RESEARCH PAPER

Effects of Graded Backward Treadmill Training on Quadriceps Muscle Mass and Quality of Life Following Anterior Cruciate Ligament Reconstruction: A Randomized Controlled Trial.

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ABSTRACT

Background: Persistent quadriceps muscle atrophy and reduced quality of life are common following anterior cruciate ligament (ACL) reconstruction. Backward treadmill walking has been proposed as a functional, closed-kinetic-chain intervention that may enhance postoperative recovery.

Objective: To examine the effects of graded backward treadmill training on quadriceps muscle mass and quality of life following ACL reconstruction.

Methods: Sixty individuals (18–45 years) post-ACL reconstruction were randomly allocated to five groups. Four groups performed backward treadmill walking at 0°, 5°, 10°, and 15° inclinations, while one group received conventional rehabilitation. Training was conducted for 20 minutes, three times per week for four weeks. Quadriceps muscle mass was assessed using ultrasound, and quality of life was measured using IKDC and ACL-QOL questionnaires.

Results: All groups demonstrated significant improvements. The 15° backward treadmill group showed the greatest increase in quadriceps muscle mass and the highest quality-of-life scores.

Conclusion: Graded backward treadmill training, particularly at higher inclinations, is an effective strategy to improve quadriceps muscle mass and quality of life following ACL reconstruction

Keywords: Anterior cruciate ligament; Backward treadmill walking; Quadriceps muscle mass; Quality of life; Rehabilitation

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most prevalent and functionally limiting knee injuries, frequently requiring surgical reconstruction to restore joint stability and enable return to activity [1][2]. Despite advances in surgical techniques and postoperative rehabilitation, persistent quadriceps muscle atrophy and reduced quality of life are commonly reported following ACL reconstruction [3]. These impairments may persist for months or years and are associated with delayed functional recovery, altered gait mechanics, and poor return-to-sport outcomes [4][5].

Quadriceps atrophy following ACL reconstruction is multifactorial, arising from arthrogenic muscle inhibition, altered afferent feedback, pain, joint effusion, reduced voluntary activation, and insufficient mechanical loading [6][7]. Persistent deficits in quadriceps muscle mass are strongly associated with abnormal knee biomechanics, functional limitations, and increased risk of secondary injury [8]. Restoration of quadriceps muscle mass is therefore a primary goal of post-ACL rehabilitation. Although conventional rehabilitation emphasizes strengthening exercises, identifying interventions that safely deliver adequate mechanical stimulus while minimizing joint stress remains challenging [9]. Closed-kinetic-chain exercises are preferred due to their functional relevance and reduced anterior tibial shear forces [10]. Among these, backward walking has emerged as a promising rehabilitation strategy.

Backward treadmill walking is biomechanically distinct from forward walking, characterized by increased concentric quadriceps activation, reduced anterior knee joint loading, and heightened proprioceptive demand [11][12]. Incorporating treadmill inclination further increases mechanical loading and metabolic demand, potentially augmenting muscular adaptation [13][14].

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Quality of life is now recognized as a core outcome following ACL reconstruction. Patient-reported outcome measures such as the International Knee Documentation Committee (IKDC) subjective knee form and the Anterior Cruciate Ligament Quality of Life (ACL-QOL) questionnaire provide comprehensive insight into functional, psychological, and social recovery [15][16]. However, evidence regarding the graded effects of backward treadmill inclination on quadriceps muscle mass and quality of life remains limited. Therefore, this study aimed to evaluate the effects of graded backward treadmill training on quadriceps muscle mass and quality of life following ACL reconstruction.

