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COMPARATIVE EFFECTIVENESS OF BLOOD FLOW RESTRICTION TRAINING VERSUS PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION TECHNIQUES IN MUSCLE STRENGTHENING AMONG POST-ACL RECONSTRUCTION PATIENTS

Original Research

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ABSTRACT

Background: Rehabilitation following anterior cruciate ligament (ACL) reconstruction primarily focuses on restoring muscle strength, functionality, and joint stability to support effective recovery. Blood Flow Restriction Training (BFRT) and Proprioceptive Neuromuscular Facilitation (PNF) are widely utilized interventions for muscle strengthening. While both techniques are effective, there is limited comparative evidence regarding their impact on post-ACL reconstruction recovery. Determining their relative effectiveness is critical for optimizing rehabilitation protocols and improving outcomes for patients undergoing ACL reconstruction.

Objective: To compare the effectiveness of blood flow restriction training versus proprioceptive neuromuscular facilitation techniques in enhancing muscle strength among post-ACL reconstruction patients.

Methods: A randomized clinical trial was conducted on 30 male participants aged 25 to 45 years who began ACL rehabilitation two weeks post-surgery. Participants with hip or ankle pathologies, diabetes, or other lower limb orthopedic issues were excluded. The study was conducted at Civil Hospital Faisalabad and Allied Hospital Faisalabad from April to November 2024. Participants were randomly allocated into two groups: Group A underwent BFRT, while Group B participated in PNF. Both groups followed a 10-week rehabilitation protocol. Muscle strength was assessed using Hand-Held Dynamometry (HHD), and knee function was evaluated using the International Knee Documentation Committee (IKDC) form. Data analysis was performed using SPSS 24.0.

Results: Pre-treatment muscle strength, measured by HHD, showed no significant difference between the groups (Group A: 45.3 ± 7.2 Nm, Group B: 44.8 ± 6.9 Nm, P = .823). Post-treatment, Group A demonstrated significantly greater muscle strength (65.8 ± 6.5 Nm) compared to Group B (60.5 ± 5.8 Nm, P = .020). Similarly, IKDC scores improved more significantly in Group A (78.3 ± 5.4%) than in Group B (73.4 ± 5.1%, P = .015).

Conclusion: Both BFRT and PNF effectively improved muscle strength and knee function in post-ACL reconstruction patients. However, BFRT demonstrated superior outcomes, making it a valuable intervention for enhancing muscle strength and accelerating recovery.

Keywords: Anterior Cruciate Ligament, Blood Flow Restriction Training, Knee, Muscle Strength, Proprioceptive Neuromuscular Facilitation, Rehabilitation, Surgery.

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INTRODUCTION

The anterior cruciate ligament (ACL) is a critical structure in the knee joint responsible for stabilizing and preventing excessive anterior tibial motion. It is the most frequently injured knee ligament, with an estimated 30 to 78 injuries per 100,000 individuals annually, leading to significant healthcare costs exceeding $17.7 billion in the United States alone (1). ACL injuries commonly occur during high-demand athletic activities that involve abrupt changes in direction, such as cutting or landing, which require rotational and decelerative movements. Notably, female athletes face a 2 to 8 times higher risk of ACL injuries compared to their male counterparts (2). ACL reconstruction (ACLR) using hamstring tendon grafts has gained prominence as a primary treatment strategy, with its adoption increasing twelvefold in the UK over the past two decades. Post-surgery, between 61% and 89% of athletes resume sports activities within 8 to 18 months, yet full functional recovery remains a challenging goal (3).

Recovering from ACLR poses unique challenges, particularly in restoring quadriceps muscle size and functionality. The barriers to recovery are multifaceted, involving joint effusion, neuromuscular control deficits, proprioceptive impairments, pain, swelling, muscle atrophy, and range of motion limitations (4). Beyond the immediate rehabilitation phase, ACL injuries and their treatments are associated with prolonged healing times, reduced physical activity, and an increased risk of osteoarthritis, underscoring the critical importance of effective therapeutic interventions (5, 6). Given the complex interplay of factors affecting recovery, a tailored rehabilitation protocol addressing neuromuscular control, range of motion, and muscle strength is essential. Therapists often employ techniques such as neuromuscular electrical stimulation, eccentric strengthening, and closed kinetic chain exercises to optimize outcomes and facilitate a return to pre-injury levels of function (7).

