The Review Of
DIABETIC
STUDIES OPEN ACCESS

Low-Intensity Resistance Training with Blood Flow Restriction versus Traditional Resistance Exercise on Isokinetic Knee Torque and Dynamic Postural Stability in Chronic Ischemic Stroke

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Abstract

Background: Chronic ischemic stroke frequently results in persistent paretic-limb weakness and impaired dynamic postural stability, limiting functional recovery.
Objective: To compare the effects of Low-Intensity Resistance Training with Blood Flow **R**estriction (LIRT-BFR) versus traditional high-load resistance training on isokinetic knee torque and dynamic postural stability in chronic ischemic stroke.
Methods: Forty patients with chronic ischemic stroke, their age ranged from 40 to 45 years old were randomly allocated to an LIRT-BFR study group (40% 1-RM with cuff inflation at 150–160 mmHg) and a traditional resistance-training control group (80% 1-RM, no cuff), each completing 5 weeks of supervised training, three sessions per week. Peak torque of paretic-side knee extension and flexion at 30°/s and 90°/s was measured using an IsoMed 2000 isokinetic dynamometer, and dynamic postural stability was assessed via the Overall Stability Index (OSI) using the Biodex Balance System. A 2×2 mixed-design MANOVA was used for between- and within-group comparisons.
Results: Both groups showed significant pre-to-post improvements in all outcomes, however, the LIRT-BFR group demonstrated significantly greater gains than the traditional resistance-training group across all isokinetic torques and OSI ($P<0.05$).
Conclusion: LIRT-BFR produced significantly greater improvements in paretic-limb isokinetic knee strength and dynamic postural stability than traditional high-load resistance training in patients with chronic ischemic stroke, supporting its use as an effective, lower-load rehabilitation strategy.

Keywords: Blood flow restriction; Isokinetic dynamometry; Postural balance; Stroke.

Introduction

Stroke remains a leading cause of long-term physical disability worldwide, frequently resulting in persistent unilateral lower-extremity weakness, impaired selective motor control, spasticity, and reduced postural stability [1]. These impairments are particularly evident in the paretic quadriceps and hamstring muscles, where reduced knee-extensor and knee-flexor strength has been directly associated with poorer functional

mobility, gait performance, and fall risk after stroke [2]. Because such deficits often persist well beyond the acute phase, restoring paretic-limb muscle performance remains a central objective of chronic-phase stroke rehabilitation [3].

Progressive resistance training is widely recommended for individuals with stroke-related lower-limb weakness, given its demonstrated capacity to increase muscle strength and improve functional motor performance without exacerbating spasticity [4]. Structured isokinetic strengthening programs targeting the knee musculature have similarly been shown to improve peak torque, gait velocity, balance, and overall mobility when incorporated into conventional stroke rehabilitation [5]. However, traditional resistance training typically requires relatively high external loads, often 60–80% of one-repetition maximum, which may be poorly tolerated by patients with residual paresis, cardiovascular comorbidities, joint pain, or reduced exercise capacity [4].

Low-intensity resistance training combined with blood-flow restriction (BFR) has emerged as a promising alternative capable of eliciting meaningful neuromuscular adaptations at substantially lower mechanical loads. During BFR training, a pneumatic cuff is applied proximally on the exercising limb to partially restrict arterial inflow and venous outflow while the individual performs low-load exercise, thereby amplifying metabolic stress and recruitment of type II muscle fibers without the joint and cardiovascular strain associated with heavy resistance training [6]. This approach may be particularly advantageous in stroke populations, in whom high-load training is not always feasible or well tolerated [7].

Emerging evidence supports the efficacy of BFR training after stroke. In a randomized controlled trial involving ischemic stroke survivors, low-load BFR resistance training performed at 40% of one-repetition maximum produced improvements in muscle strength, balance, and walking capacity comparable to those achieved with traditional high-load resistance training at 80% of one-repetition maximum [7]. Despite these encouraging findings, most existing studies have relied on global measures of muscle strength or clinical mobility outcomes, and objective, velocity-specific isokinetic assessment of the paretic knee musculature following BFR training remains scarcely investigated [7].

Isokinetic dynamometry provides a precise, reproducible method for quantifying knee-muscle performance under controlled angular velocities and has demonstrated good to excellent reliability in both healthy individuals and stroke survivors. Peak torque assessed at a slower angular velocity, such as 30°/s, reflects high-force muscle output relevant to functional tasks such as sit-to-stand transfers and stair negotiation, whereas peak torque assessed at a faster velocity, such as 90°/s, provides complementary insight into dynamic muscle performance under more functionally demanding conditions [8,9]. Notably, individuals with stroke demonstrate marked paretic-limb deficits in both knee-extensor and knee-flexor torque at these velocities compared with the non-paretic limb [9], underscoring the clinical relevance of velocity-specific assessment in this population [10]. In parallel, the Overall Stability Index (OSI), derived from computerized dynamic posturography, offers an objective, quantifiable measure of postural control, wherein lower values indicate superior dynamic balance [3].

