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# Effect of Blood Flow Restricted Resistance Training on Peak Lower Body Strength

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**Abstract: Blood flow restriction (BFR) training uses partial vascular occlusion alongside reduced mechanical loading to stimulate muscular adaptations. The present study compared between the effect of blood flow restricted resistance training (BFRRT) and conventional resistance training on peak lower body strength in sixty healthy young males aged 18-26 years. Participants were allocated to experimental (BFR) and control groups (conventional) (n=30 each). Both groups performed identical four-week squat-based training comprising of three sessions/week for four weeks. Peak lower body strength assessment was done using one-repetition maximum at baseline and post-intervention. Statistical evaluation was done using paired and unpaired t-tests for intra-group and inter-group comparisons. Significant strength improvements were noticed in both training groups. In BFR group, peak lower body strength increased from 88.17 ± 9.60 kg to 95.33 ± 10.74 kg. In control group, it improved from 90.17 ± 9.33 kg to 96.50 ± 9.75 kg ($p < 0.001$). Inter-group comparison revealed no significant difference in post-training strength outcomes ($p = 0.661$), despite numerically superior gains in the blood flow restriction group. Both BFR and conventional resistance training produced substantial peak lower body strength enhancement. Although blood flow restriction training yielded marginally greater absolute improvements, statistical equivalence between protocols suggests comparable efficacy.**

**Keywords: Arterial occlusion pressure, Blood flow restriction, Resistance training, Squat training, Strength.**

## I. Introduction

Blood flow restricted resistance training (BFRRT) is an innovative technique that combines low-load resistance exercise (20-50% of 1RM) with proximal limb vascular occlusion to elicit strength and hypertrophic gains similar to those achieved with traditional heavy-load protocols utilizing 65–85% of 1RM, while minimizing mechanical stress on joints [1]. The technique originated in 1966, following Dr. Yoshiaki Sato's personal observation of muscle pump in his lower legs while sitting in the traditional seiza position during meditation, leading to self-experiments and the development of the KAATSU system [1]. Formal scientific inquiry began in the 1990s, that eventually resulted in publication of methodological and safety guidelines for BFRRT exercise [1].

BFRRT involves a pneumatic cuff inflated to 40–80% of individual limb occlusion pressure that restricts venous outflow and partially limits arterial inflow, creating a localized hypoxic and metabolite-rich environment thus accelerating anabolic signalling despite low mechanical loads [2]. Optimal protocols for lower limb BFR training typically includes four sets following a 30-15-15-15 repetition scheme with inter-set rest intervals of 30–60 seconds, executed 2–3 sessions weekly across a 4–6 week training period [1]. Cuff pressures are individualized using Doppler ultrasound or plethysmography to determine arterial occlusion pressure, ensuring safety and efficacy [2]. This standardized approach maximizes strength gains while minimizing discomfort and adverse events. Peak lower body strength is most assessed via 1RM squat testing and isokinetic knee torque measurements. A meta-analysis of 20 clinical rehabilitation studies reported a moderate effect size (Hedges' $g = 0.52$) for strength improvements when utilizing BFR training at low intensities versus conventional low-intensity training without vascular occlusion, though slightly lower than heavy-load training (Hedges' $g = 0.67$) [3]. In athletic populations, low-load BFRRT interventions have yielded squat 1RM increase of 8–30% over 2–6 weeks, similar to gains from high-intensity protocols when pressure and volume are properly prescribed [4].

Clinically, BFRRT is especially valuable for populations unable to tolerate high mechanical loads, such as postoperative patients recovering from anterior cruciate ligament surgical repair or total knee replacement procedures, aging individuals susceptible to sarcopenic decline, and individuals with cardiac or orthopaedic limitations [3]. By mitigating disuse atrophy and accelerating strength recovery, BFRRT supports rehabilitation while preserving joint integrity and reducing injury risk. While BFR exhibits a favourable safety profile, transient discomfort, post-exercise muscle soreness with delayed manifestation, with isolated instances of exercise-induced rhabdomyolysis have been reported when protocols are misapplied [2]. Absolute contraindications include peripheral vascular disease and coagulation disorders; relative contraindications (e.g., uncontrolled hypertension, sickle cell trait) require medical clearance and careful pressure titration [2]. However, despite its growing popularity, the specific effects of BFRRT on peak lower body strength remain underexplored, with limited studies directly addressing this targeted outcome. Thus, the present study compared BFRRT versus conventional resistance training on peak lower body strength in healthy young males.