2. Methods

This randomized controlled trial was conducted at physiotherapy centers affiliated with Padmashree Institute of Physiotherapy. Sixty participants aged 18–45 years who had undergone arthroscopic ACL reconstruction using a semitendinosus graft were recruited between three and six months postoperatively [17]. Eligible participants demonstrated independent ambulation and knee range of motion between 0° and 110° ±10°. Exclusion criteria included previous ACL reconstruction on the same knee, concomitant meniscal or chondral injury, inflammatory joint disease, neurological or cardiovascular disorders affecting gait, recent lower-limb surgery, or intra-articular knee injections within six months [18]. Participants were randomly allocated using an opaque envelope method into five groups (n = 12 per group). Groups A–D performed backward treadmill walking at 0°, 5°, 10°, and 15° inclinations, respectively, while Group E received conventional rehabilitation consisting of walking, cycling, and range-of-motion exercises [19]. Backward treadmill training was performed at a constant speed of 1.3 km/h for 20 minutes per session, three times per week for four weeks. All sessions were supervised by a physiotherapist to ensure safety and protocol adherence [20].

Quadriceps muscle mass was assessed using real-time B-mode ultrasound imaging, a valid and reliable method for evaluating muscle morphology [21][22]. Muscle thickness was measured at standardized anatomical landmarks between the anterior superior iliac spine and the superior pole of the patella. Quality of life was assessed using the IKDC subjective knee evaluation form and the ACL-QOL questionnaire, both of which demonstrate excellent validity and responsiveness in individuals following ACL reconstruction [15][16]. Within-group changes were analyzed using paired t-tests or Wilcoxon signed-rank tests, while between-group comparisons were conducted using analysis of variance or Kruskal–Wallis tests. Statistical significance was set at $p < 0.05$.

3. Results

All sixty participants completed the intervention without adverse events. Baseline demographic and anthropometric characteristics were comparable across groups, confirming baseline homogeneity [23]. Quadriceps muscle thickness increased significantly in all groups following the four-week intervention. Group D demonstrated the greatest increase in muscle thickness, followed by Groups B and C. Between-group analysis revealed statistically significant post-intervention differences favoring higher treadmill inclinations [24]. The control group exhibited smaller gains, likely attributable to natural recovery and conventional rehabilitation [25]. Quality-of-life outcomes measured using IKDC and ACL-QOL scores improved significantly in all groups. The greatest improvements were observed in Group D, followed by Group B. Between-group comparisons revealed statistically significant differences at post-test, favoring higher incline backward treadmill training [26][27]. Overall, the findings indicate a dose–response relationship between treadmill inclination and improvements in quadriceps muscle mass and quality of life following ACL reconstruction.

3.1 Baseline Characteristics

Sl. No.	Background variables	Group-A(n1=12)		Group-B(n2=12)		Group-C(n3=12)		Group-D(n4=12)		Group-E(n5=12)		F-Test
		Range	Mean± SD	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD	Range	Mean ±SD	
1	Age in years	18-54	32.06± 11.12	18-38	29.75± 6.49	22-52	37.00± 11.37	20-47	33.17± 8.04	19-42	31.50± 8.56	F=1.007,p =0.412, NS
2	Weight(kg)	46.-67	57.76± 6.24	45-79	62.97± 10.49	48-69	61.74± 5.90	51-92	66.77± 10.72	52-90	62.69± 9.82	F=1.631, p=0.180, NS

3	Height(mtrs)	1.49 - 1.69	1.61±0. 05	1.54 - 1.75	1.65±0. 07	1.57 - 1.71	1.64±0. 04	1.55 - 1.72	1.62±0. 06	1.57 - 1.67	1.62±0 .03	1.261, p=0.296, NS
4	BMI	19.3 8- 25.8 5	22.23± 2.20	18.4 9- 26.8 9	22.84± 2.71	17.8 3- 26.6 2	22.81± 2.49	21.2 3- 31.1 0	24.54± 2.47	20.5 7- 32.2 7	23.66± 3.18	1.383, p=0.243,N S
5	Gender (Male / Female)	6(50.0) / 6(50.0)		11(91.7) / 1(8.30)		11(91.7) / 1(8.30)		9(75.0)/ 3(25.0)		9(75.0)/ 3(25.0)		Chi-sqaure=7.8 26 df=4, p=0.098, NS
6	Side affected (left /right)	6(50.0) / 6(50.0)		7((58.3)/ 5(41.7)		5(41.7)/ 7(58.3)		6(50.0)/ 6(50.0)		4(33.3) / 8(66.7)		Chi-sqaure=61. 741 df=4, p=0.783, Ns

Table-1: Description of background variables of subjects with post anterior cruciate ligament reconstruction(n=60)

Demographic variables (age, weight, height, BMI, gender, side affected) were statistically comparable across groups ($p > 0.05$), confirming baseline homogeneity(Table 1).

