

Achilles Tendon Rehabilitation—The Role of Blood Flow Restriction



Johnny Owens, PT^{a,*}, Mark Drakos, MD^b, Kyle Kimbrell, PT^c

KEYWORDS

- Achilles tendon repair • Blood flow restriction (BFR) • Muscle hypertrophy
- Postoperative recovery

KEY POINTS

- Blood flow restriction (BFR) can be used to reduce postoperative muscle atrophy and strength loss following Achilles tendon repair (ATR).
- BFR may address some specific and unique trouble areas for ATR rehab.
- The safety of BFR postoperatively is well established.
- Implementing BFR in preoperative and early postoperative phases is crucial.
- Progressively loading with BFR, and then transitioning gradually to traditional resistance training, optimizes recovery.

INTRODUCTION

An acute Achilles' tendon rupture is a common musculoskeletal injury, with an annual incidence of 7 to 40 events per 100,000 persons.¹ On average, patients require 6 to 12 postoperative months of limited mobility before returning to unrestricted physical activity and 1 year before returning to full strength. Early weight-bearing and mobilization have been advocated for in light of reported improvement in health-related quality of life, earlier healing responses, and greater strength improvements without risk of tendon rerupture or elongation.^{2–5} Though the literature increasingly supports the progressive use of strength and range of motion as opposed to cast immobilization, patients can still experience postoperative calf muscle atrophy and strength loss that can not only delay return to activity but also persist well over a year.⁵ Leppilahti and colleagues⁵ reported significant atrophy in 70% of patients with acute Achilles rupture

^a Department of Clinical Education and Research, Owens Recovery Science, INC, 11103 West Ave Suite 2101, San Antonio, TX 78213, USA; ^b Department of Foot and Ankle, Hospital for Special Surgery, 535 E 70th St Main Hospital, New York, NY 10021, USA; ^c Department of Clinical Education, Owens Recovery Science, INC, 11103 West Ave Suite 2101, San Antonio, TX 78213, USA
* Corresponding author.

E-mail address: johnny@owensrecoveryscience.com

Foot Ankle Clin N Am 31 (2026) 459–472

<https://doi.org/10.1016/j.fcl.2025.12.009>

[foot.theclinics.com](https://www.foot.theclinics.com)

1083-7515/26/© 2026 Elsevier Inc. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Descargado para Lucia Angulo (lu.maru26@gmail.com) en National Library of Health and Social Security de ClinicalKey.es por Elsevier en septiembre 22, 2026. Para uso personal exclusivamente. No se permiten otros usos sin autorización. Copyright ©2026. Elsevier Inc. Todos los derechos reservados.

Abbreviations	
1RM	1 repetition maximum
ATR	Achilles tendon repair
BFR	blood flow restriction
BFR-RE	blood flow restriction resistance exercise
VTE	venous thromboembolism

after 3 years. Similarly, Heikkinen and colleagues⁴ reported a 12% to 18% strength deficit between involved and uninvolved lateralities at 13 year follow-up.

Given these drawbacks, there is scope to improve postoperative rehabilitation protocols of Achilles ruptures to help patients return to preinjury levels of strength and physical activity. Blood flow restriction (BFR) exercise has emerged as a promising accelerated rehabilitation protocol that has been shown to safely attenuate postoperative losses in strength and muscle mass in patients unable to tolerate, or with contraindications to high-load resistance training.^{6–9} Thus, the purpose of this article is to explore how integrating the use of BFR into the rehab continuum following Achilles tendon repair (ATR) might augment current strategies. Within, we propose specific time points for use, considerations for dosage, target tissues with supporting physiologic rationale as well as strategies for determining when to consider moving away from BFR and how to do so.

INTRODUCTION OF BLOOD FLOW RESTRICTION

Once considered a novel and new modality for postoperative care, BFR has now become a consistently referred treatment option for orthopedic injuries. Although the bulk of clinical trials utilizing BFR have focused on its efficacy for conditions involving the knee, a recent survey of orthopedic surgeons found that 30.5% of referrals for BFR were for ATR.¹⁰ After Achilles repair, the protracted period of limited loading leads to substantial muscle atrophy and loss of strength. Unfortunately, clinicians have been limited in their ability to slow these negative postoperative changes because loads typically greater than 70% of a 1 repetition maximum (1RM) are required to restore muscle quantity and quality.¹¹ The advantage of BFR is the ability to gain similar muscle strength and hypertrophy as traditional heavy load resistance training while utilizing low loads, typically less than a 30% 1RM.^{11–13} This is accomplished by placing a pneumatic cuff on the proximal portion of the limb and inflating it to an individualized pressure to reduce arterial in-flow and completely block venous return.¹⁴ From this, a hypoxic state is created in the limb, which forces the muscle to utilize both aerobic and anaerobic metabolism while exercising at low loads.¹⁵ This emphasis on anaerobic metabolism recruits the high threshold fast-twitch muscle fibers and induces a rapid fatigue state along with inducing subsequent anabolic signaling pathways.^{15–19} Thus, BFR provides patients the ability to not only slow atrophy during periods of immobilization or limited loading but also to potentially maintain preoperative muscle strength and hypertrophy.

