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Review

Blood Flow Restriction Training for Tendinopathy Rehabilitation: A Potential Alternative to Traditional Heavy-Load Resistance Training

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Abstract: Tendinopathy is a chronic tendon disease which can cause significant pain and functional limitations for individuals, and which collectively places a tremendous burden on society. Resistance training has long been considered the treatment of choice in the rehabilitation of chronic tendinopathies, with both eccentric and heavy slow resistance training demonstrating positive clinical effects. The application of progressive tendon loads during rehabilitation is essential to not compromise tendon healing, with the precise dosage parameters of resistance training and external loading a critical consideration. Blood-flow restriction training (BFRT) has become an increasingly popular method of resistance training in recent years and has been shown to be an effective method for enhancing muscle strength and hypertrophy in healthy populations and in musculoskeletal rehabilitation. Traditional resistance training for tendinopathy requires the application of heavy training loads, whereas BFRT utilises significantly lower loads and training intensities, which may be more appropriate for certain clinical populations. Despite evidence confirming the positive muscular adaptations derived from BFRT and the clinical benefits found for other musculoskeletal conditions, BFRT has received a dearth of attention in tendon rehabilitation. Therefore, the purpose of this narrative review was threefold: firstly, to give an overview and analysis of the mechanisms and outcomes of BFRT in both healthy populations and in musculoskeletal rehabilitation. Secondly, to give an overview of the evidence to date on the effects of BFRT on healthy tendon properties and clinical outcomes when applied to tendon pathology. Finally, a discussion on the clinical utility of BFRT and its potential applications within tendinopathy rehabilitation, including as a compliment to traditional heavy-load training, is presented.

Keywords: tendinopathy; tendon; rehabilitation; musculoskeletal; blood-flow restriction training

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1. Introduction

Blood-flow restriction training (BFRT), which may also be referred to as Kaatsu, occlusion or hypoxic training, has become an increasingly popular method of resistance training in recent years [1]. BFRT involves the application of straps or pneumatic cuffs around an upper or lower limb extremity, with cuff pressure aiming to partially restrict arterial blood flow, while also occluding venous outflow while the cuff pressure remains intact [2,3]. BFRT has been shown to be an effective resistance training method for enhancing muscle strength and hypertrophy in healthy populations and in the rehabilitation of musculoskeletal pathologies and following orthopaedic surgery [4–7]. Traditional resistance training requires the application of heavy training loads and intensity of 70–100% of 1 repetition maximum (1-RM), whereas low-load BFRT (LL-BFRT) utilises significantly lower loads and training intensities of between 20–40% of 1-RM, which may be more appropriate for some clinical populations unable to train with heavy resistance [8–12]. A plethora of physiological benefits induced by BFRT have been highlighted, included beneficial adaptations to the musculoskeletal, cardiovascular, and endocrine systems with psychosocial benefits also reported such as mood and performance improvement [13–21].

Tendinopathy is a chronic tendon pathology which can cause significant pain and functional limitations for individuals, and which collectively places a tremendous burden on society and healthcare systems [22,23]. In tendinopathy, morphological changes in tendons are seen with ultrasonography and electron microscope studies, including increased tendon thickness, neovascularization, collagen disruption, and fibril disorganization, resulting from repetitive tendon microtrauma [24–26]. Neovascularization has often been linked with pain intensity via neo-vessel ingrowth and neurotransmitter release in tendinopathy and considered to have important diagnostic and prognostic value [27]. Despite being crucial in the tendinopathy repair process, the role of neovascularization has been shown to be largely ambiguous in relation to pain and function in tendinopathy, and likely plays a less important role than the release of inflammatory mediators and cytokines in tendon degeneration in tendinopathy [28]. Macroscopic and microscopic evaluation of tendon samples in tendinopathy, have demonstrated that degeneration of tendon cells plays a key role in the pathophysiology, with inflammation likely playing a key role in the early stages, but not in later stages when tendon cells have become degenerated [29]. Athletes typically experience higher tendinopathy prevalence and incidence due to repetitive jumping, landing, running and change of direction movements [30]. Collectively, tendinopathies have been shown to represent up to 30% of all musculoskeletal conditions requiring primary care intervention, with lower limb tendinopathies such as Achilles and patellar tendinopathy occurring frequently in recreational and elite athletes [31–33].

Resistance training has been regarded as the treatment of choice in the rehabilitation of chronic tendinopathies in recent years, with both eccentric and heavy slow resistance training (HSRT) demonstrating positive clinical effects, with improvements in pain, function, and tendon structure [34,35]. The application of progressive tendon loads during rehabilitation is considered essential to avoid compromising the tendon healing process, with the exercise dosage parameters of resistance training considered critical for optimal tendon response [36]. Training parameters such as high time under tension with traditional heavy loads during the early tendinopathy rehabilitation could compromise tendon healing and may be considered counterproductive [37,38]. Whilst traditional eccentric or HSRT in tendinopathy utilises heavy loads, BFRT is typically prescribed with lower intensity and loads, which may be more tolerable for those patients not able to tolerate high training loads, while still preventing muscle atrophy and promoting hypertrophy and strength increases [12]. Interventional studies have found superior or similar outcomes for pain improvement with LL-BFRT compared to conventional high-load resistance training (HL-RT) for various other musculoskeletal disorders such as osteoarthritis [7]. Recent evidence suggests that LL-BFRT may be a superior method for augmenting muscular adaptations in early musculoskeletal rehabilitation, which has been found to have comparable outcomes for inducing muscular hypertrophy and for increasing muscular strength compared to HL-RT [39]. The mechanisms of action of BFRT in muscular adaptation are not fully elucidated but are thought to be related to increased inflammation, mechanical tension and metabolic stress which augments plasma growth hormone and blood lactate levels [40,41]. Due to a paucity of research, it is unclear what effects BFRT may have on tendons, but the induced muscular milieu in response to ischemia, may facilitate adaptations in morphological and mechanical tendon properties through enhanced collagen metabolism and tendon remodelling [42,43]. Despite these potential beneficial physiological mechanisms of BFRT on tendon healing, BFRT has received a paucity of attention in tendon rehabilitation, despite the clinical benefits found for other musculoskeletal conditions and the knowledge of resistance training being the most evidence-based treatment available for some tendinopathies. Therefore, the purpose of this narrative review was threefold: firstly, to give an overview and critical analysis of the mechanisms and outcomes of BFRT in both healthy populations and in musculoskeletal rehabilitation. Secondly, to give an overview of the evidence to date on the effects of BFRT on healthy tendon properties and clinical outcomes when applied to tendon pathology. Finally, a discussion on the clinical utility of BFRT and its potential applications within tendinopathy rehabilitation, including as a compliment to traditional heavy-load training will be presented.

