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Research Article

Application of Current Knowledge of Blood Flow Restriction Training for Use on Upper Extremity Injuries

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Blood flow restriction (BFR) utilizes a cuff or tourniquet to induce muscle hypoxia by maintaining arterial flow, while restricting venous return. This technique has recently gained popularity in healthy patients and patients undergoing rehabilitation. Two studies have shown that patients who use BFR, in addition to the standard therapy protocol, following an upper extremity injury (UEI) have reduced pain and improved Patient-Reported Wrist Evaluation scores. The use of BFR in the upper extremity of healthy patients and patients with a prior lower extremity injury have shown statistically significant improvements in muscle strength and muscle hypertrophy. Further studies focusing on BFR training following various upper extremity injuries are needed to determine the potential impact on clinical outcomes. The purpose of this review was to analyze the use of BFR following lower extremity injuries, summarize the literature of BFR for upper extremity injuries, and consider the application of BFR following upper extremity injuries in the future.

BLOOD FLOW RESTRICTION TRAINING

Shinohara et al. first reported on the applications of induced muscle ischemia in low resistance strength training in 1998 (Shinohara et al. 1998). However, the concept of muscle ischemia training dates back to the 1970's in Japan, where Dr. Yoshiaki Soto applied a tourniquet around a limb to restrict muscular arterial blood flow in a technique he named "Kaatsu resistance training" (DePhillipo, Kennedy, Aman, et al. 2018). By restricting blood flow, muscle hypoxia promotes increased levels of metabolic stress when combined with strength training, which is theorized to pro-

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Conflicts of Interest Statement for Ms. Stevens

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Dr. Mary Mulcahey joined the faculty in the Department of Orthopaedic Surgery at Tulane in April 2017, as the Director of Tulane's Women's Sports Medicine Program. In that role, Dr. Mulcahey has been instrumental in the design, development, and leadership of a comprehensive approach to the care of active women. Dr. Mulcahey is currently the President of the Ruth Jackson Orthopaedic Society. Additionally, she is serving on the AANA Board of Directors, the AOSSM education committee, the AJSM Electronic Media Editorial Board, and she was selected for the AOSSM Traveling Fellowship to Europe in April 2022. Dr. Mulcahey is the team physician for Tulane's Women's Indoor and Beach Volleyball teams, the Big Easy Rollergirls, New Orleans Women's Rugby (the Halfmoons), as well as several local all girls' high schools.

Visit Dr. Mulcahey's Website

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Conflicts of Interest Statement for Dr. Mulcahey mote muscle hypertrophy (Barber-Westin and Noyes 2019; DePhillipo, Kennedy, Aman, et al. 2018; Loenneke, Wilson, et al. 2012; Yasuda, Ogasawara, Sakamaki, et al. 2011). The exact mechanism by which blood flow restriction (BFR) works has not yet been determined; however some of the proposed mechanisms that lead to muscle hypertrophy and increased strength include cell swelling, production of reactive oxygen species, elevated systemic hormone production, and intramuscular anabolic/ anticatabolic signaling (Loenneke, Fahs, et al. 2012; Loenneke, Wilson, et al. 2012; Pearson and Hussain 2015; Pope, Willardson, and Schoenfeld 2013; Takarada et al. 2000; Wilk et al. 2020). BFR is performed by placing a tourniquet or blood pressure cuff around the proximal end of an extremity and inflating it to a predetermined pressure, which can range from 60 to 270 mmHg (Hughes et al. 2017; Yasuda, Ogasawara, Sakamaki, et al. 2011). Depending on the area of the body, some extremities may not be directly occluded from BFR. For example, in the case of shoulder injuries, the torniquet is applied to the proximal upper arm in order to elicit vascular occlusion (Lambert et al. 2021). The inflated pressure has most commonly been determined by these five methods: arbitrary pressure selection, percentage of systolic blood pressure, circumference of the limb, a tightness intensity scale, or limb occlusion pressure percentage (Lorenz et al. 2021).

