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Early Functional Outcomes of Arthroscopic Anterior Cruciate Ligament Reconstruction Following a Structured Home-Based Rehabilitation Protocol: A Prospective Observational Study

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Abstract

Background: Rehabilitation is essential after anterior cruciate ligament reconstruction (ACLR), yet repeated hospital-based physiotherapy may be difficult for patients who live far from specialist centers. Evidence supporting appropriately selected home-based care exists, but early outcomes and adherence-related symptoms require careful evaluation in routine clinical settings.

Objective: This study aimed to assess short-term functional recovery after arthroscopic ACLR followed by a structured 12-week home-based rehabilitation protocol and to explore clinical factors associated with non-adherence.

Methods: This prospective observational study enrolled 20 adults aged 18-45 years with an isolated complete anterior cruciate ligament (ACL) tear at the Department of Orthopaedics of Atal Bihari Vajpayee Institute of Medical Sciences and Dr. Ram Manohar Lohia Hospital in New Delhi, India, from April 2023 to June 2024. All participants underwent single-bundle arthroscopic ACLR using a quadrupled semitendinosus-gracilis autograft and received a phased home exercise program. Lysholm Knee Score and International Knee Documentation Committee (IKDC) subjective scores were recorded preoperatively and at one, two, and three months. Repeated observations were assessed using the Friedman test for Lysholm scores and repeated-measures analysis of variance for IKDC scores. Exact categorical comparisons examined associations between adherence and age, sex, postoperative infection, persistent pain, and giving-way symptoms.

Results: Participants had a mean age of 26.10±6.32 years; 18 (90%) were male. The mean Lysholm score improved from 41.65±1.79 preoperatively to 78.80±5.67 at three months (χ^2=60.0; p<0.001). The mean IKDC score increased from 35.11±2.79 to 60.69±2.65 (F=100.7; p<0.001). At three months, 17 participants (85%) had a fair and three (15%) a good Lysholm category. Three participants (15%) were non-adherent. Non-adherence was associated with persistent pain at three months (p=0.016; Cramer's V=0.79) and giving-way sensation at one month (p=0.004; Cramer's V=0.84), but not with age or sex. No postoperative infection occurred.

Conclusion: A structured home-based protocol after arthroscopic ACLR was accompanied by substantial early improvement in patient-reported knee function. Persistent pain and early giving-way were strong markers of non-adherence in this small cohort. The findings support structured education, planned symptom surveillance, and timely escalation to supervised care, while larger controlled studies with longer follow-up are needed before comparative effectiveness can be inferred.

Categories: Trauma, Pain Management, Orthopedics
Keywords: adherence, anterior cruciate ligament reconstruction (aclr), functional outcome, home-based rehabilitation, international knee documentation committee (ikdc), lysholm knee score

Introduction

Among the most prevalent clinically important knee injuries affecting young, physically active people are anterior cruciate ligament (ACL) injuries, which usually lead to joint instability, decreased functional capacity, and limitations in sporting and occupational activities. These injuries can significantly impair knee function and quality of life and frequently happen during abrupt deceleration, turning, landing, or quick direction changes. Epidemiological studies have shown that ACL injuries happen to people of all ages, with significant differences based on sex, engagement in sports, and exposure to activities [1,2]. For carefully chosen patients with symptomatic instability, arthroscopic anterior cruciate ligament reconstruction (ACLR) is a proven surgical procedure. However, as postoperative recovery also depends on rehabilitation, muscle

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strength, neuromuscular control, and patient participation, effective surgical reconstruction by itself does not guarantee full functional restoration [3,4].

Rehabilitation following surgery is an integral component of ACLR care with the goals of reducing pain and swelling, restoring knee joint range of motion, enhancing quadriceps activation, normalising gait, and gradually regaining functional strength. Existing rehabilitation protocols are based on individual advancement according to clinical and functional milestones and not only on the time elapsed since surgery. Recovery of knee extension, sufficient quadriceps control, and progressive strengthening are especially critical in the early recovery period as prolonged muscular weakness and movement irregularities may affect subsequent functional performance [5,6]. Evidence-based recommendations further emphasise the importance of patient education, adequate exercise progression, and frequent clinical assessment to identify problems and allow safe rehabilitation [4,7].

Traditionally, rehabilitation after ACLR has been via regular hospital-based or physiotherapist-supervised exercise sessions. Supervised rehabilitation allows for individual customisation of exercise, correction of movement skills, monitoring of postoperative symptoms, and assessment of functional advancement. However, multiple hospital trips can be a huge burden in terms of cost, distance, and logistics, especially for patients who are far from specialised orthopaedic rehabilitation facilities. Travel costs, employment duties, limited physiotherapy service availability, and the challenges of attending numerous visits may hinder access to ongoing supervised care. As such, systematic home-based rehabilitation has become a potentially feasible option in selected patients, especially when clear exercise instructions, planned clinician reviews, and relevant safety precautions are put in place [8,9].

Comparative effectiveness of home-based versus supervised rehabilitation after ACLR has been explored in prior clinical investigations. In a randomised clinical trial, Wan et al. [8] investigated home-based rehabilitation with minimal supervised physiotherapy visits compared to more intensively supervised rehabilitation. Their results indicated that with a structured home-based approach, well-selected patients could achieve satisfactory early results. Similarly, several comparative studies have suggested that the results of rehabilitation may depend on the quality of exercise teaching, patient selection, adherence, and advancement and not on the location of rehabilitation alone [9,10]. Still, differences in exercise regimens, the amount of supervision, the surgical methods used, the outcome measurements, and the length of follow-up make it difficult to directly compare rehabilitation strategies. Thus, the evidence provided does not support home-based rehabilitation as uniformly equivalent or superior to supervised physiotherapy.

