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Research Article

Potential Role of Blood Flow Restriction Training in Chronic Kidney Disease

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Abstract

Blood flow restriction training (BFRT) is an efficacious exercise modality frequently employed in the rehabilitation of individuals with musculoskeletal and cardiovascular disorders. This approach facilitates low-intensity exercise while delivering substantial stimulation intensity, making it particularly advantageous for those unable to perform high-load exercises. Patients with chronic kidney disease (CKD) often face challenges such as physical inactivity, musculoskeletal deterioration, and cardiovascular complications. The integration of exercise with BFR training has demonstrated potential in enhancing the health outcomes of CKD patients, possibly exceeding the benefits of exercise alone. This review seeks to synthesize relevant literature, elucidate the potential impacts and mechanisms of action of combining BFR training with rehabilitation exercises on the health of CKD patients, and offer practical guidance on exercise prescription, safety considerations, and risk mitigation.

Keywords: Blood flow restriction training; Chronic kidney disease; Hemodialysis; Exercise rehabilitation

Introduction

Chronic kidney disease (CKD) represents a major public health concern and is anticipated to rank as the fifth leading cause of life loss globally by 2040 [1]. CKD is categorized into five stages, with the most advanced stage requiring dialysis intervention. The condition is associated with a range of clinical manifestations, including sleep disturbances, decreased cardiorespiratory fitness, reduced muscle mass, fatigue, and anorexia [2]. In Asia, approximately 434.3 million adults are affected by CKD, with up to 65.6 million individuals experiencing advanced stages of the disease [3]. In addition to pharmacological and hemodialysis therapies, many studies have indicated that exercise may also mitigate symptoms in CKD patients [4,5]. Exercise has been demonstrated to confer multiple health benefits for individuals with CKD. A number of studies have identified that both resistance training (RT) and aerobic exercise (AE) exert beneficial effects on CKD patients. RT has been associated with increased muscle strength, prevention of sarcopenia, enhancement of renal function, reduction in blood pressure, and bolstering of the body's anti-inflammatory defenses [6,7]. AE has been shown to improve cardiorespiratory fitness, mitigate cardiovascular complications, and alleviate symptoms associated with hemodialysis, including restless leg syndrome, depression, muscle spasms, and fatigue [8,9]. However, Traditional exercise programs frequently demand high intensity, which may deter individuals with CKD from engaging in such activities [2]. To mitigate this concern, BFRT emerges as a viable alternative. BFRT involves the application of an inflatable or elastic cuff on the proximal portion of a limb to restrict blood flow to the distal region [10]. This technique enables CKD patients to perform exercises at lower intensities while still attaining benefits comparable to those of moderate to high-intensity exercise [11]. By diminishing the mechanical load on the limbs and eliciting substantial metabolic stress, BFRT presents a more accessible and efficacious exercise option for individuals with CKD.

Methodology

Literature Search

A comprehensive literature search was conducted using PubMed, Web of Science, and Scopus databases with keywords such as "blood flow restriction training," "chronic kidney disease," "hemodialysis," "exercise rehabilitation," and "rehabilitation training." Studies published in English from January 2000 to January 2025 were included to ensure the inclusion of the most recent and relevant research findings. The search strategy involved combining these keywords with Boolean operators (AND, OR) to narrow down the search results. The search process is illustrated in Figure 1.