## II. Methodology

The present study followed an experimental study design. Before enrolling, all participants provided written informed consent after being thoroughly briefed on potential risks and instructed to promptly report any issues to the research team. The Institutional Ethics Committee of the School of Medical Sciences and & Sharda Hospital (Ref. No. SU/SMS&R/76-A/2022/238) approved the study.

### *Participants*

Sixty Indian male participants aged 18–26 years, each possessing a minimum of 12 months of structured resistance exercise background but no squat training in the past month, were enrolled. Individuals were excluded if they had sustained any recent or ongoing musculoskeletal injury during the preceding three-month period or if they had cardiovascular, musculoskeletal and neurological conditions [5, 6].

### *Procedure*

Based on selection criteria, participants were equally distributed into either the experimental or control group (30 per group) that received BFRRT and conventional resistance training respectively. A comprehensive clinical risk evaluation was conducted using a standardized assessment instrument [5]. Intervention equipments comprised 10 cm wide blood flow restriction cuffs, a squat rack, a 20 kg barbell with weight, and a portable ultrasound vascular doppler device. Lower body peak strength was determined via a one-repetition maximum (1RM) squat test. Both the experimental and control groups completed a four-week resistance training program consisting of three squat sessions per week. The experimental group performed weighted squat workouts with the addition of the BFR protocol adopted from established guidelines in the literature [1] (Table I).

Table I: BFR Protocol for Experimental Group

| *BFR Site* | *Restriction Pressure* | *Frequency* | *Intensity* | *BFR Time* | *Repetitions* | *Sets* | *Exercise Type* |
|---|---|---|---|---|---|---|---|
| Lower Limb (Bilateral) | 60 to 80% of Arterial Occlusion Pressure (AOP) | 3 days per week | 20% to 40% of 1 RM | 5–10 min per exercise | 30 x 15 x 15 x 15 | 2 to 4 | Weighted Squats |

The control group performed the training protocol identical in volume and movement patterns to the BFR group, with the sole exception of cuff application. For those in the BFR group, cuffs were placed just below the inguinal crease at the top of the thighs and inflated each session as per participant's arterial occlusion pressure (AOP), determined via portable ultrasound vascular doppler. This individualized AOP measurement guided cuff inflation ensured personalized pressure settings. Exercise intensity and set volume were gradually increased based on each participant's tolerance and adaptation, preserving ethical standards and minimizing discomfort. Lower body peak strength measurements were recorded at baseline and again after the fourth week of intervention. Throughout all interventions and assessments, a qualified BFR practitioner was present, and sessions were scheduled at different times to prevent group overlap.

## III. Data Analysis

Data were analysed using GraphPad Prism (version 9.5.1). Descriptive statistics (mean ± standard deviation) were calculated. Within group comparisons were performed using paired sample t-test. Between-group differences in post-intervention outcomes were analysed using unpaired t-test. All statistical tests were performed at a 95% confidence interval, and results were considered statistically significant at $p < 0.05$. All analyses assumed normal distribution of data, and assumptions were verified before test application.

## IV. Results

Peak lower body strength was assessed both at baseline and after the four-week intervention period.

Table II: Baseline Demographic Statistics of the Subjects

| *Variables* | *Experimental Group (Mean ± SD)* | *Control Group (Mean ± SD)* | *t Value* | *p Value* |
|---|---|---|---|---|
| Age (years) | 25.03 ± 2.41 | 24.70 ± 2.03 | 0.57 | 0.56 |
| Height (cm) | 172.4 ± 4.86 | 171.1 ± 4.95 | 1.02 | 0.30 |
| Weight (kg) | 71.45 ± 6.40 | 70.59 ± 6.49 | 0.51 | 0.60 |
| Peak Lower Body Strength (kg) | 88.17 ± 9.60 | 90.17 ± 9.33 | 0.81 | 0.41 |

Table II shows the demographic details and baseline characteristics of study participants. The age of the participants averaged 24.87 ± 2.22 years, reflecting a young and dynamic group. Standing at an average height of 171.8 ± 4.91 cm, the subjects presented a varied physical stature and the body weight averaged at 71.02 ± 6.40 kg. Also, the baseline peak lower body strength did not show any significant differences pointing towards a comparable lower body strength level of the participants before the administration of the training regimen.

