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RESEARCH

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Knee functional outcomes and quadriceps hypotrophy after ACL reconstruction: a prospective observational study

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Abstract

Background ACL injuries are common among athletes and individuals experiencing trauma, leading to instability and functional impairments. Post-ACL reconstruction, patients often face challenges like pain and reduced knee function, impacting their daily lives and sports participation. The aim of this study was to describe knee functional outcomes of patients with ACL tears over three months through three subsequent visits.

Methods This prospective observational study involved patients with ACL tears who were assessed pre-ACLR and at 1 and 3 months post-ACLR. Measures included Tegner Activity Scale, IKDC Subjective Knee Evaluation, Lysholm Knee Scoring Scale, pain scales, quadriceps thickness via ultrasound, and Rectus femoris and Vastus lateralis muscle activation via surface electromyography.

Results A total of 98 patients were included in the study. Significant improvements were observed in Tegner Activity Scale scores ($p < 0.001$), IKDC scores ($p < 0.001$), Lysholm scores ($p < 0.001$), and pain scores ($p < 0.001$) over the study period. Ultrasonography and surface electromyography revealed ongoing quadriceps muscle hypotrophy and reduced neuromuscular function, highlighting the need for targeted rehabilitation**.**

Conclusion Structured rehabilitation post-ACL reconstruction significantly improves functional outcomes and reduces pain. Challenges like muscle hypotrophy and decreased activation post-surgery emphasize the need for targeted rehabilitation strategies in the initial stages of recovery. Tailored programs focusing on these early deficits are crucial for optimizing recovery trajectories, enhancing knee stability, and preventing long-term complications.

Immediate attention to these issues can help refine rehabilitation protocols, ensuring more effective outcomes as patients progress through their recovery. Further research should also focus on the long-term sustainability of these improvements.

Keywords ACL reconstruction, Electromyography, Functional outcomes, Knee function, Rehabilitation, Ultrasonography

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Introduction

Knee injuries are prevalent, particularly among individuals engaged in sporting activities and those experiencing high-velocity trauma, leading to an increased likelihood of ligament injuries. The anterior cruciate ligament (ACL) is crucial for providing stability and congruence in the knee joint, working in concert with other ligaments, the joint capsule, muscles, and bones. The ACL plays a dual role in both mechanical stability and proprioception, controlling and restricting knee motion to support both static and dynamic equilibrium [1].

The annual incidence of ACL injuries in the United States is approximately 1 in 3,500 individuals, with around 400,000 ACL reconstructions performed each year [2]. The prevalence of ACL injuries among athletes ranges from 0.5% to 8.5% [1]. Along with road traffic accidents, sports involving contact, such as football, hockey, skiing, and traditional Indian sports like Kho-Kho, Kabaddi, and wrestling, are associated with a higher risk of ACL injuries [1]. Post-ACL injury, patients typically experience pain, instability, and reduced function in the affected knee joint, earning the ACL injury the moniker "the beginning of the end of the knee" [1]. Postoperative pain after ACL reconstruction significantly impacts patient-perceived outcomes and can delay the return to normal activities and rehabilitation [3]. ACL injuries garner significant attention due to their association with increased risk of subsequent knee injuries and long-term medical disabilities such as osteoarthritis along with higher risk of knee reinjury [4], with a consequently long-term disability and higher risk of early osteoarthritis [5].

Neuromuscular evaluation through electromyography provides insights into the behavior of the neuromuscular system, emphasizing the need for improved hamstring training methods to enhance neuromuscular control and reduce ACL injury risk [6]. Quadriceps weakness has been linked to adverse short- and long-term outcomes, including lower rates of return to sport, diminished quality of life, and the early onset of osteoarthritis. Thus, the short-term goals of ACL reconstruction focus on restoring joint stability and alleviating symptoms, whereas the long-term objectives aim to enable patients to return to their previous activity levels and mitigate the risk of developing osteoarthritis [7].

