

Implementation of Blood Flow Restriction for Injury Rehabilitation in the Athletic Training
Setting

Hisham Ziyout, LAT, ATC, CSCS

Master of Science Candidate

OMALS: Applied Nutrition and Physical Activity Concentration

Virginia Polytechnic Institute and State University

Dr. Matthew Hulver, PhD. Department of Human Nutrition, Food and Exercise

Michelle Rockwell, MS, RDN. Department of Human Nutrition, Food and Exercise

Michael Goforth, MS, LAT, ATC. Department of Athletics

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Abstract

Rehabilitation after an injury in athletics is a major concern for athletes and athletic trainers. The athletic trainer is responsible for returning the injured athlete back to participation as fast and safely as possible. Since it is typically unsafe to apply heavy loads, such as weights, to an extremity after an injury, atrophy tends to occur to the injured area. Blood flow restriction is a modality that is fairly new in the United States. Research has shown that blood flow restriction used during low-intensity (20-30% 1RM) loads significantly increases muscular strength and hypertrophy compared to high-intensity loads (>70% 1RM) without blood flow restriction (Pope et al, 2013). The purpose of this project was to document preliminary experiences with blood flow restriction in a collegiate athletics setting and disseminate practical information about blood flow restriction to practicing athletic trainers across the United States. Blood flow restriction has been shown to be a safe and effective resource for clinicians when helping a patient rehabilitate from surgery and return to participation faster, although minimal clinical trial evidence is available. When blood flow restriction was incorporated as a treatment modality within the Department of Intercollegiate Athletics at Virginia Tech, positive effects on injury rehabilitation and patient compliance were observed. Further research on blood flow restriction during injury rehabilitation is needed in order to help practicing athletic trainers make the best evidence-based decisions when utilizing this modality with their patient.

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Introduction

Each year, athletes are sidelined from their sport because of significant injury or surgery. In 2016, the U.S. Department of Health and Human Services Center for Disease Control and Prevention estimated an annual average of 8.6 million sport-related injuries reported (Sheu et al, 2016). This often causes muscle atrophy, along with a significant reduction in muscular strength and endurance. Blood flow restriction (BFR) involves the use of specialized bands applied to a person's extremities in order to occlude extremities. While it has been used in Japan for hundreds of years, the United States has only adopted it over the past 40 years. Despite the research supporting the multiple beneficial effects of BFR, such as improvements in muscle size, strength, endurance, bone health, and the cardiovascular system, it is not commonly found in athletic training facilities – a setting where BFR can promote physiological benefits that can expedite an athlete returning to competition. The purpose of this project was to document preliminary experiences with BFR in a collegiate athletics setting and disseminate practical information about BFR to practicing athletic trainers across the United States.

Literature Review

The purpose of the following review of literature is to provide a summary of scientific literature related to the use of BFR during injury rehabilitation. Mechanisms of BFR, specific effects of BFR in athletic populations, and safety evaluations will be included.

Mechanisms of Blood Flow Restriction during Injury Rehabilitation

Physiological Effects of Blood Flow Restriction

When the specialized band is inflated, it causes a decrease in arterial blood flow and occlusion of venous blood flow of the muscle (Bittar et al, 2018). This effect activates hypoxia-induced transcription factor, ultimately increasing the expression of vascular endothelial growth factor (VEGF) and formation of micro blood vessels in bone tissue (Bittar et al, 2018). When the blood accumulates, an increased level of growth hormone occurs because of the increased level of metabolites, such as lactic acid, hydrogen, and adenosine. This ultimately results in stimulation of chemosensitive afferents (group III & IV), which elicits a neurohormonal response to the hypothalamus, causing the increase in growth hormone (Cook et al, 2010). Research has also found that oxygen availability also dictates recruitment of higher order motor units, suggesting a possible reason for increased muscle activation during exercise with BFR (Bagley et al, 2015). In skeletal muscle, exercise with BFR reduces myostatin gene and protein expression, ultimately causing hypertrophy due to myostatin being a negative regulator of muscle mass - this may be due to the hypoxic environment and metabolic byproduct accumulation during occlusion (Bagley et al, 2015).

In 2015, Farup et al suggested an additional mechanism for muscle hypertrophy from BFR was an increase in intracellular or extracellular water retention, causing an increased strain

on the sarcolemma, which stimulates protein synthesis. Hughes et al found that an ischemic and hypoxic muscle environment causes high levels of metabolic stress. This environment causes an increase in systemic hormone production, cell swelling, production of reactive oxygen species (ROS), and fast-twitch muscle fiber recruitment (Hughes et al, 2017). Pope et al found that this ischemic and hypoxic intramuscular environment causes accelerated ATP hydrolysis, exaggerated PCr depletion, decreased pH levels, and an increased lactate production (Pope et al, 2013). Additional physiological effects include increased motor unit recruitment and cellular signaling events from the mechanical changes of the muscle fibers, causing an increase in similar muscle fiber recruitment found in traditional high-intensity exercise (Cook et al, 2010 and Bagley et al, 2015).

