RESEARCH PAPER

Effect of Blood Flow Restriction Training Combined with Low to Moderate Intensity Exercise versus Traditional Exercise on Glycaemic Control in Individuals with Type 2 Diabetes Mellitus – A Randomized Controlled Trial.

Alex Collins Mathews[1], Ajith Kumar Pichai*[1], Najla Abdul Rasheed[2], Thillaigovindarajan Senthil Kumar[3]

Corresponding Author: Ajith Kumar Pichai MPT (Cardiopulmonary sciences), Sri Ramachandra Faculty of Physiotherapy, Sri Ramachandra Institute of Higher Education and Research (DU).
Email: ajithkumarp@sriramachandra.edu.in

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ABSTRACT

Introduction: Diabetes mellitus a metabolic disorder associated with major risk factor for multiple chronic complications, that requires an effective strategies to improve or reverse the complications. Blood flow restriction training (BFRT) recently emerged as a promising adjunct, demonstrating higher potential in improving the metabolic parameters when coupled with aerobics and resistant exercises. This study aimed to investigate effect of BFRT compared with Traditional exercise on improving metabolic parameters (HbA1c, FBS), functional capacity parameters (6MWD and Vo2), and Body composition in individuals with type 2 Diabetes mellitus.

Methodology: A Randomized controlled trial, thirty adults diagnosed with Type 2 diabetes mellitus were randomly assigned into BFRT group (n=15) and Traditional exercise training group (n=15). Both groups received supervised training for a period of 12weeks, each lasting 45 minutes, 3 times a week. The outcome measures evaluated were glycated haemoglobin (HbA1c), fasting blood sugar, 6-Minute Walk Test, VO2 and body fat percentage.

Result: After the 12 weeks, both groups improved across with their clinical outcomes. The BFRT group showed a significantly greater improvements in functional capacity, with higher gains compared to control group ($p<0.001$). Between group analysis revealed significant differences favouring BFRT group for clinical outcomes ($p <0.001$), with moderate effect sizes. Although reduction in body fat percentage was observed in both groups, between group difference was not statistically significant ($p>0.05$).

Conclusion: Based on our findings, BFRT has been a notable technique used along with conventional training to improve the Metabolic parameters and aerobic capacity in individuals with type 2 diabetes mellitus.

Keywords: *Blood flow restriction training, low-moderate intensity exercises, Physical activity, Functional capacity, Type 2 Diabetes Mellitus, Body Composition, Glycaemic Control.*

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INTRODUCTION

Diabetes Mellitus was the 7th leading cause of Years Living with Disability (YLD) worldwide, with 41.2 million cases. The Global prevalence of diabetes is estimated to reach 9.5 million by 2025, a 13% rise from 2021. The International Diabetes Federation's (IDF) diabetes atlas forecasts for global diabetes prevalence were found to be severely underestimated, with an underestimation of 194.5 million instances (Ferrari et al., 2024) (Ogle et al., 2025) (Tönnies et al., 2021). Alterations in body composition, specifically increased fat mass and reduced lean muscle mass, play a central role in the pathogenesis and progression of type 2 diabetes mellitus (T2DM) (An et al., 2024). Visceral adiposity promotes insulin resistance via multiple mechanisms, including the secretion of pro-inflammatory cytokines such as TNF-α and IL-6, and increased delivery of free fatty acids and inflammatory mediators to the liver via the portal circulation. These processes impair insulin signalling in skeletal muscle and hepatocytes and contribute to chronic hyperglycaemia.