BFR performed simultaneously with low-load resistance training has been shown to produce significant muscle hypertrophy and increased strength (Hughes et al. 2017). The American College of Sports Medicine's proposed recommendations for traditional resistance training suggest at least one set of eight to twelve repetitions for eight to ten exercises, with each major muscle group targeted by at least one exercise (American College of Sports Medicine position stand 2009). In order to achieve increased neural and muscular adaptations during resistance training, a load of 80% of one repetition maximum is necessary. This 80% of maximum load is considered to be high-intensity resistance training, which can be dangerous for untrained lifters. Low-load resistance training, which is only 20%–30% of one repetition maximum, combined with BFR, can produce similar results to high-intensity training with a low risk of injury (American College of Sports Medicine position stand 2009). When physically possible, the use of low-load BFR exercises combined with high-intensity training can produce significant muscle adaptation (Gart and Wiedrich 2017). However, when high-intensity training in considered unsafe for participants, such as those with injuries or diminished strength, low-load resistance training can be a valuable adjunct for rehabilitation (American College of Sports Medicine position stand 2009; Libardi et al. 2015; Lu et al. 2020; Scott et al. 2016; Wilk et al. 2020).

BFR has been utilized in a variety of clinical settings, not just for competitive athletes (American College of Sports Medicine position stand 2009; Libardi et al. 2015; Lu et al. 2020; Scott et al. 2016; Wilk et al. 2020). Without the need to use heavy loads during resistance training, BFR can be an effective therapy for patients who have recently had an injury or older, less active patients (Centner et al. 2019; Yasuda, Fukumura, Uchida, et al. 2015; Yokokawa et al. 2008). Due to certain restrictions, the combined low-load resistance training and vascular occlusion that occurs with BFR can be used for the types of patients previously mentioned, or others who are physically unable to perform resistance exercises with an 80% maximum load. Although these populations may have different goals for their clinical outcomes, the versatility of BFR makes it an optimal training intervention (American College of Sports Medicine position stand 2009; Bowman, El-shaar, Milligan, et al. 2019; Libardi et al. 2015; Lu et al. 2020; Scott et al. 2016; Wilk et al. 2020). Previous research has examined the use of BFR with lower extremity injuries (e.g., ACL tears); however, few studies have examined the combination of low-load resistance training with BFR in upper extremity exercises (Barber-Westin and Noyes 2019; Dankel et al. 2016; Hughes et al. 2017).

BFR USE IN HEALTHY PARTICIPANTS

In 2021, Lambert et al. evaluated the use of BFR applied to the shoulder in healthy participants (Lambert et al. 2021). A total of 32 healthy adults were randomized to either the No-BFR group (control) or the BFR group. All participants performed common rotator cuff exercises twice a week for a total of eight weeks. For each exercise, participants performed one set of 30 repetitions followed by two sets of 15 repetitions and a final set to fatigue. Participants had

30 seconds of rest between sets and two minutes between different exercises. For each exercise, the BFR group had a tourniquet applied at the proximal arm with 50% occlusion, which was maintained during intra-set rests and only released during the two-minute rest periods between sets. The BFR group showed a greater increase in lean mass in the shoulder and arm, isometric strength, and muscular endurance compared to the control group (Lambert et al. 2021). Some of the muscles in the shoulder and upper extremity cannot be directly restricted by torniquet use in BFR, so the cause of the hypertrophy and strength gains are still being investigated (Dankel et al. 2016; Lambert et al. 2021). Although this study examined healthy participants, the improvements demonstrate that the use of BFR training may improve outcomes following shoulder injuries.

While the study above demonstrated statistically significant increases in strength of the upper extremities when using BFR, a randomized control trial conducted by Brumitt et al. in 2020 showed increased shoulder strength, but not to the level of statistical significance when compared to the non-BFR control group (Brumitt, Hutchison, Kang, et al. 2020). In this study, 46 healthy patients were randomized into BFR plus exercise group or to the exercise-only group (control). Patients in both groups performed sets of the exercise (30/15/15/15 repetitions) at 30% of individual one-repetition maximum, with 30 seconds of rest between sets, two days per week for a total of eight weeks. Those in the BFR group had a tourniquet applied to the proximal portion of the upper extremity set to 50% limb occlusion, for a total of eight minutes. Both groups also showed increases in the thickness of the supraspinatus tendon, but again, there was no difference between the two groups. The authors concluded that participants in both groups showed strength gains in the supraspinatus and external rotators. However, there was no difference in strength gains between the BFR plus exercise group and the control group (Brumitt, Hutchison, Kang, et al. 2020).