It is important to note that home-based rehabilitation does not mean that there is no professional guidance at all. Effective execution involves detailed patient education, specified training phases, gradual functional goals, and techniques to detect delayed recovery or postoperative problems. Patients with ongoing discomfort, oedema, limited movement, or a feeling of instability may need further clinical assessment and supervised physiotherapy. Thus, current recommendations for rehabilitation encourage customised management, taking into account symptoms, functional advancement, and patient-specific conditions [6,7]. A coordinated home rehabilitation pathway should therefore integrate independent exercise performance with planned clinical assessment and prompt escalation of care when recovery departs from projected functional milestones.

Rehabilitation adherence is another key element in evaluating home-based rehabilitation. Home rehabilitation, unlike normal supervised physiotherapy, focuses heavily on patients' grasp of prescribed exercises, motivation, confidence, and capacity to follow progression directions. Poor involvement can lead to delayed healing, although pain, perceived instability, and concern about exercise technique can also be deterrents to participation. Hence, the association between compliance and postoperative symptoms can be bidirectional. Therefore, monitoring adherence together with clinical symptoms is critical to identify those patients who may benefit from further professional help [7,11]. But connections between adherence and postoperative symptoms do not resolve the question of whether poor rehabilitation leads to chronic symptoms or if symptoms themselves limit exercise participation.

Previous systematic reviews and comparative studies have reported promising functional outcomes after appropriately structured home-based rehabilitation, although differences in supervision intensity, patient characteristics, and outcome assessment limit the certainty of the evidence [10,12]. Some studies have proposed that supervised rehabilitation may provide supplemental benefits for particular strength-related or functional goals, particularly when patients need closer supervision and individualised progression [12]. The results of this study imply that rehabilitation delivery should be individualised to the patient's clinical requirements and that no single technique is universally superior to another. Moreover, several comparison studies have focused on medium- or long-term results, although early postoperative discomfort, adherence problems, and functional evolution over the first 12 weeks remain therapeutically relevant issues.

Standardised assessment of knee discomfort, instability, activity limits, and perceived functional recovery is made possible by patient-reported outcome measures such as the Lysholm Knee Score and International Knee Documentation Committee (IKDC) subjective score [13,14]. Repeated assessments are useful to characterise the improvement postoperatively and identify patients whose recovery requires closer clinical

attention [15,16]. However, improvement in these ratings should not be taken as independent proof of improved muscle strength, mechanical stability, or preparedness to return to sport [17]. Thus, assessment of both functional trajectories and adherence-related symptoms may provide a more complete knowledge of early recovery following ACLR [18,19].

Accordingly, the present prospective observational study aimed to evaluate early functional recovery following arthroscopic ACLR using a structured 12-week home-based rehabilitation protocol among patients with isolated complete ACL tears. The primary objective was to assess changes in Lysholm Knee Score and IKDC subjective score from preoperative assessment through the first, second, and third postoperative months. The secondary objective was to explore associations between rehabilitation adherence and selected demographic and postoperative clinical factors, particularly persistent knee pain and giving-way sensations. The objective of this study is to offer clinically relevant evidence for structured patient education, scheduled follow-up, and symptom-triggered escalation to supervised rehabilitation by analysing recurrent functional outcomes and adherence-related symptoms in a tertiary-care context. The investigation is a single observational cohort study without a supervised rehabilitation comparator and is thus designed to describe early recovery trends rather than comparative effectiveness.

Materials And Methods

Study design, setting, and ethics

This was a single-center prospective observational study undertaken at the Department of Orthopaedics of Atal Bihari Vajpayee Institute of Medical Sciences and Dr. Ram Manohar Lohia Hospital in New Delhi, India. Recruitment and follow-up were from April 1, 2023, to June 30, 2024; the last case was to be enrolled by March 31, 2024, to allow for a three-month assessment. The study was approved by the Institutional Ethics Committee of Atal Bihari Vajpayee Institute of Medical Sciences and Dr. Ram Manohar Lohia Hospital (approval number: TP (MD/MS) 108/2022/IEC/ABVIMS/RMLH/1274). Written informed permission was acquired prior to enrolment. No off-label use was reported, and investigations, devices, implants, and study-related treatment were supplied. The design measured repeated measures within one cohort treated. It was suitable for reporting feasibility and early recovery in ordinary practice but lacked random assignment or a supervised rehabilitation comparator. Reporting and interpretation thus emphasise temporal change and connection rather than causal comparative effectiveness.

Participants and sample size

Eligibility criteria included age 18-45 years and a full ACL tear. Inclusion criteria were an isolated full tear amenable to reconstruction and ability to provide consent. Exclusion criteria were as follows: past surgery on the affected knee, posterior cruciate or other major ligament injury, osteoarthritis of the affected knee, intra-articular fracture, and symptomatic meniscal injury or cartilage injury affecting the subchondral bone plate on magnetic resonance imaging. The limits resulted in a more clinically homogeneous group and less confounding from lesions expected to affect weight-bearing or rehabilitation.

The sample size calculation was based on the Lysholm observations published by Dai et al. [20] with means of 46.3 and 66.3 and a pooled standard deviation of around 17.1. The estimate of 15.5 (rounded to 16) was based on a 20-point difference, a 5% type I error, a 99% power, and the normal-distribution numbers provided in the thesis. A target sample of 20 participants was set to allow for 10% attrition. All 20 enrolled participants provided the baseline and three-month outcome observations. The clinical and analytical approach is shown in Figure *1*.