2. BFRT Application Overview

The application of BFRT involves several key considerations, including cuff and training parameters and safety considerations. The recommended training loads for increasing strength and hypertrophy with BFRT are typically between 20–40% of 1-RM [44,45]. The most applied and recommend training protocol throughout the BFRT literature, is four sets of 75 (30, 15, 15, 15) repetitions, with sets often performed to either muscular failure or to completion of the set number of repetitions [46–51]. Despite variances existing in inter-set rest times throughout the literature, rest times are typically short, with cuff restriction maintained during rest, with common recommendations of between 30–60 s [52–54]. There have also been wide variances in training frequency reported throughout the literature, ranging from twice daily to once per week [55–58]. However, current recommendations for a training frequency of 2–4 times per week, mirror those of traditional resistance training for strength and hypertrophy increases [59–62]. Despite variances in the duration of BFRT interventions, three weeks or longer is typically advocated as a prerequisite for adequate strength and hypertrophy adaptations to occur [63–65]. Considerations of cuff application in BFRT are also important, with key variables of cuff pressure, width and material requiring attention [66,67]. Arterial occlusion pressure is the amount of pressure required to cease blood-flow within the targeted limb, which varies between individuals subject to characteristics such as body size and health status [68,69]. There are wide variances in occlusion pressures throughout studies, with many suggesting an individualised approach should be taken to account for individual characteristics, with recommended pressures typically ranging between 40–80% arterial occlusion [70–77]. The width of BFRT cuffs is another important consideration, as cuff width will affect the pressure required to achieve arterial occlusion, with variances in size between 3–18 cm common in studies [78–81]. Various cuff sizes are recommended and considered appropriate, provided that arterial occlusion pressure is appropriately applied, with wider cuffs requiring lower pressures [1]. BFRT cuff material can also vary, with elastic and nylon cuff materials most common in the literature [82]. Like cuff width, cuff material is not considered to impact on BFRT outcomes, provided occlusion pressure is appropriately measured and applied [83]. Attention must be paid to safety considerations during BFRT, due to the modality causing multiple systemic responses, including cardiovascular, central vascular and peripheral vascular responses [84–87]. Although BFRT has been shown to have a comparable safety profile to traditional resistance training in musculoskeletal rehabilitation [88], clinicians should remain vigilant for signs of adverse responses, such as deep vein thrombosis or venous thromboembolism [89,90]. Validated clinical prediction rules such as the Well's criteria could be used by clinicians to assess risk for vascular complications in at risk patients prior to the application of BFRT in clinical settings [1]. Despite the increase in scientific evidence supporting the clinical use of BFRT in rehabilitation, clinicians may face a variety of perceived implementation barriers such as determining training pressures, access to technology, safety screening to mitigate risk, and strategies for managing perceptual responses to BFRT, to ensure long-term compliance [91]. A recent review article has outlined some evidence-based strategies to help overcome these perceived barriers to clinical BFRT implementation [91]. The authors have developed a screening chart related to clotting risk and a decision-making funnel to guide practitioners when considering relevant participant related characteristics, to allow evidence-based informed decision making on the appropriateness of using BFRT [91]. Some evidence-based recommendations to minimize the perceptual responses as barriers to BFR training are: (i) use lower and individualized pressures, with adjustments in BFRT pressure considered throughout training; (ii) narrow cuffs should be preferred over wider cuffs when not personalizing pressures; (iii) intermittent BFRT can mitigate discomfort, (iv) training until failure should be avoided; (v) familiarization periods should be considered, (vi) communicate with patients the importance of high effort levels during BFRT [91].

An overview of the recommended training parameters for BFRT is presented in Table 1 [1]. A full discussion on the methodology, application, and safety of BFRT interventions is beyond the scope of this review and readers are directed to a recent position stand which comprehensively covers these considerations in BFRT [1].

Table 1. Model of exercise prescription with BFRT (Patterson et al., 2019 [2]).

Training Parameter	Guidelines
Frequency	2–3 times a week (>3 weeks) or 1–2 times per day (1–3 weeks)
Load	20–40% 1-RM
Restriction time	5–10 min per exercise (reperfusion between exercises)
Type	Small and large muscle groups (arms and legs/unilateral or bilateral)
Sets	2–4
Cuff	5 (small), 10 or 12 (medium), 17 or 18 cm (large)
Repetitions	(75 repetitions)—30 _ 15 _ 15 _ 15, or sets to failure
Pressure	40–80% AOP
Rest between sets	30–60 s
Restriction form	Continuous or intermittent
Execution speed	1–2 s (concentric and eccentric)
Execution	Until concentric failure or when planned rep scheme is completed

Abbreviations: 1-RM: 1 repetition maximum, AOP: arterial occlusion pressure, cm: centimetres.

3. BFRT Mechanisms

Although the exact mechanisms of effect of BFRT remain to be elucidated, several mechanisms have been theorized for the beneficial adaptations and responses elicited by BFRT, particularly in relation to increases in muscular strength and hypertrophy. The hypoxic microenvironment induced by BFRT is thought to lead to an influx and accumulation of metabolites and increased anabolic signalling and hormonal responses due to the augmented muscular fatigue and activation compared to standard training at a similar intensity [41,75]. Muscular adaptations in response to BFRT may be related to increased inflammation and metabolic stress which augments plasma growth hormone and blood lactate levels [92]. The exact role played by metabolites in response to BFRT has been debated in the literature, with some suggesting that accumulation of metabolites such as lactate and hydrogen ions combined with a decrease in intramuscular pH and phosphocreatine, stimulates afferent fibres and causes neuromuscular fatigue much earlier than traditional resistance training [75]. Several studies have found that LL-BFRT can significantly increase blood lactate levels to a higher level than controls and at a comparable level to HL-RT [93,94]. The increased presence of metabolites following BFRT is associated with a contemporaneous increase in growth hormone, inflammatory cytokines and myokines, further activating muscle satellite cells [41,75]. In response to the hypoxic environment and reduced oxygen availability, there is an increase in reactive oxygen species such as nitric oxide and a proliferation of vascular endothelial growth factor, which stimulates angiogenesis in a similar manner to traditional resistance training [95]. A further response to decreased oxygen availability and subsequent increase in muscular fatigue, is a decrease in force production resulting in increased motor unit recruitment [1]. Other purported endocrine system responses to BFRT which may impact on muscular adaptations include increases in free testosterone [96], serum growth hormone [93], insulin-like growth factor-1 (IGF-1), growth and differentiation associated serum protein-1 (GASP-1) and changes in gene activity including decreases in myostatin mRNA gene expression [97–99]. Traditional resistance training without BFRT, has also been demonstrated to result in increased metabolic stress and hormonal responses, however the increased mechanical tension from training to fatigue with BFRT may act synergistically with metabolic responses leading to increased muscular adaptations [41]. This section on mechanisms has largely focused on the potential mechanisms of action for muscular adaptations with BFRT, as the increases in muscular strength and hypertrophy are of relevance in the rehabilitation setting and may directly correlate to tendon adaptations, which are discussed in a later section. However, various other systemic and physiological systems responses have been shown with BFRT including positive effects on cardiopulmonary function [100], vascular stiffness and compliance [101–104], bone function [105], psychological function [106], musculoskeletal function [107], neural function [108], and anaerobic and aerobic exercise capacity [109–111]. A full discussion of the potential mechanisms involved in BFRT are beyond the scope of this review, and readers are directed to other reviews for a more focused analysis of BFRT mechanisms [41].