Exercise has been a cornerstone of the reversal of diabetes mellitus, as it improves insulin action through both insulin-dependent and contraction-mediated pathways (Kanaley et al., 2022) (Sampath Kumar et al., 2019). Skeletal muscle contraction rapidly stimulates GLUT4 translocation to the cell membrane, increasing glucose uptake independently of insulin; some exercise effects on muscle signalling can persist for up to 48 hours after a

**Author for Correspondence: ajithkumarp@sriramachandra.edu.in*

session (Amaravadi et al., 2024) (Reusch et al., 2013). Individuals with type 2 diabetes often have comorbidities or physical limitations that restrict their ability to perform higher-load conventional exercise (Pan et al., 2018). Blood Flow Restriction Training (BFRT) has gained attention as a feasible alternative that can elicit comparable physiological benefits at much lower loads (Lorenz et al., 2021). Blood Flow Restriction Training (BFRT) involves the application of a localised hypoxic environment that increases metabolic stress, promotes recruitment of fast-twitch muscle fibres, and activates anabolic signalling pathways even with light loads (Hughes et al., 2017).

Mechanistically, BFRT may enhance glucose uptake through increases in GLUT4 expression and improvements in mitochondrial function, making it a promising strategy for improving glycaemic control in populations unable to perform higher-intensity exercise (Centner et al., 2019) (Nascimento et al., 2022). Evidence from healthy and clinical populations shows that BFRT induced muscle hypertrophy and strength gains with loads substantially below traditional high-load resistance training (often 20–30% 1-RM) and improved aerobic capacity (Baker et al., 2020). Blood flow restriction training has emerged as a novel and promising exercise modality that involve the application of external pressure to proximal limbs, partially restricting the arterial flow and venous return. (Zhang et al., 2024) (Saatmann et al., 2021a). This technique has been shown to induce physiological adaptations similar to those achieved with high intensity training, including increased muscle hypertrophy, strength gains and enhanced metabolic responses. The metabolic stress paves a way to enhance the muscle fibre usage and hormonal responses by promoting anabolic and metabolic adaptations. (Chen et al., 2025) (Saatmann et al., 2021a)

BFRT shown to improve the body composition by acting on the glucolipid metabolism and thereby preventing the risk associated with increased body weight. Given the clinical importance of optimizing the body composition and metabolic parameters further studies are warranted.(Su et al., 2023a) (AbuEid, 2025a)Despite the evidence on BFRT specifically in people with T2DM remaining low. Limited trials have directly compared BFRT combined with low-to-moderate intensity exercise against conventional moderate-intensity exercise for glycaemic outcomes. To address this gap, the present randomized controlled trial was designed to compare the effects of BFRT combined with low-to-moderate intensity exercise versus conventional moderate-intensity exercise alone on glycaemic control (HbA1c and fasting blood sugar) and functional outcomes in adults with T2DM. We hypothesize that BFRT will produce greater improvements in HbA1c and fasting glucose and superior progress in body composition compared with conventional exercise.

METHODOLOGY:

Clinically confirmed diagnosis of type 2 diabetes for ≥2 years, under stable antidiabetic medication for a minimum of 3 months, medically cleared to participate in supervised exercise sessions, aged 35-55years are included for the trial. Subjects with uncontrolled hypertension or unstable cardiac conditions, peripheral neuropathy, vascular disease, or open wounds on the limbs and musculoskeletal limitations restricting lower-limb movement, any contraindication to exercise or blood-flow restriction, unwillingness to participate or inability to attend ≥75% of sessions are excluded. Participants were recruited based on the study's inclusion criteria and Randomized using the block randomization with a block size of 4 into two groups.

Samples: The sample size was estimated using power calculations for the outcome with an effect size of 0.53, power (1-beta), and a 90% confidence level, with a sample size of 38, based on the evidence (Ma et al., 2024), using the nMaster 2.0 software. All participants were screened using AACVPR risk-stratification guidelines, and moderate-risk participants, after obtaining informed consent. The experimental group (15) were introduced to blood flow restriction training combined with low-moderate intensity exercises for 12 weeks, and the control group (15) received routine exercises as per the hospital protocol of clinical practice guidelines for 12 weeks. The Institutional Ethics Committee clearance was obtained from SRIHER (DU) (Ref. No. CSP-III/25/JUN/22/279) and prospectively registered with the Clinical Trials Registry of India (CTRI/2025/08/092499).