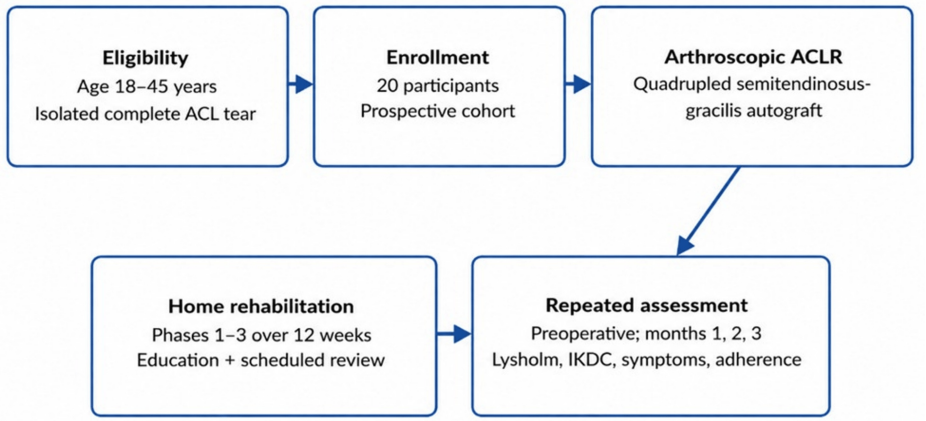


FIGURE 1: Study design, intervention pathway, and repeated outcome assessment

ACL: anterior cruciate ligament; ACLR: anterior cruciate ligament reconstruction; IKDC: International Knee Documentation Committee

Surgical procedure

All 20 patients had an ACLR with combination spinal-epidural anaesthesia using a standardised single bundle surgical regimen. The patients were placed supine with a proximal thigh tourniquet. Harvest of the semitendinosus and gracilis tendons was performed by a tiny oblique pes anserinus incision and prepared as a quadrupled hamstring autograft [21]. The knee compartments were assessed, full-thickness ACL rupture was confirmed, and remnant ligament tissue was debrided using standard anterolateral and anteromedial arthroscopic portals (Figure *2A*-*2C*). The femoral tunnel was created with an offset guide and drilled to approximately 2.5-3 cm depending on the graft diameter, while the tibial tunnel was made with an anatomical guide. The graft was carried through both tunnels and fixed on the femoral side with a variable-loop cortical button. After arthroscopic confirmation, the graft was tensioned at approximately 30° of knee flexion and fixed on the tibial side with a bioabsorbable interference screw. Figure *2D*-*2I* shows the femoral and tibial tunnel preparation, graft passage, fixation, and immediate postoperative appearance and postoperative radiographs. To decrease procedural variability and offer a consistent surgical basis for the assessment of postoperative functional outcome, standardised graft selection, reconstructive technique, and fixation procedures were developed. After surgery, patients were given intravenous fluids, antibiotic prophylaxis, analgesics, wound assessment after 48 hours, functional knee bracing, and standardised home rehabilitation instructions before release.