Basic exercise parameters of BFR resistance exercise are as follows¹⁴:

- 40% to 80% of limb occlusion pressure
- 20% to 40% of 1RM
- 30/15/15/15 rep/set scheme
- 30 second rest intervals
- 2 second concentric pace: 2 second eccentric pace
- Cuff remains inflated for the duration of the task

MECHANISMS OF ACTION

Chiefly, BFR works by accelerating the onset and amplification of fatigue.²⁰ It accomplishes this through local mechanisms that occur simultaneously as a result of the complete occlusion of the venous system and the reduction of oxygenated blood delivered to working muscle.²¹ Low-intensity exercise tasks (aerobic or resistance) preferentially utilize oxygen to generate the ATP necessary to fuel repetitive muscle contractions. The reduction in delivery of oxygenated blood to working muscle requires the use of alternate pathways to produce ATP to continue fueling the activity. These pathways, typically labeled anaerobic, produce metabolites in addition to ATP. These metabolites, specifically hydrogen ions and inorganic phosphate, cannot be cleared out of the muscle and venous system due to the restrictive cuff that has been applied. This results in a fatigue sensation building with each subsequent muscle contraction. The fatigue coupled with the reduction in resource (oxygenated blood) forces the recruitment of more and more muscle fibers to get involved in the task.^{22,23} This recruitment of additional motor units (typically type 2 motor units) and fatigue are imperative to achieve skeletal muscle adaptation via exercise in any form. Traditionally this has been accomplished via the use of high load, high intensity, or lengthy durations of exercise.

The emergence of BFR has helped physiologists better contextualize the roles load, intensity, and duration of exercise play. Thus, in many ways, BFR can be considered to simply be another exercise variable practitioners use to stress muscle sufficiently to achieve desired adaptations in muscle ultrastructure and performance. The application of this exercise approach, therefore, has implications toward a more efficient and thorough injury/surgical recovery,^{24,25} combatting progressive disorders that affect muscle quantity/quality,^{26–28} optimization of the exercise needed to achieve peak performance,^{29–31} and recently some indications that it may play a role in accelerating recovery from intense activity exposure.^{32–34}

SAFETY

The clinical safety of BFR following orthopedic surgery has been shown in several studies.^{24,35} Regardless of age, adverse responses are generally few and minor, often resolving within session.³⁶ Concern regarding venous thromboembolism (VTE) seems ill-founded given the lack of an impact on Virchow's triad and the fact BFR exercise is more in-line with prevention or management of clot than cause.^{37,38} Laboratory studies and clinical trials have not found any potential for BFR to produce VTE in acute, chronic, and postoperative conditions.^{39–41}

Following an injury to the vascular system, clot formation is a natural part of the healing process. Also, brief periods of blood stasis can lead to thrombus development without necessarily causing harmful effects. One way the body regulates thrombus progression is by activating the fibrinolytic system. Research has shown that resistance training can enhance fibrinolytic activity, with effects observed after just 1 session. This response has been noted in both young healthy individuals and older adults with coronary artery disease.^{42,43}

There is evidence suggesting that blood flow restriction resistance exercise (BFR-RE) may also enhance fibrinolytic activity. Studies indicate that applying BFR-RE to the lower limbs leads to increased levels of tissue plasminogen activator, a protein responsible for breaking down thrombi in endothelial cells.^{39,44} Moreover, brief vascular occlusion alone, even without exercise, has been associated with a significant rise in fibrinolytic factors.^{44,45} However, factors such as age, sex, and obesity could influence how the fibrinolytic system responds to exercise.⁴⁵ Following

established clinical prediction guidelines for VTE may be useful not only for applying BFR after Achilles repair but also for mobility and exercise in general.³⁸

Clinical presentations and their self-limiting nature all but ensure a gradual exposure to exercise intensity, even with BFR, thus facilitating a repeated bouts effect and providing protection against conditions like rhabdomyolysis.⁴⁶ The cardiovascular demands of BFR and exercise deserve the greatest level of concern related to ATR rehab given the incidence of occurrence in “weekend warrior” types. Fortunately, the majority of the evidence indicates BFR augments hemodynamic responses in a small but significant amount beyond low-load resistance exercise without BFR.⁴⁷ It is recommended that practitioners follow typical decision-making guidance for resistance training when prescribing BFR.⁴⁸

MANAGEMENT OF ACHILLES REPAIR

Comprehensive management of any injury in the modern health care landscape encompasses care from the acute injury through a preoperative phase where pain is often less and limitations have improved, to the acutely postoperative phase and progressing gradually until the point of return to prior level of function/performance. The latter as it relates to ATR can have a very wide berth. Therefore, the successful management of Achilles repair in any form involves problem solving a number of key time points and having the means and skill to accurately assess muscle performance and its relationship to the functional requirements of the patient’s life. A recent International Jopurnal of Sports Physical Therapy (*IJSPT*) publication by Marrone and colleagues⁴⁹ does an excellent job of providing incremental assessment strategies that inform exercise and return to activity decision-making following ATR.

Our limited understanding of how to optimally restore function following Achilles repair continues to evolve, as it does in many injuries that require surgery. As an example, a recent randomized controlled trial investigating the use of BFR after anterior cruciate ligament (ACL) reconstruction found that neither the experimental condition (BFR) nor the control (which was the first to follow current clinical practice guidelines [CPG’s]) was able to restore muscle quality or quantity to the affected limb’s quadriceps muscle at 4 to 5 months postop.⁵⁰ The hallmark of Achilles repair, unresolved gastrocnemius/soleus complex atrophy, certainly indicates lasting impairments of muscle health in this clinical presentation as well. As referenced earlier, deficits in strength have been shown to persist out to 13 years postop.⁴ While it is important to note that muscle size and strength do not share a linear relationship,^{51,52} these variables are certainly related, and undoubtedly indicate a need and potential target for postoperative therapies. Thus, novel management strategies like BFR have an opportunity to impact postop rehab substantially. Vital to their development and refinement is a comprehensive understanding of all relevant tissues and how they respond to various stimuli like the injury, the surgical procedure, and the pronounced periods of unloading associated with both the injury and surgery.