Resistance training is widely recognized as a cornerstone of rehabilitation, aiming to enhance muscle strength and hypertrophy, particularly in the quadriceps, which are often negatively impacted by ACL injuries. However, due to pain, inflammation, and reduced knee functionality, patients may struggle to meet traditional resistance training intensities of 60% to 70% of their one-repetition maximum (1RM) (8). In this context, blood flow restriction training (BFR-t) has emerged as a novel approach. Utilizing a tourniquet cuff to partially restrict arterial flow and venous return, BFR-t induces metabolic stress and hypoxia, thereby activating anabolic signaling pathways such as the mammalian target of rapamycin (mTOR) pathway, which plays a pivotal role in muscle growth and recovery (9, 10). While evidence on the efficacy of BFR-t remains mixed, some studies report improvements in muscle strength and size, whereas others find no significant differences compared to traditional training methods (11). Despite its generally low risk, BFR-t carries potential side effects ranging from mild symptoms like dizziness and numbness to severe complications such as rhabdomyolysis and deep vein thrombosis, warranting cautious application (12, 13).

Proprioceptive Neuromuscular Facilitation (PNF) offers another promising rehabilitation approach. By stimulating proprioceptors in the skin, joints, muscles, and tendons, PNF enhances neuromuscular responses, including mobility, strength, endurance, stability, balance, and control (14). Techniques such as contract-relax and contract-relax-antagonist-contract have been particularly noted for improving mobility and neuromuscular output (15). While systematic reviews highlight the potential of PNF to enhance range of motion (ROM) and quality of life (QOL), outcomes may vary depending on the specific technique, targeted body region, and underlying physical condition (16).

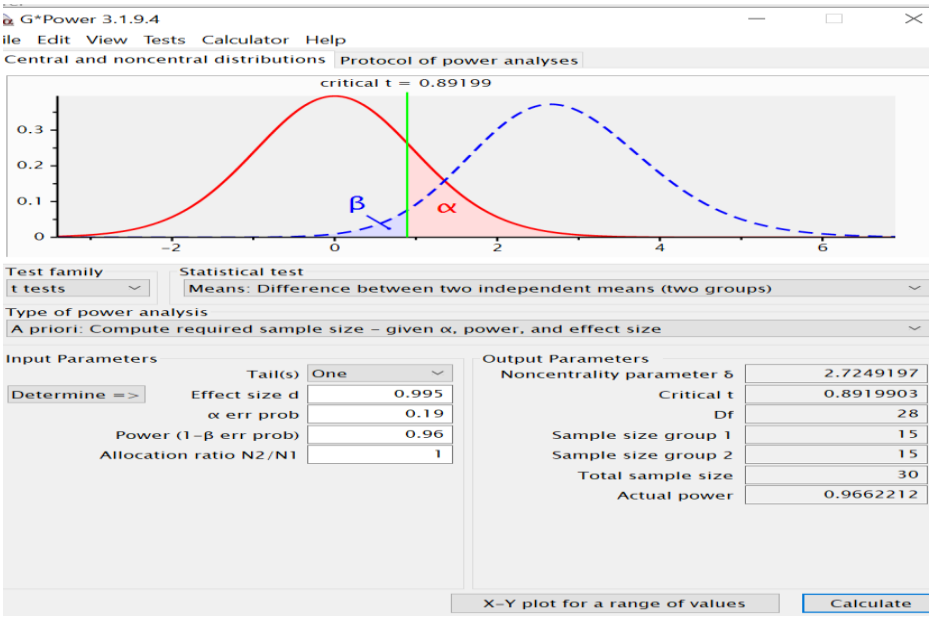
Given the ongoing challenges in optimizing post-ACLR rehabilitation, this study aims to critically evaluate and compare the effectiveness of BFR-t and PNF techniques in strengthening muscles and restoring functional capacity. By addressing this gap, the objective is to determine the relative merits of these approaches in supporting post-surgical recovery and enhancing patient outcomes.