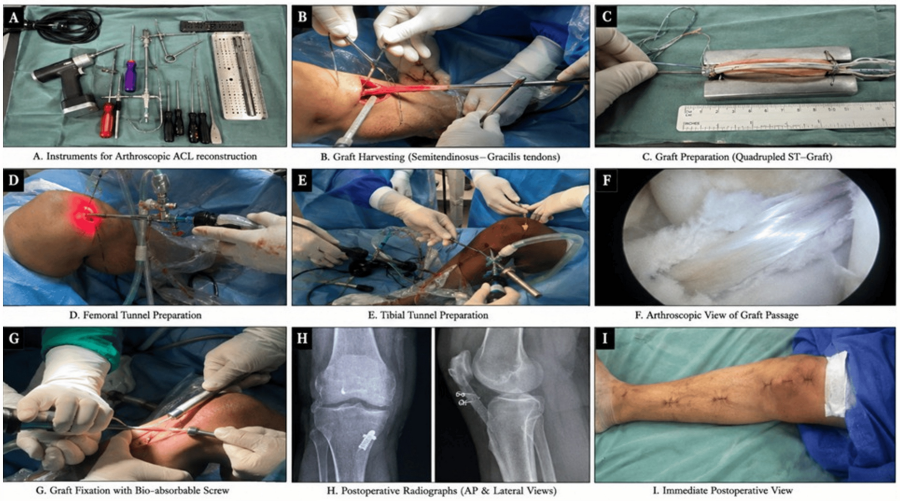


FIGURE 2: Surgical procedure

ACL: anterior cruciate ligament

Structured home-based rehabilitation protocol

All patients underwent a planned 12-week home-based rehabilitation program, including postoperative protection, pain and swelling control, restoration of knee mobility, quadriceps activation, progressive strengthening, and functional recovery. The protocol consisted of three successive steps. Phase 1 (postoperative day 1 to week 4) was focused on pain and swelling control, knee extension restoration, and quadriceps activation with brace-assisted straight-leg raises, patellar mobilisations, static quadriceps contractions, heel props, ankle pumps, and passive knee range of motion. Passive flexion and extension were initiated at eight days postoperative with a goal of approximately 90° of flexion by week 2. Partial weight-bearing advanced to complete weight-bearing by week 4 with appropriate quadriceps control. Phase 2 (weeks 5-8) focused on mobility, gait, and controlled loading with active-assisted extension, partial squats from 30° to 90°, toe lifts, wall slides, and continuation of previous exercises [22]. Closed-chain strengthening was started at week 4, and crutches were weaned at around week 8. During phase 3 (weeks 9-12), the patient performed resisted active quadriceps extension and heel slides, with gradual functional strengthening using open-chain movements beginning after week 8. Resisted hamstring strengthening was delayed until week 12, with withdrawal of the brace scheduled for week 12. Patients were given advice on icing, elevation, wound protection, and immediate clinical examination for fever, worsening wound discomfort, or moist dressings. Clinical follow-up was performed at postoperative months 1, 2, and 3, with examination of symptoms, functional results, and adherence to prescribed exercises. Adherence to rehabilitation was based on accessible categorical records of compliance. Participants were regarded as adherent when records indicated that they were compliant with the prescribed protocol and non-adherent when records indicated non-compliance. Thus, 17 participants (85%) were classified as adherent and three persons (15%) as non-adherent. Adherence was analysed as an observational categorical variable, rather than as an objective measure of exercise frequency or intensity, because standardised exercise diaries, device-based monitoring, and quantitative adherence thresholds were not available [23,24]. The rehabilitation schedule and typical workouts are summarised in Table *1* and Figure *3*.

Phase	Time	Primary goals	Core exercises/activities	Protection and progression
1	Day 1-week 4	Control pain and swelling; regain extension; activate quadriceps	Straight-leg raise with brace; patellar mobilisation; static quadriceps; heel props; ankle pumps; passive flexion and extension after day 8	Target about 90° flexion by 2 weeks; partial to full weight-bearing after quadriceps control; brace maintained
2	Weeks 5-8	Improve motion, gait, and controlled loading	Active-assisted extension; partial squats progressing 30-90°; toe raises; wall slides; continue phase 1 exercises	Closed-chain work after week 4; progress toward discontinuing crutches by week 8
3	Weeks 9-12	Increase quadriceps work and independent function	Resisted active quadriceps extension; heel slides; continue prior motion and control exercises	Open-chain exercise after week 8; no hamstring resistance for 12 weeks; brace discontinued toward week 12

TABLE 1: Structured 12-week home-based rehabilitation protocol

Patients were also instructed regarding icing, elevation, wound protection, and urgent review for fever, increasing wound pain, or a soaked dressing.



FIGURE 3: Home-based rehabilitation protocol following arthroscopic anterior cruciate ligament reconstruction

Outcomes

The primary functional outcomes were the Lysholm Knee Score and IKDC subjective knee score, assessed preoperatively and at postoperative months 1, 2, and 3 [25,26]. The Lysholm Knee Score is a validated patient-reported outcome measure assessing eight domains of knee function, including limp, support, locking, instability, pain, swelling, stair climbing, and squatting. Scores vary from 0 to 100, with higher scores reflecting greater functional status. Functional results were classified according to the following categorisation thresholds: bad (⩽64), fair (65-83), good (84-94), and excellent (95-100) [25]. Changes in functional status after surgery were determined using the same categories for each assessment session. The IKDC subjective knee score assesses knee symptoms, sports activities, and perceived functional capability on a standardised 0-100 scale, with higher values indicating greater knee function [26]. The IKDC scores were analysed as continuous variables in an effort to describe the functional progress in the first three postoperative months. Secondary outcomes included age category, sex, adherence to therapy, postoperative infection, chronic knee discomfort, and giving-way sensation. Persistent pain and giving-way symptoms were assessed at postoperative months 1, 2, and 3, and their association with adherence to rehabilitation was examined to find possible markers of delayed recovery and need for further professional monitoring. Due to the prospective observational design, these relationships were interpreted with caution and without presuming causality between rehabilitation adherence and postoperative symptoms.

Statistical analysis

Data were coded in Microsoft Excel (Microsoft Corporation, Redmond, Washington, United States) and analysed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, New York, United States). Continuous variables were summarised with mean and standard deviation and, where relevant, median, interquartile range, and range. Categorical variables were summarised with frequency, percentage, and confidence intervals reported in the source analysis. Normality was assessed with the Shapiro-Wilk test.

Because Lysholm observations were considered non-normally distributed, change across four timepoints was assessed with the Friedman test. IKDC observations were evaluated with one-way repeated-measures analysis of variance because the normality assumption was accepted in the source analysis. Associations between categorical variables were evaluated with chi-squared procedures or Fisher's exact test when expected cell frequencies were small. Cramer's V was reported for the two significant symptom-adherence associations. Statistical significance was set at $p<0.05$. Given the small exploratory sample and multiple categorical comparisons, p-values are interpreted as signals requiring confirmation rather than definitive estimates.

Results

Participant characteristics

The study analysed 20 participants with a mean age of 26.10±6.32 years, a median of 25.00 years (IQR: 22.00-29.25), and a range of 18-40 years. Sixteen (80%) were aged 18-30 years, and four (20%) were aged 31-40 years. Eighteen participants (90%) were male, and two (10%) were female. The right knee was affected in

13 cases (65%) and the left in seven (35%). Every participant underwent ACLR, and no postoperative infection was recorded. The baseline profile is summarised in Table 2.