Despite the growing body of evidence supporting BFR training in stroke rehabilitation, no study to date has directly compared low-intensity BFR resistance training with traditional high-load resistance training using velocity-specific isokinetic torque outcomes at both 30°/s and 90°/s alongside objective postural-stability assessment via OSI in patients with chronic ischemic stroke [7,8]. Addressing this gap may clarify whether a lower-load, cuff-based training modality can achieve neuromuscular and balance outcomes equivalent to conventional resistance training, with important implications for patients who cannot safely tolerate heavy external loads [6,7].

Therefore, this randomized controlled trial aimed to compare the effects of low-intensity resistance training with blood-flow restriction versus traditional resistance exercise on lower-extremity isokinetic torque and dynamic postural stability in patients with chronic ischemic stroke. The primary outcome was peak torque of paretic-side knee flexion at 30°/s, measured using the IsoMed 2000 isokinetic dynamometer [8]. Secondary outcomes were peak torque of paretic-side knee extension at 30°/s, peak torque of paretic-side knee extension at 90°/s, peak torque of paretic-side knee flexion at 90°/s, and the Overall Stability Index measured using the Biodex Balance System [3].

Design of the Study

This study was designed as a single-blind, randomized controlled trial conducted at the outpatient clinic of the Faculty of Physical Therapy, Delta University for Science and Technology, between July 2025 and September 2025. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Research Ethics Committee of the Faculty of Physical Therapy, Cairo University (approval number: P.T.REC/012/005961). The trial was registered at ClinicalTrials.gov (identifier: NCT 07292675) prior to participant enrollment. Written informed consent was obtained from all participants before enrollment, following a full explanation of the study procedures, potential risks, and benefits.

Sample Size Calculation

The sample size for this study was calculated using the G*power program 3.1.9 (G power program version 3.1, Heinrich-Heine-University, Düsseldorf, Germany) for two tailed test. The effect size for the sample size calculation was obtained from pilot study consisted on 14 patients (n=7 patients/group) distributed randomly into 2 equal groups (control group and study group) and means values of dependent primary outcome variable peak torque knee flexion 30^{o} at post-treatment were 22.80±10.20 and 30.62 ±4.50 for control group and study group, respectively. Based on the data from this study, sample size calculation based on t-tests (Means: Difference between two independent means (two groups), Type I error (α) = 0.05, power (1-β error probability) = 0.80, effect size = 0.9919817 with 2 independent groups comparison for major dependent variable outcome (flexion 30^{o}). Moreover, a total sample size for 34 participants for 2 independent group's comparison. Considering a 10% drop out rate, the appropriate minimum sample size for this study is 38 participants. Thus, the study enrolled 19 patients in each group as a minimum to ensure adequate statistical power for detecting a large clinically meaningful difference.

Participants

Forty patients with chronic ischemic stroke, aged 40 to50 years and duration of illness was 8 to 9 months, were recruited from the outpatient clinic of the Faculty of Physical Therapy, Delta University for Science and Technology, between July 2025 and September 2025. Eligible participants presented with unilateral lower-extremity paresis and mild spasticity (Modified Ashworth Scale grade 1 or 1+), and were able to understand instructions and safely perform resistance exercise and isokinetic testing. Patients with uncontrolled hypertension, unstable cardiovascular disease, severe cognitive or communication impairment, severe spasticity, or orthopedic conditions affecting knee testing were excluded. All participants provided written informed consent prior to enrollment.

Randomization and Allocation Concealment

Participants were randomized in a 1:1 ratio to the LIRT-BFR study group and traditional resistance training control group using a computer-generated randomization sequence prepared by an independent researcher not involved in recruitment, intervention, or assessment. Allocations were concealed in sequentially numbered, opaque, sealed envelopes, opened only after baseline assessment by a person uninvolved in outcome evaluation. Outcome assessors were blinded; participants and treating therapists were not blinded due to the nature of the intervention (Fig.1)