BFR USE FOLLOWING LOWER EXTREMITY INJURIES

While there is limited research related to the use of BFR following upper extremity injuries (UEI), there have been numerous studies that demonstrate significant increases in muscle strength and hypertrophy following a lower extremity injury (LEI) (Hughes et al. 2017; Kacin et al. 2021). In 2017, Hughes et al. performed a systematic review and meta-analysis of the use of blood flow restriction training in clinical musculoskeletal rehabilitation (Hughes et al. 2017). Twenty studies were included in the systematic review, which involved patients with knee osteoarthritis (n=3), ligament injuries (n=3), sporadic inclusion body myositis (n=1), and older adults who were determined to be susceptible to sarcopenia (n=13). Hughes et al. looked at BFR in both upper and lower extremities; however, all the studies evaluating the function of BFR in upper extremities were related to rehabilitation in the elderly, and not rehabilitation directly focused on an injury. In the majority of studies, BFR was used in combination with body weight exercises, low-load resistance training, elastic band resistance training, and low-moderate intensity walk training. Based on previous research, total limb occlusive pressure, and/or systolic blood pressure, tourniquet occlusive pressures ranged from 60 to 270 mmHg. The load for BFR training ranged from 10% to 30% one repetition maximum for resistance exercise, and 45% of heart rate reserve to 67 m/min^{-1} for walking exercises. BFR training ranged from two to sixteen weeks, with a frequency of two to six training sessions per week. Data from the studies that evaluated the use of BFR in the upper extremities in the elderly showed: increase in hand grip, increase in one repetition maximum in a variety of upper body exercises, and increased muscle thickness. Hughes et al. concluded that low-load training in combination with BFR proved more effective and tolerable than low-load training on its own (Hughes et al. 2017). Therefore, BFR training can potentially be a useful clinical rehabilitation tool following a LEI and in the upper extremities of older adults at risk of a loss of muscle mass (Teunis et al. 2014; Thiebaud et al. 2013).

BFR training has also been used following anterior cruciate ligament (ACL) injuries. A recent study by Kacin et al. investigated the potential role of BFR in facilitating functional and muscular adaptations of the quadriceps and hamstrings muscles in patients with an ACL rupture (Kacin et al. 2021). Thirty-six patients who were scheduled to undergo ACL reconstruction met inclusion criteria and were divided into three groups: BFR, a SHAM-BFR, and a control group. These patients were put through an ACL rehabilitation protocol (Table 2). Additionally, measurements of knee extensor and flexor muscle strength were reported along with fatigue indices, which were calculated percentage ratios between the highest and lowest peak torque value. The authors determined that the change in cross-sectional area (CSA) of the quadriceps muscle was significantly larger in the BFR group as compared to the SHAM-BFR group. Similarly, peak torque of the knee extensors was also larger in the BFR group than that of the SHAM-BFR group. Muscle biopsies were also taken form the BFR and SHAM-BFR groups before and after the rehabilitation program. It was determined that the transcriptional responses, such as VEGF-A, were upregulated in the BFR group compared to the SHAM-BFR group. There was no significant difference in mRNA expression of HIF-2α, VEGF-A, and phosphoglycerate kinase 1 in the SHAM-BFR group compared to the control group. The authors concluded that in patients with an ACL rupture, low-load resistance exercises in addition to BFR training prior to surgery can lead to hypertrophy of the quadriceps muscle and increased strength and endurance of knee extensors, while the hamstrings and knee flexors were less responsive (Kacin et al. 2021).

The results of the previously mentioned studies demonstrate that BFR can lead to increased muscle hypertrophy and strength. The protocols in each of the studies were similar, including tourniquet use and sets of repeated exercises, which can serve as a guideline for a BFR protocol following an UEI.