Characteristic	Category/statistic	Value	95% CI/distribution
Age	Mean±SD	26.10±6.32 years	-
	Median (IQR); range	25.00 (22.00-29.25); 18-40	-
Age group	18-30 years	16 (80%)	55.7-93.4%
	31-40 years	4 (20%)	6.6-44.3%
Sex	Male	18 (90%)	66.9-98.2%
	Female	2 (10%)	1.8-33.1%
Affected knee	Right	13 (65%)	40.9-83.7%
	Left	7 (35%)	16.3-59.1%
Treatment	Arthroscopic ACLR	20 (100%)	80-100%
Postoperative infection	Present	0 (0%)	No cases observed

TABLE 2: Baseline demographic and clinical characteristics (N=20)

Continuous data are presented as mean±SD or median (IQR; range), as applicable; categorical data are presented as n (%). Statistical significance was defined as $p<0.05$.

ACLR: anterior cruciate ligament reconstruction

This clustering of cases in young adults is in keeping with the epidemiology reported by Dai et al. [20]; however, this sample cannot estimate incidence. The male predominance should be interpreted considering referral patterns, exposure, and the extremely small sample; it does not imply that women are at reduced biological risk. Laterality was descriptive and did not impact the treatment regimen. When analysing the results, it is vital to remember the restrictive qualifying criteria: patients with symptomatic meniscal tears, osteoarthritis, fractures, other serious ligament injuries, or significant cartilage damage were excluded. Thus, the results are most applicable to isolated full ACL rupture.

Lysholm trajectory and categorical outcome

The Lysholm Knee Score steadily improved at all postoperative evaluations, from 41.65±1.79 preoperatively to 56.80±3.81 at month 1, 67.30±5.25 at month 2, and 78.80±5.67 at month 3, an absolute mean improvement of 37.15 points. The median increased from 42.00 to 78.50, and the observed range increased from 39-44 to 70-91. A Friedman test showed a substantial overall improvement ($\chi^2(3)=60.0$; $p<0.001$). Clinically, this improvement translates to less patient-reported knee discomfort and better performance of tasks such as walking, stair climbing, and squatting [27]. The size of the improvement reflects a substantial functional recovery, rather than a change that is simply statistically significant. Nonetheless, the observational design does not allow us to ascribe progress to home-based therapy alone. The detailed results are shown in Table 3 and Figure 4.

Timepoint	Mean (SD)	Median (IQR)	Range	Friedman test statistic, χ^2(df)	P-value
Preoperative	41.65 (1.79)	42.00 (40.75-43.00)	39-44	χ^2(3)=60.0	<0.001
Month 1	56.80 (3.81)	58.00 (54.00-60.00)	50-62		
Month 2	67.30 (5.25)	68.00 (62.00-72.00)	58-75		
Month 3	78.80 (5.67)	78.50 (75.50-82.00)	70-91		

TABLE 3: Change in Lysholm Knee Score across follow-up (N=20 at each timepoint)

Data are presented as mean (SD), median (IQR), and range. The Friedman χ^2 statistic and p-value describe the overall four-timepoint comparison. Statistical significance was defined as p<0.05.

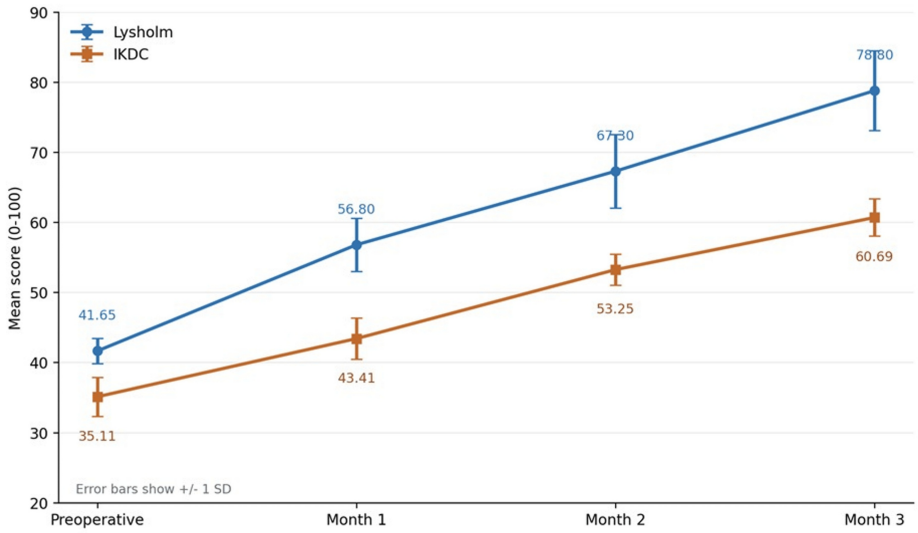


FIGURE 4: Mean Lysholm and IKDC scores from preoperative assessment through month 3

IKDC: International Knee Documentation Committee

Categorical analyses also showed clinically meaningful healing. All individuals were rated as having poor knee function preoperatively and at month 1. At month 2, 14 participants (70%) improved to fair function, while six (30%) were still poor. At three months, 17 (85%) individuals had fair and three (15%) participants had good functional status, with no participants in the bad category. Table *4* summarises these transitions and demonstrates a significant change in functional classification associated with the 37.15-point improvement. However, none of the patients had great function, demonstrating that initial symptomatic improvement was not equivalent to complete rehabilitation. Continued strengthening and neuromuscular training are crucial for recovering higher-level physical performance [28,29].

