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ANTERIOR KNEE LAXITY AND ACL MAGNETIC RESONANCE SIGNALS IN HEALTHY AND ACL-RECONSTRUCTED KNEES FOLLOWING EXERCISE

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ABSTRACT – *Objective:* The study compared anterior knee laxity and anterior cruciate ligament magnetic resonance signals between healthy and anterior cruciate ligament reconstruction (ACLR) knees after exercise to verify differences. This research can guide future training to reduce the risk of reinjury.

Materials and Methods: Fifty-four male footballers between June and August 2022 were enrolled in this case-control study. Subjects who underwent ACLR in the previous 3 years (study group) were compared with healthy volunteers (control group). Each group consisted of twenty-seven patients. Data recorded were anterior tibial translation (ATT) expressed in millimeters using an arthrometer and the ratio of ACL to fat tissue signal intensity using magnetic resonance imaging. Measurements were collected at T0 (at rest), T1 (after 40 minutes of linear running of 3.5 miles), and T2 (after 90 minutes of a regular football match).

Results: No statistical difference was observed in demographic pre-analysis features. No difference was indicated between the two groups according to ATT. Conversely, ACL natives demonstrated significant increases in the ratio of ACL to fat tissue signal intensity when compared with ACLR in the three different measurements. Regarding differences within each group, we demonstrated that anterior knee laxity increased in both groups after 90 minutes of a regular football match. The ACL MRI signal did not differ in the study group, but it increased in the control group after exercise.

Conclusions: Although exhibiting distinct MRI signals, ACL-reconstructed tendons show similar post-exercise joint laxity as healthy ligaments. Looking ahead, leveraging specific insights could help tailor training sessions for preventive purposes.

KEYWORDS: Mega prostheses, Coating, Coated and infection.

INTRODUCTION

Injuries to the anterior cruciate ligament (ACL) are common among athletes, particularly in sports that involve rapid changes in direction and jumping[1]. Anterior cruciate ligament reconstruction (ACLR) is a widely used treatment for individuals with ACL injuries, aiming to restore stability and functionality of the knee joint[2].

Injuries were most frequent at the outset of the game, with over half occurring during the first 15 minutes. A second surge of injuries was noted during the first quarter of the second half[3].

Furthermore, literature indicates that physical exercise has the potential to elevate laxity in normal knees. Stoller et al[4] demonstrated that knee laxity increased following a specific training protocol but returned to baseline levels after a subsequent rest period. The extent of alteration in the anterior drawer test results could be contingent on the type of activity the athlete engaged in before undergoing the test[4]. The increase of joint laxity, due to fatigue, has been interpreted as a consequence of the loss of muscle strength, the viscoelastic accommodation of the central and peripheral pivot ligaments, and the increase of intra-articular temperature produced by the work performed[5]. The ACL viscoelastic accommodation may be due to macro and microstructural features or the increase of vascularization[6,7].

A patient with ACLR knee runs a higher risk of sustaining a new ACL injury in either knee compared with a knee-healthy person[8]. The first 2 years after reconstruction were considered crucial for assessing knee stability[9].

However, the post-reconstruction behavior of the ACL, particularly in response to exercise-induced stress, remains an area of ongoing investigation.

Magnetic Resonance Imaging (MRI) holds the potential to detect knee anatomy and instability following different types of exercises in individuals who have undergone Anterior Cruciate Ligament (ACL) reconstruction[10,11]. Chung et al[12] and Van Dyck et al[13] demonstrated no correlation between radiographic ACL recovery and clinical knee stability. In previous studies, Lipps et al[14] identified that pivot landings, which are subjected to forces equivalent to three or more times the body weight and repetitive loading over a condensed timeframe, can induce stress ruptures in the human ACL.

These considerations are important for identifying particular athletic risk conditions during both competition and the entire training season, when the tightness of the knee ligaments and muscle tone are particularly reduced[14].

This study compares anterior knee laxity and the magnetic resonance signal of the ACL between healthy knees and those that have undergone ACL reconstruction, following exercise. This study aims to determine if there are differences in joint laxity or MRI signal intensity after exercise between the two groups. It could explain the higher risk of reinjury in ACLR knees and, furthermore, eventually identify the best training programs that could reduce this event.

MATERIALS AND METHODS

We designed a prospective, observational, case-control, monocenter study, after validation by the Ethics Committee of the Bari University Hospital (protocol number: 12/CE/2022—01 May 2022), carried out in compliance with the ethical guidelines outlined in the Declaration of Helsinki of 1964, as revised in 2013. Before being included in the study, every patient gave informed consent.