Despite ACL reconstruction, knee laxity is prevalent among 31.8% of patients exhibiting a positive Lachman test and 21.7% exhibiting a positive pivot shift [8]. Furthermore, only 65% to 70% of individuals return to their pre-injury level of sports activity [9, 10], and ACL reconstruction does not significantly reduce the risk of OA post-injury [11, 12]. Given the suboptimal outcomes for some patients, it is imperative to identify determinants of patient outcomes and function. Identifying these factors helps in advising patients considering surgery and may assist in addressing risk factors that could lead to less favourable outcomes [13]. The aim of this study was to describe knee functional outcomes of patients with ACL tears over three months through three subsequent visits, to evaluate early recovery trends and functional improvements in the initial postoperative phase, which can provide valuable insights for optimizing early rehabilitation protocols.. A well-organized rehabilitation program is crucial for the functional outcome of an ACL-reconstructed knee, promoting greater motion, increased muscular strength, and enhanced function [1].

Methods

This study was approved by the Institutional Ethics committee of All India Institute of Medical Sciences, Jodhpur [Certificate Reference Number: AIIMS/IEC/2021/3656]. Assessments were conducted using various evaluation methods at three different time points: pre-ACLR (Assessment I), 1 month post-ACLR (Assessment II), and three months post-ACLR (Assessment III). Activity levels were measured using the Tegner Activity Scale [14], Knee functional status was assessed with the 2000 IKDC Subjective Knee Evaluation Form and the Lysholm Knee Scoring Scale. Pain status was evaluated using an 11-point numeric scale. Mid-quadriceps muscle thickness was determined through ultrasonography using a linear probe (3.5–12.6 MHz). Muscle activation of the Rectus femoris and Vastus lateralis during maximal contraction was assessed using surface electromyography (sEMG). Pain symptoms were measured with the NRS scale. ($P > 0.05$)..

This hospital-based prospective observational study involved 98 patients with ACL tears presenting to the Department of Physical Medicine and Rehabilitation, AIIMS Jodhpur, from August 2023 to April 2024. Following approval from the Scientific Committee and Institute Ethics Committee participants aged 18–50 years scheduled for ACLR and met the inclusion criteria of having a confirmed ACL tear through clinical examination and imaging (MRI) were recruited. Exclusion criteria included peripheral vascular diseases, pregnancy, contraindications to exercise, psychiatric illness, acute ACL injury with tibial spine avulsion fracture, significant knee arthrosis, and locomotor disability. Written informed consent was obtained from all participants.

After a detailed history and clinical examination, MRI confirmed clinical findings. Post-arthroscopic ACL reconstruction, rehabilitation began immediately, continuing for 3 months. Full weight-bearing typically commenced from the second day post-surgery with a walker, varying if additional surgeries were performed. A knee brace was recommended for 4 to 6 weeks, or until the patient could ambulate comfortably..

Participants followed a rehabilitation plan targeting strength and neuromuscular control of the repaired limb. Initial rehabilitation included gradual range of movement, quadriceps strengthening, and neuromuscular activities. Partial weight-bearing with crutches progressed to full weight-bearing as tolerated. After three months, patients without pain, swelling, or instability were allowed to resume running and sports-specific activities [15]. Exercises to increase joint and flexibility in muscle groups, resistance training that primarily targeted the thigh muscles, balancing exercises, and coordination exercises were all part of the rehabilitation programme [16]. The supervised rehabilitation was carried out at outpatient clinic with monthly follow-up for all patients.

Assessment of quadriceps with ultrasonography

Quadriceps thickness was measured in both the normal and injured limbs of participants using a linear probe (3.5–12.6 MHz) on a Venue Go R3 ultrasound device. Participants were supine, with the probe placed transversely at the mid-point between the anterior superior iliac spine and the superior pole of the patella. Measurements were taken from the superficial border of the Rectus Femoris (RF) muscle to the femur [17] (Fig. 1). To enhance measurement accuracy, well-defined anatomical landmarks were used for each patient, and all data were collected by the same investigator to ensure consistency and improve the reliability of the results.