UPPER EXTREMITY INJURIES

An increase in sports participation among young athletes has been associated with a rise in injuries, especially those relating to overuse (DeCastro 2020; Goldberg et al. 2007; Luime et al. 2004; Mariscalco and Saluan 2011; Zaremski, Zeppieri, and Tripp 2019).Athletes who play throwing-dominant sports, such as tennis, volleyball, baseball, softball, handball, cricket, and water-polo, commonly suffer upper extremity injury (UEI), especially to the shoulder and elbow (Asker et al. 2018; da Silva 2010; Gart and Wiedrich 2017; Zaremski, Zeppieri, and Tripp 2019). Following an UEI, rehabilitation and treatment for athletes focuses on restoring function that withstands the demand of their chosen sport. Along with return to play, goals for treatment include returning to pre-injury activity level, decreasing pain, and improving function such as restoring range of motion, joint mobility, and increasing strength (Brumitt, Hutchison, Kang, et al. 2020; Gomberawalla and Sekiya 2014; Klouche et al. 2016). Current treatment for UEI in athletes includes, but is not limited to, resistance training, physical therapy, localized steroidal or analgesic injections, and surgery (Dong, Goost, Lin, et al. 2015). In recent years, the use of BFR training as treatment for musculoskeletal injuries has increased in popularity due to the positive benefits seen in healthy and athletic patients, such as strength gain and increased muscle size compared to control subjects (Barber-Westin and Noyes 2019).

BFR USE FOLLOWING UPPER EXTREMITY INJURIES

BFR training continues to grow in popularity due to its ability to produce muscle hypertrophy and increased strength, while using a lower weight load. A search was conducted in January of 2020 on PubMed, Embase, PubMed Central, Ovid, and Web of Science using terms such as , "Blood Flow Restriction", "BFR" , "KAATSU", "Vascular Occlusion" and "Shoulder", "Upper Extremity", "Rotator Cuff", "Shoulder instability", "Shoulder dislocation", to find studies related to BFR use on UEI. Two recent randomized controlled studies demonstrated the benefits of BFR on the rehabilitation process after an UEI (Cancio, Sgromolo, and Rhee 2019; Sgromolo, Cancio, and Rhee 2020). Both studies were conducted by the same group of authors in subsequent years.

Table 1. Standard rehabilitation program for all patients who participated in therapy for a distal radius fracture in the studies by Cancio, Sgromolo, and Rhee and Sgromolo, Cancio, and Rhee

Distal radius fracture rehabilitation program
Two to three sessions per week for a total of 8 weeks
Four sets of 30 repetitions of each exercise in initial set, followed by 15 repetitions in each set after
Thirty seconds of rest between each set with 1 minute rest after full exercise completion
Wrist flexion/extension over a foam wedge[a]
Forearm pronation/supination with arm at side and elbow at 90°[a]
Pinch strength assessed by a PG-60 pinch gauge[a]
3-point and lateral pinch-exerting force between the thumb and the index/long fingers
Grip strength assessed by the JAMAR Hand Dynamometer[a]

[a]In the BFR group, these exercises were performed with a restrictive tourniquet.
Protocol adapted from Cancio, Sgromolo, and Rhee and Sgromolo, Cancio, and Rhee

Table 2. Training program for ACL rehabilitation program used by Kacin et al.

ACL rehabilitation program: Knee Extension and Knee Flexion Exercises
3 week low-load training; 9 exercise sessions, 3 times a week
Exercises were completed to volitional failure
3 total sets of each exercise with 45s of rest after the 1st and 3rd sets, and 90s of rest after the 2nd set[ab]

[a]In the BFR group, these exercises were performed using the pneumatic cuff inflated to 150mmHg. Cuff was deflated during the 90s rest period.
[b]In the SHAM-BFR group, these exercises were performed using the pneumatic cuff inflated to 20mmHg. Cuff was deflated during the 90s rest period.