Subjects treated by anterior cruciate ligament reconstruction for ACL rupture (Study group) in the previous 3 years and a healthy participant (Control group) were enrolled and evaluated at our Hospital between June and August 2022. The subjects involved were male footballers and players in the third-level local division teams.

Inclusion criteria: patients' age was between 18 and 35, the dominant limb was studied, and all candidates had an adverse knee history of major traumatic events before surgery/examination.

Exclusion criteria: presence of genetic pathology with congenital laxity, history of previous infections, coagulopathies, or combined multiple ligament injuries, and a limited knee range of motion (unable to flex to 20-30°) during physical examination.

The population size was calculated using the arthrometer anterior translation values as a primary endpoint with G*Power v. 3.115. We assessed the simple size of 27 participants for the group, using an α level of 0.05, a power level of 95%, and a standard deviation of 0.9-point[16].

Between June and August 2022, forty-two patients with ACL rupture were deemed suitable for the current investigation. Twenty-seven healthy subjects were enrolled as a control group through a public survey in the Orthopedic Department. Figure 1 presents a summary of the number of patients who were enlisted, enrolled, and studied for this study in accordance with the STROBE guidelines[17].

The data collected were age, side of injury/exam, anterior knee laxity, and ACL/Fat MRI signal intensity ratio. For the study group, associate meniscal procedures were included.

Data were recorded at the following times: at rest (T0), after 40 minutes of linear running of 3.5 miles (T1), and after 90 minutes of a regular football match (T2).

Anterior knee laxity was assessed at various times by a single senior doctor at our outpatient clinic using the KT 1000 (MEDmetric Corp., San Diego, CA, USA). At 20° of knee flexion, an anterior tibial load of 89-N was applied. Each knee had at least three measurements, with the recorded median value. The anterior tibial translation (ATT) was expressed in millimeters. The ATT value between 1.5 mm and 5 mm was considered normal, while > 5 mm was considered pathological[16].

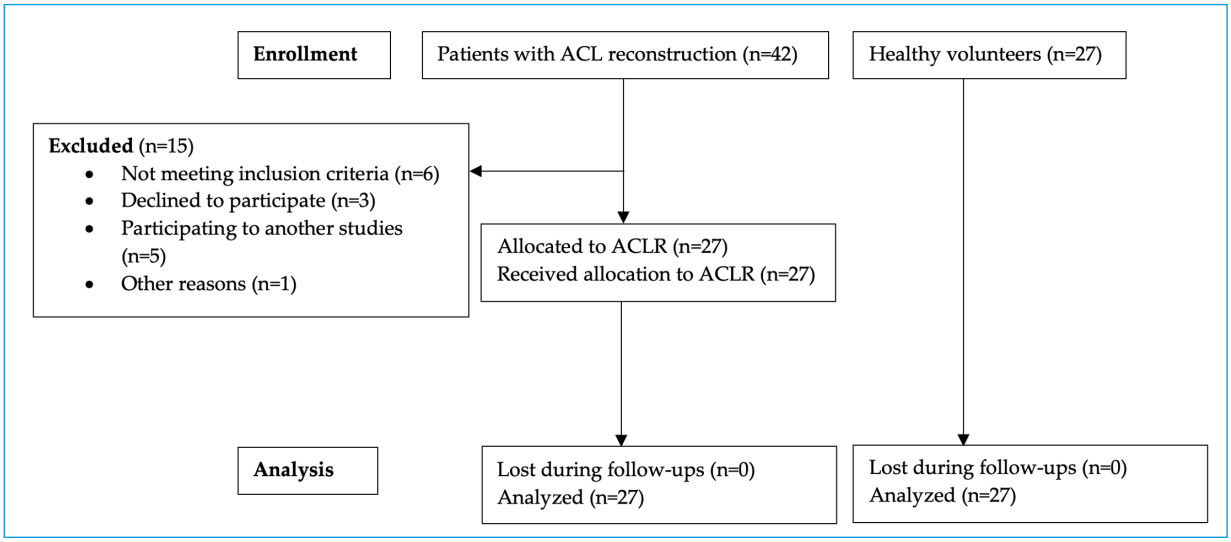

Figure 1. Flow diagram for enrollment and analysis.