4. BFRT General Outcomes

The application of LL-BFRT has shown improvements in strength, muscle function and hypertrophy in a variety of populations, including healthy young adults, older adults, high-level athletes, and patients with various medical conditions [112–116]. A systematic review which included nine studies on high level athletes only, found that LL-BFRT led to significant improvements in strength, muscle size, and markers of sports performance such as sprint, agility and jump measures compared to controls [112]. At the opposite end of the population spectrum, systematic reviews have found that LL-BFRT can increase strength and function in older and often sedentary adults compared to controls and reduce the risk of falls and musculoskeletal injuries [113–116]. Most of the research on the effects of LL-BFRT have been conducted in young healthy adult populations, with similar beneficial findings as compared to older adults and those with medical conditions. A systematic review and meta-analysis including 400 healthy adult participants from 19 randomized controlled trials (RCTs) assessed the effects of BFRT on muscle strength and cross-sectional area [117]. The addition of BFRT to exercise training was found to be effective for augmenting changes in both muscle strength and size, with the effects consistent for both resistance training and aerobic training, despite the relatively short duration of most interventions [117]. An earlier meta-analysis which included 11 studies found that BFRT resulted in significantly greater increases in strength and hypertrophy when performed with resistance training rather than walking and performing LL-BFRT 2–3 days per week resulted in greater effect sizes compared to 4–5 days per week [51]. The analysis also found significant correlations between weeks of LL-BFRT duration and strength increases but not for hypertrophy increases. More recently, a systematic review and meta-analysis including 16 RCTs, compared the effects of LL-BFRT with HL-RT on muscle strength [118]. The review found that increases in strength significantly increased with both interventions, and concluded they were equally effective for producing gains in maximal voluntary muscle strength. However, another systematic review which included 13 RCTs on healthy adults, found that although both LL-BFRT and HL-RT were effective for increasing strength, HL-RT resulted in larger strength increases than LL-BFRT, although both methods were equally effective for increasing muscle mass [39]. The superiority of HL-RT for increasing strength remained even with adjustment for potential moderators such as prescription parameters and testing methods. However, the comparable benefits of LL-BFRT to HL-RT for muscle hypertrophy also remained when accounting for the same variables [39]. Despite conflicting findings when compared with HL-RT, it's clear that LL-BRT is a superior method for muscular adaptations than LL-RT. Therefore, in clinical musculoskeletal rehabilitation settings, when HL-RT may not be appropriate or contraindicated, LL-BFRT may serve as an appropriate alternative and the ideal starting point for introducing resistance training to counteract losses in muscle strength and hypertrophy.

Despite uncertainties and controversy regarding the exact mechanisms of action explaining the effects of BFRT on muscular adaptations, there is increasingly evidence that LL-BFRT can increase strength and hypertrophy of the muscles targeted with occlusion, at a comparable or only slightly lesser rate to traditional HL-RT [20,119], and a greater rate than LL-RT [120,121]. Strength and hypertrophy increase with LL-BFRT have been observed to occur as quickly as 1–3 weeks, which is comparable to strength gains with HL-RT, but quicker for hypertrophy gains than with HL-RT [57,121,122]. Although the lower loads required with BFRT may allow for greater training frequency due to less recovery time being required, BFRT with conventional HL-RT frequency of 2–3 times per week has been shown to increase hypertrophy over 3–8 weeks of training [123–126]. Studies have assessed various outcome measures of muscle strength in response to BFRT interventions, with strength increases in isometric [127], isokinetic [128], isotonic [129], and explosive strength being found [130]. Increases in strength in the non-occluded upper limbs have also been reported following BFRT applied to the lower limbs bilaterally, suggesting systemic mechanisms are involved [96]. When LL-BFRT is compared to LL-RT with the same dosage parameters but without blood-flow restriction, strength has been shown to increase more with the application of occlusion in both the ipsilateral and contralateral limbs [20,107].

5. BFRT Musculoskeletal Rehabilitation Outcomes

Recent evidence suggests that LL-BFRT may be a superior method for augmenting muscular adaptations in early musculoskeletal rehabilitation, due to findings of comparably efficacy for inducing muscular hypertrophy and being only minimally inferior for increasing muscular strength compared to HL-RT [38,39,131,132]. Whilst traditional resistance training utilises heavy training loads of 70% or more of 1 repetition maximum (1-RM), low intensity BFRT typically uses loads in the range of 20–40% of 1RM, which may be more tolerable for patients not able to tolerate high muscle-tendon training loads, while still preventing muscle atrophy and promoting hypertrophy [11,133,134]. Additionally, BFRT has been shown to cause exercise-induced hypoalgesia through endogenous opioid and endocannabinoid mechanisms, so could therefore be a useful pain management tool in early musculoskeletal rehabilitation, particularly in the presence of an acute pain response [135–138].

In recent years, the application of BFRT as a rehabilitation method for musculoskeletal conditions has been given increased attention within various clinical populations [139]. A systematic review and meta-analysis which included 20 studies on BFRT for musculoskeletal rehabilitation, found that BFRT had an overall moderate effect on increasing strength, but was less effective than HL-RT for strength gains [7]. However, compared with LL-RT, BFRT was more effective and tolerable as a treatment method [7]. Another more recent systematic review which included 10 RCTs on BFRT in lower limb musculoskeletal conditions, concluded that LL-BFRT leads to increases in muscle strength and volume, and reduces pain at a comparable level to conventional LL-RT and HL-RT [6]. A recent systematic review and meta-analysis including five studies on knee osteoarthritis found that there was low to moderate quality evidence of no difference between LL-BFRT and traditional HL-RT for pain, function, strength, and muscle size increases [140]. Similarly, a systematic review and meta-analysis including 5 RCTs on patients with osteoarthritis and rheumatoid arthritis, found no difference between LL-BFRT and moderate and HL-RT on muscle strength, muscle mass and functionality measures, with LL-BFRT more effect for increasing strength than LL-RT [141]. Another recent meta-analysis including nine studies on various knee disorders found that muscle strength increases were comparably superior for LL-BFRT, and HL-RT compared to LL-RT, with pain improvement superior for LL-BFRT compared to LL-RT and HL-RT [142]. Systematic reviews have also found benefit of LL-BFRT for increasing muscle strength and function in clinical patients during rehabilitation for pre- and post-operative anterior cruciate ligament (ACL) reconstruction [143–147], knee surgery [148], osteoarthritis [149,150], various knee conditions [151–154], muscular atrophy [155], sarcopenia [156], and elderly patients at risk for various musculoskeletal conditions [113–116]. The safety of BFRT in musculoskeletal rehabilitation has also been assessed as comparable to standard exercise therapy, with a systematic review of 19 studies finding that the likelihood of adverse events is not increased with BFRT, despite suggestions of potential safety concerns [88].