The first study, by Cancio et al. and published in 2019, evaluated 13 patients who were treated with closed reduction and short arm cast immobilization after suffering a distal radius fracture (Cancio, Sgromolo, and Rhee 2019). These patients (mean age of 46) were randomized into the BFR group or the control group. The control group received a standard rehabilitation protocol and the BFR group received the same standard rehabilitation with BFR included in some of the exercises (Table 1) (Cancio, Sgromolo, and Rhee 2019; Sgromolo, Cancio, and Rhee 2020). Patients were followed throughout an eight-week physical therapy program and the following functional outcomes were measured: range of motion, grip strength, three-point pinch, and lateral pinch. The authors found that significant improvements were made in the reduction of pain over the course of the eight-week therapy protocol and the Patient Reported Wrist Evaluation (PRWE) Scores compared to the control group (Cancio, Sgromolo, and Rhee 2019).

These same authors performed another randomized controlled trial published in 2020, which evaluated nine patients treated with volar plate fixation following a displaced distal radius fracture (Sgromolo, Cancio, and Rhee 2020). These patients (mean age of 40) were divided into a BFR and control group, which followed the same protocols and therapy as their previous study, stated above (Table 1). The authors found similar results, with patients in the BFR group having a statistically significant reduction in pain with activity over the eight-week therapy program and in PRWE scores when compared to the control group (Sgromolo, Cancio, and Rhee 2020). Continued research is needed to determine the true impact of BFR on clinical outcomes, but these two studies demonstrate that BFR may be effective after an UEI (Pearson and Hussain 2015; Sgromolo, Cancio, and Rhee 2020). Both studies mentioned have very small sample sizes, which could be causing a Type II Statistical error where no difference is incorrectly identified. Future clinical trials should enroll more patients to increase the power of the studies.

LIMITATIONS AND THE FUTURE OF BLOOD FLOW RESTRICTION TRAINING

This study has several limitations to acknowledge. First, our data is currently limited to two studies. It is possible that searching other databases would have identified more studies. Second, In these studies, the sample sizes were not large, which could result in a data error. Finally, the two studies were both conducted by the same authors, who could have biases. With these limitations in mind, Blood Flow Restriction training continues to increase in popularity. As BFR allows participants to use exercises at a low-load with relatively the same outcomes as with a heavy-load, BFR can be applied more broadly (Sakuraba and Ishikawa 2009; Wortman et al. 2021). After an injury, most people are unable to lift their maximum repetitions and resort to low loads with longer recovery times (Ferraz, Gualano, Rodrigues, et al. 2018). By using BFR, the increase in muscle hypertrophy and strength while using low loads can get people back to their lives or sports quicker in a safe and effective manner. For this reason, while more research and clinical trials are needed, BFR is likely to be incorporated into rehabilitation protocols in the future However, in order to standardize BFR, more research is needed to be done specifically on participants following an UEI. For sports injuries in particular, research on how athletes returning to their sport is affected with the use of BFR is also needed to determine the effectiveness of the training.

SUMMARY

BFR continues to gain popularity as an alternate training program for patients who do not or cannot use heavy loads during resistance training. Although there are limited data related to the use of BFR for patients with upper extremity injuries (UEI), there are numerous studies that demonstrate improvement in muscle strength and muscle hypertrophy with the use of BFR after a lower extremity injury. These studies can serve as a guide for developing a protocol for the use of BFR following UEI. Further research focusing on BFR training following upper extremity injuries is needed to determine the potential impact on clinical outcomes.

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REFERENCES

American College of Sports Medicine position stand. 2009. "Progression Models in Resistance Training for Healthy Adults." *Medicine & Science in Sports & Exercise* 41 (3): 687–708. https://doi.org/10.1249/mss.0b013e3181915670.

Asker, Martin, Hannah L Brooke, Markus Waldén, Ulrika Tranaeus, Fredrik Johansson, Eva Skillgate, and Lena W Holm. 2018. "Risk Factors for, and Prevention of, Shoulder Injuries in Overhead Sports: A Systematic Review with Best-Evidence Synthesis." *British Journal of Sports Medicine* 52 (20): 1312–19. https://doi.org/10.1136/bjsports-2017-098254.

Barber-Westin, Sue, and Frank R. Noyes. 2019. "Blood Flow–Restricted Training for Lower Extremity Muscle Weakness Due to Knee Pathology: A Systematic Review." *Sports Health* 11 (1): 69–83. https://doi.org/10.1177/1941738118811337.