Siemens MAGNETOM® Essenza 1.5 T was used to collect magnetic resonance imaging (MRI) images. Data were acquired on 1.5 T, extremity coil: sagittal T1 spin echo before and 20 min after exercise in each case. Using software provided by the manufacturer, signal intensity measurements were taken in a circular area 2 mm in diameter (white point in Figure 2) from the middle of the ligament. To enable data standardization from image to image, the intensity measurement was also taken from the middle point of the subcutaneous fat tissue in the popliteal area, along a line passing through the center of the femoral condyles (Figure 2).

Patients were operated on by the same experienced knee surgeon and under spinal anesthesia. For all patients, an ACLR all-inside technique was performed[18]. For reconstructions, the semitendinosus tendon was harvested and prepared as quadruple grafts. We drilled closed femoral and tibial half tunnels. For reconstruction, we pointed a 110° femoral and a 55° tibial aimers (Tibial ACL Marking Hook for RetroConstruction Drill Guide® – Arthrex©, Naples, FL, USA) to the anatomical ACL footprints. The retrograde tunnel, was drilled with a FlipCutter® III Drill (Arthrex©, Naples, FL, USA), measured about 2.5 cm.

Each patient followed the same postoperative rehabilitation protocol, consistent with the latest recommendations in the literature[19].

As a primary endpoint, anterior knee laxity was quantified using the arthrometer, and data were expressed in millimeters. The change in MRI signal, as ACL/Fat MRI signal intensity ratio, was assessed as a secondary endpoint.

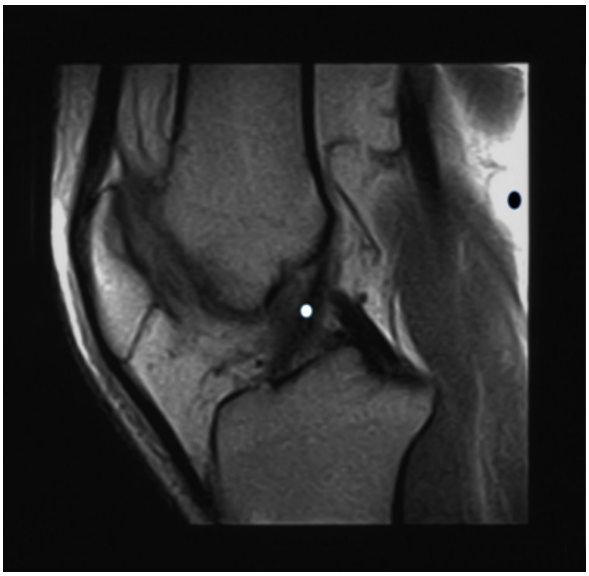

Figure 2. ACL/Fat MRI signal intensity ratio.

Statistical analysis

The SPSS program (v 23; IBM® Inc., Armonk, NY, USA) was used to gather and analyze the data. For the entire sample as well as for the follow-up, descriptive statistics were calculated. The non-homogeneous distribution of the variables was evaluated by the Kolmogorov-Smirnov test ($p > 0.05$); therefore, non-parametric tests were used. Categorical variables were indicated as percentages and numbers. Continuous variables were presented as median and interquartile range (IQR). The Mann-Whitney U test or Fischer's test were employed, as necessary, to compare the average values between the groups at the same time. The Wilcoxon test and Related-Samples Friedman's test Analysis of Variance were used to compare the value within the same group at different times. A *p*-value of less than 0.05 was accepted as statistically significant for all tests.

Table I. Key study data.

Pre-analysis features	Study group (n = 27)	Control group (n = 27)	*p*-value
Median Age, year, (IQR)	25.96 (8)	27.55 (11)	0.883*
Median BMI, Kg/m^2, (IQR)	22.18 (3.3)	21.65 (3.5)	0.216*
Left Side assessed, (%)	9 (33.3%)	6 (22.2%)	0.544†
Associate meniscal procedure (%)			
No lesion	1 (3.7%)		
Resection	17 (63%)		
Repair	9 (33.3%)		
Median time from surgery, months, (IQR)	31.62 (9)		

*Mann-Whitney U test, †Fischer test.

RESULTS

Fifty-four subjects were finally included in this study and divided into two groups, 27 patients for each group. At recruiting, we examined the study and control groups (Table I). No statistical differences emerged between groups.

No patients reported any skin complications, revision surgery, infection or mechanical failure. There were no complications during the operation or afterward.

The anterior knee laxity and changes in MRI ratio signal before and after exercises were measured and shown in Table II. There was no difference between the two groups in terms of anterior knee laxity. In contrast, ACL native demonstrated significant increases in the ratio of ACL to fat tissue signal intensity when compared with ACLR in the three different evaluations. Differences between variables within each group were illustrated in Table III.