Effects of Blood Flow Restriction on Muscle Hypertrophy and Strength

When a muscle is not used for a long period of time, it undergoes what's called "atrophy." The lack of muscle activation results in less protein synthesis, cross-sectional area, and neuromuscular impairments (Cook et al, 2010). In addition, the researchers attributed muscle atrophy to decreased skeletal muscle protein synthesis, decreased cross-sectional area, neuromuscular impairments due to lack of voluntarily recruiting motor units, and decreased transmission of neural impulses (Cook et al, 2010).

Rebuilding muscle (hypertrophy) is a major goal when rehabilitating an injury after an operation involving joints and bones. However, hypertrophy occurs when training at loads above 75% 1-repetition maximum (Cook et al, 2010). When rehabilitating from an injury, it is unsafe to train at a load that high. Blood flow restriction in conjunction with low-load resistance training has a positive effect on hypertrophy, as it increases protein synthesis and improves neuromuscular function (Cook et al, 2010; Farup et al, 2015). In addition, Cook et al found that

muscle hypertrophy is mediated through the PI3k-Akt-mTOR signaling pathway (Cook et al, 2010). Farup et al found that lifting weights with blood flow restriction at 30% 1RM produced equal muscle hypertrophy compared to lifting weights without blood flow restriction at 80% 1RM (Farup et al, 2015).

It has been shown that using blood flow restriction while walking increases muscular strength and cross sectional area, isotonic exercises improves muscular strength more because of the greater amount of muscle work and accumulation of metabolites found during isotonic movements (Loenneke et al, 2011). It can also be used in conjunction with Russian stimulation – an electrical stimulation modality that is often used to recruit muscle fibers and cause hypertrophy (Mattocks et al, 2018). The combination of Russian stimulation and blood flow restriction can be a great tool for clinicians to use for patients recently undergoing surgery. In addition, it is less time-consuming than traditional strength training and replaces heavy-load training when a patient is injured (Farup et al, 2015; Hughes et al, 2017).

Effects of Blood Flow Restriction on Cardiovascular Endurance & Bone Health

One of the most commonly neglected areas during rehabilitation is cardiovascular endurance. Early in the healing process, it is difficult to address this area, particularly if resources are not available because of restrictive budgets. Therefore, clinicians may neglect this area and focus mainly on getting full range of motion, muscle girth, strength, and proprioception back to the involved area. Blood flow restriction has been shown to increase muscular strength and cross sectional area when used with low-intensity cardiovascular exercise, such as walking (4-6 km/h at a 5% grade each set; total of 5 sets for 3 minutes each; 1 minute rest intervals between sets) or cycling (Pope et al, 2013 and Renzi et al, 2010). Additionally, walking with blood flow restriction twice daily for two weeks increases endurance capacity and correlates with

an increase in oxidative enzymes, capillary density, stroke volume, and glycogen stores (Pope et al, 2013).

The combination of blood flow restriction and cardiovascular exercise has also shown to increase heart rate and blood pressure because of the compromised venous return; therefore, it is important to monitor the patient and avoid high-intensity activity (Mattocks et al, 2018). Using blood flow restriction while walking appears to be a great tool for clinicians to improve cardiovascular endurance when their patients are not medically cleared to begin jogging or running.

While muscle hypertrophy is often a major goal during rehabilitation from arthroscopic intervention, bone healing is another major goal-especially after a fracture. Weight-bearing activity is found to stimulate bone growth; however, many patients are prohibited from bearing weight on the involved bone after surgery to allow the bone to heal. Blood flow restriction has been shown to improve bone remodeling without the need for high-intensity training, thought to be mediated, in part, by increasing circulating bone-specific alkaline phosphate (BAP) and growth hormone (GH) levels (Beekley et al, 2005).

Rehabilitation from a sports injury is not the only time blood flow restriction can be used. It is often used in the general and elderly populations, as it can provide benefits to both. People in the general population use blood flow restriction to increase muscle strength, size, and endurance for improving performance and body image. Simply walking 67 meters per minute at 45% of maximum heart rate can improve aerobic endurance (Hughes et al, 2017). Scott et al found that elderly adults who trained 4 days per week for 10 weeks using low-intensity walking (20 minutes at 45% heart rate reserve) showed increases in maximum knee joint strength (~15%) and thigh muscle cross-sectional area (~3%) when combined with BFR (Scott et al, 2015). Blood

flow restriction allows the elderly population to improve bone health and prevent bone fractures without using heavy loads, reducing the pain in their joints.