Bowman, E.N., R. El-shaar, H. Milligan, et al. 2019. "The Proximal and Distal Effects of Blood Flow Restriction Therapy on Upper and Lower Extremity Strengthening: A Randomized Controlled Trial." *Orthop J Sports Med*, 7.

Brumitt, J., M.K. Hutchison, D. Kang, et al. 2020. "Blood Flow Restriction Training for the Rotator Cuff: A Randomized Controlled Trial." *Int J Sports Physiol Perform*, 1–6.

Cancio, J.M., N.M. Sgromolo, and P.C. Rhee. 2019. "Blood Flow Restriction Therapy after Closed Treatment of Distal Radius Fractures." *J Wrist Surg* 8 (4): 288–94.

Centner, Christoph, Patrick Wiegel, Albert Gollhofer, and Daniel König. 2019. "Effects of Blood Flow Restriction Training on Muscular Strength and Hypertrophy in Older Individuals: A Systematic Review and Meta-Analysis." *Sports Medicine* 49 (1): 95–108. https://doi.org/10.1007/s40279-018-0994-1.

Dankel, Scott J., Matthew B. Jessee, Takashi Abe, and Jeremy P. Loenneke. 2016. "The Effects of Blood Flow Restriction on Upper-Body Musculature Located Distal and Proximal to Applied Pressure." *Sports Medicine* 46 (1): 23–33. https://doi.org/10.1007/s40279-015-0407-7.

DeCastro, A. 2020. "Common Upper-Extremity Injuries." *Prim Care* 47 (1): 105–14.

DePhillipo, N.N., M.I. Kennedy, Z.S. Aman, et al. 2018. "The Role of Blood Flow Restriction Therapy Following Knee Surgery." *Expert Opinion. Arthroscopy* 34 (8): 2506–10.

Dong, W., H. Goost, X.B. Lin, et al. 2015. "Treatments for Shoulder Impingement Syndrome: A PRISMA Systematic Review and Network Meta-Analysis." *Medicine (Baltimore)* 94 (10): e510.

Ferraz, R.B., B. Gualano, R. Rodrigues, et al. 2018. "Benefits of Resistance Training with Blood Flow Restriction in Knee Osteoarthritis." *Med Sci Sports Exerc* 50 (5): 897–905.

Gart, Michael S., and Thomas A. Wiedrich. 2017. "Therapy and Rehabilitation for Upper Extremity Injuries in Athletes." *Hand Clinics* 33 (1): 207–20. https://doi.org/10.1016/j.hcl.2016.08.016.

Goldberg, Andrea S, Leslie Moroz, Angela Smith, and Theodore Ganley. 2007. "Injury Surveillance in Young Athletes: A Clinician's Guide to Sports Injury Literature." *Sports Medicine* 37 (3): 265–78. https://doi.org/10.2165/00007256-200737030-00005.

Gomberawalla, Mustafa M., and Jon K. Sekiya. 2014. "Rotator Cuff Tear and Glenohumeral Instability : A Systematic Review." *Clinical Orthopaedics & Related Research* 472 (8): 2448–56. https://doi.org/10.1007/s11999-013-3290-2.

Hughes, Luke, Bruce Paton, Ben Rosenblatt, Conor Gissane, and Stephen David Patterson. 2017. "Blood Flow Restriction Training in Clinical Musculoskeletal Rehabilitation: A Systematic Review and Meta-Analysis." *British Journal of Sports Medicine* 51 (13): 1003–11. https://doi.org/10.1136/bjsports-2016-097071.

Kacin, Alan, Matej Drobnič, Tomaž Marš, Katarina Miš, Maja Petrič, Daša Weber, Tina Tomc Žargi, David Martinčič, and Sergej Pirkmajer. 2021. "Functional and Molecular Adaptations of Quadriceps and Hamstring Muscles to Blood Flow Restricted Training in Patients with ACL Rupture." *Scandinavian Journal of Medicine & Science in Sports* 31 (8): 1636–46. https://doi.org/10.1111/sms.13968.