It was found that anterior knee laxity measurements were significantly increased in both groups at the 90-minute football game (T2). On the other hand, comparison between rest (T0) and linear running (T1) demonstrated knee laxity increase, although not statistically significant. Regarding the MRI signal, we observed no statistically significant changes in the study group, whereas a significant progressive increase in the MRI signal was found in the control group.

DISCUSSION

Anterior cruciate ligament (ACL) injuries and their subsequent reconstructions are of utmost significance in sports medicine. Understanding the response of reconstructed ACLs to various stressors, such as exercises, provides crucial information for clinicians, athletes, and rehabilitation specialists. This is the first study to analyze both anterior knee laxity and MRI signal of the ACL in healthy knees and those that have undergone ACL reconstruction, following exercise. Anterior knee laxity and the MRI signal ratio serve as potential markers for evaluating knee stability and graft integrity post-ACLR.

The aim of this study was to determine if there were any differences in terms of joint laxity or MRI signal between the two groups that could explain the higher risk of reinjury in ACLR knees, and, furthermore, to identify the best training programs that could reduce this event.

ACL lesions are one of the most frequent injuries in athletes. A recent publication by Mazza et al[20] described a substantial incidence of ACL in-

Table II. Differences in anterior knee laxity and MRI signal between groups.

		Study group (n = 27)	Control group (n = 27)	*p*-value
Median ATT, mm, (IQR)	T0	1.63 (1.66)	0.99 (2.09)	0.580*
	T1	1.95 (1.39)	1.86 (1.63)	0.337*
	T2	3.16 (1.46)	2.16 (1.93)	0.16*
Median ACL/Fat MRI signal intensity ratio, (IQR)	T0	0.23 (0.06)	0.26 (0.05)	0.003*
	T1	0.21 (0.06)	0.28 (0.01)	0.001*
	T2	0.26 (0.10)	0.36 (0.10)	0.001*

*Mann-Whitney U test.

Table III. Differences in anterior knee laxity and MRI signal within each group.

	Study group (n = 27)	Control group (n = 27)	*p*-value
Median ATT, mm, (IQR)	T0 *vs*. T1	0.124*	0.220*
	T0 *vs*. T2	0.007*	0.015*
	T1 *vs*. T2	0.057*	0.136*
	Analysis of variance	0.008†	0.121†
Median ACL/Fat MRI signal intensity ratio, (IQR)	T0 *vs*. T1	0.414*	0.009*
	T0 *vs*. T2	0.471*	0.001*
	T1 *vs*. T2	0.079*	0.001*
	Analysis of variance	0.236†	0.001†

*Wilcoxon test, †Related-Samples Friedman's test, Analysis of variance.

juries among top soccer players in Europe. They confirmed soccer as a sport at risk of ACL injury. The author also assumed that ACLR could be considered a standardized and dependable surgical procedure, leading to a high return to play rate in a reasonable timeframe. Nevertheless, there was a brief drop in the performance of professional soccer players[20].

Our results showed a noteworthy increase in anterior knee laxity measurements for both groups during the 90-minute football game (T2). This observation aligns with the understanding that prolonged and demanding physical activities can lead to joint laxity. It suggests that the stresses endured during a football match have a cumulative effect on the knee joint, potentially leading to an increase in laxity and confirming the results of previous studies[19,20]. During intermittent exercise, Shultz et al[21] examined resistance differences, multidirectional knee instability, or landing biomechanics and found antero-posterior laxity, varus-valgus laxity, and internal-external rotation laxity increased with sport activity. This increase was greater in women and in participants with higher initial knee laxity[21].

The increase in joint laxity, due to fatigue, has been interpreted as a consequence of the loss of muscle strength, the viscoelastic accommodation of the central and peripheral pivot ligaments, and the increase in intra-articular temperature produced by the work performed[5]. The ACL viscoelastic accommodation may be due to macro and microstructural features[22] as a consequence of the increase in vascularization[7]. Several authors confirmed the increase in joint laxity of the knee after exercise[23].

Nonetheless, competition settings are frequently accompanied by extra internal and external stressors, and injury risk may increase if these stressors are not managed. Typically, training sessions occur in a more controlled environment than competition conditions. Therefore, it should be easier to reduce non-contact ACL injuries in training, as described by a meta-analysis by Chia in 2022[24]. They concluded that competition and training settings were significantly different. Indeed, during competitions, there were additional internal and external stressors whose failure could increase the risk of injury.