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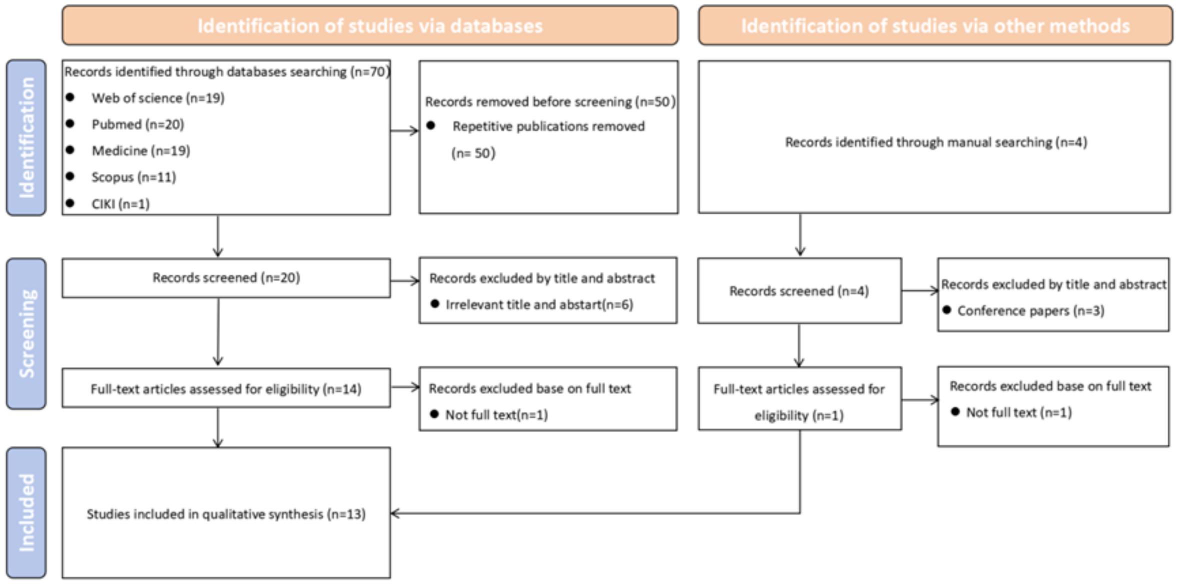

Figure 1: Flow chart of the study selection.

Inclusion and Exclusion Criteria

Inclusion Criteria: Peer-reviewed articles focusing on the effects of BFRT in CKD patients, reporting physiological outcomes such as muscle strength, cardiovascular health, and inflammatory markers, and providing detailed methodologies and results.

Exclusion Criteria: Articles not specifically addressing BFRT in CKD, studies with insufficient data or methodological flaws, and non-peer-reviewed articles.

Data Extraction and Analysis

Data extraction focused on study design, participant characteristics, intervention modes, outcome measures, and key findings. Studies were critically appraised for their methodological quality and relevance to the research question. The final inclusion results are shown in Table 1.

Potential Use of Blood Flow Restriction Training in Chronic Kidney Disease

Blood Flow Restriction Combined with Resistance Training

BFRT was initially introduced in the exercise population as a method to enhance the effects of increasing muscle strength when combined with RT [12,16]. The American Association of Sports Medicine states that traditional RT is only effective when muscle contraction reaches 70% of the one-repetition maximum (1 RM), and the promotion of muscle hypertrophy is not significant when the contraction is below 70% of 1 RM [13]. However, BFRT can achieve the desired effect of high-intensity RT by utilizing only 20% to 40% of 1 RM, making it an efficient method for promoting muscle hypertrophy [14].

Evidence from various studies supports the efficacy of BFRT+RT in enhancing muscle strength and hypertrophy [15-17]. For instance, a study on weightlifters who underwent 6 weeks of squat training found that the BFRT+RT group (30% 1RM, 2 times/week) experienced greater increases in thigh muscle strength and cross-sectional area compared to the RT group alone [15]. Similar results were observed in studies focusing on the upper limbs, where healthy subjects who underwent 8 weeks of BFRT (20% 1RM, twice/week) exhibited more significant increases in upper arm lean body mass, strength, and muscle endurance compared to high-intensity RT alone [18]. These findings were further confirmed in studies involving patients with CKD. Silva et al. [19] demonstrated that eight weeks of BFRT combined with low-intensity upper limb RT significantly improved muscle strength and upper arm circumference in CKD patients. Additionally, the BFRT group experienced lower levels of discomfort during exercise compared to the traditional RT group [20]. These studies suggest that BFRT may serve as an effective exercise modality to maintain or enhance muscle strength in CKD patients.

