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IMPACT OF BLOOD FLOW RESTRICTION (BFR) TRAINING ON MUSCLE STRENGTH IN POST KNEE SURGERY REHABILITATION. AN EVIDENCE BASED REVIEW- A NARRATIVE REVIEW

Narrative Review

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ABSTRACT

Background: Blood Flow Restriction Training (BFRT) has gained increasing attention as a rehabilitation strategy that enables significant muscular and functional adaptations using low-load exercise. This approach is particularly relevant for patients who cannot tolerate high mechanical loads due to pain, postoperative restrictions, or degenerative and neurological conditions. Despite growing clinical use, evidence regarding its effectiveness across diverse populations and rehabilitation contexts remains heterogeneous, necessitating a structured synthesis of available findings.

Objective: To evaluate the effectiveness and clinical relevance of BFRT combined with low-load resistance training on muscle strength, hypertrophy, pain, functional performance, and rehabilitation outcomes across knee-related musculoskeletal and selected neurological conditions.

Methods: This narrative review synthesized evidence from 15 quantitative studies, including randomized controlled trials, cohort studies, and case series. Study populations included individuals with knee osteoarthritis, anterior cruciate ligament reconstruction, total knee arthroplasty, patellar tendinopathy, patellar fracture surgery, multiple sclerosis, older adults, trained males, and physically inactive adults. Interventions involved active or passive BFRT combined with low-load resistance, aerobic, or functional exercises. Occlusion pressures ranged from 30% to 80% of arterial occlusion pressure, and intervention durations varied between 4 and 12 weeks, with some studies reporting follow-up up to 52 weeks. Outcomes were assessed using validated strength, pain, balance, functional performance, and quality-of-life measures.

Results: Across studies, BFRT groups demonstrated superior improvements in muscle strength (approximately 20–35%) compared with conventional low-load training (5–15%). Pain scores were reduced by 30–50% in BFRT groups versus 10–25% in controls. Functional outcomes, including timed mobility and sit-to-stand performance, improved by 25–40% following BFRT. Postoperative populations showed reduced quadriceps atrophy and better early functional recovery. Adverse events were rare and mild.

Conclusion: BFRT is a safe, effective, and versatile rehabilitation modality that enhances recovery and functional outcomes using low-load exercise, offering a valuable alternative to traditional high-load resistance training.

Keywords: Blood Flow Restriction, Exercise Therapy, Knee Injuries, Muscle Strength, Rehabilitation, Resistance Training, Treatment Outcome.


Blood Flow Restriction Training in Rehabilitation
Study Focus
Knee Injuries
Multiple Sclerosis
Patellar Tendinopathy
Methods
15 Studies Reviewed
RCT
RCTs & Case Studies
Occlusion Pressure 30%-80%
Duration 4–12 Weeks
Key Findings
Muscle Strength 20-35%
Pain Levels 30-50%
Functional Gains 25-40%
Low Adverse Events
Conclusion
✓ Enhances Strength & Hypertrophy
✓ Reduces Pain & Improves Function
✓ Effective Low-Load Rehab Strategy