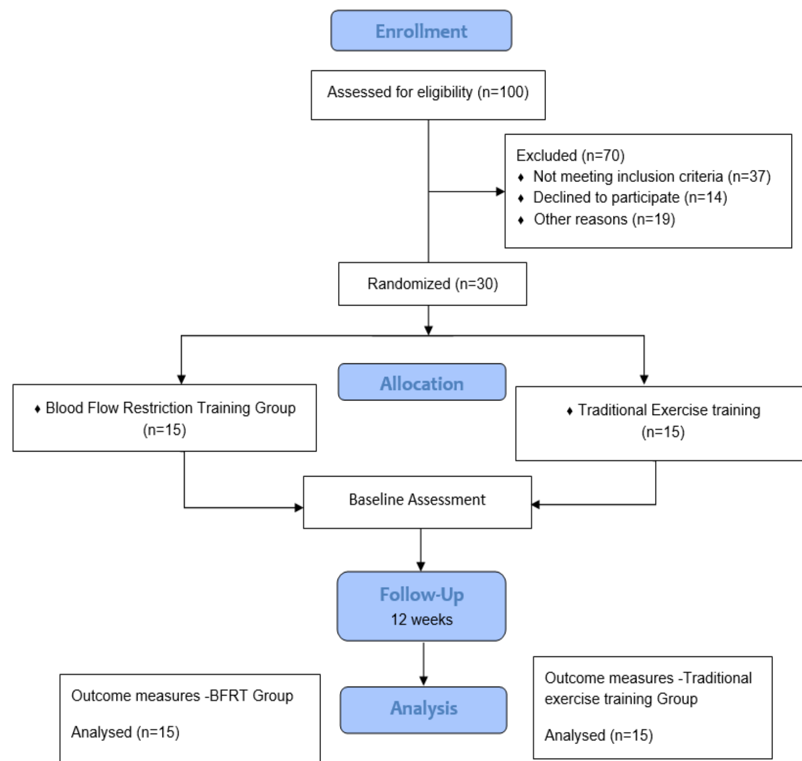

Figure 1: Consort Participants flow.

Adherence and Safety Parameters:
Each participant was scheduled for 24 sessions (3 sessions/week × 12 weeks). Session attendance was recorded in an adherence logbook. Completion of ≥ 20sessions (≥ 85 %) was considered adequate adherence, while 70–84 % attendance was classified as moderate adherence. Missed sessions were rescheduled within the same week whenever feasible. No adverse events, injuries, or exercise-related complications were reported during the study. Training was stopped immediately if participants experienced symptoms like chest pain, severe breathlessness, dizziness or near-syncope, distal numbness, tingling, pallor, or coldness, sharp or escalating musculoskeletal pain any symptom suggestive of circulatory compromise. All adverse events were documented and reviewed by a medical professional

Procedure:

Exercise Protocol

a. Intervention Group:
Participants performed a structured, supervised upper- and lower-limb exercise program incorporating low-load resistance and aerobic training under partial blood flow restriction**.** Elastic occlusion bands were placed at the most proximal portion of the limbs (arms and thighs) during exercise. The cuff pressure was standardized to approximately 10% of limb circumference**,** corresponding to ~40% of arterial occlusion pressure (AOP**)** (Aniceto & da Silva Leandro, 2022). Bands remained inflated throughout the exercise sets and were deflated during inter-exercise rest intervals. A physiotherapist supervised all sessions, and participants were closely monitored for pain, numbness, or dizziness.

b. Control Group
A structured, supervised upper- and lower-limb exercise program incorporating low-load resistance and aerobic training was incorporated. All sessions were supervised by a physiotherapist, and participants were closely monitored for pain, dizziness, etc. The participants were trained three times a week, beginning with an initial phase consisting of low-load resistance training, followed by a progression phase with increased exercise volume.