In the last few years there has been an exponential proliferation in interventional research applying LL-BFRT interventions within musculoskeletal rehabilitation settings, due to the ever-increasing indications of therapeutic efficacy. The ever-growing body of evidence includes RCT evidence of potential efficacy for a plethora of musculoskeletal conditions including, polymyositis and dermatomyositis [157], osteoarthritis [158–163], pre and post-operative ACL reconstruction [164–169], patellofemoral pain [170–172], post knee arthroscopy [173], rheumatoid arthritis [174,175], and muscle atrophy [176,177]. Many RCTs have also found benefits of BFRT in elderly populations at risk for sarcopenia and other medical and musculoskeletal disorders [178–187]. Preliminary evidence from non-RCT study designs have indicated potential efficacy of LL-BFRT for ankle sprains [188,189], ankle fractures [190], shoulder injuries [191], reactive arthritis [192], thoracic outlet syndrome [193], inclusion body myositis [194], knee arthroplasty [195], tibial fractures [196], meniscus repair [197], patellar instability [198] and spinal cord injury [199]. The application of BFRT to general chronic medical conditions is also continuing to expand, with recent studies indicating potential efficacy for chronic conditions such as type-2 diabetes [200,201], chronic kidney disease and renal decline [202,203], hypertension [204], cardiovascular disease [205,206], cancer [207,208], and coma patients [209,210].

6. Effects of BFRT on Healthy Tendons

Due to a paucity of research, it is unclear what physiological effects BFRT may have on tendons, but the induced ischemic muscular milieu with BFRT may facilitate morphological and mechanical tendon properties through enhanced collagen metabolism and tendon remodelling [42,43]. Despite these potential beneficial physiological mechanisms of BFRT on tendon healing, the method of training has received a dearth of attention in tendon rehabilitation. This is even more surprising considering the clinical benefits found for other musculoskeletal conditions and the knowledge of resistance training being the most evidence-based treatment available for tendinopathies. However, in the last few years, studies investigating the effects of BFRT on tendon properties in healthy individuals, and clinical outcomes in tendon pathology, have begun to emerge in the literature.

Several studies have investigated the effects of LL-BFRT on healthy tendons, including tendon morphological and mechanical properties (Table 1). A three-arm RCT with 55 participants, compared the effects of LL-BFRT (20–35% of 1-RM) with HL-RT (70–85% OF 1-RM) and a non-exercise control group on healthy Achilles tendon properties [211]. Participants performed standing and seated resisted calf raises, three times per week for 14 weeks, at 50% occlusion pressure applied to the proximal thigh. Tendon morphological and mechanical properties were assessed by ultrasound, with the Achilles tendon adaptations comparable between both intervention groups. Both groups had significant increases in tendon stiffness and cross-sectional area (CSA), with gastrocnemius strength gains and muscle hypertrophy also comparably increased in both groups [211]. Similar findings were seen in a RCT comparing LL-BFRT (20–35% of 1-RM) with HL-RT (70–85% OF 1-RM) in healthy patellar tendons [212]. Participants performed standing and seated resisted calf raises, bilateral leg press and knee extension, three times per week for 14 weeks, at 50% occlusion pressure applied to the proximal thigh. Patellar tendon properties were assessed by ultrasound and magnetic resonance imaging (MRI), with substantial changes found in both groups. Like the previous study on the Achilles tendon, both groups significantly increased tendon stiffness and CSA, and had comparable increases in muscle mass and strength. The only outcome that was significantly different between groups, was that knee extension 1RM was greater in the LL-BFRT group [212]. Findings from these RCTs suggests that LL-BFRT performed over 14 weeks produce similar Achilles and patellar tendon adaptations to traditional HL-RT. However, a cohort study comparing LL-BFRT (20% of 1-RM) with HL-RT (80% of 1-RM) did not find that LL-BFRT increased vastus lateralis tendon stiffness, whereas HL-RT significantly increased tendon stiffness [213]. Participants performed resisted knee extension three times per week for 12 weeks, with an occlusion pressure of 37.7% on the proximal thigh. Stiffness of the vastus lateralis tendon aponeurosis and patellar tendon were assessed by ultrasound during isometric knee extension [213].

Studies have also compared LL-BFRT to LL-RT in healthy tendons, investigating the effects of single training sessions and longer interventions. A RCT compared a single session of LL-BFRT (30% of 1-RM) with HL-RT on healthy Achilles tendons [214]. Participants performed three sets of 15 repetitions with 30% occlusion pressure at the proximal thigh. Tendon thickness was assessed by ultrasound, with the LL-BFRT group having a significantly greater reduction in tendon thickness compared to standard LL-RT, immediately and 24 h after exercise. The authors postulated that the significant difference in tendon thickness between groups may be associated with neurotendinous fluid movement in response to LL-BFRT [214]. Another RCT comparing LL-BFRT to LL-RT in healthy Achilles tendons over six weeks found no difference in leg stiffness with a maximal hopping test between groups, which was used to measure tendon stiffness [215]. Although there was no change in tendon stiffness, both groups equally improved calf muscle thickness and 1RM strength. A RCT comparing LL-BFRT (30% of 1-RM) to LL-RT in healthy supraspinatus tendons, found both groups significantly increased tendon thickness, with no significant difference between groups [216]. Participants performed side-lying external rotation twice per week for eight weeks with 50% occlusion pressure at the proximal upper arm. Tendon thickness was assessed with ultrasound and rotator cuff strength with dynamometry, both of which equally increased in both groups. One RCT has compared a single session of LL-BFRT to LL-RT and HL-RT in healthy Achilles tendons, measuring changes in tendon thickness with ultrasound [217]. Participants performed four sets and 75 total repetitions of resisted plantarflexion, with 30% occlusion pressure under the knee joint. Achilles tendon thickness was significantly reduced immediately after, 60 min and 24 h post LL-BFRT, with no changes found in the other two groups [217]. One cross-sectional study has assessed changes in skin temperature of the Achilles tendon, following a single session of heel raises performed with LL-BFRT (30% of 1-RM) and LL-RT [218]. An occlusion pressure of 80% was applied to the distal lower leg and thermograms used to assess tendon skin temperature. Region specific changes in tendon skin temperature were found, with greater and longer reductions at the Achilles tendon insertion following LL-BFRT, but not at the free tendon or musculotendinous junction [218].