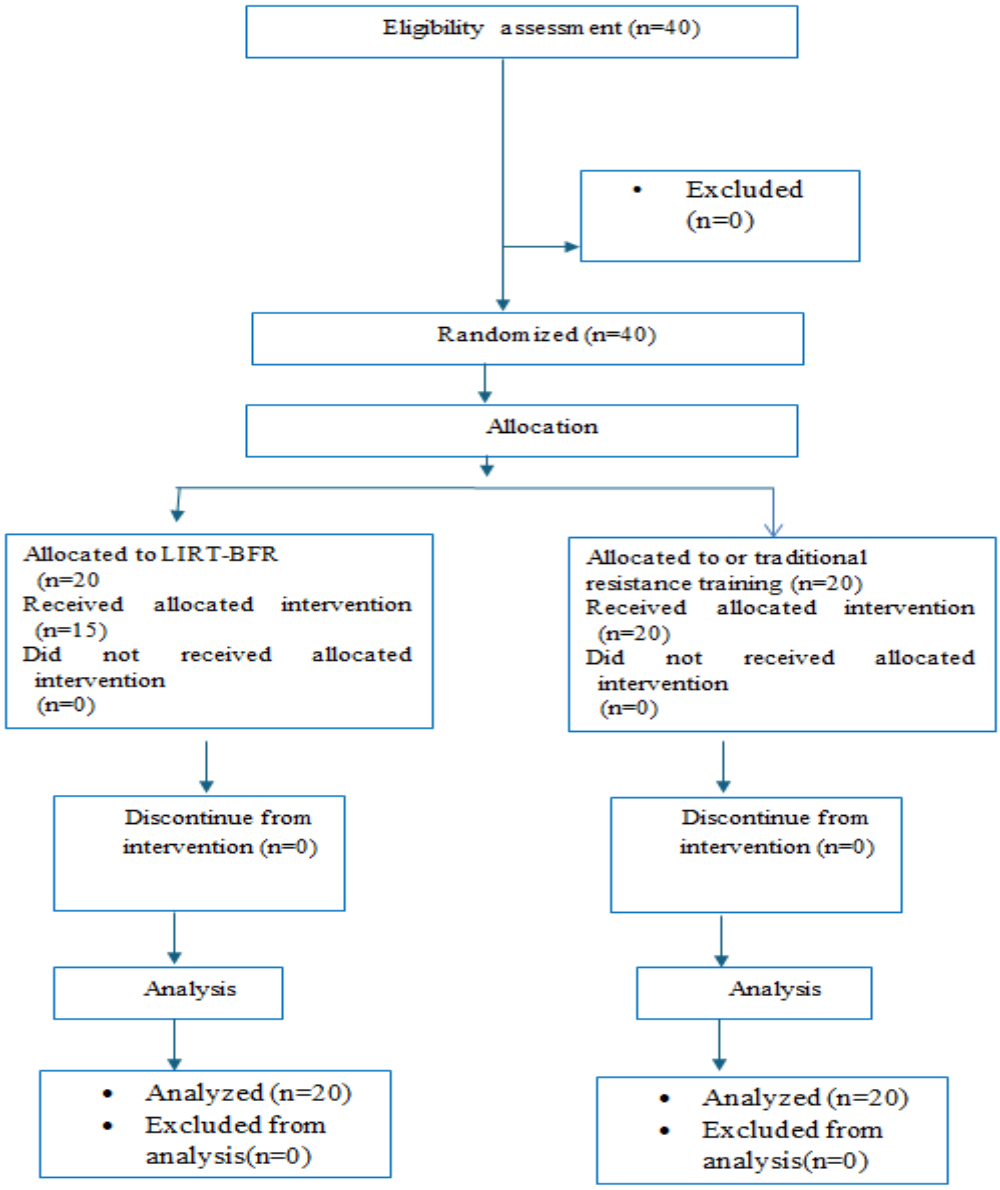

Figure 1. Flow chart

Outcome Measures

All outcomes were assessed baseline and post 5 weeks of intervention.

Primary outcome Isokinetic Knee flexion Torque

Isokinetic knee-flexor and knee-extensor performance of the paretic limb was assessed using an IsoMed 2000 isokinetic dynamometer (D&R Ferstl GmbH, Hemau, Germany), which has demonstrated good reliability for isokinetic strength measurement when standardized protocols and a familiarization session are used. Participants were seated with the hip flexed to approximately 80–85° and the knee positioned so that the shank was horizontal; the pelvis, trunk, and thigh were stabilized with padded straps, and the lateral femoral condyle was aligned with the dynamometer's axis of rotation, with the lever arm attached to the distal tibia using a padded cuff. After a 5-minute submaximal cycling warm-up and familiarization contractions, gravity correction was applied according to the manufacturer's procedure, and participants

performed maximal concentric knee flexion and extension through their full available range of motion at angular velocities of 30°/s and 90°/s. For each condition (extension 30°/s, flexion 30°/s, extension 90°/s, flexion 90°/s), three to four maximal repetitions were obtained with standardized rest intervals, and the highest peak torque value was used for analysis and expressed in Newton metres (N·m) [11].

Dynamic Postural Stability

Dynamic postural stability was assessed using the Overall Stability Index (OSI) of the Biodex Balance System SD (Biodex Medical Systems, Shirley, NY), a computerized platform that quantifies sway in the sagittal and frontal planes, with higher OSI values indicating greater instability and lower values indicating better postural control. Participants stood barefoot on the platform in a bilateral stance with feet shoulder-width apart, arms at their sides, and eyes open, and completed three 20-second dynamic-stability trials at a preset stability level; the mean OSI across the three trials was used for analysis, and the Biodex OSI has shown acceptable test–retest reliability and significant correlation with Berg Balance Scale scores in individuals with stroke, supporting its use as a quantitative balance outcome [12].

