Received: 9 November 2023 | Accepted: 11 December 2023

DOI: 10.1002/ksa.12036

Knee Surgery, Sports Traumatology, Arthroscopy WILEY

Medial meniscal lesions increase antero-posterior laxity in knees with anterior cruciate ligament injury

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Funding information

None

Abstract

Purpose: The aim of this study was to quantify the impact of concomitant meniscal lesions on knee laxity using a triaxial accelerometer in a large population of patients affected by anterior cruciate ligament (ACL) injury.

Methods: A total of 326 consecutive patients (261 men and 65 women, mean age 31.3 ± 11.3) undergoing primary ACL reconstruction, were preoperatively evaluated through Lachman and pivot shift tests using a triaxial accelerometer to quantify knee laxity. An analysis based on the presence of meniscal tears assessed during surgery was performed to evaluate the impact of meniscal lesions on knee laxity.

Results: The anterior tibial translation (Lachman test) presented significantly higher values in patients with medial meniscal lesions (7.3 ± 1.7 mm, $p = 0.049$) and both medial and lateral meniscal lesions (7.7 ± 1.6 mm, $p = 0.001$) compared to patients without concomitant meniscal lesions (6.7 ± 1.3 mm). Moreover, patients with both medial and lateral meniscal lesions presented significantly higher values of anterior tibial translation compared to patients with lateral meniscal lesions ($p = 0.049$). No statistically significant differences were found between the groups in terms of tibial acceleration (pivot shift test).

Conclusion: This study demonstrated that the contribution of concomitant meniscal lesions to knee laxity can be objectively quantified using a triaxial accelerometer in ACL-injured knees. In particular, medial meniscus lesions, alone or in association with lateral meniscus lesions, determine a significant increase of the anterior tibial translation compared to knees without meniscus tears.

Level of Evidence: Level IV.

KEYWORDS

accelerometer, anterior cruciate ligament (ACL), knee, laxity, meniscal lesion, meniscus

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Abbreviations: ACL, anterior cruciate ligament; ADL, activities in daily living; ANOVA, analysis of variance; BMI, body mass index; EQ-5D, EuroQol 5 Dimension 5 Level; EQ-VAS, EuroQol-Visual Analogue Scale; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; mm, millimetres; MRI, magnetic resonance imaging; SPSS, statistical package for the social sciences; VAS, Visual Analogue Scale.

Marco Franceschini and Davide Reale equally contributed to this article.

INTRODUCTION

Anterior cruciate ligament (ACL) tears are among the most common lesions affecting the knee, especially in sport-active young patients [1–3]. The main function of ACL is to stabilise the anterior tibial translation relative to the femur, besides limiting excessive knee extension, knee varus and valgus movements, and tibial rotation [4]. Given the ACL functions, the clinical assessment of ACL injuries is based on the evaluation of the anterior tibial translation, usually through the Lachman test or the anterior drawer test, and on the evaluation of the antero-lateral rotatory laxity through the pivot shift test [5]. While commonly used in clinical practice to diagnose ACL rupture, these tests present some limitations. There is a significant variability in their execution and interpretation, and they do not permit to quantify objectively a torn-ACL knee laxity [6, 7]. Moreover, they do not allow a precise evaluation of the contribution that concomitant intra-articular lesions can have on knee laxity [8].

Different technologies such as robotic-assisted devices and navigation systems have been developed over time to objectively evaluate knee laxity in patients affected by ACL lesions [7, 9–11]. These tools can offer reliable and precise measurements and proved usefulness in the surgical and research settings. However, they do not represent a suitable solution for the routine use in the clinical practice, where arthrometers can play instead a key role. The Kinematic Rapid Assessment (KiRA—OrthoKey) is a non-invasive triaxial accelerometer that can be easily employed in clinical practice to quantify knee laxity in cases of suspected ACL injury [12, 13]. Previous studies demonstrated the ability of this device to quantify the Lachman and pivot shift tests in ACL-deficient knees [7, 11]. However, no studies addressed the potential of this approach to identify specific laxity patterns and raise suspicion on the presence of concomitant intra-articular lesions that could guide subsequent therapeutic decisions. Among these, meniscal tears can affect knee laxity in patients with ACL injury, with cadaveric studies confirming the significance of menisci as secondary knee stabilisers [14, 15]. The possibility to have an objective measurement in the clinical setting to quantify meniscal lesions contribution to laxity would be of clinical relevance to evaluate and manage torn-ACL knees.