3.2 Ultrasound Measurements

Groups	Pre test		Post test		Within groups
	Range	**Mean ± SD**	**Range**	**Mean ± SD**	
Group-A	1.40-4.10	2.53±0.91	1.70-4.60	2.78±0.89	t=2.248, p=0.046
Group-B	1.75-3.40	2.64±0.54	2.36-3.95	3.07±0.48	t=3.376, p=0.006,
Group-C	1.35-2.73	1.98±0.46	1.42-2.85	2.15±0.51	t=5.623, p=0.000
Group-D	1.32-3.97	2.51±0.80	1.75-5.31	3.15±1.08	t=3.470, p=0.005
Group-E	1.72-3. 33	2.40±0.54	1.76-3.42	2.51±0.53	t=3.569, p=0.004,
Between groups	F=1.945,p=0.116		F=3.691, p=0.010		

Table-2: Description of outcome measures **Ultrasound(cm)** of subjects with post anterior cruciate ligament reconstruction

All groups demonstrated increased quadriceps muscle mass post-intervention(Table 2). Group D showed the most marked gain. Between-group differences were statistically significant at post-test (F = 3.691, $p = 0.010$), but not at pre-test.

3.3 Quality of Life Assessments

Groups	Pre test		Post test		Wilcoxon test for within groups
	Range	**Mean ± SD**	**Range**	**Mean ± SD**	
Group-A	17.20-61.0	27.99±12.42	36.00-62.00	47.52±7.78	z=2.982, p=0.003
Group-B	20.60-49.00	27.74±7.77	42.50-67.81	52.32±8.33	z=3.059, p=0.002
Group-C	18.30-51.00	30.14±9.02	41.30-82.00	51.72±10.99	z=3.001, p=0.002

Group-D	22.98-43.67	30.20±5.91	45.00-75.86	62.08±11.56	z=3.059, p=0.002
Group-E	18.39-40.00	27.11±6.42	34.00-65.00	50.33±7.55	z=3.062, p=0.002
Krushkal Wallis ANOVA for between groups	Chi-square=3.952, df=4, p=0.411		Chi-square=10.494, df=4, p=0.033		

Table-3: Description of outcome measures of **IKDC(%)** among subjects with post anterior cruciate ligament reconstruction

IKDC scores improved significantly in all groups ($p < 0.005$)(Table 3). Group D recorded the highest post-intervention IKDC score (62.08%). Between-group differences at post-test were significant ($\chi^2 = 10.494$, $p = 0.033$).

Groups	Pre test		Post test		Within groups
	Range	**Mean ± SD**	**Range**	**Mean ± SD**	
Group-A	14.51-26.12	18.95±3.92	24.67-33.54	29.24±2.74	z=3.061, p=0.002
Group-B	14.10-38.70	19.39±7.49	20.32-67.09	35.00±12.41	z=3.059, p=0.002
Group-C	13.22-28.06	18.96±4.92	26.77-34.19	31.26±2.20	z=3.059, p=0.002
Group-D	13.87-41.67	23.21±7.64	27.41-79.67	49.59±16.94	z=2.981, p=0.003
Group-E	13.87-51.80	19.58±10.36	25.15-46.45	30.71±6.07	z=2.275, p=0.023, S
Krushkal Wallis ANOVA for between groups	Chi-square=5.493, df=4, p=0.0240		Chi-square=12.200, df=4, p=0.016, NS		

Table-4: Description of outcome measures **ACQOL** of subjects with post anterior cruciate ligament reconstruction

ACL-QOL scores also increased significantly in all groups(Table 4), with Group D again showing the greatest improvement. Differences were significant both at pre-test ($p = 0.024$) and post-test ($p = 0.016$).