Assessment of quadriceps with surface electromyography

Surface electromyography (sEMG) for the Rectus Femoris and Vastus Lateralis muscles was conducted using the Nihon Kohden Neuropack® X1 MEB-2300 system. Unipolar electrodes were placed on the patient's skin after preparation. For the Rectus Femoris, the active electrode was positioned at the anterior thigh midpoint between the superior pole of the patella and the anterior superior iliac spine, with the reference electrode at the quadriceps tendon. The patient was instructed to flex the hip and extend the knee in a supine position. For the Vastus Lateralis, the active electrode was placed one handbreadth above the patella on the lateral thigh, with the reference electrode at the quadriceps tendon. The patient was instructed to extend the knee and lift the heel from the plinth in a supine position. sEMG signals were collected during muscle relaxation, minimal contraction, and maximal contraction, with maximum motor unit action potential signals sampled to assess muscle activity during knee extension exercises with resistance applied just above the ankle [18, 19] (Fig. 2).

A convenient sample size of 98 patients was taken because of the time-bound nature of the study. Data analysis was performed using IBM SPSS version 26. After assessing normality of data using Shapiro–Wilk test ($p > 0.05$), results were presented as medians (Q1, Q3). The Wilcoxon Signed Ranks Test was used to evaluate the significance of improvement between preACLR and postACLR 1 month as well as between postACLR 1 and 3 months, with $p \leq 0.05$ considered significant (95% confidence interval).

Results

Our study included 98 patients diagnosed with ACL injury of knee joints. Youngest patient included in study was of 18 years however oldest one was of 50 years of age with mean age of 29.70 years with Standard deviation of 7.78. The Tegner Activity Scale showed significant differences across the three visits. Pre-injury scores were high, with a median of 7.00 (6.00, 8.75). This decreased

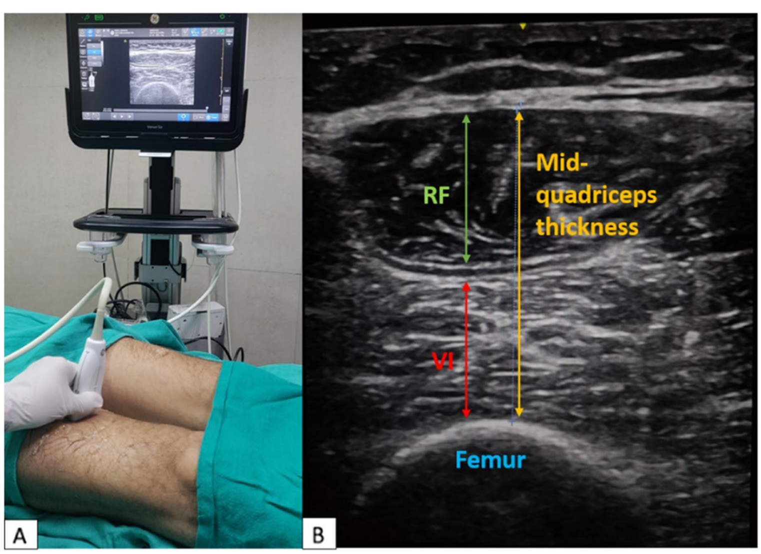

Fig. 1 **A** Measurement of quadriceps thickness in short axis by USG at mid point of ASIS and Superior pole of patella; muscle thickness was measured as the distance between the superficial border of RF muscle and the superficial border of femur. RF: Rectus femoris; VI: Vastus intermedius