BFRT+RT also has a positive impact on the cardiovascular system. In a study involving healthy adults, four weeks of knee extension training at 30%1RM, four times a week, with restricted blood flow to the lower extremities, resulted in superior improvements in macrovascular and microvascular function compared to a control group with a 75%1RM exercise load intervention [21]. Similar results were observed after four weeks of training at 20%1RM [22]. Another study involving eight weeks of elbow flexion and extension training found that the BFRT group (30%1RM, five times a week) had increased production of vascular endothelial growth factor in their muscles, while experiencing significant reductions in resting heart rate and cardiac output, when compared to a group without BFRT intervention [23]. Moreover, compared to high/low-intensity RT alone, BFRT with low-intensity RT is more beneficial for blood pressure regulation and autonomic nervous system modulation in patients with CKD [24]. These findings suggest that BFRT+RT may be an effective exercise strategy for improving cardiovascular issues in patients with chronic kidney disease. Patients with CKD often experience a persistent systemic inflammatory response. Recent studies have shown that BFRT can effectively modulate this inflammatory response. For instance, one study found that after a short-term (3-day) intervention combining BFRT with low-intensity

Table 1: The final inclusion results.

Author	Research design	Objects	Intervention	Outcome Measures	Key Findings
Deus, Lysleine Alves de et al.	RCT	stage-2 CKD(n=105)	BFRT + Low-Intensity RT (six mouths)	Inflammatory Markers, Glucose Homeostasis	BFRT significantly reduced inflammatory markers and improved glucose homeostasis.
Barbosa, Jefferson Bn et al.	RCT	stage-4/5 CKD (n=26)	BFRT + Low-Intensity RT (six mouths)	Muscle Strength, Vascular health	BFRT increased cephalic vein diameters in both groups and was effective in increasing the diameter of the radial artery.
Corrêa, Hugo de Luca et al	RCT	Adult CKD patients on HD(n=48)	BFRT + RT (50 min)	Prothrombotic agent D-dimer	Patients with borderline baseline D-dimer levels (400-490 ng/mL) displayed increased risk of elevating D-dimer over the normal range (≥500 ng/mL)
Corrêa, Hugo Luca et al.	RCT	stage-2 CKD(n=105)	BFRT + Low-Intensity RT (six mouths)	GFR, Uremic Parameters, Cytokine Profile	Resistance training for 6 months in stage 2 CKD patients with and without BFRS maintains GFR, improves uremic parameters, cytokine profile regulation, and the klotho-FGF23 axis, slowing disease progression.
Corrêa, Hugo Luca et al	RCT	Hypertensive patients in stage 2 of CKD(n=90)	BFRT + Low-Intensity RT (six months)	Blood Pressure, Oxidative Stress	Low-load RT+BFR is a promising non-pharmacological strategy to control blood pressure, oxidative stress, vasoactive peptides, and consequently, attenuate the decrease of the eGFR.
Silva, Isabella B et al.	RCT	Adult CKD patients on HD(n=26)	BFRT + RT (eight weeks)	Muscle Strength	BFRT has a muscle-building effect similar to RT
de Deus, Lysleine Alves et al.	RCT	Stages 1 to 5 who do not need hemodialysis(n=10533)	BFRT + RT (six months)	Antioxidant Defense, Cardiac Autonomic Function	Resistance training with and without blood flow restriction improved antioxidant defence, decreased pro-oxidative myeloperoxidase, improved cardiac autonomic function, and slowed the decrease in renal function.
Nobre, Rony et al.	RCT	Adult CKD patients on HD(n=6074)	BFRT + AE (twelve weeks)	Hemodynamic Responses	Intradialytic aerobic exercise with blood flow restriction does not seem to be associated with a higher hemodynamic burden than conventional aerobic exercise.
Clarkson, Matthew J et al.	RCT	Adult CKD patients on HD(n=75)	BFRT + AE (three months)	Physiological Outcomes	Blood flow restriction exercise improves key physiological outcomes of aerobic exercise affecting independence and quality of life, while reducing the burden on patients.
Cardoso, Rodrigo Kohn et al.	RCT	Adult CKD patients on HD(n=66)	BFRT + AE (twelve weeks)	Walking Endurance	Among chronic kidney disease patients, intradialytic exercise of low/moderate intensity with blood flow restriction was more effective in improving walking endurance than conventional exercise or no exercise.
Cardoso, Rodrigo Kohn et al.	RCT	Adult CKD patients on HD(n=42)	BFRT + AE (eight weeks)	General Health	The use of BFRT for exercise programs during HD can improve the general health of this population
Clarkson, Matthew J et al.	Crossover Study	End stage kidney disease patients(n=10)	BFRT + AE	Hemodynamic Safety	Hemodynamic safety and tolerability of restricted blood flow during hemodialysis aerobic exercise were comparable to standard aerobic exercise.
Dias, Etiene C et al.	Crossover Study	Adult CKD patients on HD(n=22)	BFRT + AE (four HD sessions)	Hemodialysis Adequacy	Intradialytic exercise with BFR was more effective than standard exercise in increasing HD adequacy.