Results
Following 12 weeks of intervention, the experimental group demonstrated a marked improvement in 6-minute walk distance and VO2 in the paired analysis with baseline values ($p < 0.05$). However, no statistically viable difference was observed between the intervention and control group for these outcomes ($p > 0.05$). Body fat%, HbA1c and FBS were found to be non-significant in both within-group and between-group analysis ($p > 0.05$). However, favourable trends were observed across most measures in the intervention group despite the absence of statistical significance, suggesting potential beneficial effects of the exercise program that may become significant with a longer intervention duration or larger sample size.

DISCUSSION

Glycaemic Control:
Mild to moderate intensity training combined with Blood flow restriction for a period of 12 weeks has produced improvements in the glycaemic control of diabetic individuals compared to traditional exercises alone, even though the result is not statistically significant. From the data obtained, in the experimental group, the HbA1c value

dropped from 8.45± 1.30 to 8.32 ± 1.19% while it had decreased from 8.20 ±0.5 to 8.15 ± 0.51% in the control group. Similarly, FBS declined by 2.24% in the BFRT group while it reduced by 1.28% in the control group. These changes occurred as a result of BFRT strongly stimulating insulin-independent glucose uptake with the help of skeletal muscle. Muscle contraction BFR training increases calcium entry into muscle cells, which activates the CaMKII and AMPK signalling, which helps in GLUT4 translocation to the sarcolemma. Our study finding is in alignment with Christiansen et al., who found that 6 weeks of cycling with BFR had raised muscle GLUT4 content by (≈+28%) and net glucose uptake in the BFR-trained leg compared to the control group Christiansen, D et al.). BFRT has also been shown to support NO and antioxidant defences in muscles, which in turn improves glucose uptake. Additionally, the increased metabolic stress and lactate levels by BFRT can cause a rise in counter-regulatory hormones; growth hormone and IGF-1, which in turn support muscle insulin sensitivity and promote glycogen storage (Saatmann et al., 2021b) (AbuEid, 2025b) showed that 8 weeks of BFR walking in T2DM patients had reduced fasting glucose levels (~8%) and significantly raised VO_2 max levels (AbuEid, 2025b). A majority of studies supported the fact that BFRT may reduce HbA1c levels by enhancing GLUT4 translocation. Therefore, we support that BFRT can intensify both insulin-dependent and insulin-independent pathways of glucose disposal, which leads to significant levels of glycaemic improvements, including HbA1c and FBS.

Body Composition-

The BFRT group has shown significant reductions in adiposity as compared to the control group. Body fat percentage had decreased from 32.07 ± 5.21% to 30.0 ± 5.05% in the BFRT, whereas a smaller reduction, from 31.2 ± 2.4% to 30.41 ± 2.80%, had been found in the control group. This fat loss can occur due to multiple specific adaptations to BFRT. First, BFRT can significantly facilitate muscle anabolism through metabolite-driven Motor signalling. The accumulated metabolites and the swollen cells during BFRT can initiate mTOR/p70S6K and MAPK pathways, and help in circulating GH/IGF-1 levels to rise, hence they improve muscle protein synthesis despite low mechanical loads (Dagenais et al., 2016). BFRT may produce an elevation in circulating growth hormone concentration (Takarada et al., 2000), which may support muscle protein synthesis and lean mass acceleration. An increase in lean mass may indirectly elevate resting metabolic rate, thereby contributing to a reduction in fat mass. Secondly, BFRT induce substantial metabolic stress and local hypoxia, leading to disturbance in cellular energy and an increase in the ADP: ATP ratio (Abe et al., 2010). Such conditions can strongly stimulate AMPK/ACC signalling (via increased ADP: ATP ratios), thus improving fatty-acid oxidation (Winder & Hardie, 2026). In other words, BFRT can shift substrate use toward lipid utilisation during and after exercise. The above mechanisms are in line with our findings and previous studies, like Su et al., who noted that obese subjects undergoing low-intensity BFR-RT showed a marked reduction in body fat% and waist-to-hip ratio and an increase in lean mass. Similarly, (Su et al., 2023b) found that BFRT in older T2DM patients made significant reductions in fat mass and BMI. In conclusion, BFRT occurs to strengthen the hormonal and intracellular signals (e.g. GH/IGF-1, AMPK activation) that, in turn, amplify muscle growth and lipolysis. The result is accelerated fat loss and an improved body composition – a particularly useful effect in T2DM, where visceral obesity and muscle loss can exaggerate insulin resistance.