The aim of this study was to quantify the impact of concomitant meniscal lesions on knee laxity using a triaxial accelerometer in a large population of patients affected by ACL injury. The hypothesis was that the use of a triaxial accelerometer could detect the impact of meniscal lesions on ACL-injured knees laxity.

MATERIALS AND METHODS

The present study was approved by the hospital Ethics Committee of the Rizzoli Orthopaedic Institute (Prot. Nr. 0007043). The investigation was performed at a highly specialised referral centre for knee pathologies and sports medicine. Patients aged between 18 and 60 years undergoing primary ACL reconstruction between March 2018 and December 2022 were enroled in the present study. Exclusion criteria included concomitant posterior cruciate ligament and collateral ligaments insufficiency, uncorrected deformities in the lower extremities, knee osteonecrosis, history of infections or autoimmune diseases. Informed consent was obtained from each patient for study participation at the time of hospitalisation. Baseline demographics were collected for each patient: age, sex, body mass index (BMI), affected side, and time injury-to-surgery. A total of 326 consecutive patients met the inclusion criteria. Seventeen patients had already undergone knee surgery: 11 medial meniscectomies, 3 lateral meniscectomies, 1 plica removal, 1 microfracture, and 1 quadriceps tendon repair. Further details are reported in Table 1.

Clinical baseline evaluation of the included patients was performed through the following scores: Knee injury and Osteoarthritis Outcome Score (KOOS), International Knee Documentation Committee subjective score (IKDC) score, Tegner activity scale, Visual Analogue Scale (VAS) for pain, EuroQol-VAS (EQ-VAS), and EuroQol 5 Dimension 5 Level (EQ-5D). The baseline values of the clinical scores are reported in detail in Table 2.

Lachman and pivot shift tests were performed preoperatively using the KiRA triaxial accelerometer at manual-maximum load on both knees, the involved and the contralateral side. All the tests were performed on awake patients before surgery and before anaesthesia by a surgeon trained on the use of the triaxial accelerometer. Intraoperative arthroscopic findings and associated performed procedures were reported for each patient. The

TABLE 1 Baseline demographic characteristics of the included patients.

Age, year (Mean ± SD)	31.3 ± 11.3
Sex, M:W	261:65
BMI, kg/m^2 (Mean ± SD)	24.7 ± 3.6
Side, right:left	145:181
Time to surgery, *m* (median)	9 (range 1−240)

Abbreviations: BMI, body mass index; M, men; m, months; SD, standard deviation; W, women; y, years.

intraoperative arthroscopic evaluation revealed no concomitant meniscal lesion in 96 patients (No-ML Group), medial meniscus lesions in 123 patients (Med-ML Group), lateral meniscus lesions in 55 patients (Lat-ML Group), and both menisci lesions in 52 patients (Med+Lat-ML Group). An analysis based on the presence of the meniscal tears assessed during surgery was performed to evaluate the impact of meniscal lesions on knee laxity.

TABLE 2 Baseline clinical scores of the included patients.

	Mean ± standard deviation
KOOS pain	74.8 ± 17.5
KOOS symptoms	68.3 ± 17.1
KOOS ADL	80.5 ± 18.3
KOOS sport/Rec	51.5 ± 28.6
KOOS QoL	39.9 ± 18.9
IKDC subjective score	53.5 ± 15.0
Tegner preinjury	6.1 ± 2.0
Tegner presurgery	2.8 ± 1.7
VAS	2.8 ± 2.7
EQ-VAS	70.3 ± 17.1
EQ-5D	0.6 ± 0.3

Abbreviations: ADL, Activities in Daily Living; EQ-5D, EuroQol 5 Dimension 5 Level, EQ-VAS EuroQol-Visual Analogue Scale; IKDC, International Knee Documentation Committee subjective score; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, Quality of Life; Sport/Rec, Sport and Recreation, VAS, Visual Analogue Scale for pain.