7. BFRT in Tendon Rupture Rehabilitation

Like tendinopathies, partial or complete tendon ruptures are common in both the general population and athletes, with the Achilles tendon having the highest prevalence of ruptures [219]. Like tendinopathy, tendon ruptures can also cause significant pain, disability and functional limitations and are associated with significant societal and healthcare costs, whether treated surgically or conservatively, with there being a lack of consensus on optimal rehabilitation methods for tendon ruptures [220]. Progressive resistance training is also considered an essential element of rehabilitation following tendon rupture to counteract muscle atrophy and stimulate tendon repair, whether treated conservatively or surgically [221]. Currently only two case reports exist in the literature describing a LL-BFRT intervention applied during the rehabilitation of a tendon rupture. An intervention consisting of manual therapy, laser therapy, and resistance training including LL-BFRT forearm and elbow exercises was applied to a weightlifter following a biceps tendon rupture [222]. Parameters of BFRT included 80 mmHg occlusion pressure, and four sets (30, 15, 15, 15 repetitions) performed daily for 14 weeks, with progressive increases in training resistance. The patient improved clinical symptoms and returned to pre-injury weightlifting activity. Another case report on rehabilitation for and Achilles tendon rupture investigated an isolated LL-BFRT (30% of 1-RM) intervention which included leg press and calf press exercises [223]. Two participants performed 4 sets (30, 15, 15, 15 repetitions) at 80% occlusion pressure at the proximal thigh. Both patients improved strength and power as assessed by isokinetic testing and returned to sports activity.

8. BFRT in Tendinopathy Rehabilitation

Only three studies have investigated LL-BFRT in patients with tendinopathy, two case reports and one case series, all with patellar tendinopathy. A case report on two collegiate decathletes with patellar tendinopathy investigated a LL-BFRT intervention with single leg press and decline squat exercises [224]. The two athletes performed four sets of 15–30 repetitions twice per week for 12 weeks during the competitive season with 80% occlusion pressure at the proximal lower extremity. Both patients improved clinical outcomes (pain and function), strength (leg press 1-RM) and had improvements in tendon thickness and resolution of hypoechoic tendon regions on ultrasound. Another case report investigated LL-BFRT (30% of 1-RM) in a basketball player with patellar tendinopathy [225]. A variety of exercises were performed 5–6 days per week, with 3 sets of 15 repetitions and occlusion pressure of 160–180 mmHg at the proximal lower limb. The patient improved clinical outcomes and returned to playing competitive basketball. The patella tendon was assessed by MRI, which found that signal intensity was reduced following the LL-BFRT intervention, suggesting improved tendon structure. A case series which included seven patients with patellar tendinopathy, investigated a three-week LL-BFRT (30% of 1-RM) intervention including single leg press and knee extension exercises [226]. Patients performed six sets of 5–30 (30, 25, 20, 15, 10, 5) repetitions, three times per week at an occlusion pressure of 120 mmHg, with volume progressed based on pain response. Despite the intervention being short-term, all patients improved clinical outcomes (pain and function), strength (dynamometry), and tendon vascularity (ultrasound Doppler) diminished by 31% despite no changes in tendon thickness. The intervention also recorded a very high adherence rate of 98%, suggesting LL-BFRT may be a feasible and effective method for patellar tendinopathy rehabilitation [226]. Whilst it is not possible to make definitive recommendations regarding LL-BFRT interventions for use in clinical practice for tendinopathy rehabilitation, protocols such as that by Skovlund et al [226]. may serve as an implementation example of a BFRT protocol with clinical utility and a high adherence rate. The protocol of four sets (30, 15, 15, 15 repetitions) is commonly recommended in the BFRT and was investigated in some of the tendon pathology case reports and RCTs on healthy tendons, so it may therefore serve as an alternative protocol for clinicians to the Skovlund et al [226]. protocol for Achilles and patellar tendinopathy.

9. Resistance Training in Tendinopathy

Resistance training has been synonymous with tendinopathy rehabilitation for many years, particularly lower limb tendinopathies, due to the large body of evidence supporting its use [227,228]. The concept of resistance training using isolated eccentric actions to treat lower limb tendinopathy was first suggested by Stanish et al., (1986) [229] and then later popularised by the publication of the Alfredson eccentric heel-drop protocol for Achilles tendinopathy [230]. Since then, eccentric resistance training has become the most explored and recommended method for treating Achilles and patellar tendinopathies, due to consistently positive findings for pain and function improvement [231,232]. The training parameters of the Alfredson eccentric heel-drop protocol have also been applied to patellar tendinopathy in the form of an eccentric single-leg decline squat protocol, which has shown clinical efficacy [233,234]. Heavy eccentric overload training using inertial flywheel devices has also been shown to be an effective prevention and rehabilitation method for patellar tendinopathy [235–237]. Resistance training protocols combining concentric, eccentric, and plyometric training have also shown efficacy in treating Achilles tendinopathy [238,239]. Despite conflicting findings regarding the necessity for the elimination of concentric actions from isotonic contractions [240–243], isolated eccentric training does appear to be a more effective tendinopathy strategy than concentric training [244–246]. However, some studies have reported that up to 45% of patients have poor long-term outcomes for pain and function following heavy eccentric training, with poor findings often more common in the general population compared to athletic populations [247]. More recently, heavy slow resistance training (HSRT), with heavy loaded isotonic contractions has been shown to have comparable or greater outcomes for pain and function improvement for patellar tendinopathy [35,248–250], Achilles tendinopathy [34], and plantar heel pain [251,252]. Regardless of whether eccentric or HSRT interventions are employed to treat tendinopathies, it is widely accepted that protocols must be delivered with heavy loads to be capable of deriving positive changes in tendon architecture and mechanical properties [36,253]. Slowly performed muscle contractions under heavy loads are postulated to stimulate tendon adaptations through mechano-transduction of the high forces and loads, which translates to improved tendon compliance and remodeling, with increased collagen production and reduced neovascularization and tendon thickness which has been associated with pain [254,255]. Despite these positive effects and physiological mechanisms of HL-RT on tendon structure in tendinopathy, there will inevitably be certain clinical populations who are unable to begin tendon rehabilitation with HL-RT, due to contraindications, advanced age, co-morbidities, or reduced exercise tolerance. Whilst its clear at present that HL-RT should remain the treatment of choice in treating tendinopathies, due to the myriad of evidence showing effectiveness, LL-BFRT may serve as a compliment or regression method for those unable to tolerate HL-RT. Tables 2–5 provides an overview of the traditional resistance training paradigms in tendinopathy rehabilitation, with the addition of the LL-BFRT protocol by Skovlund et al. [226] as a potentially alternative option, expanding the clinical applicability of resistance training to previously neglected clinical populations.

Table 2. Studies on BFRT in healthy tendons.