Advancements in surgical technique like the percutaneous achilles repair system (PARS) approach and the Speed Bridge (Arthrex Inc, Naples, FL) have moved the needle substantially toward more successful and quicker recoveries simply by using small incision and reducing the time spent nonweight-bearing.^{53,54} Despite this, the loading profile following ATR remains substantially less than prior to injury. Therefore, the magnitude of changes affecting the lower limb in response to unloading may be less, but they have certainly not been attenuated. This is evidenced by the fact that the clinician must still be mindful of loading too heavy too fast and stretching out the repair. Other well-known hurdles in the recovery after Achilles repair include

restoring end of range plantar flexion force production, restoring power output for return to jumping/running, and ultimately returning to the potentially very high levels of activity of a physically demanding profession.

BFR exercise may provide a means of maintaining or improving muscle size and health while the repaired Achilles heals. Additionally, recent evidence has indicated that BFR coupled with resistance exercise may provide a positive countermeasure to the unloading effects on bone and tendon following AT rupture and ATR.⁵⁵ Further, BFR has been shown to stimulate angiogenesis through upregulation of pro-angiogenic factors, which may enhance healing of both the tendon repair site and the surgical incision.^{56,57} BFR likely fits best in the preoperative and early postoperative phases of the ATR where we now have the ability to load in a controlled manner as a result of the aforementioned surgical advancements. In fact, Hansen and colleagues⁵⁸ has demonstrated recently that beginning BFR earlier in the rehab continuum helps to preserve calf muscle mass. Paramount to this are the utilization of exercise tasks that can be incrementally progressed as tissue capacities improve.

Preoperative Blood Flow Restriction Implementation

While traditionally prehabilitation refers to a few weeks of physical therapy prior to a surgical procedure, we prefer to conceptualize prehab as beginning the moment of injury in cases like AT rupture or ACL tear. This is, in part, due to emerging knowledge that the injury itself may contribute to muscular changes that impair the restoration of muscle function, while it is an established fact that disuse contributes to similar changes in muscle.^{59,60} These changes are presumed to be a result of the amplification of the myostatin gene. Therefore, early interventions to attempt to counter this may be very valuable to the overall health of muscle. Kakehi and colleagues⁶¹ have demonstrated that simply cycling inflations of the tourniquet for 5 rounds of 5 minutes twice daily slowed the disuse-induced amplification of myostatin. This is often referred to as “cyclic/passive BFR” or a “cell swelling protocol” after the mild swelling it causes in muscle as a result of depriving the sodium–potassium pumps in the muscle of oxygen.

While attempting to address the aforementioned, one must not lose sight of well-established targets of postinjury or prehab programs like the management of pain, edema, and range of motion. These should certainly take precedence. Fortunately, ischemic preconditioning, a close cousin of cyclic/passive BFR, has been shown to reduce pain temporarily and in our experience has been used successfully as a pain-relieving technique early postinjury.⁶² In this early phase after injury, high-frequency exposures to rehab may be optimal because of the temporary nature of treatment strategies to address pain and edema, while the implementation of BFR is intended to be a surrogate for daily weight-bearing activity.^{63,64} Further, the status of the individual is changing rapidly, and frequent assessment will also serve as means of ensuring the “prehab” is scaled properly, including determining when frequency of visits can be reduced. Clearly, high-frequency visits may not be possible given the constraints of the modern medical system, but this only changes the frequency of visits as it is the responsibility of the rehab clinician to utilize interventions that are appropriately scaled. This also highlights a need for research to elucidate and substantiate the value of such an approach.

Progression of exercise, specifically load, during this phase can happen rapidly and should be prioritized. BFR can assist with this progression through pain-relieving mechanisms as well as through its ability to facilitate an adaptive stimulus much earlier in the loading continuum.^{65–69} Historically, in the prehab phase, a great emphasis has been placed upon increasing force production in key muscle groups like the quad for

example, prior to total knee arthroplasty. Franz and colleagues⁷⁰ have proposed that given the metabolic crisis and subsequent disuse that follow surgery, perhaps more emphasis should be placed upon exposure of pertinent tissues to metabolic stress in the prehab phase to increase their resilience postoperatively. An initial exploration by Franz indicates that his theory may have foundation. Finally, the low-load nature of BFR has resulted in experimentation with high-frequency high-effort exposures that have resulted in a shortened time to achieve adaptation in muscle.¹⁸ A tertiary finding of this approach has been a latent supercompensation effect that has been proposed as a potential tool for the initial days of space travel.⁷¹ This strategy might also be applied in clinical scenarios like the last few days prior to Achilles surgery. The desired effect would be providing a cushion postop where the muscle is in a recovery phase for a few days to counter the effects of extreme disuse that are inevitable immediately following surgery.

As a rule, we recommend surgery for acute Achilles ruptures to regain strength and advocate for repair as soon as possible after the injury. While ruptured, the muscle is no longer connected to the calcaneus and has nothing to contract against. Even with weight-bearing, the muscle atrophies and enzymes that breakdown muscle rise. Patients may lose sarcomeres in the muscle and some of these changes may be permanent. As such we recommend expedited surgery and rehab as soon as is safely feasible.