Klouche, Shahnaz, Nicolas Lefevre, Serge Herman, Antoine Gerometta, and Yoann Bohu. 2016. "Return to Sport After Rotator Cuff Tear Repair: A Systematic Review and Meta-Analysis." *American Journal of Sports Medicine* 44 (7): 1877–87. https://doi.org/10.1177/0363546515598995.

Lambert, Bradley, Corbin Hedt, Joshua Daum, Carter Taft, Kalyan Chaliki, Eden Epner, and Patrick McCulloch. 2021. "Blood Flow Restriction Training for the Shoulder: A Case for Proximal Benefit." *American Journal of Sports Medicine* 49 (10): 2716–28. https://doi.org/10.1177/03635465211017524.

Libardi, C., M. Chacon-Mikahil, C. Cavaglieri, V. Tricoli, H. Roschel, F. Vechin, M. Conceição, and C. Ugrinowitsch. 2015. "Effect of Concurrent Training with Blood Flow Restriction in the Elderly." *International Journal of Sports Medicine* 36 (5): 395–99. https://doi.org/10.1055/s-0034-1390496.

Loenneke, Jeremy P., C.A. Fahs, L.M. Rossow, T. Abe, and M.G. Bemben. 2012. "The Anabolic Benefits of Venous Blood Flow Restriction Training May Be Induced by Muscle Cell Swelling." *Medical Hypotheses* 78 (1): 151–54. https://doi.org/10.1016/j.mehy.2011.10.014.

Loenneke, Jeremy P., Jacob M. Wilson, Pedro J. Marín, Michael C. Zourdos, and Michael G. Bemben. 2012. "Low Intensity Blood Flow Restriction Training: A Meta-Analysis." *European Journal of Applied Physiology* 112 (5): 1849–59. https://doi.org/10.1007/s00421-011-2167-x.

Lorenz, Daniel S., Lane Bailey, Kevin E. Wilk, Robert E. Mangine, Paul Head, Terry L. Grindstaff, and Scot Morrison. 2021. "Blood Flow Restriction Training." *Journal of Athletic Training* 56 (9): 937–44. https://doi.org/10.4085/418-20.

Lu, Yining, Bhavik H. Patel, Craig Kym, Benedict U. Nwachukwu, Alexander Beletksy, Brian Forsythe, and Jorge Chahla. 2020. "Perioperative Blood Flow Restriction Rehabilitation in Patients Undergoing ACL Reconstruction: A Systematic Review." *Orthopaedic Journal of Sports Medicine* 8 (3): 232596712090682. https://doi.org/10.1177/2325967120906822.

Luime, JJ, BW Koes, IJM Hendriksen, A Burdorf, AP Verhagen, HS Miedema, and JAN Verhaar. 2004. "Prevalence and Incidence of Shoulder Pain in the General Population; a Systematic Review." *Scandinavian Journal of Rheumatology* 33 (2): 73–81. https://doi.org/10.1080/03009740310004667.

Mariscalco, Michael W., and Paul Saluan. 2011. "Upper Extremity Injuries in the Adolescent Athlete." *Sports Medicine and Arthroscopy Review* 19 (1): 17–26. https://doi.org/10.1097/jsa.0b013e31820d5680.

Pearson, Stephen John, and Syed Robiul Hussain. 2015. "A Review on the Mechanisms of Blood-Flow Restriction Resistance Training-Induced Muscle Hypertrophy." *Sports Medicine* 45 (2): 187–200. https://doi.org/10.1007/s40279-014-0264-9.

Pope, Zachary K., Jeffrey M. Willardson, and Brad J. Schoenfeld. 2013. "Exercise and Blood Flow Restriction." *Journal of Strength and Conditioning Research* 27 (10): 2914–26. https://doi.org/10.1519/jsc.0b013e3182874721.

Sakuraba, Keishoku, and Takuji Ishikawa. 2009. "Effect of Isokinetic Resistance Training under a Condition of Restricted Blood Flow with Pressure." *Journal of Orthopaedic Science* 14 (5): 631–39. https://doi.org/10.1007/s00776-009-1374-3.

