 2021;141:447-54.
12. Raghavan S, Teo SH, Al-Fayyadh MZ, Ali MR, Ng WM. Variation in Kaplan fiber insertion to the distal femur and surgical implications: A cadaveric anatomical study comparing Asian and Caucasian knees. Knee 2022;38:56-61.
13. Jakob RP, Hassler H, Staeubli HU. Observations on rotatory instability of the lateral compartment of the knee. Experimental studies on the functional anatomy and the pathomechanism of the true and the reversed pivot shift sign. Acta Orthop Scand Suppl 1981;191:1-32.
14. Amis AA. Anterolateral knee biomechanics. Knee Surg Sports Traumatol Arthrosc 2017;25:1015-23.
15. Smith PA, Thomas DM, Pomajzl RJ, Bley JA, Pfeiffer FM, Cook JL. A Biomechanical study of the role of the anterolateral ligament and the deep iliotibial band for control of a simulated pivot shift with comparison of minimally invasive extra-articular anterolateral tendon graft reconstruction versus modified lemaire reconstruction after anterior cruciate ligament reconstruction. Arthroscopy 2019;35:1473-83.
16. Marom N, Greditzer HG 4th, Roux M, Ling D, Boyle C, Pearle AD, *et al*. The incidence of Kaplan fiber injury associated with acute anterior cruciate ligament tear based on magnetic resonance imaging. Am J Sports Med 2020;48:3194-9.
17. Ahldén M, Sernert N, Karlsson J, Kartus J. A prospective randomized study comparing double-and single-bundle techniques for anterior cruciate ligament reconstruction. Am J Sports Med 2013;41:2484-91.
18. Getgood A, Brown C, Lording T, Amis A, Claes S, Geeslin A, *et al*. The anterolateral complex of the knee: Results from the international ALC consensus group meeting. Knee Surg Sports Traumatol Arthrosc 2019;27:166-76.
19. Wytrykowski K, Swider P, Reina N, Murgier J, Laffosse JM, Chiron P, *et al*. Cadaveric study comparing the biomechanical properties of grafts used for knee anterolateral ligament reconstruction. Arthroscopy 2016;32:2288-94.
20. Gali JC, Filho JC, Marques MF, Almeida TA, da Silva PA, LaPrade RF. Capsulo-osseous layer retensioning and distal Kaplan fiber surgical reconstruction: A proposed anatomical lateral extra-articular tenodesis approach. Arthrosc Tech 2021;10:e159-64.
21. Watanabe S, Nagai K, Hoshino Y, Kataoka K, Nakanishi Y, Araki D, *et al*. Influence of injury to the Kaplan fibers of the iliotibial band on anterolateral rotatory knee laxity in anterior cruciate ligament injury: A retrospective cohort study. Am J Sports Med 2022;50:3265-72.
22. Lynch TB, Bernot JM, Oettel DJ, Byerly D, Musahl V, Chasteen J, *et al*. Magnetic resonance imaging does not reliably detect Kaplan fiber injury in the setting of anterior cruciate ligament tear. Knee Surg Sports Traumatol Arthrosc 2022;30:1769-75.
23. Devitt BM, Klemm HJ, Kirby J, Batty LM, Webster KE, Whitehead TS, *et al*. Effect of radiological evidence of Kaplan fiber injury on the clinical and functional outcomes after acute anterior cruciate ligament reconstruction. Am J Sports Med 2022;50:3557-64.
24. Devitt BM, Al'khafaji I, Blucher N, Batty LM, Murgier J, Webster KE, *et al*. Association between radiological evidence of Kaplan fiber injury, intraoperative findings, and pivot-shift grade in the setting of acute anterior cruciate ligament injury. Am J Sports Med 2021;49:1262-9.

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