RCT: Randomized Clinical Trial; RT: Resistance Training; AE: Aerobic Exercise.

RT, there was a significant 163% increase in plasma M2-macrophages, which are known to inhibit inflammation, and an 18% decrease in interleukin-6 (IL-6) levels. In contrast, no such changes were observed in the high-intensity RT group [25]. Another study demonstrated that an intermediate-term (8-week) BFRT combined with low-intensity RT regimen reduced levels of inflammatory biomarkers, including CD40 ligands, and serum C-reactive protein concentration [26,27]. Furthermore, long-term (6-month) BFRT combined with low-intensity RT has been shown to benefit patients with stage 2 CKD. Both the RT-only and BFRT combined with low-intensity RT groups exhibited improvements in uremic parameters and inflammatory response. Although the inflammatory marker monocyte chemotactic protein 1 did not show significant changes, it exhibited a large effect size and a tendency toward improvement [28].

The development of diabetic nephropathy can accelerate the progression of CKD [29]. However, studies have shown that RT-induced glucose regulation can prevent the progression of CKD [30]. Specifically, a 6-month BFRT combined with low-intensity RT intervention has been shown to regulate glucose homeostasis and the hormone mediators of glucose uptake in CKD patients, thereby slowing down the progression of glomerular filtration rate [30].

In conclusion, BFRT combined with RT has shown promising results in improving muscle mass, cardiovascular fitness, reducing inflammation, and maintaining blood glucose homeostasis in patients with CKD. This exercise mode holds great potential as an efficient intervention for CKD patients.

Blood Flow Restriction Combined with Aerobic Training

AE, also known as endurance exercise, is a form of long-term continuous exercise targeting the major muscle groups in the body. This type of exercise relies on aerobic oxidation to generate the energy needed, which not only improves cardiopulmonary function but also regulates human metabolism, such as blood sugar and lipid levels [31]. BFRT combined with AE has been shown to amplify metabolic stress and provide additional benefits beyond those achieved with AE alone.

Research on healthy adults has demonstrated that short-term BFRT (cuff pressure ≥130 mmHg) combined with low-intensity AE is more effective in increasing aerobic capacity and overall health compared to high-intensity AE [32]. This enhanced effect may be attributed to BFRT's ability to improve blood circulation in the limbs, thereby enhancing aerobic capacity [33]. For instance, a 6-week walking exercise with restricted blood flow was found to improve venous compliance in the limbs of untrained elderly females [34]. Additionally, observations on patients with heart failure revealed that six months of BFRT cycling enhanced exercise ability and serum BNP levels (a reflection of left ventricular function) [35]. These findings suggest that BFRT can significantly enhance the effects of AE on muscle endurance and cardiovascular function.