Author, Study Design, Population	Intervention, Exercises, Duration	Training Parameters	Outcome Measures	Outcomes, Results
Centner et al. 2019 [69] RCT, n = 55, Healthy Achilles tendon	1.LL-BFRT: standing and seated calf raises (20–35% 1RM) 2. High load RT (70–85% 1RM) 3. Control, 14 weeks	Sets: 3, Reps; 6–12, Freq: 3 × WK, Prog: increase resistance (5% of 1rm every 4 WK, 20–35%), Int: 20–35% of 1RM. Rest: 1 min between sets, 3 min between exercises. Occlusion pressure: 50% at proximal thigh	Tendon and muscle properties (US), isometric strength (MVC—isokinetic dynamometer).	Both groups had comparable increases in tendon stiffness and CSA, gastrocnemius muscle CSA and strength. No changes in control group.
Centner et al. 2021 [74] RCT, n = 29, Healthy patellar tendon	1.LL-BFRT: bilateral leg press and knee extension, standing and seated calf raises (20–35% 1RM) 2. High load RT (70–85% 1RM), 14 weeks	Sets: 4, Reps: 30, 15, 15, 15, Freq: 3 × WK, Prog: increase resistance (5% of 1rm every 4 WK, 20–35%), Int: 20–35% of 1RM. Rest: 1 min between sets, 3 min between exercises. Occlusion pressure: 50% at proximal thigh	Tendon and muscle properties (US and MRI), strength (1-RM).	Both groups had comparable increases in tendon stiffness and CSA, muscle mass and strength, knee extension 1RM was higher in BFRT group.
Chulvi-Medrano et al. 2020 [70] RCT, n = 56, Healthy Achilles tendon	1. LL BFRT: plantarflexion 2. LL RT, single session	Sets: 3, Reps; 15, Freq: single session, Prog: NR, Int: 30% of 1RM. Rest: 30 s between sets. Occlusion pressure: 30% at proximal thigh	Tendon thickness (US)	BFRT group had significantly greater decrease in tendon thickness compared to LL-RT, immediately and 24 h after exercise.
Gavanda et al. 2020 [72] RCT, n = 21, Healthy achilles tendon	1. LL BFRT: plantarflexion 2. LL RT, 6 weeks	Sets: 4, Reps; to muscular failure, Freq: 2 × WK, Prog: occlusion pressure increased every 4 WKs, Int: 30% of 1RM, Rest: 30 s between sets. Occlusion pressure: 60% below patella.	Calf volume, gastrocnemius muscle thickness (US), maximal hopping test for leg stiffness, 1RM smith machine calf raise, pain (VAS)	Leg (tendon) stiffness and calf volume did not change, VAS, 1RM and muscle thickness improved equally in both groups.
Kubo 2006 [76], Cohort, n = 9, Healthy patellar tendon and VL aponeurosis	1. LL BFRT (20% of 1RM): knee extension 2. HL RT (80% of 1RM), 12 weeks	Sets: 4, Reps; 25, 18, 15, 12, Freq: 3 × WK, Prog: NR, Int: 20% of 1RM. Rest: 30 s between sets. Occlusion pressure: 37.7% at proximal thigh	knee extension torque (MVC—dynamometer)) Tension of VL, calculated from MVC, and muscle volume mmobilizat. Stiffness of VL tendon (US) during isometric knee extension.	Both groups significantly increased MVC and muscle volume of quadriceps femoris. Specific tension of VL increased significantly 5.5% for HL, but not for LL. Tension and tendon properties were found to remain following LL BFRT, whereas they increased) significantly after HL RT.
Picon-martinez et al. 2021 [71] RCT, n = 52, healthy achilles tendon	1. LL BFRT (30% 1RM): plantarflexion 2. LL RT (30% 1RM) 3. HL RT (75% 1RM), single session	Sets: 4, Reps; 30, 15, 15, 15, Freq: single session, Prog NR, Int: 30% of 1RM, Rest: 30 s between sets.) Occlusion pressure: 30% under knee joint	Achilles tendon thickness (US): immediately, 60 min and 24 h after training.	Achilles tendon thickness was significantly reduced immediately after, 60 min and 24 h post-LL BFRT, unchanged in other groups.
Brumitt et al. 2020 [75] RCT, n = 46, healthy supraspinatus tendon	1. LL BFRT: side-lying external rotation 2. LL RT, 8 weeks	Sets:4 , Reps; 30, 15, 15, 15, Freq: 2 × WK, Prog: NR, Int: 30% of 1RM. Rest: 30 s between sets.) Occlusion pressure: 50% at proximal upper arm	Rotator cuff strength (dynamometry), supraspinatus tendon thickness (US)	BFRT did not augment rotator cuff strength gains or tendon thickness when compared to RT. Both groups significantly increased rotator cuff strength and tendon size.
Canfer et al. 2021 [73] Cross sectional, n = 12, healthy achilles tendon	1. LL BFRT: bodyweight SL heel raise 2. LL RT	Sets: 4, Reps; 30, 15, 15, 15, Freq: single session, Prog: NR, Int: 30% of 1RM) Rest: 30 s between sets. Occlusion pressure: 80% at distal lower leg.	Thermograms to assess Achilles tendon skin temperature (Tskin)	Region specific changes in Tskin were found, with greater and longer reductions at the Achilles insertion following BFRT.

Abbreviations: LL-BFRT: low-load blood flow restriction training, HL-RT: high load resistance training, RM: repetition maximum, Tskin: skin temperature, SL: single leg, US: ultrasound, MRI: magnetic resonance imaging, NR: not reported, Int: intensity, Freq: frequency, Prog: Progression, RCT: randomised controlled trial, VL: vastus lateralis, MVC: maximum voluntary contraction, VAS: visual anologue scale, NRS-P: pain numeric rating scale, SLDS: single leg decline squat, n: number, WK: week, ROM: range of motion, CSA: cross sectional area.

Table 3. Studies on BFRT in tendon rupture rehabilitation.

Author, Study Design, Population	Intervention, Exercises, Duration	Training Parameters	Outcome Measures	Outcomes, Results
Wentzell 2018 [67], Case report, n = 1, Biceps tendon rupture	Manual therapy, laser therapy, progressive strength training including LL BFRT: Isometric forearm pronation and supination, elbow flexion and extension 14 weeks	Sets: 4, Reps: 30,15,15,15, Freq: 7 × WK, Prog: increase resistance (1.5–4 lbs) difficulty and ROM, Int: 10–30% MVC. Occlusion pressure: 80 mmHg at proximal arm.	Pain (NPRS), Function (DASH, Mayo Elbow Performance Index score.	Patient improved clinical outcomes and returned to preinjury activity (weightlifter).
Yow et al. 2018 [68] Case report, n = 2, Achilles tendon rupture	LL BFRT: Leg press, calf press, 6 weeks	Sets: 4, Reps: 30, 15, 15, 15, Freq: NR, Prog: NR, Int: 30% of 1RM. Occlusion pressure: 80%, 180 mm Hg at proximal thigh.	Strength and power (isokinetic testing—Biodex system).	Patients improved strength and power and returned to sports.