Evaluation with KiRA

For the Lachman test, the patient was positioned in supine position, with the knee flexed at 30° and fixed in a leg holder to keep it in a neutral position [16]. The device was placed at the distal lower leg of the patient and fixed with an elastic strap in contact with a shin guard to optimise the stability of the sensor. Three consecutive measurements were performed for each knee by applying an anterior force at maximum load to the proximal calf, first in the noninjured knee, then in the injured one. The acquired value for each knee was the mean of the three measurements performed, expressed in mm with the accuracy of one decimal (Figure 1).

For the pivot shift test, the patient was positioned in supine position, with the knee extended. The device was positioned and fixed to the proximal tibia between the Gerdy tubercle and the tibial tuberosity. Three consecutive measurements were performed on each leg flexing the knee from the extended position with the tibia internally rotated while applying a valgus and vertical compressive force to the knee, first in the noninjured knee, then in the injured one [17]. The acquired value for each knee was the mean of the three measurements performed, expressed in m/s^2 with the accuracy of one decimal (Figure 1).

Statistical analysis

All continuous data were expressed in terms of the mean and the standard deviation of the mean, the

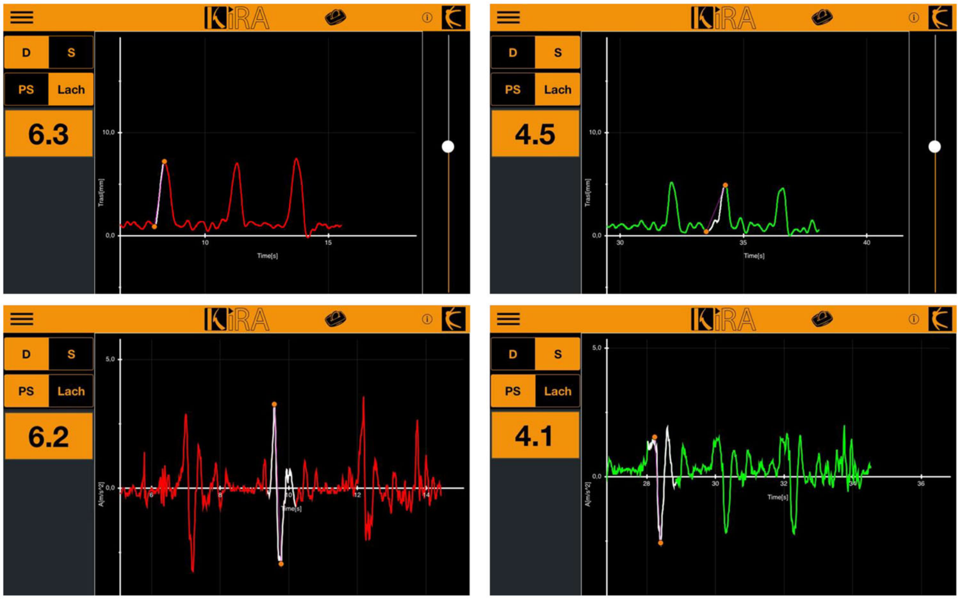

FIGURE 1 Lachman test (top row) and pivot shift test (bottom row) quantification with the KiRA measurement system software interface in ACL-injured knee (left column) and in the contralateral knee (right column).

categorical data were expressed as frequency and percentages. The Shapiro-Wilk test was performed to test the normality of continuous variables. The Levene test was used to assess the homoscedasticity of the data. The analysis of variance (ANOVA) test was performed to assess the between groups differences of continuous, normally distributed and homoscedastic data, the Mann Whitney non-parametric test was used otherwise. The ANOVA test, followed by post hoc Sidak test for pairwise comparisons, was performed to assess the among groups differences of continuous, normally distributed and homoscedastic data, the Kruskal Wallis non-parametric test, followed by post hoc Mann Whitney test with Bonferroni correction for multiple comparisons, was used otherwise. The Pearson χ^2 test, evaluated using the exact test, was performed to investigate relationships between categorical variables. A post hoc power analysis was performed and assuming an effect size equal to 0.34, a post hoc power of 0.99 was obtained. For all tests $p < 0.05$ was considered significant. The statistical analysis was performed using SPSS v.19.0 (IBM Corp.).