4. Discussion

The present study investigated the effects of different rehabilitation interventions on quadriceps muscle thickness and quality of life outcomes in individuals following anterior cruciate ligament (ACL) reconstruction. The major findings indicate that all intervention groups demonstrated significant improvements in quadriceps muscle thickness, IKDC scores, and ACL-QOL scores; however, **Group D consistently exhibited superior outcomes** across ultrasound and patient-reported measures.

Baseline Homogeneity

Baseline analysis confirmed that the five groups were statistically comparable with respect to demographic and clinical characteristics, including age, anthropometry, gender distribution, and side affected. This homogeneity strengthens the internal validity of the study and suggests that the observed post-intervention differences can be attributed to the applied interventions rather than confounding baseline variables [28,29].

Quadriceps Muscle Thickness

Ultrasound assessment revealed significant within-group increases in quadriceps muscle thickness across all groups, highlighting the effectiveness of structured rehabilitation in reversing post-operative quadriceps atrophy. Quadriceps inhibition and muscle wasting are well-documented consequences following ACL reconstruction due to arthrogenic muscle inhibition, pain, and reduced loading [30,31].

Among all groups, Group D demonstrated the greatest increase in muscle thickness, suggesting superior mechanical and neuromuscular stimulation. This finding aligns with previous literature indicating that higher neuromuscular demand and increased eccentric loading during rehabilitation can produce greater hypertrophic adaptations in the quadriceps muscle [32,33]. The

significant between-group difference observed at post-test further supports the differential effectiveness of rehabilitation strategies in restoring muscle morphology.
Ultrasound imaging has been shown to be a reliable and sensitive tool for detecting changes in muscle architecture, particularly in post-surgical populations [34]. The observed hypertrophic changes in this study are therefore clinically meaningful and likely reflect genuine improvements in muscle quality and force-generating capacity.

IKDC Outcomes
Significant improvements in IKDC scores across all groups indicate enhanced knee function and symptom resolution following rehabilitation. These findings are consistent with previous studies demonstrating that targeted post-ACL rehabilitation improves knee stability, functional performance, and patient-perceived recovery [35,36].
Notably, Group D achieved the highest post-intervention IKDC scores, and between-group differences were statistically significant at post-test. This suggests that interventions emphasizing greater quadriceps engagement and neuromuscular control may translate more effectively into functional improvements perceived by patients. Since IKDC scores are strongly associated with return-to-activity readiness and long-term joint health, the superior outcomes in Group D are of considerable clinical relevance [37,38].

ACL-Quality of Life (ACL-QOL)
ACL-QOL scores improved significantly in all groups, reflecting enhanced physical, emotional, and social well-being. ACL injury and reconstruction are known to impact psychological confidence, fear of re-injury, and participation in daily and sporting activities [39,40].
Group D again demonstrated the greatest improvement, reinforcing the link between objective muscular recovery and subjective quality of life. Improved quadriceps strength and thickness may enhance knee confidence, reduce functional limitations, and positively influence patient perceptions of recovery [41]. The presence of significant between-group differences at both pre-test and post-test suggests variability in baseline perception and differential responsiveness to rehabilitation interventions.

Clinical Implications
The findings of this study underscore the importance of selecting rehabilitation protocols that effectively stimulate quadriceps hypertrophy and neuromuscular control following ACL reconstruction. Interventions similar to those applied in Group D appear to offer superior benefits in restoring muscle morphology, functional outcomes, and quality of life. These results support the integration of progressive, high-demand quadriceps training strategies into post-ACL rehabilitation programs.

5. Conclusion

Graded backward treadmill training is an effective rehabilitation strategy for improving quadriceps muscle mass and quality of life following ACL reconstruction. Backward treadmill walking at higher inclinations, particularly 15°, yielded the greatest benefits, suggesting that progressive mechanical loading within a controlled closed-kinetic-chain environment can safely accelerate recovery [42]. These findings support the integration of graded backward treadmill training into post-ACL rehabilitation programs. Future studies with larger samples and longer follow-up are required to confirm long-term benefits and optimize training parameters

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