Intervention

All participants completed a 5-week supervised program, three sessions per week. Each session began with 20 minutes of low-to-moderate intensity aerobic exercise (10 minutes treadmill walking and 10 minutes cycling), identical in both groups, followed by resistance training prescribed as a percentage of baseline 1-RM and re-assessed weekly to maintain the target intensity [7].

The low-intensity resistance training with blood flow restriction (LIRT-BFR) group performed six lower-limb exercises (knee extension, hip flexion, hip extension, hip abduction, straight-leg raise, leg press, squat) at 40% of 1-RM [7]. Each exercise was completed for three sets of 10 repetitions, with 1-minute rest between sets and 3 minutes between exercises [7]. A pneumatic cuff was placed proximally on the thigh and inflated to 150–160 mmHg during sets and inter-set rests, then deflated during the 3-minute inter-exercise rests, consistent with published BFR resistance-training protocols [6]. Blood pressure, heart rate, oxygen saturation, and adverse symptoms were monitored throughout to ensure safety [6].

The traditional resistance-training group performed the same six exercises, using the same set–rep and rest structure, but at 80% of 1-RM without blood-flow restriction. Weekly 1-RM reassessment was used to maintain the target intensity, and the same aerobic warm-up and physiological monitoring were applied in this group, ensuring that the only systematic difference between groups was the use of low-load BFR versus high-load conventional resistance training [7].

Statistical Analysis

Normality of data distribution was assessed using the Shapiro-Wilk test, which confirmed that all outcome variables were normally distributed ($P>0.05$). Homogeneity of variance was assessed using Levene's test, which revealed no significant differences in variance between groups ($P>0.05$). Based on these findings, parametric statistical analysis was conducted.

The statistical analysis was conducted by using statistical SPSS package program version 25 for Windows (SPSS, Inc., Chicago, IL). Quantitative data are expressed as mean and standard deviation for patient's demographic data, peak torque knee and overall stability index variables. While, qualitative data are reported as frequency and percentage for gender and MAS variables and compared statistically between both groups by Chi-square test. Independent t-test used to compare between two groups for demographic data variables. Cohen's d to calculate effect size with Cohen's d of 0.2 being a small effect, 0.5 a medium effect, and 0.8 a large effect. Mixed design 2 x 2 multivariate analysis of variance (MANOVA) test was used for the first independent variable (between subject factors) was the tested group with 2 levels (control group vs. study group) and the second independent variable (within subject factor) was measuring periods with 2 levels (pre-treatment vs. post-treatment) with the main dependent variables (peak torque knee and overall stability index). Bonferroni test was used to compare between pairwise within and between groups of the tested variables which F was significant from MANOVA test. Eta squared (η^2) from MANOVA test is an effect size ranged from 0 to 1, with higher values indicating a larger influence of the predictor, typically

interpreted as 0.01 (small), 0.06 (medium), and 0.14 (large). All statistical analyses were significant at level of probability ($P \leq 0.05$).

Results

Patient's baseline demographic data are presented in Table (1). Forty patients were participated and randomly allocated into either the control group (n = 20) and the study group (n = 20). No statistically significant differences (P>0.05) between the control group and study group related to patients age (P=0.297), weight (P=0.876), height (P=0.977), BMI (P=0.812), duration of illness (P=0.059), gender (P=0.752), and MAS (P=1.000). Furthermore, the calculated Cohen's d effect sizes for all demographic data variables ranged from negligible to small (d = -0.01 to 0.34), with all 95% confidence intervals crossing zero, confirming that no observed differences at baseline of clinical trial.

Table 1. Patient's demographic data in both groups

Items	Groups		Cohen's d (95% CI)	-value
	Control group (n=20)	Study group (n=20)		
Age (year)	42.85 ± 1.59	42.35 ±1.38	0.34 (-0.29 – 0.96)	0.297
Weight (kg)	80.80 ±7.41	81.15 ±6.69	-0.05 (-0.67 – 0.57)	0.876
Height (cm)	170.95 ±5.96	171.00 ±4.71	-0.01 (-0.63 – 0.61)	0.977
BMI (kg/m^2)	27.61 ±1.49	27.73 ±1.84	-0.07 (-0.69 – 0.55)	0.812
Duration of illness (months)	8.90 ±0.78	9.35 ±0.67	-0.62 (-1.25 – 0.02)	0.059
Gender (females : males)	9 (45%) :11 (55%)	10 (50%) : 10 (50%)	–	0.752
MAS (1 : 1+)	9 (45%) :11 (55%)	9 (45%) :11 (55%)	–	1.000