Timepoint	Poor, n (%)	Fair, n (%)	Good, n (%)	Excellent, n (%)
Preoperative	20 (100)	0 (0)	0 (0)	0 (0)
Month 1	20 (100)	0 (0)	0 (0)	0 (0)
Month 2	6 (30)	14 (70)	0 (0)	0 (0)
Month 3	0 (0)	17 (85)	3 (15)	0 (0)

TABLE 4: Lysholm functional categories over time (N=20 at each timepoint)

Data are presented as n (%). Lysholm categories: poor: ≤64; fair: 65-83; good: 84-94; and excellent: 95-100.

The results are consistent with prior studies assessing rehabilitation after ACL surgery in general. Connors et al. [27] observed progressive improvement in Lysholm in patients receiving physiotherapy-guided and home-based rehabilitation, and Farinelli et al. [28] reported good outcomes with minimally supervised rehabilitation. However, differences in follow-up time, patient characteristics, and rehabilitation intensity limit a direct comparison. Therefore, the present three-month mean score of 78.80 is optimistic early progress rather than complete functional restoration. Crucially, the improvement of 37.15 points and the fact that all patients moved out of the poor functional group offer complementary evidence of therapeutic benefit. However, most participants were still in the fair group, indicating lingering deficits and the need for further rehabilitation [29,30]. These findings provide evidence for the feasibility of structured home-based rehabilitation as part of early postoperative management, but highlight the need for longer-term assessments and objective functional testing to demonstrate sustained recovery, knee stability, and readiness for return to demanding physical activities.

IKDC trajectory

The IKDC subjective knee score showed a progressive improvement at the three-month postoperative follow-up, ranging from 35.11±2.79 preoperatively to 43.41±2.93 at month 1, 53.25±2.19 at month 2, and 60.69±2.65 at month 3. The mean absolute improvement was 25.58 points, and repeated-measures analysis of variance showed a statistically significant time impact ($F=100.7$; $p<0.001$). This improvement was paralleled by a steady increase in median IKDC scores, demonstrating a progressive recovery of patient-reported knee function (Table 5). The 25.58-point improvement is of clinical significance as the IKDC instrument measures knee symptoms, functional activities, and perceived restrictions. The reliability and responsiveness of the IKDC subjective knee evaluation form have been demonstrated by Irrgang et al. [25], confirming its use for monitoring recovery after surgery. Previous studies have likewise indicated a minimal clinically meaningful difference of roughly 11.5 points after ACLR; however, thresholds varied depending on the study group and timing of assessment. The mean IKDC improvement of 25.58 points exceeded the cited minimal clinically important difference of approximately 11.5 points, suggesting a clinically meaningful average improvement in patient-reported knee function. However, individual change scores are necessary to determine how many participants achieved this threshold. However, patient-level change scores are necessary for establishing individual clinically relevant improvement.

Timepoint	Mean (SD)	Median (IQR)	Range	Repeated-measures ANOVA statistic	P-value
Preoperative	35.11 (2.79)	35.60 (32.20-37.15)	29.9-39.0	F=100.7	<0.001
Month 1	43.41 (2.93)	43.05 (42.23-45.07)	37.9-49.4		
Month 2	53.25 (2.19)	52.80 (51.70-54.30)	48.3-57.5		
Month 3	60.69 (2.65)	60.35 (58.60-63.20)	56.3-65.5		

TABLE 5: Change in IKDC subjective score across follow-up (N=20 at each timepoint)

Data are presented as mean (SD), median (IQR), and range. Repeated-measures ANOVA was used for the overall time effect. Statistical significance was defined as $p<0.05$.

IKDC: International Knee Documentation Committee; ANOVA: analysis of variance

Adherence, pain, and giving-way symptoms

Of the 20 individuals, 17 (85%) were assessed as adherent to the structured home-based rehabilitation program, and three (15%) were classed as non-adherent. There were no statistically significant relationships between rehabilitation adherence and age category (p=0.509) and sex (p=1.000). However, the pattern of symptoms postoperatively was different between groups.

Persistent knee pain at month 1 was reported by two non-adherent participants (66.7%) compared with four adherent participants (23.5%; p=0.202). At month 2, the corresponding proportions were 66.7% and 11.8% (p=0.088). By month 3, persistent pain was reported by two non-adherent participants (66.7%) and none of the adherent participants, indicating a statistically significant association (p=0.016). Similarly, giving-way sensation at month 1 was reported by all three non-adherent participants (100%) compared with one adherent participant (5.9%; p=0.004). These findings, summarised in Table *6*, suggest a possible relationship between rehabilitation participation and postoperative symptoms. Nevertheless, the associations require cautious interpretation because only three participants were non-adherent, making subgroup estimates highly sensitive to individual observations.

Factor/time	Non-adherent (n=3)	Adherent (n=17)	Test statistic (χ^2)	P-value	Interpretation
Age group (18-30 years)	2/3 (66.7%)	14/17 (82.4%)	0.392	0.509	Not significant
Male sex	3/3 (100%)	15/17 (88.2%)	0.392	1.000	Not significant
Persistent pain, month 1	2/3 (66.7%)	4/17 (23.5%)	2.260	0.202	Not significant
Persistent pain, month 2	2/3 (66.7%)	2/17 (11.8%)	4.804	0.088	Not significant
Persistent pain, month 3	2/3 (66.7%)	0/17 (0%)	12.593	0.016	Significant; Cramer's V=0.79
Giving-way, month 1	3/3 (100%)	1/17 (5.9%)	14.118	0.004	Significant; Cramer's V=0.84
Giving-way, month 2	1/3 (33.3%)	0/17 (0%)	5.965	0.150	Not significant
Giving-way, month 3	1/3 (33.3%)	0/17 (0%)	5.965	0.150	Not significant
Postoperative infection	0/3 (0%)	0/17 (0%)	Not estimable	-	No events

TABLE 6: Associations between clinical factors and non-adherence

Data are presented as n/N (%) within each adherence group. Exact categorical tests were used for sparse cells. Statistical significance was defined as p<0.05.