RESULTS

The mean anterior tibial translation acquired by the device during the Lachman test (Figure 2) was 7.2 ± 1.7 mm in the ACL-injured knees and 5.3 ± 1.1 mm in the contralateral side, with a statistically significant difference between two mean values ($p < 0.0005$). The mean anterior tibial translation was 7.2 ± 1.6 mm in men and 6.9 ± 1.7 mm in women (p = n.s.). Age, BMI, and time to surgery did not influence the anterior tibial translation evaluated with the device.

The mean tibial acceleration acquired by the device during the pivot shift test (Figure 2) was 5.9 ± 1.3 m/s^2 in the ACL-injured knees and 4.5 ± 0.9 m/s^2 in the contralateral side, with a statistically significant difference between the two mean values ($p < 0.0005$). Male patients presented higher values (5.9 ± 1.3 m/s^2) of tibial acceleration at pivot shift test measured with KiRA than female patients (5.5 ± 1.2 m/s^2) in ACL-injured knees ($p = 0.017$). Age, BMI, and time to surgery did not influence the tibial acceleration evaluated with the device.

The analysis performed based on the meniscal status assessed during surgery demonstrated a mean anterior tibial translation (Lachman test) of 6.7 ± 1.3 mm in ACL-injured knees without concomitant meniscal lesions (No-ML Group), 7.3 ± 1.7 mm in case of concomitant medial meniscus lesions (Med-ML Group), 7.0 ± 1.9 mm in case of concomitant lateral meniscus lesions (Lat-ML Group), and 7.7 ± 1.6 mm if both menisci were involved (Med+Lat-ML Group). Patients with medial meniscal lesions ($p = 0.049$) and both medial and lateral meniscal lesions ($p = 0.001$) presented significantly higher values of anterior tibial translation compared to patients without concomitant meniscal lesions. Moreover, patients with both medial and lateral meniscal lesions presented significantly higher values of anterior tibial translation compared to patients with lateral meniscal lesions ($p = 0.049$). No statistically significant differences were observed between the other groups. A statistically significant difference ($p = 0.006$) in side-to-side anterior tibial translation delta was reported between No-ML Group (1.5 ± 0.9 mm) and Med+Lat-ML Group (2.2 ± 1.3 mm) (Figure 3).

No statistically significant differences were found between groups in terms of tibial acceleration (pivot shift test). Table 3 reports the values of anterior tibial translation and tibial acceleration acquired during Lachman and pivot shift tests for each group.

DISCUSSION

The main finding of this study is that the contribution of concomitant meniscal lesions to knee laxity can be objectively quantified using a triaxial accelerometer in

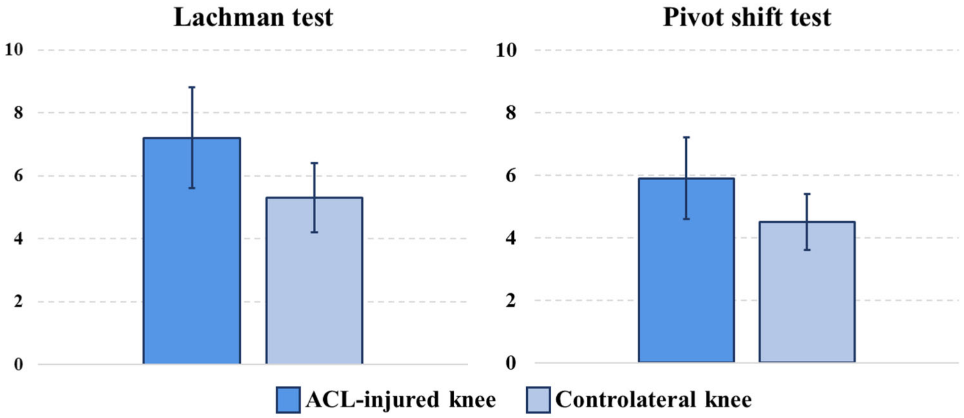

FIGURE 2 Lachman (left) and pivot shift (right) mean values measured in the injured and control knees. A statistically significant difference between ACL-injured knees and contralateral knees was found for both tests (both $p < 0.0005$).