Our study also showed that the stress resulting from the competition produced a significantly higher rate of anterior tibial translation as compared to that determined by training.

When an ACL lesion occurs, the use of the semitendinosus tendon as a graft represents a valid treatment. The "ligamentization" is described as the healing process through a metaplasia of the ACL graft[25]. Avascular necrosis, revascularization, resynovialization, and remodeling are considered the four stages involved in the restitutio ad integrum of the ACL. Every phase of remodeling significantly influences the biomechanical characteristics of the graft, so there are times when the implant is functionally weak and most vulnerable to damage[26]. Howell et al[27] confirmed these results with MRI contrast media, concluding that the neo ligament had not acquired any neovascularization during the 2 years following implantation. Vogl et al[28] confirmed this issue in a two-year prospective study using contrast-enhanced MRI to evaluate revascularization of the graft after surgery. The authors described that the anterior cruciate ligament required about twenty-four months for healing[28]. These are the reasons why we avoided including patients who underwent ACLR in the two years prior to the study.

Regarding ACLR knee results, we reported a knee laxity increase after sport, which was statistically significant after a regular football match, while it was not statistically different after a training session like linear running. These results are similar to healthy knees, considering subjects were evaluated 3 years after reconstruction. Sumen et al[29] demonstrated that the anterior translation in-

creased in healthy subjects after a workout (200 m of linear running and with changes of direction, stairs, and jumps for one hour) and observed the same trend in knees that had already undergone transplantation for LCA injury. They correlated their clinical data with MRI findings. The MRI exam showed an increase in the ACL signal intensity after exercise, while in the reconstructed ligaments, the signal itself showed no changes.

According to the literature, as regarding to MRI examinations, we found the intensity of the healthy ACL increased after exercise. These changes are probably the consequence of an intra-ligamentous increase in water content induced by ACL and the synovial membrane after exercise, according to the concepts previously exposed[29].

In trans-planted ACLs, the nonvariation of the MRI signal after workout was demonstrated. The absence of statistically significant changes in the study group suggests that ACL-reconstructed knees might exhibit a relatively stable MRI signal response to exercise-induced stresses. This could indicate that the reconstructed ACLs are withstanding the challenges posed by the exercise without exhibiting significant structural changes in accordance with the assumptions made by Sumen et al[29] and Johnson et al[30]. All of the aforementioned investigations showed that, despite having distinct MRI signals, ACLR with tendon grafts function like healthy ligaments in terms of post-exercise joint laxity. In the study group, the excessive change in MRI signal intensity could be considered a risk factor for pathology[29].

The novelty of this study lies in the evaluation of ACLR knees under different working conditions and their comparison with healthy knees. This topic in the literature has not yet been widely discussed.

Limitations

This study has some limitations. It is a male-only study, and the subjects could be increased. Additionally, the follow-up period examined two different types of physical activity only.

The findings of this study have clinical and practical implications for both athletes and healthcare professionals. The increase in knee laxity during prolonged exercise emphasizes the importance of monitoring joint stability during high-intensity activities. Athletes and individuals post-ACL reconstruction should be aware of the potential for joint laxity alterations during extended physical exertion. Furthermore, the differing MRI signal responses between the ACLR and control groups indicate the need for tailored approaches to rehabilitation and exercise prescription.

Further studies are needed with a much larger sample, considering female players to also evaluate the gender difference.

CONCLUSIONS

The study's findings underline the multifaceted response of the ACLR and native ACL to exercise-induced stress. While anterior knee laxity remained consistent, the divergence in MRI signal ratios may be associated with the higher risks of reinjury in ACLR knees than in native knees. Further exploration into the structural and mechanical differences between the two groups post-exercise should be promoted to refine post-ACLR rehabilitation protocols and enhance the understanding of ACL behavior under dynamic conditions.

Ethics Approval

This study was approved by the Ethics Committee of the Bari University Hospital (protocol number: 12/CE/2022—01 May 2022), carried out in compliance with the ethical guidelines outlined in the Declaration of Helsinki of 1964, as revised in 2013.

Informed Consent

Prior to being enrolled in this study, all patients provided a written informed consent.

Data Availability

The corresponding author can provide the data described in this study upon request. Due to privacy concerns, the information is not publicly available.

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Conflict of Interest

The authors declare no conflict of interest.

Authors' Contributions

All authors agreed to be involved for all aspects of the study and participated in data analysis, composing and reviewing the paper. They also gave their final approval of the published version.

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