Postoperative Blood Flow Restriction Implementation

The early postoperative phase is similar to the early postinjury phase. The key components of this phase that the clinician treats are pain, edema, and a large reduction in physical activity. Historically, the first 2 weeks following ATR are categorized as a protective phase, during which the range of motion into dorsiflexion is blocked via temporary cast or a boot with heel lifts that can be incrementally reduced in height. This serves to reduce the likelihood of stretching out the repair while allowing partial weight-bearing. Also, by using a minimally invasive approach with small incisions, the concerns regarding wound healing can be tempered and weight-bearing can be advanced safely. By manipulating the supercompensatory response of high-frequency BFR during the prehab phase, we have attempted to provide a window postoperatively that can be used to focus on pain and edema with little concern for a few days over disuse. However, we would suggest that after 3 to 4 days, an emphasis needs to begin to be placed upon counteracting the limited weight-bearing in the involved limb. We know from a large body of evidence that the quadriceps and soleus muscles begin to atrophy very fast during unloading.^{72,73} One of the chief contributors to this atrophy in addition to reductions in muscle protein synthetic rates are increases in myostatin that scar down muscle and make restoring muscle quality and quantity more difficult.⁶⁰ Therefore, clinicians need a strategy to address this. The quad can be programmed in a traditional manner with load at 2 to 3 times a week frequency utilizing a hypertrophy-type training regimen. The calf obviously cannot be loaded, and therefore, the clinician will need to program much like they did early following injury via cyclic/passive BFR approach.^{63,64} Fortunately, the calf musculature in healthy individuals seems to respond nicely to BFR on the same limb even if it is not targeted with exercise; this could further help to delay the need to provide some active contraction to limit atrophy.⁷⁴ However, as soon as isometrics to tolerance in the boot are permissible, they should be combined with BFR. Other low-load activities that could be combined with BFR during this phase while eliciting some active contraction from the calf could be bike pedaling, weight-shifting, walking in the AlterG, walking in the boot, or any other movements targeting the kinetic chain.

As the ability to load the Achilles and move it through larger ranges of motion increases, exercises can be progressed with BFR to elicit higher levels of effort and fatigue in the calf, which will allow reductions in frequency. The progression of exercise should be toward what we consider an optimal stimulus for hypertrophy, which would be plantar flexion exercises with both straight and bent knee, loaded to 20% to 30% of 1RM at a 60% to 80% limb occlusion pressure and using the typical 30/15/15/15 rep set scheme. This should result in a large amount of fatigue if not muscular failure and should be performed at least twice weekly. This will result in a weekly volume of 16 sets of exercise for the week, 8 of which will be working sets if proper loads and

Table 1
Achilles repair blood flow restriction rehabilitation protocol

Postoperative Timeline	Exercise
Postoperative Day 2 – Week 2: Splint removal/BFR therapy initiation	1. Straight leg raises 2. Side-lying leg raises
Postoperative Week 2 – Week 6	1. Ankle plantarflexion/dorsiflexion—The progression for this exercise movement will be ankle pumps (active plantarflexion and dorsiflexion to neutral with no resistance) to ankle pumps with a resistance thera-band, and finally to pumps using a leg press machine with increasing weighted resistance. Resistance and loading will not be used until approved by the physician and/or physical therapist 2. Straight leg raises—Progress to using thera-band or weights over time based on individual patient's capabilities 3. Side-lying leg raises—Progress to using thera-band or weights over time based on individual patient's capabilities 4. Long arc quads—Progress to using thera-band or weights over time based on individual patient's capabilities
Postoperative Week 6 – Week 12	1. Leg press toe raises—Start initially doing the exercise bilaterally with approximately 40 lbs or whatever the patient can tolerate. Progress to using additional weight and performing the exercise unilaterally based on individual patient's capabilities 2. Leg press—Begin doing exercise bilaterally. Progress to using weight over time and doing the exercise unilaterally based on individual patient's capabilities 3. Glute bridges—Begin doing exercise bilaterally. Progress to using weight over time and doing the exercise unilaterally based on individual patient's capabilities 4. Romanian dead lift (RDL)—Progress to using weight over time and doing the exercise unilaterally based on individual patient's capabilities

Courtesy of Drakos et al.

pressures are achieved. It is thought that around 10 sets of weekly volume is necessary to drive muscular hypertrophy.⁷⁵ This number is higher for the trained individual due to their training status. We would suggest considering a higher volume than 10 sets is likely necessary for the gastroc/soleus complex given the large volume of work these tissues are susceptible to with a typical daily activity suggestion of 10,000 steps.⁷⁶ Tracking daily steps and weekly training volume are likely very valuable to ensure a continued progression of activity in order to seamlessly restore function. Hullfish and colleagues⁷⁷ and Baxter and colleagues⁷⁸ are important resources that can help guide the incremental progression of loading during this and later phases.

Moving Away from Blood Flow Restriction/Late Phase Blood Flow Restriction Training Blocks

The use of BFR will be necessary well into the intermediate phase (weeks 6–12) of rehab after ATR. It is possible that it will be needed beyond this phase, but by 12 weeks, the clinician should at least be considering how to achieve the necessary training volumes with physical loading of 65% 1RM and greater. Removing BFR from the program should not, however, be a decision based upon weeks postop, it should be criteria driven by objective measurement and individual patient status.