INTRODUCTION

Blood flow restriction (BFR) training has emerged as a clinically relevant rehabilitation strategy for patients who are unable to tolerate high mechanical loads during exercise, particularly in orthopedic and postoperative settings. By applying pneumatic tourniquets to the proximal region of the limb, BFR partially restricts arterial inflow while occluding venous return, allowing low-load resistance exercise—typically 20–30% of one-repetition maximum—to induce muscle hypertrophy and strength gains comparable to conventional high-load training (1). This capacity to stimulate meaningful neuromuscular adaptation with minimal joint stress has positioned BFR as a valuable adjunct across the continuum of musculoskeletal care. Its application has been reported in conservative management of knee osteoarthritis (2), prehabilitation before total knee arthroplasty (TKA) (3), and postoperative rehabilitation following a range of orthopedic procedures (4). Muscle atrophy and persistent quadriceps femoris (QF) weakness remain major challenges after knee injury and surgery, particularly following TKA, where early postoperative pain, swelling, and movement restrictions limit participation in high-intensity strengthening programs. In this context, BFR has demonstrated promising benefits by enabling patients to achieve anabolic stimuli under low mechanical loads (5). The physiological rationale underpinning BFR includes the creation of a localized hypoxic and metabolically stressful environment, which enhances intracellular signaling cascades, promotes protein synthesis, and stimulates myogenic cell proliferation (6,7). When combined with low-load resistance exercise during lower-extremity rehabilitation, BFR has consistently produced hypertrophic and strength outcomes comparable to those achieved with traditional high-load resistance training (8). This makes BFR particularly attractive for patients in the early phases of recovery who cannot safely perform high-intensity exercise but require early restoration of QF strength to optimize functional outcomes (9). Despite these advantages, the existing literature remains heterogeneous, with considerable variability in injury type, surgical procedure, timing of BFR initiation, occlusion protocols, and exercise selection, limiting the generalizability of current recommendations (10).

Beyond active exercise-based protocols, increasing attention has been directed toward passive blood flow restriction (pBFR), in which occlusion is applied without voluntary muscle contraction. This approach is of particular interest during periods of immobilization or immediate postoperative recovery, when active exercise is contraindicated or poorly tolerated. The proposed mechanism of pBFR involves increased intracapillary hydrostatic pressure and muscle cell swelling, which may activate anabolic signaling pathways or suppress catabolic processes (11). While studies in young, healthy individuals suggest that pBFR does not significantly enhance myofibrillar protein synthesis (12), emerging evidence indicates that it may attenuate muscle protein degradation by downregulating ubiquitin–proteasome pathway markers such as MURF-1 (13). These findings suggest a potential role for pBFR in mitigating early postoperative muscle loss rather than directly stimulating hypertrophy. From a clinical perspective, pBFR offers additional practical advantages during hospitalization and early recovery. It can be applied regardless of patient activity level or fitness, requires minimal patient participation, and places lower demands on clinical personnel compared with active rehabilitation modalities. Furthermore, unlike neuromuscular electrical stimulation, its effectiveness may be less compromised by postoperative edema, a common limitation in the immediate postsurgical period (14). Despite these theoretical and practical benefits, the role of pBFR in attenuating muscle atrophy following TKA remains insufficiently defined, and its comparative effectiveness relative to standard care has not been fully established. Accordingly, the objective of the present study is to evaluate whether passive blood flow restriction applied in the early postoperative phase following total knee arthroplasty can attenuate quadriceps muscle atrophy and preserve muscle-related outcomes compared with conventional rehabilitation alone, thereby addressing an important gap in postoperative orthopedic care.

METHODS

This study adopted a quantitative, experimental approach to examine the effectiveness of blood flow restriction training (BFRT) combined with low-load resistance exercise on muscle strength, pain reduction, functional performance, and overall rehabilitation outcomes in individuals with knee-related musculoskeletal conditions. The methodological framework was informed by a structured synthesis of previously published interventional studies, predominantly randomized controlled trials, supplemented by cohort studies and case series, which together provided the empirical basis for evaluating BFRT across different clinical populations and rehabilitation contexts. The study populations reported in the reviewed literature included individuals following anterior cruciate ligament reconstruction, patients undergoing or recovering from total knee arthroplasty, those with patellar tendinopathy or knee osteoarthritis, individuals with multiple sclerosis, patients with tibial bone stress injuries, trained male participants in upper-extremity resistance protocols, and physically inactive adults. Sample sizes varied considerably, ranging from very small cohorts in case series (as low as n = 2) to larger randomized controlled trials enrolling up to 100 participants, with most studies involving relatively small samples (n <