The two statistically significant associations presented in Table *6* are further illustrated in Figure *5*. The percentage differences detected are large, but interpretation is constrained by the small number of non-adherent subgroup members. This group consists of one participant, representing 33.3 percentage points. Estimates are thus unstable and may be vulnerable to sampling variance. Also, the observational design does not allow us to determine if poor adherence was the reason for persisting symptoms or pain, instability, fear of movement, or other unmeasured factors that limited participation in exercise. Thus, the data should be viewed as exploratory relationships and not as proof of a causal association.

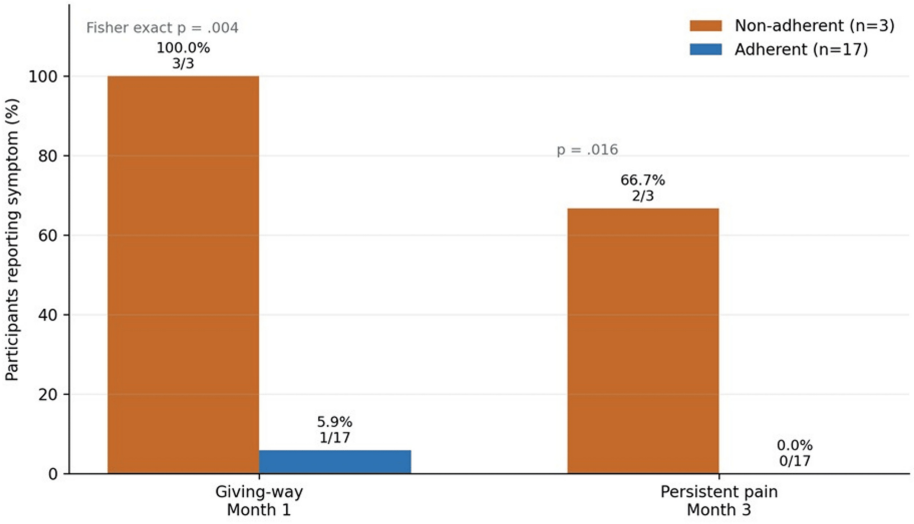


FIGURE 5: Significant symptom differences between non-adherent and adherent participants

Clinically, these findings emphasise the significance of monitoring postoperative symptoms and rehabilitation involvement. Reevaluation of quadriceps activation, knee mobility, gait, brace use, exercise technique, and probable mechanical problems may be required in patients with early failure or persistent pain. When healing is delayed, further supervised rehabilitation may be needed. However, small sample size, lack of objective adherence monitoring, and lack of a reference group limit generalisability. Larger prospective studies are needed to see if these connections are maintained and if focused adherence assistance enhances functional recovery after ACL surgery.

Relationship to comparative rehabilitation evidence

The present findings are intermediate between two simplistic viewpoints. There was no supervised control group; hence, they do not indicate that supervised physiotherapy is unnecessary. They do not imply that home rehabilitation is unsuccessful, as both patient-reported outcomes improved substantially and 85% of the population continued the program. The most plausible interpretation is that an organised home pathway may be combined with a favourable early recovery in chosen patients with single ACL injuries, as far as education and follow-up are kept.

This conditional view finds support in earlier trials. Previous studies have shown that organised home programs can provide satisfactory outcomes [21]. Positive recovery was highlighted by Barié et al. [22] regardless of the program design; however, Ashy et al. [19] and Farinelli et al. [28] found no evidence to support the need for routine intense supervision in all selected patients. Barié et al. [22] found advantages for supervised rehabilitation on various outcomes up to one year, compared to standard care. The differences between trials probably reflect more than the location of the visit: dose of supervision, skill of the therapist, selection of patients, graft process, progression of exercise, measurement of outcome, and compliance all differ [29].

So a stratified model is supported by the literature [30]. Low-risk individuals with simple instructions, appropriate support, good early quadriceps control, and straightforward symptom trajectories may be able to finish much of the program at home. Additional contact or formal physiotherapy should be given to patients with giving-way, persistent pain, loss of movement, noticeable oedema, poor understanding of activity, or poor compliance. This model marries the accessibility advantages of such models with the attention of scarce supervision to the patients most likely to benefit.

Discussion

The present prospective observational study showed considerable early functional improvement after arthroscopic ACLR with a structured 12-week home-based rehabilitation strategy. The mean Lysholm Knee Score improved from 41.65±1.79 preoperatively to 78.80±5.67 after three months, a difference of 37.15 points (χ^2=60.0; p<0.001). Similarly, the mean IKDC subjective score improved from 35.11±2.79 to 60.69±2.65, a 25.58-point improvement (F=100.7; p<0.001). The findings demonstrate clinically important improvements in patient-reported knee discomfort and functional ability early after surgery. But the study did not have a comparison group, so it is not possible to say that the benefits shown were only due to the home-based rehabilitation protocol.