Abbreviations: LL-BFRT: low-load blood flow restriction training, HL-RT: high load resistance training, RM: repetition maximum, NR: not reported, Int: intensity, Freq: frequency, Prog: Progression, MVC: maximum voluntary contraction, NRS-P: pain numeric rating scale, VISA-P: Victorian Institute of Sport Assessment Patellar, n: number, WK: week.

Table 4. Studies on BFRT in tendinopathy rehabilitation.

Author, Study Design, Population	Intervention, Exercises, Duration	Training Parameters	Outcome Measures	Outcomes, Results
Skovlund et al. 2020 [64], Case series, n = 7, Patellar tendinopathy	1. LL-BFRT: SL leg press, knee extension, 3 weeks	Sets: 6, Reps: 5–30, Freq: 3 × WK, Prog: increase volume based on pain response, Int: 10RM, (30% of 1RM). Maximum 105 reps per session. Occlusion pressure: 120 mm Hg at proximal thigh	Pain (NRS-P, SLDS), Function (VISA-P) Tendon vascularity (US), Knee extensor strength (MVC—static dynamometry)	Intervention was effective for improving clinical outcomes and strength. Pain with SLDS reduced by 50%. Tendon vascularity diminished by 31%. No changes in tendon thickness.
Cuddeford et al. 2020 [66] Case report, n = 1, Patellar tendinopathy	1. LL-BFRT: SL leg press, SLDS, 12 weeks	Sets: 4, Reps: 15–30; Freq 2 × WK: Prog: increase resistance (10 lbs Inc.), Int: 15–30RM (1RM testing). Occlusion pressure: 80% at proximal lower limb	Pain (VAS), Function (VISA-P), Tendon size (US), hip and knee strength (dynamometry, SL leg press 1RM)	Patients improved clinical outcomes and strength and returned to sports activity. Improvements in tendon thickness and resolution of hypoechoic region
Sata 2005 [65], Case report, n = 1, Patellar tendinopathy	1. LL-BFRT: straight leg raises, hip abduction and adduction, calf raise, squat, crunch, back extension, basketball shooting, 3 weeks	Sets: 3, Reps; 15, Freq: 5–6 × WK, Prog: NR Int: 15rm (30% of 1RM). Occlusion pressure range: 160–180 mmHg at proximal lower limb.	MRI (signal intensity). Thigh circumference	Patient improved clinical outcomes and returned to playing basketball MRI signal intensity was reduced, and thigh circumference was increased.

Abbreviations: LL-BFRT: low-load blood flow restriction training, HL-RT: high load resistance training, RM: repetition maximum, SL: single leg, US: ultrasound, MRI: magnetic resonance imaging, NR: not reported, Int: intensity, Freq: frequency, Prog: Progression, RCT: randomised controlled trial, MVC: maximum voluntary contraction, VAS: visual anologue scale, NRS-P: pain numeric rating scale, VISA-P: Victorian Institute of Sport Assessment Patellar, SLDS: single leg decline squat, n: number, WK: week.

Table 5. Resistance training protocols in lower limb tendinopathy.

Characteristics of Resistance Training Protocols in Lower Limb Tendinopathy							
Protocol	**Tendinopathy**	**Exercise Type**	**Sets, Repetitions**	**Frequency**	**Duration**	**Progression**	**Pain**
Stanish and Curwin	Achilles	Eccentric- concentric, power	3, 10-20	Daily	12 weeks	Speed then load	Enough load to be painful in 3rd set
Alfredson	Achilles	Eccentric	3, 15	2 × daily	12 weeks	Increase load as able (backpack)	Enough load to achieve moderate pain
Silbernagel	Achilles	Eccentric-concentric, balance, plyometric	Various	Daily	12 weeks	Volume, type of exercise	Acceptable within defined limits
Beyer	Achilles	Isotonic (HSRT)	3-4, 15-6	3 × week	12 weeks	15-6RM, increase load as able (external weight machine)	Acceptable if not worse after exercise
Rathleff	Plantar heel	Isotonic (HSRT)	3-5, 12-8	3 × week	12 weeks	12-8RM, Increase load as able (backpack)	Acceptable if not worse after exercise
Kongsgaard	Patellar	Isotonic (HSRT)	4, 15-6	3 × week	12 weeks	15-6RM, Increase load as able (external weight machine)	Acceptable if not worse after exercise
Ruffino	Patellar	Eccentric overload (inertial flywheel)	4, 12	1 × week	12 weeks	8RM, increase resistance (flywheel devices)	Acceptable within defined limits
Skovlund	Patellar	Isotonic (BFRT)	6, 5-30 (30, 25, 20, 15, 10, 5)	3 × week	3 weeks	Increase volume as able (external weight machine)	Acceptable within defined limits

Abbreviations: RM: repetition maximum; HSRT: Heavy slow resistance training, BFRT: Blood flow restriction training.

10. Clinical Implications and Practical Application

Despite the paucity of research to date on the application of LL-BFRT in tendinopathy rehabilitation, the previously reviewed studies indicate that LL-BFRT can produce beneficial clinical effects and structural adaptations to both healthy and pathological tendons. Although no confirmatory RCTs have yet been conducted in a tendinopathy population, preliminary case reports and case series evidence have shown clinical improvements, safety, and feasibility of LL-BFRT in both tendinopathy and tendon rupture rehabilitation. The body of evidence for tendon adaptations following LL-BFRT is more robust for healthy tendons, due to several high-quality RCTs existing, particularly for the Achilles and patellar tendons. The documented beneficial effects of LL-BFRT on the morphological and mechanical properties of healthy tendons include improvements in tendon thickness, vascularity, stiffness, skin temperature and neovascularization. Although these confirmed beneficial adaptations in healthy tendons have not been confirmed in pathological tendons, preliminary evidence in tendinopathy has shown improvements in tendon thickness, vascularity, and signal intensity on MRI. However, further large scale high-quality RCTs are required to confirm these positive adaptations in tendinopathy, despite preliminary evidence being suggestive of clinical and structural tendon benefit. Although definitive conclusions and recommendations on LL-BFRT are not possible until such evidence exists, there is a clear scientific rationale supporting its clinical use. The evidence for positive adaptations in healthy tendons and the body of evidence showing clinical improvement following LL-BFRT for other comparable musculoskeletal disorders is suggestive of possible efficacy of LL-BFRT as a tendinopathy treatment. Given these findings and the increased research intensity within the BFRT field in recent years, particularly its application within musculoskeletal rehabilitation, it could be considered surprising how little attention has been given to its application in tendinopathy.