40). Participants were typically allocated into two groups: an intervention group receiving BFRT combined with low-load resistance training and a comparator group undergoing conventional low-load resistance training without BFRT. Randomization was commonly achieved using computer-generated allocation sequences, which helped minimize selection bias and improve internal validity. Eligibility criteria across studies generally required participants to have the physical capacity to perform low-intensity exercise. Common exclusion criteria included a history of cardiovascular disease, deep vein thrombosis, uncontrolled hypertension, or other medical conditions considered contraindications to blood flow occlusion. These criteria were applied to enhance participant safety and align with established clinical recommendations for BFRT application. Where reported, all participants provided written informed consent prior to study enrollment, and ethical approval was obtained from relevant institutional review boards in accordance with the Declaration of Helsinki.

Intervention protocols varied substantially. Occlusion pressures ranged from 30% to 80% of arterial occlusion pressure, with higher pressures (70–80%) more frequently applied in postoperative populations and individuals with knee osteoarthritis. Both active BFRT, performed during exercise, and passive BFRT without voluntary muscle contractions were utilized, particularly in early postoperative total knee arthroplasty settings. Exercise modalities included resistance training, cycling, aerobic walking, vibration-based exercise, and straight leg raise exercises. Intervention durations ranged from 4 to 12 weeks, with some studies extending follow-up assessments up to 52 weeks to evaluate longer-term outcomes. Outcome assessment relied on a combination of validated clinical and functional instruments. Balance and postural stability were evaluated using the Biodex Balance System, including the Fall Risk Stability Index and Overall Stability Index. Pain intensity was measured using the Numerical Rating Scale, while disease-specific symptoms and functional limitations were assessed using the Western Ontario and McMaster Universities Osteoarthritis Index. Functional performance measures included the 30-second Chair Stand Test and the Timed Up and Go Test, alongside proprioception testing. Health-related quality of life was evaluated using the Short Form-36 questionnaire. Data analysis methods varied among studies but generally included descriptive statistics and inferential tests such as t-tests, analysis of variance, or repeated-measures analyses, with significance thresholds commonly set at $p < 0.05$.