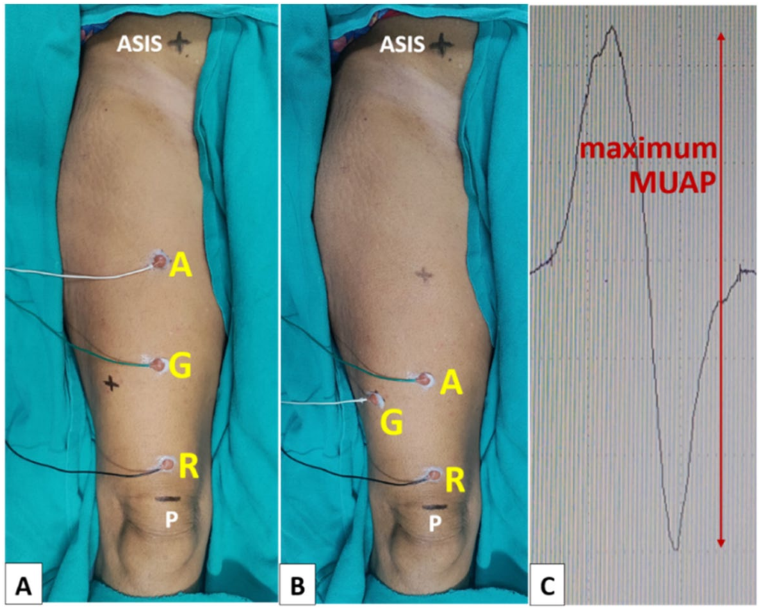

Fig. 2 Position of electrodes for electromyography. RF (image **A**) and VL (image **B**) muscle. Active electrode(A), Reference electrode(R), Ground electrode(G); image **C**: Graph showing MUAPs on maximal active contraction of examined muscle

drastically to a median of 1.00 (0.00, 1.00) preoperatively, remaining at 1.00 (1.00, 1.00) one month postoperatively, and then increasing to 3.00 (3.00, 4.00) three months postoperatively. The changes were statistically significant with P values < 0.001 between all 3 visits.

The IKDC scores improved significantly over time. Preoperatively, the median score was 11.49 (5.75, 20.69). One month postoperatively, the score improved to 31.03 (20.69, 36.78) and further increased to 56.32 (44.83, 64.37) at the three-month postoperative mark ($P < 0.001$).

The Lysholm scores showed a similar pattern of improvement. The median score was 17.50 (6.00, 25.75) preoperatively, increased to 42.50 (32.00, 50.00) at one month postoperatively, and reached 72.00 (60.25, 82.00) by three months postoperatively ($P < 0.001$).

The NRS pain scores decreased significantly over time. Preoperatively, the median pain score was 9.00 (7.25, 10.00). This reduced to 5.00 (4.00, 7.00) one month postoperatively and further decreased to 3.00 (2.00, 3.00) by three months postoperatively ($P < 0.001$) (Table 1).

The quadriceps thickness of the injured limb showed a significant reduction from preoperative measurements (3.98 cm) to one month postoperative (3.31 cm), but then a slight increase at three months (3.49 cm), with all changes being statistically significant ($P < 0.001$). The percent deficit in quadriceps thickness compared to the normal limb increased significantly from 5.40% preoperatively to 20.95% one month postoperatively, slightly decreasing to 20.56% at three months. The changes were significant between Assessment 1–2 ($P < 0.001$), but not between assessment 2–3 ($P = 0.1$).

Evaluation of the MUAP amplitude on sEMG of the rectus femoris muscle for the injured limb showed a decrease from preoperative values (2007 μV) to one