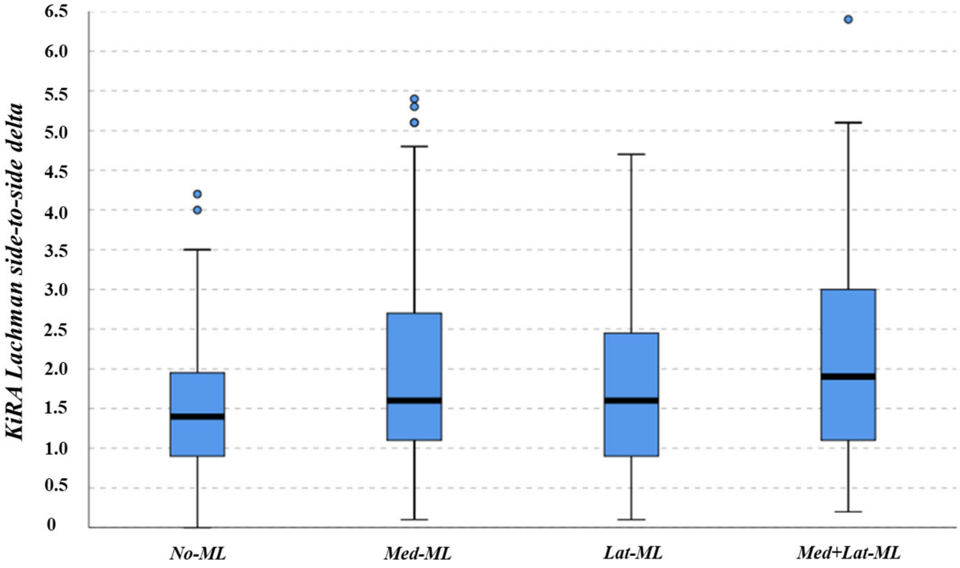

FIGURE 3 Side-to-side anterior tibial translation delta. Lat-ML, lateral meniscus lesion; Med+Lat-ML, both menisci lesion; Med-ML, medial meniscus lesion; No-ML, no meniscal lesion.

TABLE 3 Triaxial accelerometer data in injured knees based on the meniscal status.

	Lachman test	Pivot shift test
No-ML Group (96 patients)	6.7 ± 1.3 mm	5.7 ± 1.2 m/s^2
Med-ML Group (123 patients)	7.3 ± 1.7 mm[a]	6.0 ± 1.4 m/s^2
Lat-ML Group (55 patients)	7.0 ± 1.9 mm	5.8 ± 1.5 m/s^2
Med + Lat-ML Group (52 patients)	7.7 ± 1.6 mm[b]	6.0 ± 1.2 m/s^2

Note: Values are expressed as mean ± standard deviation.

Abbreviations: Lat-ML Group, lateral meniscus lesion; Med+Lat-ML Group: both menisci lesion; Med-ML Group, medial meniscus lesion; No-ML Group, no meniscal lesion.

[a] Significant difference vs No-ML Group;

[b] Ssignificant difference vs No-ML Group and Lat-ML Group.

ACL-injured knees. In particular, medial meniscus lesions, alone or in association with lateral meniscus lesions, determine a significant increase of the anterior tibial translation compared to knees without meniscus tears.