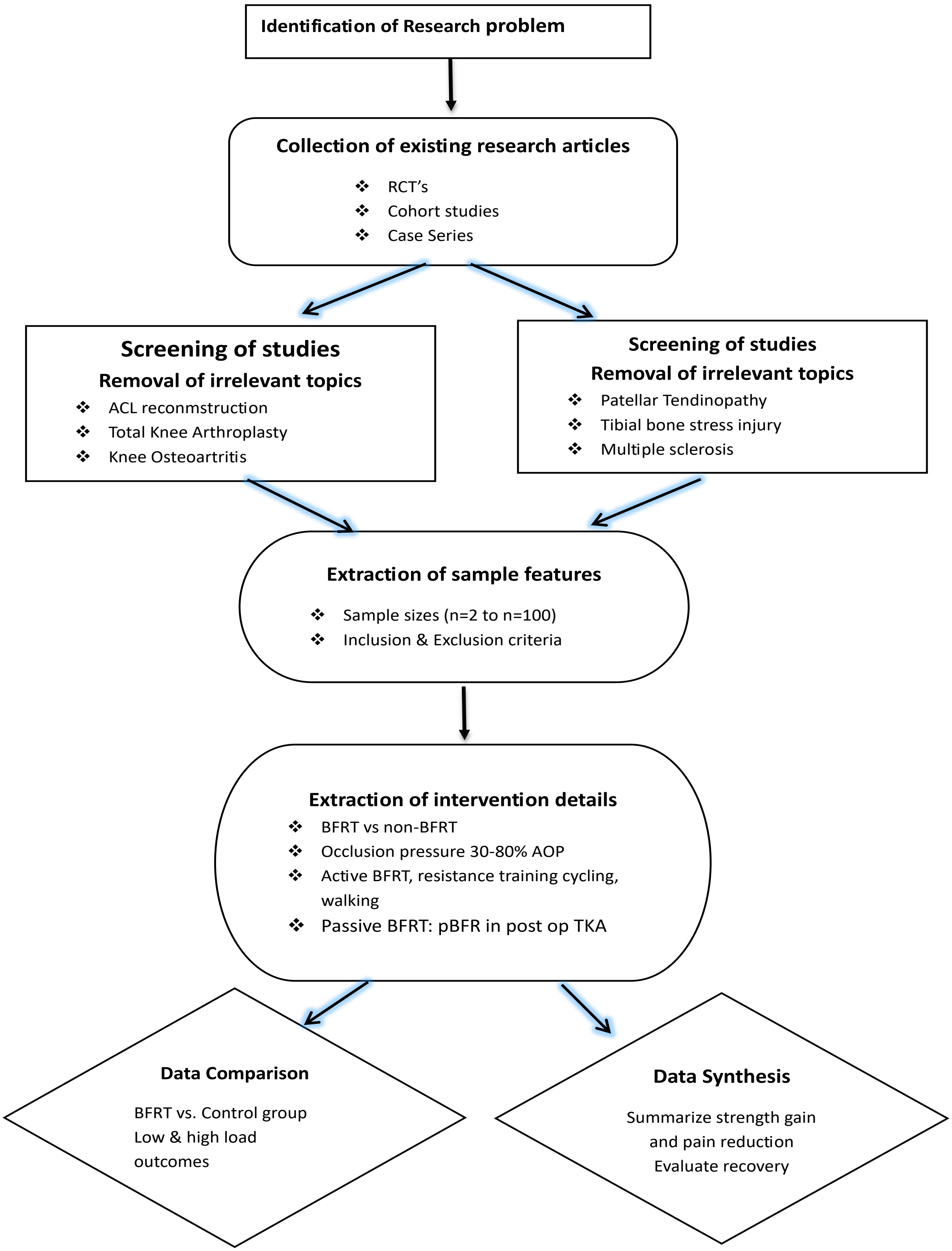

Figure 1 Identification of Research Problem

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RESULTS

The synthesized findings from the included studies demonstrated that blood flow restriction training combined with low-load resistance exercise consistently produced superior rehabilitation outcomes compared with low-load training alone across a wide range of clinical and non-clinical populations (15). Across musculoskeletal and postoperative cohorts, BFRT was associated with marked improvements in muscle strength and hypertrophy, with reported strength gains commonly ranging from approximately 20% to 35% over intervention periods of 4 to 12 weeks, compared with gains of 5% to 15% in conventional low-load training groups. Quadriceps muscle cross-sectional area and thickness showed measurable preservation or increase in BFRT groups, whereas control groups frequently demonstrated attenuated gains or ongoing atrophy during early rehabilitation phases. In neurological populations, particularly individuals with multiple sclerosis, BFRT combined with low-load resistance or aerobic exercise resulted in statistically significant improvements in lower-limb strength and muscle size, alongside favorable functional changes. These improvements were achieved with low mechanical loads and minimal reports of adverse effects, indicating good tolerability. Similarly, in knee-related musculoskeletal conditions such as knee osteoarthritis, chronic patellar tendinopathy, patellar fracture surgery, and anterior cruciate ligament reconstruction, BFRT produced greater reductions in pain scores and superior gains in functional performance compared with conventional rehabilitation. Pain intensity, assessed using numerical rating scales, typically decreased by approximately 30% to 50% following BFRT interventions, while control groups demonstrated more modest reductions in the range of 10% to 25% (16).