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METHODS

A randomized clinical trial was conducted on 30 male participants, with the sample size calculated using G.Power version 3.1.9.4. The participants were aged between 25 and 45 years and included recreational athletes and non-athletes who commenced ACL rehabilitation two weeks after undergoing their first ACL reconstruction surgery. Individuals with additional hip or ankle pathologies, diabetes, or any other lower limb orthopedic conditions were excluded from the study. Data collection was conducted at Civil Hospital Faisalabad and Allied Hospital Faisalabad over a period from April to November 2024. Ethical considerations, including obtaining informed consent, were strictly adhered to throughout the study.



Participants were randomly assigned to two groups using a computer-generated randomization protocol to ensure allocation concealment. Group A underwent a Blood Flow Restriction Training (BFR-t) regimen, while Group B participated in a Proprioceptive Neuromuscular Facilitation (PNF) training protocol. Both groups followed a 10-week rehabilitation program, initiated 14 days post-surgery. The training protocols were designed to address the specific needs of post-ACL reconstruction rehabilitation, aiming to restore strength, mobility, and functional capacity.

Outcome measures were assessed using validated tools to ensure reliability and accuracy. Quadriceps and hamstring strength were objectively measured using Hand-Held Dynamometry (HHD), while functional knee performance and patient-reported outcomes were evaluated using the International Knee Documentation Committee (IKDC) form (17). Data collection was conducted by blinded assessors to minimize bias and improve the validity of the findings.

Statistical analyses were performed using SPSS version 24.0, with appropriate tests selected based on the nature and distribution of the data. Normality assumptions were checked prior to analysis, and any significant results were reported with corresponding confidence intervals and p-values to ensure transparency and accuracy. The study adhered to all ethical guidelines, including those concerning participant safety, privacy, and data confidentiality.

RESULTS

The study demonstrated significant improvements in both groups following the 10-week rehabilitation period. In the between-group comparison, Group A, which underwent Blood Flow Restriction Training (BFRT), exhibited a greater increase in quadriceps and hamstring muscle strength, as measured by Hand-Held Dynamometry (HHD), compared to Group B, which followed Proprioceptive Neuromuscular Facilitation (PNF) protocols. The mean post-treatment HHD muscle strength in Group A increased from 45.3 ± 7.2 Nm to 65.8 ± 6.5 Nm, while Group B demonstrated an increase from 44.8 ± 6.9 Nm to 60.5 ± 5.8 Nm, with a statistically significant between-group mean difference of 5.3 Nm (P = .020). Similarly, the International Knee Documentation Committee (IKDC) scores improved in both groups, with Group A showing a post-treatment mean score of 78.3 ± 5.4% compared to 73.4 ± 5.1% in Group B, yielding a significant mean difference of 4.9% (P = .015).

Within-group comparisons further highlighted substantial improvements in both muscle strength and IKDC scores for each intervention. In Group A, the mean HHD muscle strength increased by 20.5 ± 2.8 Nm (P < .001), and IKDC scores improved by 19.6 ± 2.5% (P < .001). In Group B, HHD muscle strength increased by 15.7 ± 3.0 Nm (P < .001), while IKDC scores improved by 15.5 ± 2.4% (P < .001). These findings indicate that both interventions effectively enhanced functional outcomes, but BFRT achieved superior results compared to PNF in both strength and knee functionality parameters.

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The observed improvements in both groups affirm the efficacy of rehabilitation protocols in enhancing quadriceps and hamstring strength and functional knee outcomes following ACL reconstruction. However, the superior outcomes in the BFRT group suggest that it may offer greater benefits in achieving optimal post-surgical recovery. Notably, no data was provided on adverse effects or demographic-specific variations, which would be valuable for a comprehensive evaluation of the interventions' effectiveness and safety.