As previously discussed, resistance training has the highest quality evidence of effectiveness out of all tendinopathy treatments, with heavy-load eccentric and HSRT typically recommended due to their documented beneficial effects [256–259] The long-held belief that resistance training must be applied with heavy-loads to derive positive adaptations in tendinopathy could be a potential barrier and explanation for the dearth of the application of BFRT in the literature. However, the lack of investigation of LL-BFRT in tendinopathy rehabilitation, may be counterproductive, as it could be an alternative option for those populations unable to tolerate traditional heavy-load training. Indeed, there may even be clinical scenarios where the practice of heavy-load training is contraindicated such as in early rehabilitation for acute tendinopathies or tendon rupture, or in patients who are frail, elderly or have significant medical co-morbidities [260]. The 'one-size-fits-all' approach to tendinopathy rehabilitation of prescribing heavy-load resistance training which has become widespread in recent years, is an unrealistic and potentially counterproductive and detrimental practice [261]. There is significant heterogeneity which exists within tendinopathy as a disease entity and in its environmental and clinical presentation, due to the unique individual factors and circumstances of each patient [262]. Therefore, a homogenous prescription of heavy-load training across a heterogeneous disease population is inappropriate and may potentially help to explain why despite its clear benefits, traditional heavy-load training may only be up to 50% effective for long-term clinical improvement in tendinopathy [247].

Changes in healthy tendon properties have been shown to be comparable between LL-BFRT and HL-RT, with these positive adaptations representing a possible explanation for the clinical benefit that has been shown in tendinopathy rehabilitation studies. It is widely considered that to optimally derive tendon adaptations with resistance training, heavy loads are required to increase the magnitude of effect [36,263,264]. However, the multitude of physiological responses induced by LL-BFRT could be considered greater than that provided by traditional training. The potent microenvironment created by LL-BFRT and the muscular and tendinous physiological milieu it induces, may negate the requirement of heavy-loads to derive positive adaptations. Although this line of inquiry is hypothetical and unproven in tendinopathy, the evidence from studies in healthy tendons and the preliminary evidence in tendinopathy, at least warrants a heighted attention for further investigation. If such findings are confirmed in future research, the consequences for tendinopathy rehabilitation may be significant, with a potential paradigm shift in resistance training treatment recommendations, away from the current homogenous heavy-loading prescriptions for all patients. The availability of LL-BFRT as a proven, safe, and efficacious treatment option, would increases the viability of options for clinicians and give patients more choice in treatment selection, which may have far-reaching implications in areas such as training adherence, which has been identified as a problem area in resistance training for tendinopathy [259]. Whilst athletic individuals and those with resistance training experience may have less issues adhering to HL-RT, there may be implementation barriers to its prescription in those unaccustomed to HL-RT or resistance training in general such as elderly populations or those with significant co-existing medical issues [265,266]. Evidence from other musculoskeletal disorders, has already indicated that LL-BFRT is a safe, viable and effective method for prescribing resistance training in rehabilitation populations unable to tolerate traditional HL-RT for a multitude of reasons such as limited mobility and high pain levels. For example, LL-BFRT has been found to be effective for reducing pain, improving function, and increasing muscle strength and hypertrophy in early rehabilitation for several musculoskeletal disorders suggesting similar benefits may be achievable within tendinopathy populations. The lower training intensity and loads required with LL-BFRT to derive muscle and tendon adaptations, typically range between 20–40% of 1RM, which would likely be more tolerable for patients not able to tolerate high muscle-tendon training loads which are typically 70% of 1RM in HSRT protocols, while still preventing muscle atrophy and promoting hypertrophy and strength increases [7–12]. Future research should also investigate the feasibility of individualised prescription of LL-BFRT for tendinopathies and the combination of LL-BFRT with other effective treatment option for tendinopathies such as extracorporeal shockwave therapy [267].

11. Future Research—Current Trials on BFRT in Tendon Rehabilitation

Despite their being no RCTs completed to date investigating BFRT in tendon rehabilitation, it is clear from a search of currently registered RCTs (clinicaltrials.gov) that increased attention is being given to the potential clinical utility of BFRT in tendon pathology. A recently published conference abstract of a completed yet unpublished RCT on BFRT following surgery for Achilles tendon ruptures, indicates that BFRT is superior compared to standard physical therapy for increasing absolute strength in the operative calf [268]. Whilst full details of the RCT and BFRT parameters are yet to be published, these preliminary findings are encouraging and mirror the findings of the case series and case reports to date on BFRT in tendon pathologies. The first RCT investigating the effects of LL-BFRT compared to HL-RT in patellar tendinopathy is underway in Denmark [269], by the same research group who conducted the positive case series included in this review [226]. This trial will be the first step in determining if definitive recommendations can be made for BFRT in tendinopathy, building on the preliminary evidence included in this review. Positive findings from this RCT may require a paradigm shift in the clinical rehabilitation of tendinopathy, from the belief that HL-RT is a prerequisite for improving outcomes in tendinopathy, to a possible future where both HL-RT and LL-BFRT are both viable rehabilitation methods, giving clinicians and patients more options and choice during rehabilitation. Other currently in-progress RCTs of BFRT interventions for tendon pathologies include for postoperative biceps tendon rupture [270], lateral elbow tendinopathy [271,272], Rotator cuff tendinopathy [273], and rotator cuff tears [274]. The field of clinical tendon rehabilitation eagerly awaits the outcomes of these trials, as findings of therapeutic utility will have wide ranging clinical implications for potentially enhancing patient outcomes [275].

12. Conclusions

The comparable effects of LL-BFRT to HL-RT and superiority over LL-RT for muscular adaptations such as strength and hypertrophy have been previously demonstrated, with recent findings suggesting the same may be true for tendon adaptations. Despite the paucity of research on the effects of BFRT on healthy tendons and in tendon pathologies such as tendinopathy, preliminary evidence suggests beneficial tendon adaptations do occur, along with improvements in clinical outcomes such as pain and function, which is encouraging. Studies highlighted in this review have found comparable tendon adaptations are derived from LL-BFRT and HL-RT in healthy lower and upper limb tendons, with the greatest evidence for Achilles and patellar tendons. Despite clear evidence of efficacy for its application for other musculoskeletal conditions, BFRT is a novel method in tendinopathy rehabilitation. Therefore, definitive conclusions, and recommendations on BFRT for tendinopathy rehabilitation cannot be made at present, which should be addressed in future research, due to the potential therapeutic benefits highlighted in this review. Despite this, this review makes some preliminary implementation suggestions based on the current limited evidence, which clinicians should interpret with caution, until further confirmatory research exists. The addition of LL-BFRT as a viable rehabilitation method in tendinopathy rehabilitation would be complimentary to currently utilised HL-RT interventions and provide more rehabilitation options for clinicians and for patients unable to tolerate HL-RT during tendon rehabilitation.

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Abbreviations

1RM	1 repetition maximum
ACL	Anterior cruciate ligament
BFRT	Blood flow restriction training
CSA	Cross-sectional area
LL-BFRT	Low-load blood flow restriction training
LL-RT	Low-load resistance training
HL-BFRT	High-load blood flow restriction training
HL-RT	High-load resistance training
HSRT	Heavy slow resistance training
MRI	Magnetic resonance imaging
RCT	Randomised controlled trial

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