A simple way to gradually progress away from BFR is to replace 1 exercise at a time with heavy loading. This ensures the maintenance of training volume while also limiting soreness from the increased load. Another strategy that we have used successfully is to utilize heavy loading days and BFR days. If for example, training 3 days a week, Monday could be the heavy day while Wednesday and Friday are BFR days. This could progress to Monday and Friday as heavy days while Wednesday remains a BFR day.

As the weeks progress and the patient is regaining energy storage capabilities of the tendon, particularly if a muscle size deficit persists, it could be beneficial to feather in a month or so of BFR as a means of altering the training stimulus to push through a sticking point. It has been demonstrated that in highly trained individuals that BFR, even in small doses, can provide an adaptive stimulus that load could not.⁷⁹ And since BFR has been shown to increase Achilles tendon stiffness similarly to heavy loading, there is no concern over a negative effect of this training modification.^{80,81}

SUMMARY

In conclusion, the rehabilitation process for acute Achilles tendon rupture is critical for restoring function and preventing reinjury. While traditional protocols emphasize restricted activity, the integration of BFR therapy has shown significant promise. It enables strength improvements with lower loads, thereby reducing the risk of overloading the healing tendon. Additionally, early application of BFR in rehabilitation has been associated with faster recovery timelines, enhanced muscle hypertrophy, and improved quality of life. Early BFR may even improve the quality of the healing tendon.⁸² These findings underscore the potential of BFR to transform standard rehabilitation practices for Achilles tendon injuries. Future research should focus on optimizing BFR protocols and understanding long-term outcomes to further enhance recovery strategies and patient care (Table 1).

(At the onset of the BFR therapy sessions which will occur 2–3 times per week, the tourniquet cuff will be placed around the patient's thigh. Physical therapists will guide patients to complete exercises at 80% of LOP, but final pressure for the duration of the exercises will be the maximum pressure tolerated by the patient between 60% and 80% limb occlusion pressure (LOP). Four sets of each exercise will be completed

for reps of 30, 15, 15, and 15 during each set. Thirty second breaks will be taken between each set. Additional aspects of physical therapy outside these strengthening exercises will be per standard of care physical therapy.)

CLINICS CARE POINTS

- Passive/cyclic BFR (5 minutes inflation $\times$ 5 rounds, twice daily) effectively slows atrophy during immobilization without requiring active muscle contraction—ideal for the first 3-4 days postoperatively.
- BFR allows safe strengthening at 20-30% of 1RM, enabling therapeutic loading well before traditional heavy resistance ($\geq 70\%$ 1RM) would be safe for the healing tendon.
- Individualize occlusion pressure to 40-80% of limb occlusion pressure (LOP) to optimize safety and efficacy across different patient limb sizes and compositions.
- BFR enhances angiogenesis, potentially promoting healing of both the tendon repair and the surgical incision—a dual benefit beyond muscle preservation alone.
- Transition from BFR to traditional loading is criteria-based, not time-based: begin replacing BFR sessions with heavy-load training once patients demonstrate adequate strength and tissue healing capacity.
- The gastrocnemius-soleus complex may require higher weekly training volumes (>10 sets) due to its normal high-volume daily loading demands compared to other muscle groups.

DISCLOSURE

J. Owens and K. Kimbrell receive compensation from a BFR education company and device distributor (Owens Recovery Science). J. Owens is a consultant for Delfi Medical Innovations, a BFR device manufacturer. M. Drakos is a consultant for Arthrex and Extremity. He is also President of the Quigley Society's Executive Board.

REFERENCES

1. Holm C, Kjaer M, Eliasson P. Achilles tendon rupture—treatment and complications: a systematic review. *Scand J Med Sci Sports* 2015;25(1):e1–10.
2. Booth FW. Physiologic and biochemical effects of immobilization on muscle. *Clin Orthop* 1987;219:15–20.
3. Cetti R, Christensen SE, Ejsted R, et al. Operative versus nonoperative treatment of achilles tendon rupture. A prospective randomized study and review of the literature. *Am J Sports Med* 1993;21(6):791–9.
4. Heikkinen J, Lantto I, Flinkkilä T, et al. Augmented compared with nonaugmented surgical repair after total achilles rupture: results of a prospective randomized trial with thirteen or more years of Follow-up. *J Bone Joint Surg Am* 2016;98(2): 85–92.
5. Leppilahti J, Lähde S, Forsman K, et al. Relationship between calf muscle size and strength after achilles rupture repair. *Foot Ankle Int* 2000;21(4):330–5.
6. Johns W, Wiafe B, Hammoud S. Blood flow restriction following ACL reconstruction. *Video J Sports Med* 2023;3:263502542211482. <https://doi.org/10.1177/26350254221148215>.
7. Kara D, Ozcakar L, Demirci S, et al. Blood flow restriction training in patients with rotator cuff tendinopathy: a randomized, assessor-blinded, controlled trial. *Clin J Sport Med Off J Can Acad Sport Med* 2024;34(1):10–6.