Quantitative variables data (age, weight, height, BMI, and duration) are expressed as mean ±standard deviation and compared by t-independent test.
Qualitative variables data (gender and MAS) are reported as frequency (percentage) and compared by Chi-square test. MAS: modified Ashworth scale
CI: confidence interval;P-value: probability value; P-value > 0.05: non-significant

The overall of statistical analysis (Table 2) using 2x2 mixed design MANOVA revealed that a significant effect for group (Wilks' lambda = 0.142, F-value = 87.361, P=0.0001, partial η^2= 0.858), demonstrating overall differences between both groups. A significant main effect for time was also observed (Wilks' lambda = 0.021, F-value= 676.066, P=0.0001, partial η^2= 0.979), indicating significant changes across all outcome measures from pre- to post-intervention. Most importantly, there was a significant group × time interaction effect (Wilks' lambda = 0.155, F-value=78.427, P=0.0001, partial η^2 = 0.845), indicating that the pattern of change over time differed significantly between the two groups.

The univariate analysis for flexion 30^o (Table 2) revealed a significant group × time interaction (F-value=14.228, P= 0.0001, partial η^2= 0.158), along with significant main effects for time (F-value = 54.968, P = 0.0001, partial η^2 = 0.420), and group (F-value = 36.589, P = 0.0001, partial η^2= 0.325). The flexion 30^o at pre-treatment (Table 3), both groups reported moderate-to-severe flexion 30^o with no significant between-group difference (P = 0.112). However, at post-treatment there was a significant difference (P<0.05) in flexion 30^o between both groups. Following the intervention, study demonstrated a significantly greater increased in flexion 30^o compared to the control group (MD = 7.68, 95% CI: 5.48 – 9.89, P=0.0001). While, both groups achieved significant (P<0.05) within-group improvements, the study group exhibited a substantially larger improvement percentage (42.09% vs. 15.00%) and a larger effect size (partial η^2 = 0.452

vs. 0.080), indicating that the experimental intervention had a greater clinical impact on flexion 30° increasing.

The analysis revealed there were significant in flexion 90° (Table 2) due to group × time interaction for (F-value = 33.333, P= 0.0001, partial η^2= 0.305), main effects for time (F-value =105.656, P= 0.0001, partial η^2= 0.582) and group (F-value=10.895, P= 0.001, partial η^2= 0.125). Pre-treatment flexion 90° (Table 3) was comparable between groups with no significant effect (P= 0.084). However, at post-treatment, the study group demonstrated significantly greater improvement compared to the control group (MD = 6.00, 95% CI: 4.14 – 7.87, P=0.0001). Both groups achieved significant within-group improvements (control group: MD = 2.98, P= 0.002; study group: MD = 10.63, P=0.0001), with the study group showing a higher improvement percentage (64.90% vs. 16.54%) and a larger effect size (partial η^2 = 0.629 vs. 0.118).

The extension 30° (Table 2) was significantly affected by group × time interaction was found (F-value=17.959, P=0.0001, partial η^2=0.191) with significant the main effect for time (F-value =83.758, P=0.0001, partial η^2=0.524) and group effect (F-value=32.395, P=0.0001, partial η^2=0.299). No significant (P>0.05) in extension 30° (Table 3) at baseline (P=0.307) between both groups, but a significant difference (P<0.05) was observed at post-treatment (MD = 7.11, 95% CI: 5.09 – 9.13, P=0.0001). There were significant (P<0.05) increase in extension 30° at pot-treatment compared to pre-treatment within control group (P=0.001) and study group (P=0.0001) with large effect sizes (partial η^2 = 0.137 and 0.541, respectively) with the study group showing a higher improvement percentage (35.73% vs. 13.64%)

There were significant (P<0.05) in extension 90° (Table 2) related to group × time interaction (F-value=57.974, P=0.0001, partial η^2= 0.433), main effects of time (F-value=192.635, P=0.0001, partial η^2=0.717) and group (F-value=69.079, P=0.0001, partial η^2=0.476). No significant effect (P>0.05) at baseline in extension 90° (P=0.623) between both groups (Table 3), however, post-treatment analysis revealed a statistically significant and clinically meaningful between-group difference favoring the study group (MD=10.54, 95% CI: 8.67 – 12.40, P=0.0001). Extension 90° Within-group analyses showed significant improvements in both groups; the control group (MD = 4.14, P=0.0001) and study group (MD = 14.22, P=0.0001). Notably, the study group improvement percentage (62.67%) more than control group (18.60%), with a large effect size (partial η^2 = 0.652) compared to control group (partial η^2 = 0.205).

For overall stability index (Table 2), a significant group × time interaction was detected (F-value=30.324, P=0.0001, partial η^2=0.252). The main effects for time were significant (F-value=72.751, P=0.0001, partial η^2=0.473), and group (F-value=39.153, P=0.0001, partial η^2=0.359). At pre-inversion overall stability index (Table 3) was similar across groups (P=0.839), however, post-intervention analysis revealed a statistically significant between-group difference favoring the study group (MD = 1.06, 95% CI: 0.96–1.16, P=0.0001). Within-group improvements were significant in both groups (P=0.0001), with the study group demonstrating a larger effect size (partial η^2 = 0.659 vs. 0.562) and a greater improvement percentage (63.84% vs. 34.97%) compared to control group.