FUNCTIONAL CAPACITY:

BFRT can produce remarkable changes in aerobic fitness and endurance. The BFR group in this study has shown a greater level of 6MWD when compared to the control group. These findings are in alignment with the study by Abe T 2010 where BFRT administered for a long period of time has brought vascular and muscular adaptations: it induces angiogenesis through vascular endothelial growth factor (VEGF) and hypoxia-inducible factor-1α (HIF-1α) and capillary recruitment in muscle, hence improving blood flow and also oxygen delivery (Abe et al., 2010). These adaptations, along with increased mitochondrial content (p38/PGC-1α–driven), are found to increase oxidative metabolism, which supports enhanced aerobic metabolism (Christiansen et al., 2019). Alongside, BFRT efficiently activates fast-twitch fibres even during low-intensity exercises due to heightened metabolic stress and local hypoxia. This early recruitment of type II fibres produces greater gain in muscle power and endurance than low-intensity exercise alone. Therefore, submaximal tasks like walking become less demanding and easy to accomplish, thereby bringing improvements in 6MWD. Studies show that when moderate intensity exercise is combined with BFR, it induces a greater demand on the cardiovascular system when compared to standard non-BFR groups (elevated TSBP/DBP and cardiac work). Over time, this stimulus can lead to greater improvements in VO2 and 6MWD (Suggitt et al., 2024). **Limitations of the study**: The study has a few limitations. Firstly, the use of circumference-based pressure estimation may have resulted in variability in actual occlusion pressure among participants. Secondly, only 20-30% of AOP has been applied to the interventional group instead of 40-60% of AOP, leading to possible differences in clinical effects.

CONCLUSION:

The results of this study showed a marked increase in VO_2 max after 12 weeks of BFR walking when compared to the control group. Thus, the improved muscle perfusion along with increased capillarization and enhanced muscle oxidative capacity with BFRT can explain its remarkable effect on functional fitness. Our findings found that when BFRT is incorporated alongside the standard exercise regimen, there can be a marked improvement in physical function and aerobic capacity when compared with standard care alone. Clinically, the large gains in 6MWD and VO_2 highlight BFRT's potential to improve functional capacity. Future research should therefore involve larger, longer-term randomised trials with a standardised BFRT protocol with at least 40-60% of arterial occlusion

pressure to verify these results, explicitly measuring insulin sensitivity.

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Table 1: Baseline Demographic and Clinical Characteristics of Study Participants

Baseline variables	Control (n=15)	BFRT (n=15)	p-value
Age	54.2(5.9)	52.4(9.2)	0.495

Gender (%) (n)			
Female	26.6% (4)	46.6% (7)	0.334
Male	73.3% (11)	53.3% (8)	
Height	164.1(6.03)	164.4(6.5)	0.897
Weight	72.6(6.1)	70.8(7.03)	0.355
BMI	26.8(0.8)	26.2(1.2)	0.121
Systolic BP	136.6(4.5)	137.13(5.16)	0.056
Diastolic BP	87.4(3.1)	86.6(2.9)	0.001
Baseline HR	79.2(4.4)	78.6(3.2)	0.544
Duration of Diabetes (Years)	7(2.1)	6.6(2.5)	0.708
Comorbidities (%) (n)			
Hypertension	26.6% (4)	26.6% (4)	0.818
Hypertension + Dyslipidaemia	53.3% (8)	60% (9)	
None	20% (3)	13.3% (2)	

Table 2: Comparison of outcomes between groups and within groups before and after the intervention.