8. Ohta H, Kurosawa H, Ikeda H, et al. Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. *Acta Orthop Scand* 2003;74(1):62–8.
9. Takarada Y, Takazawa H, Ishii N. Applications of vascular occlusion diminish disuse atrophy of knee extensor muscles. *Med Sci Sports Exerc* 2000;32(12):2035–9.
10. Castle JP, Tramer JS, Turner EH, et al. Survey of blood flow restriction therapy for rehabilitation in sports medicine patients. *J Orthop Traumatol* 2023;38:47–52.
11. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009;41(3):687–708.
12. Lixandrão ME, Ugrinowitsch C, Berton R, et al. Magnitude of muscle strength and mass adaptations between high-load resistance training versus low-load resistance training associated with blood-flow restriction: a systematic review and meta-analysis. *Sports Med* 2018;48(2):361–78.
13. Grønfeldt BM, Lindberg Nielsen J, Mieritz RM, et al. Effect of blood-flow restricted vs. heavy-load strength training on muscle strength: systematic review and meta-analysis. *Scand J Med Sci Sports* 2020. <https://doi.org/10.1111/sms.13632>.
14. Patterson SD, Hughes L, Warmington S, et al. Blood flow restriction exercise: considerations of methodology, application, and safety. *Front Physiol* 2019;10:533.
15. Fatela P, Mendonca GV, Veloso AP, et al. Blood flow restriction alters motor unit behavior during resistance exercise. *Int J Sports Med* 2019. <https://doi.org/10.1055/a-0888-8816>.
16. Davids CJ, Næss TC, Moen M, et al. Acute cellular and molecular responses and chronic adaptations to low-load blood flow restriction and high-load resistance exercise in trained individuals.pdf. *J Appl Physiol* 2021. <https://doi.org/10.1152/jappphysiol.00464.2021>.
17. Fry CS, Glynn EL, Drummond MJ, et al. Blood flow restriction exercise stimulates mTORC1 signaling and muscle protein synthesis in older men. *J Appl Physiol* 2010;108(5):1199–209.
18. Nielsen JL, Aagaard P, Bech RD, et al. Proliferation of myogenic stem cells in human skeletal muscle in response to low-load resistance training with blood flow restriction. *J Physiol* 2012;590(17):4351–61.
19. Ellefsen S, Hammarström D, Strand TA, et al. Blood flow-restricted strength training displays high functional and biological efficacy in women: a within-subject comparison with high-load strength training. *Am J Physiol Regul Integr Comp Physiol* 2015;309(7):R767–79.
20. Eiken O, Bjurstedt H. Dynamic exercise in man as influenced by experimental restriction of blood flow in the working muscles. *Acta Physiol Scand* 1987;131(3):339–45.
21. Asmussen E, Nielsen M. Experiments on nervous factors controlling respiration and circulation during exercise employing blocking of the blood flow. *Acta Physiol Scand* 1964;60:103–11.
22. Moritani T, Sherman WM, Shibata M, et al. Oxygen availability and motor unit activity in humans. *Eur J Appl Physiol* 1992;64:552–6.
23. Flewwelling LD, Hannaian SJ, Cao V, et al. What are the potential mechanisms of fatigue-induced skeletal muscle hypertrophy with low-load resistance exercise training? *Am J Physiol Cell Physiol* 2024. <https://doi.org/10.1152/ajpcell.00266.2024>.

24. Hughes L, Paton B, Rosenblatt B, et al. Blood flow restriction training in clinical musculoskeletal rehabilitation: a systematic review and meta-analysis. *Br J Sports Med* 2017;51(13):1003–11.
25. LaPrade RF, Monson JK, Schoenecker J. Editorial commentary: blood flow restriction therapy continues to prove effective. *Arthroscopy* 2021;37(9):2870–2.
26. Bane A, Wilson L, Jumper J, et al. Effects of blood flow restriction resistance training on autonomic and endothelial function in persons with Parkinson's disease. *J Parkinsons Dis* 2024;1–15.
27. Mañago MM, Cohen ET, Alvarez E, et al. Feasibility of low-load resistance training using blood flow restriction for people with advanced multiple sclerosis: a prospective cohort study. *Phys Ther* 2024;104(1). <https://doi.org/10.1093/ptj/pzad135>.
28. Conceição MS, Ugrinowitsch C. Exercise with blood flow restriction: an effective alternative for the non-pharmaceutical treatment for muscle wasting. *Journal of Cachexia, Sarcopenia and Muscle* 2019. <https://doi.org/10.1002/jcsm.12397>.
29. Smith NDW, Scott BR, Girard O, et al. Aerobic training with blood flow restriction for endurance athletes: potential benefits and considerations of implementation. *J Strength Condit Res* 2021. <https://doi.org/10.1519/JSC.0000000000004079>.
30. Tollefson LV, Schoenecker J, Solie B, et al. Lower extremity blood flow restriction training in athletes significantly improves strength related outcomes in 58% of studies compared to non-BFR control. *Arthroscopy* 2024. <https://doi.org/10.1016/j.arthro.2024.12.005>.
31. Wortman RJ, Brown SM, Savage-Elliott I, et al. Blood flow restriction training for athletes: a systematic review. *Am J Sports Med* 2020;363546520964454.
32. Page W, Swan R, Patterson SD. The effect of intermittent lower limb occlusion on recovery following exercise-induced muscle damage: a randomized controlled trial. *J Sci Med Sport* 2017;20(8):729–33.
33. Patterson SD, Swan R, Page W, et al. The effect of acute and repeated ischemic preconditioning on recovery following exercise-induced muscle damage. *J Sci Med Sport* 2021;0(0). <https://doi.org/10.1016/j.jsams.2021.02.012>.
34. Oliva-Lozano JM, Patterson SD, Chiampas G, et al. Blood flow restriction as a post-exercise recovery strategy: a systematic review of the current status of the literature. *Biol Sport* 2024;41(3):191–200.
35. Perera E, Zhu XM, Horner NS, et al. Effects of blood flow restriction therapy for muscular strength, hypertrophy, and endurance in healthy and special populations: a systematic review and meta-analysis. *Clin J Sport Med* 2022;32(5):531–45.
36. Prue J, Roman DP, Giampetruzzi NG, et al. Side effects and patient tolerance with the use of blood flow restriction training after ACL reconstruction in adolescents: a pilot study. *Int J Sports Phys Ther* 2022.
37. Bond CW, Hackney KJ, Brown SL, et al. Blood flow restriction resistance exercise as a rehabilitation modality following orthopaedic surgery: a review of venous thromboembolism risk. *J Orthop Sports Phys Ther* 2019;49(1):17–27.
38. Hillegass E, Lukaszewicz K, Puthoff M. Role of physical therapists in the management of individuals at risk for or diagnosed with venous thromboembolism: evidence-based clinical practice guideline 2022. *Phys Ther* 2022. <https://doi.org/10.1093/ptj/pzac057/6585463>.
39. Clark BC, Manini TM, Hoffman RL, et al. Relative safety of 4 weeks of blood flow-restricted resistance exercise in young, healthy adults. *Scand J Med Sci Sports* 2011;21(5):653–62.