Table 2. Table 2. Group, Time, and Group × Time Interaction Effects for Multivariate and Univariate Analyses

Variables	Item	Wilks' Lambda	Partial η^2	F-value	P-value
Overall	Group effect	0.142	0.858	87.361	0.0001*
	Time effect	0.021	0.979	676.066	0.0001*
	Group x time interaction	0.155	0.845	78.427	0.0001*
KF 30°/s	Group effect	–	0.325	36.589	0.0001*
	Time effect	–	0.420	54.968	0.0001*
	Group x time interaction	–	0.158	14.228	0.0001*
KF 90°/s	Group effect	–	0.125	10.895	0.001*
	Time effect	–	0.582	105.656	0.0001*

	Group x time interaction	–	0.305	33.333	0.0001*
KE 30°/s	Group effect	–	0.299	32.395	0.0001*
	Time effect	–	0.524	83.758	0.0001*
	Group x time interaction	–	0.191	17.959	0.0001*
KE 90°/s	Group effect	–	0.476	69.079	0.0001*
	Time effect	–	0.717	192.635	0.0001*
	Group x time interaction	–	0.433	57.974	0.0001*
OSI	Group effect	–	0.359	39.153	0.0001*
	Time effect	–	0.473	72.751	0.0001*
	Group x time interaction	–	0.252	30.324	0.0001*

η^2: partial eta square; P-value: probability value; *Significant (P<0.05)

Table 3. Within and between group's comparison for peak torque knee and overall stability index

Variable	Items	Groups (Mean ±SD)		Change (MD)	95% CI	Effect size (partial η^2)	F-value	P-value[1]
		Control group (n=20)	Study group (n=20)					
Flexion 30° /s	Pre-treatment	19.00 ±3.87	20.79 ±3.96	1.78	-0.42 – 3.9	0.033	2.592	0.112
	Post-treatment	21.85 ±3.18	29.54 ±2.84	7.68	5.48 – 9.89	0.388	48.22	0.0001
	Change (MD)	2.85	8.75					
	95% CI	0.64 – 5.05	6.55 – 10.96					
	Improvement %	15.00%	42.09%					
	Effect size (partial η^2)	0.080	0.452					
	F-value	6.632	62.564					
	P-value[2]	0.012*	0.0001*					
Flexion 90° /s	Pre-treatment	18.02 ±3.33	16.38 ±2.43	1.63	-0.22 – 3.5	0.039	3.057	0.084
	Post-treatment	21.00 ±3.01	27.01 ±2.98	6.00	4.14 – 7.87	0.351	41.17	0.0001
	Change (MD)	2.98	10.63					
	95% CI	1.11 – 4.84	8.76 – 12.49					
	Improvement %	16.54%	64.90%					
	Effect size (partial η^2)	0.118	0.629					
	F-value	10.149	128.840					
	P-value[2]	0.002*	0.0001*					
Extension 30° /s	Pre-treatment	25.80 ±3.91	26.84 ±2.87	1.04	-0.97 – 3.0	0.014	1.057	0.307
	Post-treatment	29.32 ±3.79	36.43 ±1.74	7.11	5.09 – 9.13	0.393	49.29	0.0001
	Change (MD)	3.52	9.59					
	95% CI	1.50 – 5.52	7.57 – 11.61					
	Improvement %	13.64%	35.73%					
	Effect size (partial η^2)	0.137	0.541					
	F-value	12.074	89.643					
	P-value[2]	0.001*	0.0001*					

Extension 90° /s	Pre-treatment	22.23 ±2.27	22.69 ±3.50	0.4(	-1.40 – 2.3	0.003	0.243	0.623
	Post-treatment	26.37 ±3.02	36.91 ±2.90	10.5	8.67 – 12.40	0.625	126.81	0.0001
	Change (MD)	4.14	14.22					
	95% CI	2.28 – 6.01	12.36 – 16.08					
	Improvement %	18.60%	62.67%					
	Effect size (partia η^2)	0.205	0.652					
	F-value	19.626	130.983					
	P-value[2]	0.0001*	0.0001*					
Overall stability index	Pre-treatment	3.66 ±0.14	3.65 ±0.12	0.01	-0.08 – 0.1(	0.001	0.042	0.839
	Post-treatment	2.38 ±0.14	1.31 ±0.19	1.0(	0.96 – 1.1(	0.338	19.40	0.0001
	Change (MD)	1.28	2.33					
	95% CI	1.18 – 1.38	2.24 – 2.43					
	Improvement %	34.97%	63.84%					
	Effect size (partia η^2)	0.562	0.659	0.56	0.659			
	F-value	24.382	36.724					
	P-value[2]	0.0001*	0.0001*					