The categorical Lysholm results give further clinical insight. All subjects, despite poor functional status preoperatively, attained fair functional status at three months, with 15% attaining good functional status. There were no participants in the excellent category. This distribution is in line with the expected course of early ACLR rehabilitation, where the recovery of knee range of motion, quadriceps activation, gait control, and basic functional activities generally precedes the complete recovery of muscle strength, neuromuscular coordination, and sport-related performance. van Melick et al. [3] stressed that postoperative rehabilitation should be guided by established clinical milestones rather than by time alone. Similarly, Heinz et al. [1] highlighted the significance of gradual strengthening, neuromuscular training, and functional assessment after ACLR. More recent evidence-based recommendations also acknowledge that the restoration of strength symmetry, mobility quality, and preparedness for demanding tasks sometimes takes longer than the first three postoperative months [7]. Thus, the majority of fair and good outcomes in the present trial are indicative of encouraging early functional improvement rather than inadequate efficacy of treatment.

Part of the reported gains may be attributed to the organised progression of rehabilitation exercises. The initial exercises focused on controlling pain and swelling, restoring knee extension, patellar mobilization, and quadriceps activation. The rehabilitation program then progressed to knee flexion exercises, controlled weight-bearing, and strengthening activities. It has been shown that quadriceps strength is a key determinant of postoperative knee function and persistent strength deficiencies may negatively affect functional performance after ACLR [16,17]. The results suggest the use of progressive muscle activation and strength training in rehabilitation programs. However, quadriceps strength and neuromuscular performance were not directly measured in the present study, and consequently, the particular impact of different rehabilitation components cannot be determined.

The results have implications for the viability of home rehabilitation. Carefully selected patients may have satisfactory results with structured home exercise programs in combination with patient education and periodic clinical assessment [8,9]. This has been suggested by prior comparative research. However, therapy at home should not be understood as rehabilitation without guidance by professionals. Clear directions for exercise, adequate progression, monitoring of symptoms, and quick clinical reassessment are key. The results of the present study suggest the potential value of this technique during the early recovery phase, especially in settings where geographical distance, cost of treatment, and unavailability of physiotherapy services limit opportunities for regular supervised sessions.

Another therapeutically relevant element was adherence to rehabilitation. Of the participants, 17 (85%) were classed as adherent and three (15%) as non-adherent. Persistent knee pain at three months was substantially linked with non-adherence ($p=0.016$) and giving-way sensation at one month ($p=0.004$). These results imply that pain and felt instability postoperatively may aid in identifying patients in need of further examination or rehabilitation treatment. However, the non-adherent subgroup consisted of only three participants, and the identified connections were statistically unstable and susceptible to the outcomes of individual participants. The nature of these links, however, remains to be seen. Persistent pain and instability may discourage participation in exercise, and insufficient rehabilitation progression may potentially result in weakness or lower functional confidence. Thus, these data should be considered as exploratory relationships rather than proof of a causal relationship between non-adherence and postoperative symptoms.

Clinically, the findings indicate an individualised strategy to rehabilitation which is sensitive to symptoms. Patients with excellent functional advancement, adequate quadriceps control, and uncomplicated postoperative recovery can continue the specified activities at home and with planned clinician assessment. However, if pain is severe, the knee gives way repeatedly, swelling occurs, movement is restricted, or the patient has trouble doing the exercises, the situation should be reevaluated and the patient considered for further supervised physiotherapy. Such an approach is congruent with current rehabilitation recommendations focusing on individualised progression and functional criteria [1,3,7].

There are a number of restrictions to acknowledge. The study comprised just 20 people from a single center, which reduces statistical power and generalisability. Lack of a supervised rehabilitation control group prohibits conclusions about comparative effectiveness. Rehabilitation adherence was captured categorically with no objective exercise monitoring, and only three subjects were non-adherent. Also, early recovery was measured at the three-month follow-up but not long-term functional outcomes. Objective measures of knee laxity, range of motion, quadriceps strength, hop performance, and return to sport readiness were not available. Future multicenter controlled studies with larger populations, standardised adherence monitoring, and objective functional evaluation, with a follow-up of 12-24 months, are needed. Overall, findings provide promising evidence of early functional recovery from the patient perspective after ACLR with structured home-based rehabilitation while emphasising the necessity of continuous rehabilitation, symptom surveillance, and individualised clinician supervision.

Conclusions

This prospective observational study demonstrated significant early improvements in patient-reported knee function following arthroscopic ACLR and a structured 12-week home-based rehabilitation protocol among patients with isolated ACL tears. The mean Lysholm Knee Score increased from 41.65 preoperatively to 78.80

at three months, representing a 37.15-point improvement, while the mean IKDC subjective score increased from 35.11 to 60.69, representing a 25.58-point improvement (both p<0.001). At three months, 85% of participants achieved fair and 15% achieved good Lysholm functional outcomes, indicating meaningful early recovery despite persistent functional limitations. Significant associations were observed between rehabilitation non-adherence and giving-way sensation at one month (p=0.004) and persistent knee pain at three months (p=0.016). However, these exploratory findings require cautious interpretation because only three participants were classified as non-adherent. The results suggest that structured home-based rehabilitation, supported by patient education, scheduled follow-up, and symptom-based clinical assessment, may represent a feasible component of early postoperative management for appropriately selected patients. Nevertheless, the absence of a supervised physiotherapy comparison group prevents conclusions regarding the superiority or equivalence of home-based rehabilitation. The small sample size, short follow-up duration, and lack of objective functional assessments further limit generalisability. Larger controlled studies with longer follow-up are required to establish comparative effectiveness, long-term functional outcomes, and optimal rehabilitation strategies following ACLR.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Institutional Ethics Committee of Atal Bihari Vajpayee Institute of Medical Sciences and Dr. Ram Manohar Lohia Hospital issued approval TP (MD/MS) 108/2022/IEC/ABVIMS/RMLH/1274. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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