BFRT+AE also demonstrated improvements in muscle mass, a factor that had not been previously examined in studies. For example, in healthy young men, three weeks of blood flow-restricted walking training (50 m/min, 20 min/day, 6 days/week) increased the cross-sectional area and muscle volume of the thigh muscle by 4%-7%, and isometric strength by 8%-10% [36]. In contrast, simple walking training without BFRT had no impact on muscle circumference and strength [36]. When the exercise time was shortened, exercise frequency reduced (40% VO2max, 15 min/day, 3 days/week), and the intervention period extended to eight weeks, individuals in the BFRT group still experienced muscle hypertrophy and improvement in VO2max in the thigh, while the control group without BFRT did not exhibit any improvement [37]. This phenomenon was further demonstrated in a study of long-distance runners, where after eight weeks of running training (50% heart rate reserve, 15 min/day, 3 days/week), the BFRT group showed significantly better increases in maximum running performance, isometric knee extensor and flexor strength, and knee extensor endurance compared to the non-BFRT group [38]. These findings suggest that BFRT+AE is more effective in promoting muscle mass compared to AE alone. Therefore, it is speculated that BFRT+AE, similar to BFRT+RT, can address musculoskeletal decline and cardiovascular system diseases in patients with CKD, making it a suitable exercise method for this patient population.

In fact, BFRT+AE is highly recommended for CKD patients undergoing dialysis treatment [9]. Previous studies have suggested that BFRT+AE may lead to abnormal hemodynamics, but other studies have found that patients undergoing dialysis experience similar hemodynamic safety and tolerability during AE participation as with standard aerobic exercise [39]. It is important to note that BFRT intervention during dialysis treatment is more effective in improving the adequacy of hemodialysis compared to AE alone [40]. Additionally, AE with blood flow restriction during dialysis can significantly enhance the walking ability of CKD patients compared to AE alone or no exercise, thereby improving their quality of life and reducing their burden [41,42]. In conclusion, BFRT combined with low-intensity RT or AE is beneficial for improving the overall health of both healthy individuals and CKD patients. It has been proven that BFRT is more suitable for the CKD population than traditional forms of exercise, and it is recommended for use in the exercise rehabilitation of CKD patients.

Potential Mechanisms of Blood Flow Restriction Training to Improve Renal Function in Chronic Kidney Disease

The mechanisms by which BFRT mitigates muscle mass loss and cardiovascular issues are becoming increasingly well-understood. BFRT is believed to amplify metabolic stress, a key factor in promoting muscle hypertrophy and enhancing cardiovascular fitness [43]. Additionally, the low mechanical tension resulting from the applied load can also stimulate muscle growth [43]. These exercise-induced effects can be attributed to several mechanisms, including changes in muscle fiber recruitment [11], enhanced muscle cell ion transport [44], improved mitochondrial function [33], hormone regulation [45], cell swelling [43], and increased nitric oxide production [46]. Collectively, these mechanisms contribute to muscle growth and cardiovascular health. In addition, the anti-inflammatory, renal function-related protein regulation, and antioxidant effects of BFRT offer extra benefits for patients with CKD.

Anti-inflammatory Effects

BFRT's capacity to improve renal function is attributed to its anti-inflammatory and antioxidant properties. Chronic inflammation is a significant contributor to kidney damage and the progression of CKD [47]. Recent research has shown that BFRT combined with RT can increase the release of irisin and SIRT-1 in muscle tissue [30]. These proteins subsequently induce the release of adiponectin, which not only promotes the expression of anti-inflammatory substances [48-50], but also activates the AMPK/SIRT-1 axis to release more adiponectin, thereby enhancing the anti-inflammatory response [51]. Furthermore, the activation of SIRT-1 inhibits the expression of pro-inflammatory proteins, such as C-reactive protein and leptin, and fibrinolytic factors, such as GDF-15 and TGF-β [51]. Irisin also counteracts fibrosis through its interaction with TGF-β [52,53]. This cascade of physiological events helps to minimize kidney damage and slow the progression of renal lesions, as evidenced by improvements in estimated glomerular filtration rate (eGFR) [30].

Regulation of Renal Function-Related Proteins

Klotho, an anti-aging protein found in the kidney, plays a regulatory role in renal function and possesses anti-inflammatory properties [54]. Conversely, FGF23, a protein derived from bone, is a marker of worsening renal function, as it increases urinary phosphate excretion and reduces calcitriol levels, the active form of vitamin D [55]. Exercise, particularly through the activation of the classical Wnt-β-Catenin pathway, regulates the expression of Klotho and FGF23 [4]. A study involving patients with stage 2 CKD demonstrated that low-intensity BFRT had effects similar to high-intensity RT in regulating FGF23 expression and increasing Klotho concentration [55]. This suggests that BFRT may enhance the activation of the Wnt-β-Catenin pathway through resistance training, thereby influencing kidney function.