Table 1 Knee functional outcome characteristics of the study participants

Knee function scales score***	Preinjury	Assessment 1 (preACLR)	Assessment 2 (1 m Post ACLR)	Assessment 3 (3 m Post ACLR)	*P* value*	*P* value**
Tegner activity scale	7.0 (6.0, 8.8)	1.0 (0.0, 1.0)	1.0 (1.0, 1.0)	3.0 (3.0, 4.0)	< .001	< .001
2000 Ikdc subjective knee evaluation score	NA	11.5 (5.8, 20.7)	31.0 (20.7, 36.8)	56.3 (44.8, 64.4)	< .001	< .001
Lysholm knee scoring scale	NA	17.5 (6.0, 25.8)	42.5 (32.0, 50.0)	72.0 (60.2, 82.0)	< .001	< .001
NRS pain scale	NA	9.0 (7.3, 10.0)	5.0 (4.0, 7.)	3.0 (2.0, 3.0)	< .001	< .001

* Between assessment 1–2

** Between assessment 2–3

*** Median (Q1, Q3)

NA not assessed

month postoperative (1828.50 µV), and further to three months postoperative (1661.50 µV), with significant changes between Assessment 1–2 ($P<0.001$), but not between Assessment 2–3 ($P=0.1$.). The percent deficit in MUAP amplitude compared to the normal limb increased from 13.05% preoperatively to 30.87% one month postoperatively, and further to 39.78% at three months, with all changes being statistically significant ($P<0.001$ for Assessment 1–2, and $P=0.017$ for Assessment 2–3). The vastus lateralis muscle also showed a significant decrease in MUAP amplitude from preoperative values (831 µV) to one month postoperative (747.50 µV), with further reduction at three months (728.50 µV), and significant changes between Assessment 1–2 ($P<0.001$), but not between Assessment 2–3 ($P=0.6$.). The percent deficit in MUAP amplitude increased from 16.07% preoperatively to 26.94% one month postoperatively, and to 32.12% at three months, with significant changes ($P<0.001$ for Assessment 1–2, and $P=0.1$for Assessment 2–3) (Table 2).

Discussion

The most important finding of this study was that, despite significant improvements in functional and pain measures over a three-month period following ACL reconstruction, the quadriceps muscle remained weak, showing persistent hypotrophy and reduced activation. Tegner Activity Scale scores showed a dramatic decrease post-injury, reflecting the injury's impact on physical activity, with gradual improvement by three months postoperatively ($P<0.001$). Antonio Klasan, et al.'s study highlighted the predictive value of preoperative Tegner activity levels for successful return to sport (RTS) two years after ACL reconstruction (ACLR), underscoring that patients with higher preinjury Tegner levels were more likely to return to their previous sport and achieve comparable activity levels post-surgery [20]. Many studies have reported good to excellent results following ACL reconstruction, however there are still a percentage of patients who are unable to return to their pre-injury level of activity [13]. Significant improvements were also observed in IKDC Subjective Knee Evaluation scores and Lysholm scores, as well as in pain reduction indicating substantial knee recovery from preoperatively to three months postoperatively ($P<0.001$). Kowalchuk et al. highlighted the influence of preoperative factors like BMI and smoking on postoperative IKDC outcomes, suggesting that addressing these factors could optimize recovery [13]. These findings are aligning with findings from Kapoor et al. on the effectiveness of ACL reconstruction in restoring knee function. They reported a similar trend of improvement in Lysholm scores, with a significant increase from 69.33 preoperatively to 96.03 at final follow-up ($p<0.001$) [1]. Okoroha et al. compared pain levels between different autografts, noting higher pain levels with bone-patellar tendon-bone (BTB) compared to hamstring tendon (HS) [3]. Our results suggest that despite initial postoperative pain, patients undergoing ACL reconstruction experience notable pain relief and improved comfort as they progress through recovery. This underscores the effectiveness of rehabilitation and