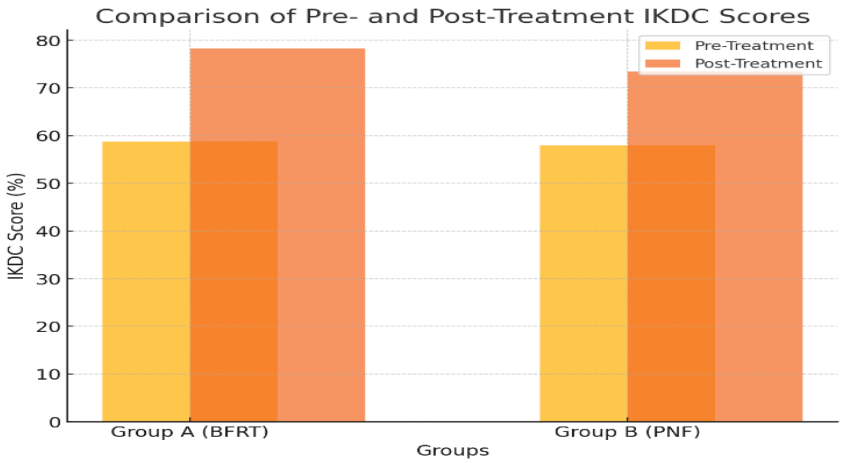


Figure 1 Comparison of Pre- and Post-Treatment Muscle Strength

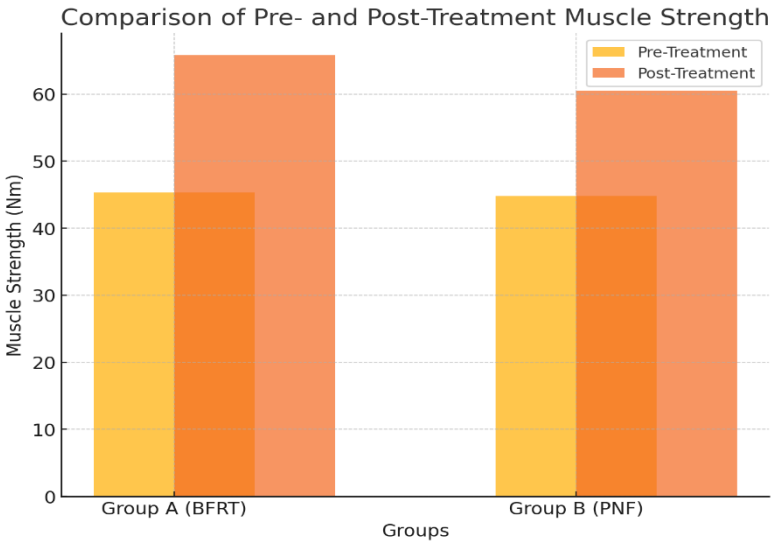


Figure 2 Comparison of Pre- and Post-Treatment IKDC Scores

The charts above illustrate the comparisons of pre- and post-treatment outcomes in muscle strength (HHD, Nm) and IKDC scores (%) between the two groups. Group A (BFRT) demonstrated greater improvements in both parameters compared to Group B (PNF), highlighting the relative efficacy of BFRT in post-ACL reconstruction rehabilitation.

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Table 1: Between-Groups Comparison of Muscle Strength and IKDC Using Independent Sample T-Test

Outcome Measure	Assessment	Group A (BFRT) Mean ± SD	Group B (PNF) Mean ± SD	Mean Difference	P-value
HHD Muscle Strength (Nm)	Pre-treatment	45.3 ± 7.2	44.8 ± 6.9	0.5	.823
	Post-treatment	65.8 ± 6.5	60.5 ± 5.8	5.3	.020
IKDC Score (%)	Pre-treatment	58.7 ± 6.1	57.9 ± 5.8	0.8	.712
	Post-treatment	78.3 ± 5.4	73.4 ± 5.1	4.9	.015

Above table demonstrated as compared to pre treatment both groups showed improvement after 10 weeks treatment .