Antioxidant Defense Mechanisms

BFRT also regulates the level of reactive oxygen species (ROS) after exercise, thereby improving the antioxidant capacity of CKD patients [56]. In a 6-month study, CKD patients undergoing BFRT+RT exhibited decreased levels of myeloperoxidase, a pro-oxidation marker, and increased levels of p-oxophosphorase-1, an antioxidant marker, in their plasma. This indicates enhanced antioxidant defense and reduced oxidative stress [56]. Similar results were observed in hypertensive CKD patients after 6 months of low-load RT+BFRT intervention [20]. The ischemic and hypoxic conditions created by the hemostatic cuff during BFRT lead to reduced skeletal muscle mitochondrial biosynthesis and decreased ROS production [57]. Upon pressure release, oxygen restoration below the hemostatic site causes a sudden increase in ROS levels, accompanied by a significant upregulation of skeletal muscle antioxidant enzymes, such as CuZn-SOD, GPX-1, and CAT, resulting in overall improved antioxidant defense [58,59].

Safety of Blood Flow Restriction Training

Safety concerns associated with BFRT have historically included thrombosis, abnormal cardiovascular reactions, rhabdomyolysis, and limb numbness. These concerns have contributed to its limited adoption among clinicians.

Thrombus Problems

There is ongoing debate regarding the potential of BFRT to cause blood clots. Some scholars argue that long-term inappropriate arterial occlusion pressure during BFRT may have harmful effects on endothelial cells [60]. This is because prolonged restriction of blood flow can negatively impact the inner wall of blood vessels, increasing the risk of necrosis and shedding of vascular endothelial cells. Additionally, it can expose subcutaneous collagen, activate the coagulation system, and increase blood viscosity, thereby potentially leading to venous thrombosis [61].

However, a study conducted on patients undergoing orthopedic surgery found that 12 BFRT+RT sessions performed 6 weeks after knee surgery did not show any signs of thrombosis on dual ultrasound scans [62]. Another study by Madarame et al. [63] assessed clotting markers in 9 subjects with a history of ischemic heart disease after bilateral lower limb knee extension at 20%1RM. Although the clotting markers were significantly elevated, they were still within the clinically normal range.

Overall, while there is ongoing discussion about the potential risks of BFRT on blood clot formation, the available evidence suggests that proper implementation of BFRT protocols may not significantly increase the risk of thrombosis.

Cardiovascular Problems

Abnormal cardiovascular reactions caused by BFRT often occur during exercise. In a study conducted by Thomas et al. [64], it was found that combining BFRT with low-intensity RT and high-intensity RT significantly increased heart rate and blood pressure during exercise, bringing it closer to the upper limit that the human body can regulate. This poses a greater risk of cardiovascular diseases. However, other studies have shown that when BFRT is combined with RT at 20% to 30% of one-repetition maximum (1RM), the acute changes in blood pressure are greater compared to the same intensity group without BFRT, but comparable to or smaller than the changes seen during traditional high-intensity RT [65]. In another study by Zhao et al. [66], the effects of high-intensity RT, low-intensity RT, and BFRT combined with low-intensity RT on hypertensive patients were observed. After 12 weeks of intervention, it was found that the BFRT group experienced a more significant decrease in resting systolic blood pressure. Additionally, the balance adjustment ability of the sympathetic and parasympathetic nerves in this group improved significantly, and the heart rate recovery rate after exercise was also significantly increased. These findings indicate that BFRT not only helps regulate blood pressure but also enhances the autonomic regulatory function of the cardiovascular system.