Table III: Within Group Comparison of Peak Lower Body Strength in Experimental Group

| Peak Lower Body Strength (kg) (n=30) | *Baseline* | | *$4^{th}$ Week* | | *Mean Difference* | *t* | *P* |
|---|---|---|---|---|---|---|---|
| | *Mean* | *Std. Deviation* | *Mean* | *Std. Deviation* | | | |
| | 88.17 | ± 9.60 | 95.33 | ± 10.74 | 7.16 | 15.58 | < 0.001* |

* Statistically significant at p<0.001.

Table III shows within group comparison of peak lower body strength within the experimental group. Pre-intervention peak lower body strength measured 88.17 ± 9.60 kg, which increased to 95.33 ± 10.74 kg after four weeks. The mean difference in peak lower body strength was 7.16 kg, with a standard deviation of ± 2.52 kg. Paired samples t-test analysis revealed statistical significance ($p < 0.001$), demonstrating substantial within-group improvement in peak lower body strength (Fig. 1).

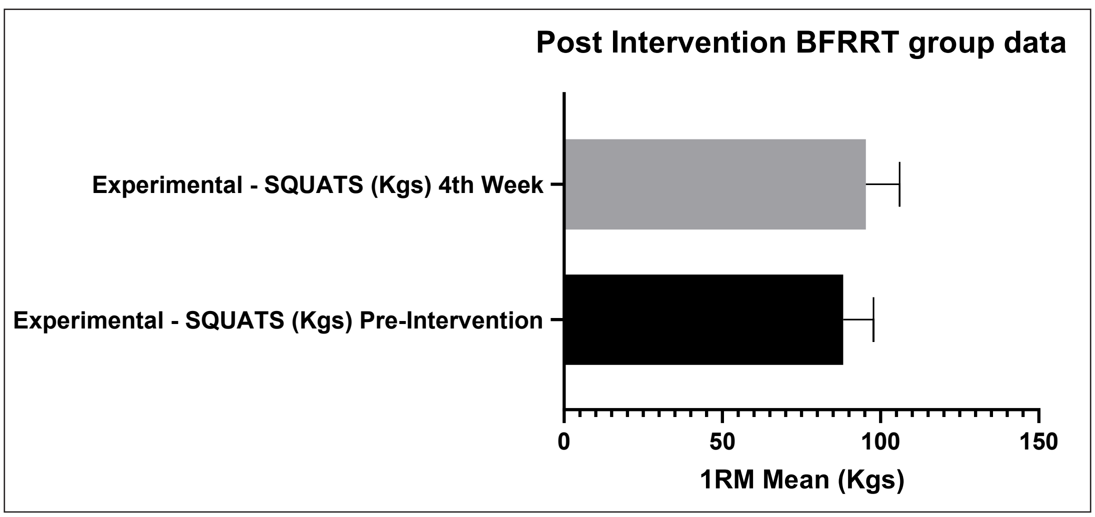


Fig. 1: Post Intervention Peak Lower Body Strength in Experimental (BFRRT) Group ($p < 0.05$)

Table IV: Within Group Comparison of Peak Lower Body Strength in Control Group

| Peak Lower Body Strength (n=30) | *Baseline* | | *$4^{th}$ Week* | | *Mean Difference* | *t* | *P* |
|---|---|---|---|---|---|---|---|
| | *Mean* | *Std. Deviation* | *Mean* | *Std. Deviation* | | | |
| | 90.17 | ± 9.33 | 96.50 | ± 9.75 | 6.33 | 15.43 | < 0.001* |

* Statistically significant at p<0.001.

Table IV shows the within group comparison of peak lower body strength in control group. The peak lower body strength before the training program was 90.17 ± 9.33 kg, which increased to 96.50 ± 9.75 kg after four weeks. The mean difference in peak lower body strength was 6.33 kg, with a standard deviation of ± 2.24 kg. Paired samples t-test analysis revealed statistical significance ($p < 0.001$), demonstrating substantial within-group improvement in peak lower body strength (Fig. 2).