Table 2 Assessment by ultrasonography and SEMG

Quadriceps thickness by ultrasonography	Assessment 1 (preACLR)	Assessment 2 (1 m Post ACLR)	Assessment 3 (3 m Post ACLR)	*P* value*	*P* value**
Quadriceps thickness by ultrasonography* **					
Quadriceps thickness of injured limb	4.0 (3.5, 4.5)	3.3 (3.1, 3.7)	3.5 (3.0, 4.0)	<.001	<.001
Percent deficit in thickness of injured limb compared to normal limb	**5.4 (2.5, 8.8)**	21.0 (15.7, 27.4)	20.6 (12.8, 27.6)	<.001	0.1
Maximum MUAP of Rectus Femoris muscle on SEMG * **					
MUAP for injured limb	2007.0 (1400.8, 3189.8)	1828.5 (1118.5, 2568.3)	1661.5 (1250.3, 1942.8)	<.001	0.1
Percent deficit in MUAP for injured limb compared to normal limb	13.1 (6.9, 28.1)	30.9 (22.5, 43.9)	39.8 (30.2, 51.0)	<.001	0.017
Maximum MUAP of Vastus lateralis muscle on SEMG * **					
MUAP for injured limb	831.0 (644.8, 1479.5)	747.5 (582.8, 1478.5)	728.5 (537.0, 1348.5)	<.001	0.6
Percent deficit in MUAP for injured limb compared to normal limb	16.1 (11.8, 21.0)	26.9 (19.7, 34.7)	32.1 (26.6, 39.5)	<.001	0.1

* Between assessment 1–2

** Between assessment 2–3

*** Median (Q1, Q3)

pain management strategies in enhancing patient outcomes following ACL surgery.

Ultrasonography revealed significant reductions in quadriceps thickness postoperatively, highlighting ongoing muscular changes and the need for targeted rehabilitation to restore muscle function. Suner-Keklik et al. reported persistent muscle atrophy and decreased strength post-ACL reconstruction, emphasizing the prolonged impact on muscle morphology [21].

Surface electromyography (sEMG) serves as a valuable tool for analyzing muscle function, offering a non-invasive method to assess muscle activity. While it is widely used in research, its potential in clinical practice remains underutilized. In the context of ACL injury rehabilitation, sEMG provides objective, quantitative data on quadriceps muscle function, movement patterns, and localized muscle fatigue, which can significantly enhance deeper insights into neuromuscular performance, potentially leading to more tailored and effective rehabilitation strategies [22]. sEMG indicated significant decreases in motor unit action potential (MUAP) amplitudes for the rectus femoris and vastus lateralis muscles, underscoring the need for tailored rehabilitation to enhance neuromuscular function. Studies by de Sire et al. and Marshall et al. highlighted the critical role of muscle activation and proprioceptive input in knee stability and function [23, 24]. Hongxing Cui et al.'s study findings demonstrated significant differences in EMG characteristics across different rehabilitation phases, highlighting which muscles require more targeted training [18]. However, this decline can be reduced by a proper rehabilitation programme, by using sEMG. We can determine which muscle needs more training and improves the functional status of patients. These findings signifies the importance of monitoring quadriceps wasting post-ACLR, for implementing effective patient-supervised rehabilitation programs to avoid the risk of reinjury.

Our study and related literature collectively emphasize the critical importance of tailored rehabilitation programs following ACL reconstruction. Significant improvements in functional scores such as the Tegner Activity Scale, IKDC, and Lysholm, along with pain reduction, highlight the dynamic nature of recovery and the effectiveness of structured rehabilitation.

Quadriceps and hamstrings weakness are common after anterior cruciate ligament (ACL) injury and reconstruction, and muscle atrophy often persists even with being actively engaged in exercise [25, 26]. Although our study focused specifically on the quadriceps muscle, surface electromyography (sEMG) offers real-time feedback to tailor rehabilitation plans by identifying muscles that require more targeted training. Additionally, ultrasonography provides an objective means to monitor muscle recovery and refine rehabilitation interventions as needed.

Although this study has a relatively short follow-up period of three months, limiting our ability to assess long-term outcomes such as full return to sport or the development of complications like osteoarthritis, it provides crucial insights into the early postoperative phase. The sample size, based on convenience rather than formal calculation, may also affect the generalizability of the findings.