Rhabdomyolysis

Exercise-induced rhabdomyolysis is a condition that can occur during resistance training. It has been found that low-intensity resistance training with BFRT can have similar muscle-building effects as high-intensity resistance training. However, it is important to note that improper training with BFRT can also lead to rhabdomyolysis, just like traditional high-intensity training [67]. BFRT tends to create higher metabolic stress, which may increase the risk of muscle damage [68]. There have been reported cases of severe rhabdomyolysis in individuals who underwent BFRT, such as a 30-year-old obese Japanese man in 2016 [69]. However, a large survey conducted in Japan showed that the probability of rhabdomyolysis was only 0.008% prior to this case [70]. Subsequent studies have indicated that the incidence of rhabdomyolysis after BFRT is still relatively low, ranging from 0.07% to 0.2% [71]. Therefore, while there is a potential risk of rhabdomyolysis with BFRT, the current risk level remains low.

Numb of the Limbs

In 2018, a survey conducted among 250 BFRT users revealed that numbness was the most frequently reported issue after BFRT [72]. This occurs because the cuff restricts both blood flow and nerve conduction [62]. However, this problem is temporary and can be prevented by selecting the appropriate cuff pressure [73] and limiting the duration of BFR [74].

In summary, while BFRT affects various systems in the body, current safety literature suggests that the risk of adverse events is minimal when BFRT is applied correctly. Therefore, it can be safely utilized in both healthy individuals and specific populations with diseases [68,75].

Risk Prevention of Using Blood Flow Restriction Training

Due to the presence of safety concerns in BFRT, it is crucial to prioritize risk management by implementing standardized risk screening, ensuring proper equipment usage, and making informed exercise prescription selections.

Risk Screening

Before engaging in exercise, individuals with diseases, particularly those with CKD, typically undergo an exercise load test. This test is essential in managing exercise intensity and preventing the exacerbation of cardiovascular problems during physical activity. However, patients undergoing dialysis treatment may not have the physical strength to perform this test. In such cases, the Rating of Perceived Exertion (RPE) is commonly used to gauge exercise intensity. Monitoring heart rate and blood pressure during exercise is crucial, as is assessing the patient's RPE [76]. It is important to note that BFRT may have adverse effects, so it is vital to screen for contraindications before implementing a long-term exercise regimen. The risk screening scale proposed by Nascimento D et al. [77] is the most recent tool for evaluating exercise rehabilitation in patients with chronic diseases. This scale is also applicable to individuals with chronic kidney disease and can greatly assist clinicians in determining whether to incorporate BFRT into the patient's treatment plan.

Use of the Devices

BFRT is convenient and easy to operate, and can be completed without the assistance of large instruments, among which the essential device is the hemostatic cuff, which is divided into two kinds of quantifiable and non-quantifiable.

For quantifiable devices, the most commonly used cuff pressure in the upper limb is 50% systolic blood pressure [32,78,79], and 50% of the resting limb occlusive pressure in the lower limb is the most common in patients with CKD [28,40,41,79]. However, quantifiable devices are economically costly, and elastic cuffs are an option for patients with CKD. Since the elastic cuff cannot be directly quantified, Wilson et al. [80] proposed a test method of subjective perceived pressure, which took 7 levels of subjective pressure (10 levels in total) without discomfort and pain as the pressure standard of the unquantifiable cuff. This method is often used in clinical practice. Patients with CKD are physically weak, so it is recommended to start with cuff pressure below the expected cuff pressure regardless of the device used in such patients [81].

Non-quantifiable devices are mostly elastic cuffs and nylon cuffs. Elastic knee pads are recently proposed compression devices, which are expected to replace the tourniquet used in traditional BFRT due to their greater fatigue stimulation [82]. In the lower extremities, using a cuff of the same width but made of two different materials appeared to make little difference in terms of resting artery occlusion or repeated concentric failure (blood flow substitution) [83]; In the upper limb, the material has a great influence on the resting artery occlusion pressure, which should be noted in the rehabilitation training related to BFRT in the upper limb of CKD patients [84].

In addition to the material of the pressure belt, the length and width of the pressure belt also play a very important role in training. Generally, the length of the arm pressure belt is 50-90cm, the width is 3-5cm, and the length of the leg pressure belt is 90-175cm, the width is 5-18cm [85]. In addition, it is important to note that when applying a tourniquet for the first time, releasing cuff pressure too quickly may cause a temporary increase in [K+] throughout the body, increasing the risk of arrhythmia in the subject [86].