Data are reported as mean ± standard deviation (SD); MD: Mean difference; CI: confidence interval; η^2: partial eta square; P-value: probability value; *Significant (P<0.05)
P-value [1]: probability value between both groups at pre- and post-treatment and compared statistically by post-hoc pairwise Bonferroni test
P-value [2]: probability value between pre- and post-treatment within each group and compared statistically by post-hoc pairwise Bonferro test

Discussion

The main finding of this trial is that both training approaches improved lower-limb strength and dynamic balance in patients with chronic ischemic stroke, but low-intensity resistance training with blood flow restriction (LIRT-BFR) produced consistently larger gains than traditional high-load resistance training in knee-extension and knee-flexion peak torque at 30°/s and 90°/s and in the Overall Stability Index (OSI). This pattern suggests that BFR is not merely an alternative when heavy loads are poorly tolerated; it may be a preferable strengthening strategy for many chronic stroke survivors.

All participants demonstrated significant improvements, confirming that a 5-week programme of structured lower-limb resistance training is effective for increasing paretic-limb strength and dynamic postural stability in the chronic phase after stroke [7, 11]. The more favourable changes observed in the LIRT-BFR group indicate that combining low external loads (40% 1-RM) with vascular restriction created a stronger training stimulus than using high loads (80% 1-RM) alone, despite identical exercise selection, volume, and session structure between groups [7]. In practical terms, how the load was applied (under BFR) appeared more important than simply how heavy the load was.

Our results extend the work of Ahmed et al. [7], who reported that both LIRT-BFR and traditional high-intensity resistance training improved muscle strength, balance, and walking capacity in ischemic stroke survivors, with comparable or slightly greater gains in the BFR group on several functional measures. By including velocity-specific isokinetic knee torque and OSI, outcomes that are highly sensitive to neuromuscular and balance changes, the present trial adds more objective detail, showing that LIRT-BFR also outperforms high-load training on these quantitative parameters in a homogeneous sample of chronic ischemic stroke [7,11,12].

The magnitude of the between-group differences observed in this trial warrants specific consideration. While Ahmed et al. reported that LIRT-BFR produced strength and functional gains comparable to, or only

modestly greater than, traditional high-load resistance training, the present trial found substantially larger differentials favoring LIRT-BFR, with improvement percentages reaching 62.67% versus 18.60% for knee-extension torque at 90°/s and 63.84% versus 34.97% for the Overall Stability Index. This pattern diverges from the broader BFR literature, in which low-load BFR training is most often reported as non-inferior to, rather than clearly superior to, conventional heavy-load resistance training. Several factors may help explain this discrepancy. First, the present trial used a fixed, relatively high cuff pressure (150–160 mmHg) applied consistently across all six exercises, which may have produced a greater cumulative metabolic stimulus than protocols using lower or individualized occlusion pressures. Second, the traditional resistance-training comparator in this trial trained at a fixed 80% 1-RM without concurrent load progression beyond weekly re-assessment, potentially limiting the comparator group's adaptive response relative to protocols with more aggressive progressive overload. Third, differences in participant characteristic including the narrow age range, chronic but relatively homogeneous stroke duration (8–9 months), and mild spasticity level may have created a sample particularly responsive to the metabolic and neural adaptations elicited by BFR, in ways that are not necessarily generalizable to broader stroke populations. Finally, the relatively short 5-week duration may have disproportionately favored the BFR group if traditional high-load training requires a longer adaptation period to fully manifest its strength benefits in a neurologically impaired population. Given that this magnitude of superiority has not been consistently reported elsewhere, this finding should be interpreted as hypothesis-generating rather than conclusive, and warrants replication in larger, multicenter trials before LIRT-BFR is broadly recommended as superior rather than merely equivalent to conventional resistance training in chronic stroke rehabilitation.

Traditional strength guidelines state that heavy loads (≥70% 1-RM) are required to optimize muscle hypertrophy and maximal force production [6, 13]. Blood flow restriction training challenges this view by using low loads (typically 20–40% 1-RM) combined with partial vascular occlusion, creating a high-fatigue, high-metabolic-stress environment within the muscle [6,14,15]. Under BFR, even modest loads can recruit fast-twitch motor units earlier and more extensively, and elicit hormonal and cellular responses similar to those seen with conventional high-load training [14]. In chronic stroke survivors, who often have impaired motor unit recruitment and residual weakness, this mechanism is particularly attractive because it allows fast-twitch fibres to be engaged without imposing high mechanical loads on hemiparetic joints and soft tissues.