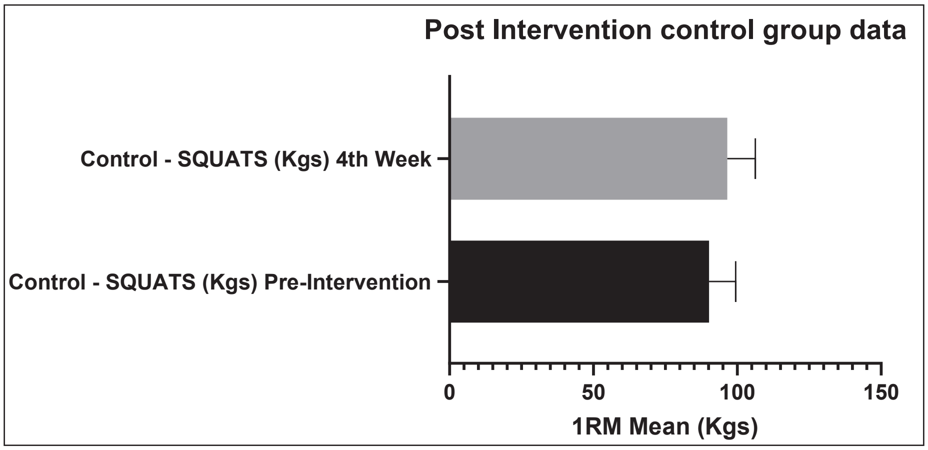


Fig. 2: Post Intervention Peak Lower Body Strength in Control Group ($p < 0.05$)

Table V: Between Group Comparison of Post Intervention Peak Lower Body Strength

| | *Groups* | *Mean* | *Std. Deviation* | *Mean Difference* | *t* | *P* |
|---|---|---|---|---|---|---|
| Peak Lower Body Strength | Experimental (n=30) | 95.33 | ± 10.74 | 1.17 | 0.44 | 0.661* |
| | Control (n=30) | 96.50 | ± 9.75 | | | |

* Non-significant at p>0.05.

Table V shows the comparison between the post intervention results between the groups, reported as statistically not significant ($p > 0.05$) (Fig. 3).

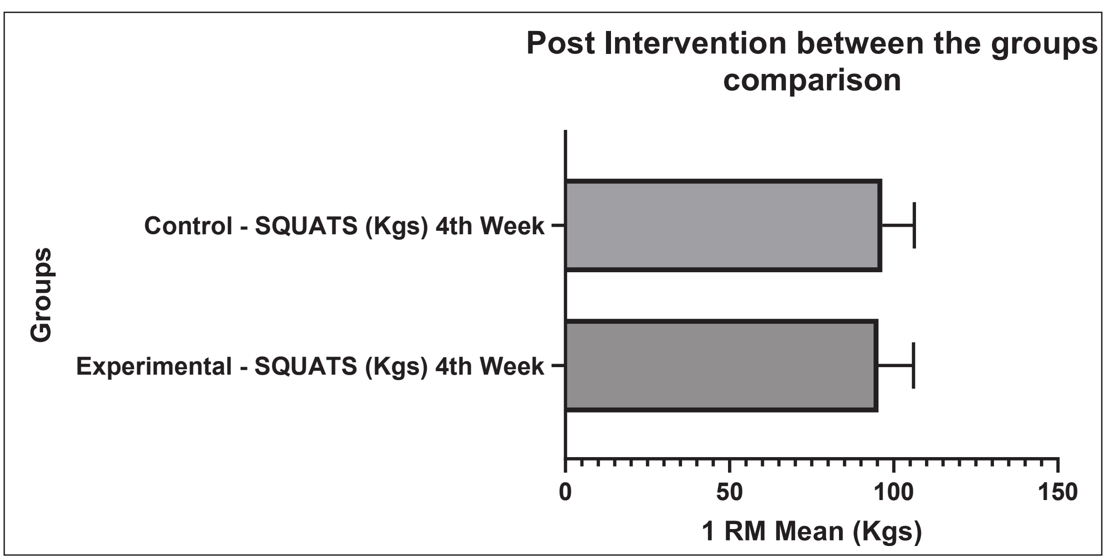


Fig. 3: Comparison of Post Intervention Peak Lower Body Strength Between Both the Groups ($p > 0.05$)

## V. Discussion

The aim of this study was to evaluate how a four-week BFRRT influences peak lower body strength in young males. Findings indicate that participants who trained with BFR cuffs achieved greater gains in peak strength than those following conventional resistance training, underscoring BFRRT's effectiveness for boosting lower-body force production. These superior gains are likely driven by the distinct physiological effects of BFR. By partially occluding blood flow during low-load exercises, BFRRT creates a metabolically challenging environment that amplifies muscle fibre recruitment, elevates intramuscular metabolite accumulation, and enhances anabolic hormone release [1]. Together, these mechanisms accelerate muscle hypertrophy and strength development despite using lighter loads.