Blood Flow Restriction Training Exercise Prescription Recommendation in Patients With CKD

There is currently no definitive recommendation for exercise prescription for patients with CKD. However, this paper aims to provide a summary of exercise prescriptions for CKD patients based on existing literature. The exercise prescriptions for CKD patients participating in RT and AE are presented in Table 2 and Table 3, respectively. When designing exercise plans for patients with CKD, it is important to adhere to the principles of FITT-VP, with a particular focus on proper exercise load. Many experts believe that using BFRT with a load ranging from 20% to 40% of their one-rep max (1RM) can promote muscle growth and improve muscle strength. However, it has been suggested that when using the lower end of this range (20% 1RM), higher cuff pressure may be necessary to stimulate muscle growth [87]. On the other hand, some studies have shown that using a load of 10% 1RM in patients with cardiovascular diseases can not only activate muscles but also reduce the burden of exercise [88]. In patients with CKD, excessive exercise load can lead to cardiovascular issues and diminish their motivation to exercise [76]. Previous studies on CKD patients have typically started resistance training with a load of 30% 1RM and gradually increased it to 50% 1RM [28,30,89,90]. As for aerobic exercise, it is generally recommended to begin at 60% of the maximum heart rate or with moderate RPE, and then gradually increase it to 70% of the maximum heart rate [40,79].

Table 2: Recommended prescription for BFRT + RT in CKD patients.

Guidelines	
Frequency	Was performed at least three times per week
Intensity	Start with a 30% of 1 RM
Groups	3 groups (8-12 times each)
Group intermittent	1min
Type of movement	Simple resistance movement of the upper and lower limbs
Progress	Gradually increasing to 50% 1 RM, the number of repeats can be reduced
Cuff pressure	Upper limbs: 50% systolic blood pressure; lower limbs: 50% of resting limb occlusion pressure

Table 3: Recommended prescriptions for BFRT + AE in patients with CKD.

Guidelines	
Frequency	Was performed at least three times per week
Intensity	Starting with a 60% maximum heart rate or moderate RPE
Time	20 min
Groups	2 groups (10 minutes for each group)
Group intermittent	20 min
Type of movement	Biking or walking
Progress	Gradually increased to 70% maximum heart rate while the total time was constant
Cuff pressure	Upper limbs: 50% systolic blood pressure; lower limbs: 50% of resting limb occlusion pressure

According to current literature, it is recommended that patients with CKD engage in exercise at least three times per week to increase their daily physical activity [30,91]. The recommended exercise modes include RT which can involve using stretch pullers or elastic bandages, knee flexion and extension, lift dumbbells, sit-ups, etc. [20,28,30,89]. AE is also beneficial and common activities include walking, jogging, and cycling [20,40,42]. Additionally, flexibility training is generally combined with aerobic exercise training and should be done at the beginning and end of the exercise session. However, it is important to note that universal exercise recommendations may not be suitable for all patients with CKD, as individualized approaches are necessary to adapt to the specific disease situation, risk factors, and individual needs in order to maximize the benefits of exercise [92].

Conclusions

A growing body of literature supports the use of BFRT in the exercise rehabilitation of patients with CKD. BFRT, combined with RT and AE, has proven effective in addressing muscle mass decline and cardiovascular issues in CKD patients. It also reduces inflammation, regulates proteins related to kidney function, and enhances the synthesis of antioxidant enzymes, all of which aid in CKD rehabilitation. BFRT can be a suitable exercise method for CKD patients if strict contraindication screening is conducted before intervention and pressure equipment is used correctly with an appropriate exercise prescription. It is important to note that the exercise prescription recommended for CKD patients is based on previous literature and has not been validated across all ethnic groups within the CKD population. Therefore, future research should focus on further investigating exercise rehabilitation for CKD patients, particularly in relation to different ethnic groups.

Declarations

Ethics Approval and Consent to Participate

This study is a review article and does not involve any primary data collection from human participants or animals. Therefore, ethical approval and consent to participate are not applicable.

Consent for Publication

All authors agree to the publication of this manuscript and have provided their consent.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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