The greater increases in knee-extensor and knee-flexor peak torque at both 30°/s and 90°/s in the LIRT-BFR group are consistent with this mechanistic explanation [7, 11]. Torque gains at the slower velocity (30°/s) reflect improved maximal strength, whereas gains at the faster velocity (90°/s) indicate enhanced dynamic muscle performance. The fact that LIRT-BFR improved torque at both velocities suggests that it produced broad neuromuscular adaptations, rather than a narrow effect limited to a single testing speed [11]. In parallel, the larger reductions in OSI in the BFR group imply that these strength improvements translated into better control of sway on an unstable platform, not just higher dynamometer values [12, 16, 17].

Systematic reviews of BFR exercise in neurological populations have reported that BFR can increase muscle strength and functional performance in people with stroke, spinal cord injury, multiple sclerosis, and Parkinson's disease, and that it is generally well tolerated when appropriate screening and protocols are used [18, 19]. However, most available trials involve small samples, diverse protocols, and rely heavily on clinical tests of mobility rather than precise isokinetic or quantitative balance measures [18, 19]. By incorporating IsoMed 2000 isokinetic dynamometry and Biodex-derived OSI, our study provides higher-resolution evidence that LIRT-BFR can generate superior neuromuscular and dynamic-balance adaptations compared with matched high-load resistance training in chronic ischemic stroke [11, 12].

Our findings are also consistent with evidence from musculoskeletal and general rehabilitation populations, where low-load BFR often produces strength gains comparable to, or greater than, those achieved with traditional heavy-load protocols, without detrimental changes in vascular or neural function [14, 20]. Collectively, these data support the view that BFR is a legitimate, evidence-based option for lower-limb strengthening in neurologic rehabilitation, rather than an experimental or niche technique.

From a clinical perspective, the results offer several practical advantages. First, LIRT-BFR enabled patients to train at 40% 1-RM yet achieved greater improvements in isokinetic torque and OSI than traditional resistance training at 80% 1-RM [7]. This is particularly relevant for stroke survivors with joint pain, early osteoarthritis, or limited tolerance to heavy loads, who may not be able to perform high-intensity strengthening safely or consistently [14, 21]. Second, the superior OSI improvements in the BFR group suggest that strength gained under BFR conditions contributes meaningfully to dynamic balance, an important determinant of fall risk and safe community ambulation [2, 12, 16]. Third, the intervention (six lower-limb exercises, three sets of 10 repetitions, plus a short aerobic component) is feasible in routine outpatient practice, making it realistic to implement in everyday neurorehabilitation settings [7].

Safety is a key consideration in any BFR protocol, especially in neurological populations. Survey data indicate that most therapists using BFR in people with neurologic conditions consider it generally safe, with adverse effects mainly limited to local discomfort from cuff pressure or transient fatigue [22]. Controlled studies in other populations have shown that low-load BFR can increase strength without harmful changes in blood pressure, arterial stiffness, coagulation markers, or nerve conduction when appropriate screening and monitoring are implemented [14, 20]. In our trial, we used conservative cuff pressures (150–160 mmHg), standardized screening, close monitoring of blood pressure, heart rate, and oxygen saturation, and explicit stopping rules; no serious adverse events were observed [7, 14, 15]. This does not imply that BFR is risk-free, and stroke patients with uncontrolled hypertension, significant vascular disease, or autonomic instability require careful medical evaluation. However, our results- and existing systematic reviews- support the view that LIRT-BFR can be used safely in carefully selected chronic stroke patients when protocols are standardized and closely monitored [18,19,20].

The trial has several strengths. Methodologically, it employed a single-blind randomized design, concealed allocation, identical non-specific co-interventions in both groups (same aerobic warm-up and session structure), and blinded assessment of objective dynamometer and Biodex outcomes [7, 11, 12]. The use of isokinetic knee torque at two velocities and OSI provides a nuanced view of how LIRT-BFR and high-load training influence both strength and dynamic balance, complementing the more global information obtained from clinical scales [2, 11, 12]. Additionally, the sample was restricted to chronic ischemic stroke survivors 8–9 months post-onset, which reduces variability related to stroke stage and improves internal validity.

Limitations should also be acknowledged. This was a single-center trial with a modest sample size and a relatively short intervention period (5 weeks), and we did not include long-term follow-up. Our participants were limited to a narrow age range, chronic phase, mild spasticity, and ischemic stroke, which constrain generalizability to older individuals, those with more severe disability or spasticity, or hemorrhagic stroke [7].

Conclusion

In summary, this trial shows that both low-intensity BFR resistance training and traditional high-load resistance training are effective for improving lower-limb strength and dynamic balance in chronic ischemic stroke survivors, but LIRT-BFR produced consistently greater gains in isokinetic knee torque and OSI under matched experimental conditions. Together with converging evidence from stroke and other neurologic populations, these findings support the integration of carefully monitored low-load BFR into chronic stroke rehabilitation programs as a powerful, lower-load alternative to conventional high-intensity resistance training.

Acknowledgments

The authors were thankful to all patients who participated in this work.

Disclosure statement

No conflicts of interest.

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