Importantly, this study emphasizes the persistent quadriceps weakness observed during the early postoperative period, despite improvements in function and pain. This underscores the critical need for enhanced, early-phase rehabilitation strategies focused on muscle activation, particularly for the quadriceps, to prevent long-term deficits. Utilizing tools like ultrasonography and surface electromyography (sEMG) in clinical practice can help tailor rehabilitation protocols during this crucial phase, promoting better neuromuscular recovery and potentially reducing the risk of reinjury. These insights are essential for optimizing care immediately following ACL reconstruction, leading to improved outcomes and patient quality of life. Targeted strategies are necessary to optimize quadriceps muscle recovery, restore neuromuscular function, and mitigate long-term deficits, especially in populations with compromised muscle adaptive remodeling. Overall, personalized rehabilitation approaches are crucial for enhancing recovery, preventing further injury, and improving the quality of life for ACL injury patients.

Conclusions

Our study demonstrated significant improvements in functional and pain measures over the three-month period following ACL reconstruction, as evidenced by notable gains in Tegner Activity Scale, IKDC, and Lysholm scores, alongside reduced pain levels. Despite these functional improvements, ultrasonography and surface electromyography (sEMG) revealed persistent quadriceps hypotrophy and decreased neuromuscular function. These findings underscore the need for enhanced, early-phase rehabilitation strategies focused on muscle activation to address ongoing muscle weakness. Although conclusions about long-term outcomes are limited by the short follow-up period, the results emphasize the importance of personalized rehabilitation programs tailored to optimize quadriceps recovery and prevent potential long-term deficits. This approach is crucial for improving patient outcomes and quality of life following ACL reconstruction. Further research with extended follow-up is needed to fully understand the long-term impacts and effectiveness of these rehabilitation strategies.

Limitations

While our study provided valuable insights into ACL injury recovery over a three-month period with three visits, longer-term follow-up is crucial to assess the sustainability of functional improvements and identify potential late complications post-ACL reconstruction. The effectiveness of rehabilitation programs may vary due to factors such as individual compliance, therapist expertise, and rehabilitation protocol variations, which were not extensively controlled for in our study and could influence outcomes. Additionally, the study did not differentiate outcomes based on specific surgical techniques or graft types, which are known to impact recovery trajectories and functional outcomes. Future research addressing these limitations will enhance the validity and applicability of findings, contributing to improved ACL injury management and rehabilitation strategies.

Abbreviations

ACL	Anterior Cruciate Ligament
BFRT	Blood Flow Restriction Training
BFR	Blood Flow Restriction
ACLR	Anterior Cruciate Ligament Reconstruction
1-RM	One Repetition Maximum
cACLR	Conventional Anterior Cruciate Ligament Rehabilitation
AOP	Arterial occlusion pressure
RF	Rectus femoris
ASIS	Anterior superior iliac spine
SD	Standard Deviation

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

Dr. Nagma Sheenam, Dr. Ravi Gaur and Dr. Nitesh Manohar Gonnade, wrote the main manuscript text. Dr. Abhinav Dixit guided for protocol's drafting and made significant contributions to the surface electromyography (SEMG) assessments. Dr. Abins T K collected Ultrasound data and surface EMG data and prepared the Fig. 2 and Table 2. Dr. Chinchu K prepared Table 1 and discussion writing in manuscript.

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Data availability

Data is provided as supplementary information files.

Declarations

Ethics approval and consent to participate

The study was conducted in compliance with the Declaration of Helsinki and was approved by the Institutional Ethical Committee of the All India Institute of Medical Sciences, Jodhpur. All methods were carried out in accordance with relevant guidelines and regulations. Informed consent was obtained from all individual participants included in the study.
Institutional Ethics committee registration number: AIIMS/IEC/2021/3656.

Consent for publication

Not applicable. All data used in the study are anonymized.

Competing interests

The authors declare no competing interests.

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