Menisci are important structures in the knee not only for their role in load bearing distribution and transmission between the articular surfaces, but also for joint stabilisation [18–22]. This is a key aspect, since meniscal tears represent one of the most common injuries in orthopaedics, with a mean annual incidence of 60−70 per 100.000 [23], and since patients undergoing ACL reconstruction have been reported to have a meniscus tear incidence from 55% up to nearly 80% [24–28]. Meniscal lesions should therefore be carefully considered when performing ACL reconstruction surgery to restore knee stability [29–32]. In fact, while meniscectomy can increase the femoro-tibial contact stress and anterior tibial translation in ACL-deficient knees, meniscal repair showed to increase antero-medial knee laxity [8, 33]. In this scenario, it is paramount to understand the role that menisci play in knee biomechanics and how meniscal lesions can affect knee laxity, as their contribution to knee stability could influence the results of ACL surgery.

Previous studies documented the importance of the menisci as secondary stabilisers in the knee joint. Walker et al. demonstrated in a cadaveric study the key role of the medial meniscus in both force transmission and joint stability, showing that the anterior horn limited the anterior femoral displacement, while the central body of the meniscus represented a restraint to the femoral subluxation [34]. Another biomechanical study conducted by DePhillipo et al. demonstrated that also ramp lesions (tears of the peripheral attachment of the posterior horn of the medial meniscus at the menisco-capsular junction) can lead to an increase in anterior tibial translation, rotations, and pivot shift [35]. The important role of the medial meniscus in controlling knee stability has been highlighted in knees with ACL lesions. Allen et al. investigated the role of medial meniscus in ACL-deficient knees through a robotic force-moment sensor, demonstrating an increase in the resultant force in the human medial meniscus in response to an anterior tibial load compared to ACL-intact knees [36]. Similarly, Levy et al. used an in vitro knee testing apparatus to demonstrate greater increases in anterior tibial displacement after medial meniscus excision in ACL-deficient knees than those already increased after the isolated section of the ACL compared to intact knees [37].

The results of the current study are in line with this experimental evidence, and provide an important step toward the translation of these concepts from the research setting to the assessment of ACL-injuried knees in the clinical routine. The objective quantification of anterior tibial translation at the Lachman test confirmed the role of menisci in patients with ACL-deficiency. Most importantly, only isolated medial meniscus lesions were found to be critical in influencing the anterior translation of the tibia, with a statistically significant difference compared to patients with isolated ACL injury. On the other hand, isolated lateral meniscus lesions did not statistically increase the anterior translation of the tibia. This confirmed the results of a previous cadaveric study conducted by Musahl et al. on intact knees, ACL-deficient knees, or knees after sectioning the medial meniscus, the lateral meniscus, and finally both menisci [38]. The authors reported that the anterior tibial translation significantly increased after medial but not lateral meniscectomy, confirming that medial meniscus is an important secondary restraint during the Lachman test, while the lateral meniscus has a relatively more important secondary restraining role to the combined axial and rotatory loads. In this regard, these authors reported an increased laxity after lateral meniscectomy to the pivot shift test.

Similar findings on rotatory laxity were reported in a study conducted by Musahl et al. on 41 patients with ACL injury. The authors reported that rotatory knee laxity evaluated as the anterior translation of the lateral tibial compartment during the pivot-shift manoeuvre was significantly higher in knees with magnetic resonance imaging evidence of either a medial meniscus injury or lateral meniscus injury [39]. The current study also quantified the pivot shift test in patients with ACL-deficiency. Knees with meniscal lesions reported higher values in terms of tibial acceleration compared to knees with intact menisci, although these results did not reach statistically significant differences in this series. However, the authors reported the rotatory laxity in terms of anterior translation of the lateral tibial compartment while in the present study results were expressed in terms of tibial acceleration during pivot shift test. Moreover, unlike the cited study performed by Musahl et al., in the present study patients were not evaluated under anaesthesia, and this could have influenced the results. As reported by Nakamura et al., objective quantification of knee laxity through the use of accelerometers can be influenced when evaluating aware patients or under anaesthesia [40].