	Control group			**BFRT group**			**Adjusted mean difference**		
Outcomes	***Pre***	***Post***	***p-value***	***Pre***	***Post***	***p-value***	***Control Vs BFRT***	***p-value***	***Effect Size***
6MWD	330 (70)	428 (55)	<.0001	334 (69)	517 (83)	<.0001	86.71	0.0002	0.406
Vo2 Max	5.3 (0.5)	6 (0.5)	<.0001	5.3 (0.5)	8.5 (1.5)	<.0001	0.49	0.0003	0.382
HbA1C	8.1 (0.5)	8 (0.5)	0.753	8.5 (1)	7.5 (1)	0.026	0.87	0.0000	0.454
FBS	148 (11)	161 (13)	0.015	154 (21)	140 (22)	<.003	24.51	0.0001	0.412
Body fat %	23 (14)	30(2)	0.590	31 (5)	30 (5)	0.068	0.35	0.0692	0.117

Table 3. Exercise Prescription for Blood Flow Restriction Training.

Component	**Split A (Initial Phase, Weeks 1–2)**	**Split B (Progression Phase, After 2 weeks)**
Frequency	3 sessions per week	3 sessions per week
Intensity	~20–30% of 1RM dumbbell load; 'cuff pressure ≈ 40% AOP (or ~15% of arm circumference)	~20–30% of 1RM dumbbell load; cuff pressure ≈ 40% AOP (or ~15% of arm circumference)
Time	~30-35 minutes per session (3 resistance exercises + 3 minutes BFRT aerobics)	~45 minutes per session (4 resistance exercises + 5 minutes BFRT aerobics)
Type	Dumb bell resistance training 3 exercises + aerobic drills	Dumb bell resistance training 4 exercises + aerobic drills

[RM: Repetition Maximum, AOP: Arterial occlusion pressure, BFRT: Blood flow restriction training]

Table 3: Comparison of Exercise response after the 12 weeks of intervention between groups.

	Control group (n=15)	**BFRT (n=15)**	**p-value**
Peak HR	29(5.3)	30.3(3.1)	0.413
Recovery HR	13.7(2.7)	16.6(3.5)	0.11

RPE	13.4(1.1)	11.8(0.8)	0.0003

[RPE- Rating of Perceived Exertion; HR- Heart Rate; BFRT- Blood Flow Restriction Training;

Figure 1: Comparison of 6-minute walked distance between the groups.

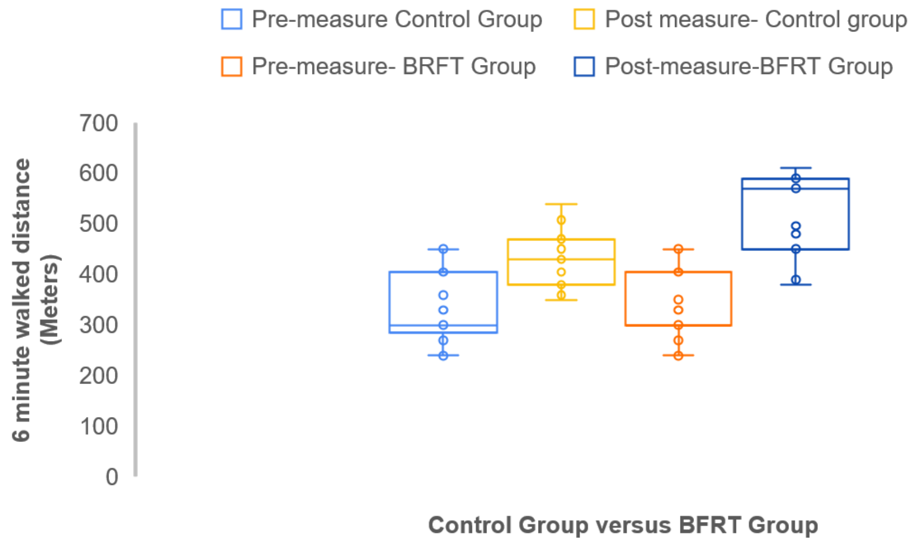

Figure 2: Comparison of HbA1C between groups.