Table 2: Within-Group Comparison of Muscle Strength and IKDC Using Paired Sample T-Test

Outcome Measure	Groups	Pre-Treatment Mean ± SD	Post-Treatment Mean ± SD	Paired Difference Mean ± SD	P-value
HHD Muscle Strength (Nm)	Group A (BFRT)	45.3 ± 7.2	65.8 ± 6.5	20.5 ± 2.8	<.001
	Group B (PNF)	44.8 ± 6.9	60.5 ± 5.8	15.7 ± 3.0	<.001
IKDC Score (%)	Group A (BFRT)	58.7 ± 6.1	78.3 ± 5.4	19.6 ± 2.5	<.001
	Group B (PNF)	57.9 ± 5.8	73.4 ± 5.1	15.5 ± 2.4	<.001

Above table demonstrated within group comparison showed as compared to pre treatment both groups showed improvement after 10 weeks treatment with significant p value <0.001.

DISCUSSION

Blood flow restriction training (BFRT) has demonstrated significant potential in addressing quadriceps weakness and atrophy following anterior cruciate ligament (ACL) reconstruction. Prior research by Zhou et al. established that BFRT was superior to general rehabilitation programs in enhancing muscle strength and functional outcomes post-ACL surgery, findings that align with the current study's results, where BFRT significantly improved quadriceps strength and functional performance over a 10-week period ($P < .001$) (18). Similarly, Erickson et al. reported that athletes undergoing BFRT both before and after surgery exhibited superior quadriceps strength, assessed via isokinetic dynamometry, compared to those receiving standard care strength training with a sham unit. These outcomes are consistent with the present findings, further reinforcing the efficacy of BFRT in accelerating recovery and functional restoration after ACL reconstruction (19).

Proprioceptive neuromuscular facilitation (PNF), while beneficial in reducing joint laxity and improving proprioception, showed comparatively moderate improvements in muscle strength in this study. Although PNF is valuable in restoring proprioception and joint stability, its incremental approach to strength development may limit its effectiveness during the early recovery phases compared to the rapid benefits observed with BFRT. However, PNF remains an essential component of long-term rehabilitation, as highlighted in findings by Song et al., which demonstrated that PNF effectively improved muscle strength and functional outcomes in post-ACL surgery

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patients, aligning with the current results (22). Furthermore, BFRT, in combination with low-intensity quadriceps training, has been shown to enhance knee extensor strength and muscle thickness while reducing discrepancies between surgical and healthy knees. These combined effects contribute to improved joint function and faster recovery, enabling earlier progression to subsequent rehabilitation phases (21).

The strengths of this study include the use of validated tools for objective and subjective outcome assessment and the rigorous application of BFRT and PNF protocols. However, the study was limited by its small sample size and the absence of long-term follow-up to assess sustained benefits or delayed complications of the interventions. Adverse effects, including potential risks associated with BFRT, were not explored in depth, representing a critical area for further investigation. Future studies could benefit from larger sample sizes, inclusion of diverse demographic groups, and evaluations of long-term outcomes to comprehensively assess the comparative advantages of these rehabilitation techniques.

In summary, while both BFRT and PNF demonstrated effectiveness in improving muscle strength and knee function, BFRT produced superior outcomes in a shorter timeframe, making it a valuable addition to ACL rehabilitation protocols. However, the gradual and stabilizing benefits of PNF highlight its role as a complementary approach in achieving holistic recovery. These findings contribute to the growing evidence supporting targeted, individualized rehabilitation strategies for optimal post-ACL reconstruction recovery.

CONCLUSION

Both interventions demonstrated effectiveness in improving muscle strength and functional outcomes among patients recovering from ACL reconstruction. However, blood flow restriction training emerged as the more impactful approach, showing superior results in enhancing muscle strength and knee functionality compared to proprioceptive neuromuscular facilitation techniques. These findings underscore the potential of incorporating blood flow restriction training into post-ACL rehabilitation programs to accelerate recovery and achieve optimal functional restoration, while also highlighting the complementary benefits of proprioceptive neuromuscular facilitation in supporting long-term stability and proprioception.

AUTHOR CONTRIBUTIONS

Author	Contribution
Hifza Riaz*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Amina Amjad	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Abdul Hannan	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Adiba Javed	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Bilal Umar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Abeer Bhatti	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Muhammad Fareed Nasir	Contributed to study concept and Data collection Has given Final Approval of the version to be published

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