40. Madarama H, Kurano M, Takano H, et al. Effects of low-intensity resistance exercise with blood flow restriction on coagulation system in healthy subjects. *Clin Physiol* 2010. Available at: <http://onlinelibrary.wiley.com/doi/10.1111/j.1475-097X.2010.00927.x/full>.
41. Tennent DJ, Hylden CM, Johnson AE, et al. Blood flow restriction training after knee arthroscopy: a randomized controlled pilot study. *Clin J Sport Med* 2017; 27(3):245–52.
42. deJong AT, Womack CJ, Perrine JA, et al. Hemostatic responses to resistance training in patients with coronary artery disease. *J Cardiopulm Rehabil* 2006; 26(2):80–3.
43. El-Sayed MS. Fibrinolytic and hemostatic parameter response after resistance exercise. *Med Sci Sports Exerc* 1993;25(5):597–602.
44. Nakajima T, Takano H, Kurano M, et al. Effects of KAATSU training on haemostasis in healthy subjects. *International Journal of KAATSU Training Research* 2007; 3(1):11–20.
45. Stegnar M, Meta P. Fibrinolytic response to venous occlusion in healthy subjects: relationship to age, gender, body weight, blood lipids and insulin. *Thromb Res* 1993;69(1):81–92.
46. Sieljacks P, Matzon A, Wernbom M, et al. Muscle damage and repeated bout effect following blood flow restricted exercise. *Eur J Appl Physiol* 2016;116(3): 513–25.
47. Takano H, Morita T, Iida H, et al. Hemodynamic and hormonal responses to a short-term low-intensity resistance exercise with the reduction of muscle blood flow. *Eur J Appl Physiol* 2005;95(1):65–73.
48. Severin R, Sabbahi A, Albarrati A, et al. Blood pressure screening by outpatient physical therapists: a call to action and clinical recommendations. *Phys Ther* 2020. <https://doi.org/10.1093/ptj/pzaa034>.
49. Marrone W, Andrews R, Reynolds A, et al. Rehabilitation and return to sports after achilles tendon repair. *Int J Sports Phys Ther* 2024;19(9):1152–65.
50. Erickson LN, Owen MK, Casadonte KR, et al. The efficacy of blood flow restriction training to improve quadriceps muscle function after ACL reconstruction. *Med Sci Sports Exerc* 2024. <https://doi.org/10.1249/MSS.0000000000003573>.
51. Jessee MB, Dankel SJ, Bentley JP, et al. A retrospective analysis to determine whether training-induced changes in muscle thickness mediate changes in muscle strength. *Sports Med* 2021. <https://doi.org/10.1007/s40279-021-01470-5>.
52. Loenneke JP, Buckner SL, Dankel SJ, et al. Exercise-induced changes in muscle size do not contribute to exercise-induced changes in muscle strength. *Sports Med* 2019. <https://doi.org/10.1007/s40279-019-01106-9>.
53. Martin KD, Crouser NJ, Khan IA. Minimally invasive mid-substance achilles tendon repair using the Percutaneous Achilles Repair System (PARS). *JBJS Es-sent Surg Tech* 2022;12(3):e21, 00050.
54. McWilliam JR, Mackay G. The internal brace for midsubstance achilles ruptures. *Foot Ankle Int* 2016;37(7):794–800.
55. Lambert B, Han A, Goble H, et al. Paper 54: effects of blood flow restriction rehabilitation after achilles tendon rupture repair – a randomized trial. *Orthop J Sports Med* 2024;12(7_suppl2). <https://doi.org/10.1177/2325967124s00066>.
56. Ferguson RA, Hunt JEA, Lewis MP, et al. The acute angiogenic signalling response to low-load resistance exercise with blood flow restriction. *Eur J Sport Sci* 2018;18(3):397–406.