The use of accelerometers can help clinicians to better evaluate knees with ACL injuries, also raising suspicion of potential concomital meniscal lesions and on their impact on the laxity of the affected knees. The preoperative device use in this study allowed to underline the impact of meniscal lesions in association with ACL injury, showing an increased knee laxity. The use of accelerometers could provide useful information also when performed after surgery. In a previous study, Berruto et al. perfomed a postoperative evaluation of patients with ACL injury through the knee arthrometer KT-1000 to quantify the Lachman test and the KiRA to quantify the pivot shift test at least 6 months after surgery [6]. By evaluating knee laxity after surgery, authors assessed the extent of the performed treatment, finding comparable values of the operated knees and the controlateral healthy knees. In this light, future studies focusing on the treatment of concomitant meniscal lesion in ACL reconstruction should include also a postoperative objective evaluation using an accelerometer, to properly estimate the impact of the performed meniscal treatment on knee stability.

The present study has some limitations. First, the preoperative knee laxity evaluation was performed in awake patients before anaesthesia. This could affect the data obtained with the measurements. However, while the same assessment should carried out in patients after anaesthesia in the operating room can reach more reliable findings, this technology offers the added value of the easy and non-invasive clinical use also in the outpatient setting, compared to more precise but more complex and invasive research approaches to quantify knee laxity. Second, a classification of the type of meniscal lesions has not been performed, and as a result, no subanalysis has been conducted based on this aspect. This could add a level of heterogeneity which could have contributed to the lack of significance found when assessing the rotatory laxity. Future studies should quantify the impact of the different patterns of meniscal lesions on knee laxity, and their possible evaluation through knee accelerometers. Despite these limitations, the results of this study are of clinical relevance since it was demonstrated the possibility to objectively quantify with an easy to use accelerometer the impact of meniscal lesions on knee laxity in ACL-injured knees in clinical practice. This could help clinicians in planning and performing an appropriate treatment of meniscal tears during ACL reconstruction surgery to restore optimal knee stability. Starting from these results, future studies should further investigate the potential of evaluating knees in the outpatient setting and to non-invasively discern the contribution of different types of meniscus lesions to knee laxity, offering useful information to properly manage patients undergoing ACL reconstruction surgery.

CONCLUSIONS

This study demonstrated that the contribution of concomitant meniscal lesions to knee laxity can be objectively quantified using a triaxial accelerometer in ACL-injured knees. In particular, medial meniscus lesions, alone or in association with lateral meniscus lesions, determine a significant increase of the anterior tibial translation compared to knees without meniscus tears. The noninvasive evaluation of knee laxity with accelerometers could provide useful information when managing patients affected by ACL lesions.

AUTHOR CONTRIBUTIONS

Giuseppe Filardo and Stefano Zaffagnini: Conceptualization and supervision. Davide Reale and Marco Franceschini: Methodology. Marco Franceschini, Angelo Boffa, and Luca Andriolo: Data curation. Marco Franceschini and Angelo Boffa: Writing—original draft preparation. Luca Andriolo, Davide Reale, Fabio Tortorella, Alberto Grassi, and Giuseppe Filardo: Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENTS

The authors acknowledge Elettra Pignotti for her help with the statistical analysis. Open access funding provided by BIBLIOSAN.

CONFLICT OF INTEREST STATEMENT

Stefano Zaffagnini is a consultant surgeon for Smith and Nephew and DePuy Synthes. The remaining authors declare no conflict of interest.

ETHICS STATEMENT

The study was approved by the Ethics Committee of the IRCCS Istituto Ortopedico Rizzoli (Prot. Nr. 0007043). All the enrolled patients signed the informed consent. The Ethics Committee did not authorise sharing the raw patients' data. The calculated average values, which protect patients' privacy, are detailed in the manuscript.

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How to cite this article: Franceschini, M., Reale, D., Boffa, A., Andriolo, L., Tortorella, F., Grassi, A. et al. (2024) Medial meniscal lesions increase antero-posterior laxity in knees with anterior cruciate ligament injury. *Knee Surgery, Sports Traumatology, Arthroscopy*, 32, 135–142. https://doi.org/10.1002/ksa.12036