Scott, Brendan R., Jeremy P. Loenneke, Katie M. Slattery, and Ben J. Dascombe. 2016. "Blood Flow Restricted Exercise for Athletes: A Review of Available Evidence." *Journal of Science and Medicine in Sport* 19 (5): 360–67. https://doi.org/10.1016/j.jsams.2015.04.014.

Sgromolo, Nicole M., Jill M. Cancio, and Peter C. Rhee. 2020. "Safety and Efficacy of Blood Flow Restriction Therapy after Operative Management of Distal Radius Fractures: A Randomized Controlled Study." *Journal of Wrist Surgery* 09 (04): 345–52. https://doi.org/10.1055/s-0040-1712504.

Shinohara, M., M. Kouzaki, T. Yoshihisa, and T. Fukunaga. 1998. "Efficacy of Tourniquet Ischemia for Strength Training with Low Resistance." *Eur J Appl Physiol Occup Physiol* 77 (1–2): 189–91.

Silva, R.T. da. 2010. "SPORTS INJURIES OF THE UPPER LIMBS." *Rev Bras Ortop* 45 (2): 122–31.

Takarada, Yudai, Yutaka Nakamura, Seiji Aruga, Tetuya Onda, Seiji Miyazaki, and Naokata Ishii. 2000. "Rapid Increase in Plasma Growth Hormone after Low-Intensity Resistance Exercise with Vascular Occlusion." *Journal of Applied Physiology* 88 (1): 61–65. https://doi.org/10.1152/jappl.2000.88.1.61.

Teunis, Teun, Bart Lubberts, Brian T. Reilly, and David Ring. 2014. "A Systematic Review and Pooled Analysis of the Prevalence of Rotator Cuff Disease with Increasing Age." *Journal of Shoulder and Elbow Surgery* 23 (12): 1913–21. https://doi.org/10.1016/j.jse.2014.08.001.

Thiebaud, Robert S., Jeremy P. Loenneke, Christopher A. Fahs, Lindy M. Rossow, Daeyeol Kim, Takashi Abe, Mark A. Anderson, Kaelin C. Young, Debra A. Bemben, and Michael G. Bemben. 2013. "The Effects of Elastic Band Resistance Training Combined with Blood Flow Restriction on Strength, Total Bone-Free Lean Body Mass and Muscle Thickness in Postmenopausal Women." *Clinical Physiology and Functional Imaging* 33 (5): 344–52. https://doi.org/10.1111/cpf.12033.

Wilk, Michal, Michal Krzysztofik, Aleksandra Filip, Robert G. Lockie, and Adam Zajac. 2020. "The Acute Effects of External Compression With Blood Flow Restriction on Maximal Strength and Strength-Endurance Performance of the Upper Limbs." *Frontiers in Physiology* 11 (June):567. https://doi.org/10.3389/fphys.2020.00567.

Wortman, R.J., S.M. Brown, I. Savage-Elliott, Z.J. Finley, and M.K. Mulcahey. 2021. "Blood Flow Restriction Training for Athletes: A Systematic Review." *Am J Sports Med* 49 (7): 1938–44.

Yasuda, T., K. Fukumura, Y. Uchida, et al. 2015. "Effects of Low-Load, Elastic Band Resistance Training Combined With Blood Flow Restriction on Muscle Size and Arterial Stiffness in Older Adults." *J Gerontol A Biol Sci Med Sci* 70 (8): 950–58.

Yasuda, T., R. Ogasawara, M. Sakamaki, et al. 2011. "Combined Effects of Low-Intensity Blood Flow Restriction Training and High-Intensity Resistance Training on Muscle Strength and Size." *Eur J Appl Physiol* 111 (10): 2525–33.

Yokokawa, Y., M. Hongo, H. Urayama, T. Nishimura, and I. Kai. 2008. "Effects of Low-Intensity Resistance Exercise with Vascular Occlusion on Physical Function in Healthy Elderly People." *Biosci Trends* 2 (3): 117–23.

Zaremski, J.L., G. Zeppieri Jr., and B.L. Tripp. 2019. "Sport Specialization and Overuse Injuries in Adolescent Throwing Athletes: A Narrative Review." *J Athl Train* 54 (10): 1030–39.