57. Larkin KA, Macneil RG, Dirain M, et al. Blood flow restriction enhances post-resistance exercise angiogenic gene expression. *Med Sci Sports Exerc* 2012;44-(11):2077–83.
58. Hansen OB, Papson A, Eble SK, et al. Effect of blood flow restriction therapy following achilles rupture and repair: a randomized controlled trial. *Foot & Ankle Orthopaedics* 2022;7(1).
59. Fry CS, Johnson DL, Ireland ML, et al. ACL injury reduces satellite cell abundance and promotes fibrogenic cell expansion within skeletal muscle. *J Orthop Res* 2017. <https://doi.org/10.1002/jor.2302>.
60. Wall BT, Dirks ML, Snijders T, et al. Substantial skeletal muscle loss occurs during only 5 days of disuse. *Acta Physiol* 2014;210(3):600–11.
61. Kakehi S, Tamura Y, Kubota A, et al. Effects of blood flow restriction on muscle size and gene expression in muscle during immobilization: a pilot study. *Physiological Reports* 2020;8(14):e14516.
62. Memtsoudis SG, Della Valle AG, Jules-elysse K, et al. Perioperative inflammatory response in total knee arthroplasty patients: impact of limb preconditioning. *Reg Anesth Pain Med* 2010;35(5):412–6.
63. Kubota A, Sakuraba K, Sawaki K, et al. Prevention of disuse muscular weakness by restriction of blood flow. *Med Sci Sports Exerc* 2008;40(3):529–34.
64. Slys JT, Boston M, King R, et al. Blood flow restriction combined with electrical stimulation attenuates thigh muscle disuse atrophy. *Med Sci Sports Exerc* 2020. <https://doi.org/10.1249/MSS.0000000000002544>.
65. Hughes L, Grant I, Patterson SD. Aerobic exercise with blood flow restriction causes local and systemic hypoalgesia and increases circulating opioid and endocannabinoid levels. *J Appl Physiol* 2021;131(5):1460–8.
66. Hughes L, Patterson SD. Low intensity blood flow restriction exercise: rationale for a hypoalgesia effect. *Med Hypotheses* 2019;132:109370.
67. Hughes L, Patterson SD. The effect of blood flow restriction exercise on exercise-induced hypoalgesia and endogenous opioid and endocannabinoid mechanisms of pain modulation. *J Appl Physiol* 2020. <https://doi.org/10.1152/jappphysiol.00768.2019>.
68. Korakakis V, Whiteley R, Epameinontidis K. Blood flow restriction induces hypoalgesia in recreationally active adult male anterior knee pain patients allowing therapeutic exercise loading. *Phys Ther Sport* 2018;32:235–43.
69. Song JS, Spitz RW, Yamada Y, et al. Exercise-induced hypoalgesia and pain reduction following blood flow restriction: a brief review. *Phys Ther Sport* 2021.
70. Franz A, Queitsch FP, Behringer M, et al. Blood flow restriction training as a prehabilitation concept in total knee arthroplasty: a narrative review about current preoperative interventions and the potential impact of BFR. *Med Hypotheses* 2018;110:53–9.
71. Hughes L, Hackney KJ, Patterson SD. Optimization of exercise countermeasures to spaceflight using blood flow restriction. *Aerosp Med Hum Perform* 2022.
72. Kilroe S, Fulford J, Jackman S, et al. Temporal muscle-specific disuse atrophy during one week of leg immobilization. *Medicine* 2019. <https://doi.org/10.1249/MSS.0000000000002200>.
73. Hackney KJ, Ploutz-Snyder LL. Unilateral lower limb suspension: integrative physiological knowledge from the past 20 years (1991–2011). *Eur J Appl Physiol* 2012;112(1):9–22.
74. Bowman EN, Elshaar R, Milligan H, et al. Proximal, distal, and contralateral effects of blood flow restriction training on the lower extremities: a randomized

- controlled trial. *Sport Health* 2019. <https://doi.org/10.1177/1941738118821929>. 1941738118821929.
75. Schoenfeld BJ, Ogborn D, Krieger JW. Dose-response relationship between weekly resistance training volume and increases in muscle mass: a systematic review and meta-analysis. *J Sports Sci* 2017;35(11):1073–82.
 76. Tudor-Locke C, Bassett DR Jr. How many steps/day are enough?: preliminary pedometer indices for public health. *Sports Med* 2004;34(1):1–8.
 77. Hullfish TJ, Woods MM, Kwon MP, et al. The difference in achilles tendon loading within immobilizing boots based on ankle angle, boot type, and walking speed. *Orthop J Sports Med* 2024;12(10):23259671241283806.
 78. Baxter JR, Corrigan P, Hullfish TJ, et al. Exercise progression to incrementally load the achilles tendon. *Med Sci Sports Exerc* 2021;53(1):124–30.
 79. Bjørnsen T, Wernbom M, Kirketeig A, et al. Type 1 muscle fiber hypertrophy after blood flow-restricted training in powerlifters. *Med Sci Sports Exerc* 2018. <https://doi.org/10.1249/MSS.0000000000001775>.
 80. Centner C, Jerger S, Lauber B, et al. Similar patterns of tendon regional hypertrophy after low-load blood flow restriction and high-load resistance training. *Scand J Med Sci Sports* 2023. <https://doi.org/10.1111/sms.14321>.
 81. Centner C, Lauber B, Seynnes OR, et al. Low-load blood flow restriction training induces similar morphological and mechanical achilles tendon adaptations compared to high-load resistance training. *J Appl Physiol* 2019. <https://doi.org/10.1152/jappphysiol.00602.2019>.
 82. Bechan Vergara I, Puig-Diví A, Amestoy Alonso B, et al. Effects of low-load blood flow restriction training in healthy adult tendons: a systematic review and meta-analysis. *J Bodyw Mov Ther* 2024;39:13–23.