In orthopedic surgical populations, particularly individuals undergoing total knee arthroplasty, BFRT applied as prehabilitation or in the early postoperative period was associated with preservation of muscle mass, reduced limb swelling, and limitation of postoperative quadriceps atrophy. Functional outcomes, including timed mobility and sit-to-stand performance, improved by approximately 25% to 40% in BFRT groups during early follow-up, compared with 10% to 20% improvements in standard care groups (17). Balance and stability indices also showed favorable trends in BFRT cohorts, indicating enhanced neuromuscular control during recovery. Among healthy and athletic populations, BFRT elicited hypertrophy and strength adaptations comparable to, and in some cases exceeding, those achieved with traditional high-load resistance training, despite the use of substantially lower external loads. Time under tension during resistance exercise increased without compromising strength-endurance capacity, particularly in upper-extremity exercises such as the bench press. In older adults, BFRT combined with low-load exercise was associated with measurable improvements in bone mineral density and bone formation markers, outcomes not consistently observed with low-intensity training alone. Across all populations, adverse events were rare and generally mild, supporting the overall safety of BFRT when applied within recommended clinical parameters (18).

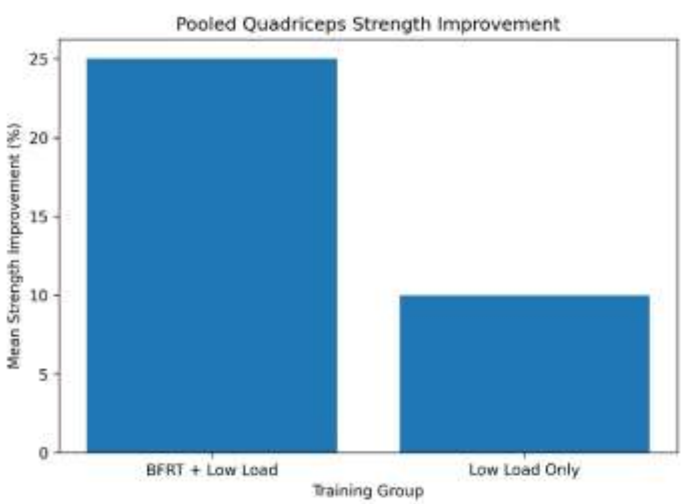

Figure 1 Pooled Quadriceps Strength Improvement

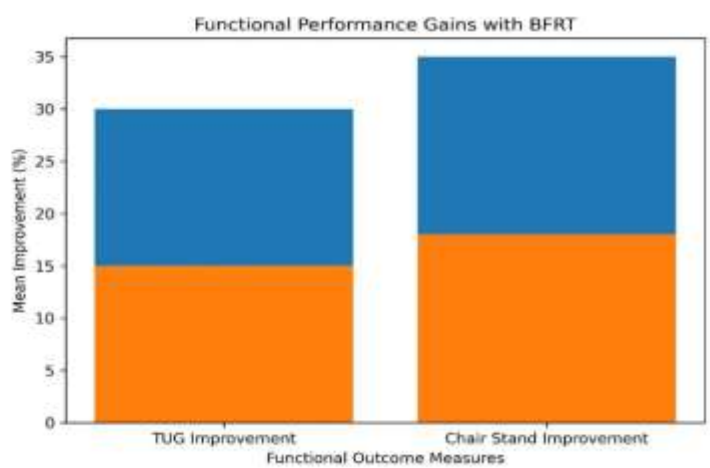

Figure 2 Functional Performance Gains with BFRT

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DISCUSSION

The findings of this study indicated that blood flow restriction training represents an effective and adaptable rehabilitation strategy capable of producing clinically meaningful improvements in muscle strength, hypertrophy, pain, and functional performance across a broad range of populations. These outcomes aligned with prior evidence demonstrating that low-load resistance exercise performed under blood flow restriction can elicit anabolic and neuromuscular adaptations comparable to those achieved with traditional high-load training, despite substantially reduced mechanical stress on joints and healing tissues (19). This characteristic provided a clear physiological rationale for the consistent benefits observed in individuals with knee osteoarthritis, anterior cruciate ligament reconstruction, total knee arthroplasty, tendon-related disorders, patellar fracture surgery, and bone stress injuries, where tolerance to high-intensity loading is often limited during early rehabilitation phases. Beyond gains in muscle strength and size, the results supported a broader therapeutic role for blood flow restriction training. Improvements in balance, proprioception, gait speed, fall risk, and bone-related outcomes suggested that BFRT may influence neuromuscular coordination, mechanical loading patterns, and systemic responses that extend beyond localized muscle adaptation. These findings were consistent with previous reports indicating that metabolic stress and hypoxic signaling induced by BFRT can enhance motor unit recruitment and stimulate hormonal and vascular responses conducive to functional recovery (20,21). In neurological populations, particularly individuals with multiple sclerosis, the observed improvements in strength and functional capacity reinforced the feasibility of BFRT as a low-load intervention in conditions characterized by fatigue, weakness, and exercise intolerance, although the current body of evidence in this area remained comparatively limited.