Physiologically, BFRRT amplifies metabolic stress, elevating intramuscular concentrations of lactate, hydrogen ions, and inorganic phosphate to trigger earlier recruitment of high-threshold type II muscle fibres and greater motor unit synchronization than low-load exercise alone [2]. These metabolic perturbations activate the mammalian target of rapamycin (mTOR) pathway, augment growth hormone release up to 290 times above baseline, and stimulate satellite cell proliferation, collectively enhancing muscle protein synthesis and cross-sectional area [1]. Consequently, BFRRT emerges as a powerful strategy for improving lower-body strength in populations seeking to minimize joint stress while maximizing training adaptations. Systematic synthesis of existing literature through comprehensive review and quantitative meta-analytical techniques determined that BFRRT and traditional heavy-load resistance protocols yield comparable strength adaptations, with moderate effect sizes favouring BFRRT in isometric strength outcomes [7].

The outcomes documented in this study are in line with established scientific literature that has demonstrably shown the efficacy of BFR methodology in promoting muscular strength development and hypertrophic adaptations [8]. This observation carries particular relevance for populations requiring modified loading strategies and reduced biomechanical stress, including younger participants, competitive athletes, and individuals undergoing rehabilitation interventions. Parallel systematic investigation and meta-analytic examination of the BFR application combined with low-intensity resistance training protocols on lower limb musculature in middle-aged to older populations demonstrated that BFRRT protocols substantially enhanced lower extremity strength performance, with training session frequency identified as a critical determinant, particularly three weekly sessions producing optimal strength improvements [9]. These findings complement the present study by highlighting that even in older populations, BFRRT can elicit substantial strength adaptations, further validating its physiological efficacy across age groups and training intensities.

Research has also demonstrated that BFR training can improve endothelial function, which in turn contributes to better functional performance [10]. Another study has shown that BFR training can elevate immune cell counts and enhance immune function in immunocompromised individuals highlighting the benefits on immune functions of the body [11]. The findings of our study also align with previous research that suggest significant strength and muscle hypertrophy improvement in varied age groups [12, 13, 14]. Consistent with previous research, low-intensity resistance exercise coupled with BFR has been demonstrated to generate strength and muscle mass improvements equivalent to conventional heavy-load resistance protocols, yet supplementing already elevated-intensity training with this technique does not yield additional adaptive responses, highlighting its primary utility in contexts where heavy loading is not feasible [15, 16]. Research evidence indicates that low-intensity BFR training utilizing concentric muscle actions resulted in superior gains in muscle hypertrophy and strength development compared to eccentric-emphasis resistance protocols, suggesting contraction type influences adaptive outcomes [17]. Evidence also indicates that practical BFR methods can stimulate acute hypertrophy-related responses without increasing muscle damage, while factors such as body position can modulate the occlusion stimulus and subsequent adaptations [18, 19]. Collectively, evidence shows that short-duration low-load BFRRT facilitates rapid increases in muscle hypertrophy and strength; however, progressive training load increments do not invariably improve these adaptive responses, and when implemented appropriately, the intervention demonstrates safety profiles, though ongoing assessment of long-term effects remains advisable [20, 21, 22]. BFRRT presents an effective option for those unable to perform heavy lifting because of injury, age, or other limitations.

Among younger individuals, implementing BFR to their strength routines can yield noteworthy gains while reducing the likelihood of overuse injuries and joint strain. Additionally, the lightweight, portable nature of BFR equipment makes it suitable for diverse settings ranging from home workouts to athletic facilities. Despite robust evidence supporting BFRRT's efficacy, research gaps persist regarding sex-specific adaptations, larger population count, long-term retention of strength gains following training cessation, and the optimal integration of BFRRT with traditional high-load resistance programs. It would also be important to control and record participant's nutritional intake and sleep habits, given their significant influence performance outcomes. Future investigations addressing these areas will improve guidelines and expand BFR's role in both performance enhancement and rehabilitation. Moreover, expanding the scope to examine how BFR training affects endurance, and power would yield a more complete picture of its potential advantages.

## VI. Conclusion

It can be concluded that both BFRRT and conventional training are effective in improving peak lower-body strength in young adult males. However, slight superior improvements in peak lower-body strength in the BFR group highlight its promise as an effective alternative to conventional resistance training. BFRRT emerges as a paradigm shifting approach for augmenting peak lower body strength under low mechanical stress.

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