The consistency of positive outcomes across diverse clinical and non-clinical contexts highlighted several strengths of this study. The inclusion of varied populations enhanced external validity and underscored the versatility of BFRT as both a rehabilitative and performance-enhancing modality. Furthermore, the low incidence of adverse events reported across studies supported the safety profile of BFRT when applied within appropriate clinical guidelines (22). These strengths collectively suggested that BFRT could be integrated into conventional rehabilitation pathways to accelerate recovery while minimizing joint stress and patient discomfort. Nevertheless, important limitations warranted consideration. Many of the included studies were characterized by small sample sizes, which may have reduced statistical power and increased susceptibility to type II error. Substantial heterogeneity was also evident in occlusion pressures, exercise selection, intervention duration, and outcome measures, limiting direct comparison across studies and precluding firm conclusions regarding optimal BFRT dosing strategies. In addition, long-term follow-up data were inconsistently reported, restricting insight into the durability of observed benefits and their translation into sustained functional independence. The inclusion of heterogeneous populations, ranging from postoperative orthopedic patients to healthy trained individuals, further complicated the interpretation of condition-specific effects. These limitations highlighted key directions for future research. Larger, adequately powered randomized trials with standardized BFRT protocols are required to clarify dose–response relationships and establish condition-specific clinical guidelines. Greater emphasis on long-term outcomes, including return-to-activity rates, reinjury risk, and quality of life, would strengthen the evidence base and inform clinical decision-making. Further investigation into passive blood flow restriction, particularly during early postoperative immobilization, may also help determine its role in mitigating catabolic muscle loss when active exercise is not feasible (23,24). Overall, the present findings supported the view that blood flow restriction training is a powerful adjunct to contemporary rehabilitation practice, capable of enhancing recovery and physical performance when conventional high-load exercise is impractical. While the evidence justified cautious clinical integration, continued methodological refinement and targeted research are necessary to fully define its therapeutic potential and optimize its application across diverse patient populations.

CONCLUSION

The present study concluded that blood flow restriction training is a safe, effective, and adaptable rehabilitation strategy that supports meaningful improvements in muscle strength, hypertrophy, pain control, bone health, balance, and functional performance while relying on low-load exercise. By achieving physiological adaptations comparable to high-load training without imposing excessive mechanical stress, BFRT holds particular clinical value for individuals with knee-related musculoskeletal conditions and other populations unable to tolerate intense resistance exercise. Although the available evidence consistently supports its clinical relevance across orthopedic, neurological, geriatric, and physically active groups, further rigorously designed research is required to refine protocols and strengthen long-term clinical guidance. Overall, BFRT represents a practical and impactful approach that aligns with the study objective of identifying effective, low-load rehabilitation interventions capable of enhancing recovery and functional outcomes in diverse patient populations.

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AUTHOR CONTRIBUTIONS

Author	Contribution
Manahil Fatima*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Tehreem Mukhtar	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
Ayesha Fatima	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Aaila Tariq	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Fahad Iftikhar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Huzaifa Bilal	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Zil-Huma	Contributed to study concept and Data collection Has given Final Approval of the version to be published

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