Effects of Blood Flow Restriction without Accompanying Activity

Blood flow restriction can also be used without activity. Applying BFR during periods of bed rest or immobilization is a novel strategy to aid in recovery when unloaded movements cannot be tolerated (Scott et al, 2015). This phenomenon can be useful for clinicians when their patient is immobilized for long periods of time after surgery. It is very common for a person to be immobilized for 4-6 weeks to allow an area to heal properly (Prentice, 2016). Blood flow restriction can increase muscular size and strength without joint movement by applying 238mmHg of pressure with a 9cm wide cuff (Loenneke et al, 2012). However, the physiological reason for these findings are still uncertain. A theory behind the increases in muscular strength and size is the acute bouts of muscle swelling, along with cellular dehydration causing the down regulation of MTOR signaling. Therefore, the increased muscle swelling may stimulate the MTOR pathway (Loenneke et al, 2012). Another theory behind the benefits of blood flow restriction without joint movement is an increase in electromyography (EMG) activity. Loenneke et al found that EMG activity was 40% lower when exercise was completed without blood flow restriction (Loenneke et al, 2012). These findings lead to the assumption that the reason for the benefits found when blood flow restriction is used without joint movement is because of an increase in EMG activity; however, there can be no changes in EMG activity if there is no muscle activation. More research on blood flow restriction without joint movement is warranted to discover the physiological effects taking place. Nonetheless, preventing atrophy during the early stage of rehabilitation can ultimately expedite the recovery process and allow for a quicker return to activity.

Parameter Considerations When Using Blood Flow Restriction

Frequency

During injury rehabilitation, patients are typically advised to do their rehabilitation exercises at least 2-3 times per week in a physical therapy clinic, depending on their insurance. Patients are often advised to complete their exercises at home as a part of their Home Exercise Program (HEP). In athletic training facilities, it is not uncommon for an athlete to complete their rehabilitation exercises 5 times per week. Depending on the case, some athletes may come in to the athletic training facility for rehabilitation two times per day. Since a training intensity of 20% of 1RM produces minimal muscle damage, less recovery time is necessary, allowing the training frequency to be increased (Yasuda et al, 2005). Cook et al found that rehabilitation with BFR twice daily for two weeks caused a 24% increase in IGF-1, leading to an anabolic response due to the increased levels of growth hormone. The researchers also found that rehabilitation with BFR twice per week for 8 weeks caused a significant increase in strength, cross-sectional area, and muscular endurance (Cook et al, 2015). Loenneke et al found an increase in muscular strength and hypertrophy when BFR was used 2-3 days per week (Loenneke et al, 2011). Scott et al found that 6 weeks of low-load BFR bench press training (3 days each week at 30% 1RM) increased the CSA of the triceps brachii (4.9%) as well as the pectoralis major (8.3%) (Scott et al, 2015). The researchers also found that 8 weeks of low-load knee extension training (twice per week using three sets of 15 repetitions) at 20% 1RM resulted in a large increase in knee extension 1RM (40.1%) in addition to a substantial increase in quadriceps CSA (6.3%) (Scott et al, 2015).

Sets & Reps

When using BFR, it is important to prescribe appropriate sets and repetitions. The most commonly used protocol is 1 set of 30 repetitions, followed by 3 sets of 15 repetitions (Mattocks et al, 2018). However, beneficial effects were also observed when the patient completed 15-30 repetitions, followed by short rest intervals of 30 seconds (Pope et al, 2013). Scott et al reported typical training volumes ranging from 45-75 repetitions of each exercise per session or exercise to volitional fatigue; however, low-load BFR training can also significantly increase muscle size and strength without the need to train to failure. Extended periods of training to failure may lead to increased physiological markers of over-training (Scott et al, 2015).

The majority of research studies on low-load resistance exercise with BFR show that using relatively brief inter-set rest periods of 30-60 seconds because brief rest periods between sets are associated with an increase in metabolic stress (Scott et al, 2015). The general consensus appears to be that the restriction should be maintained during the rest periods to increase the metabolic stress. If applied appropriately, venous outflow will be occluded, and the clearance of metabolites between sets will be diminished (Scott et al, 2015). In addition, the venous pooling occurring during the rest interval will increase cellular swelling, which is considered to be an important factor in the hypertrophic response. This phenomenon is thought to be a large reason for the beneficial physiological responses to BFR with resistance exercise.

Characteristics of the Specialized Bands

Cuff Size

Similar to taking a patient's blood pressure, it is important to choose the correct cuff size. Wider cuffs transmit pressure differently than narrow cuffs (Loenneke et al, 2011). For example, a wider cuff inflated to the same pressure as a narrow cuff will restrict more blood flow, which can impact the amount of muscle growth (Mattocks et al, 2018). Wider cuffs (13.5 cm) have been shown to cause greater ratings of pain and perceived exertion (Scott et al, 2015). Additionally, wider cuffs may obstruct the patient's normal range of motion (Scott et al, 2015). Patients with larger limbs require greater pressure applied by the cuffs, and smaller patients will require lower pressures; patients with high blood pressures will require higher cuff pressure (Mattocks et al, 2018). Due to these different variables, it is important for the clinician to apply a specific cuff size and pressure to each individual patient (Mattocks et al, 2018).

Cuff Material

Over the years, clinicians have used different types of cuff material when implementing BFR. Different materials include pneumatic cuffs, hand-pumped blood pressure cuffs, elastic wraps, and nylon wraps (Hughes et al, 2017 and Mattocks et al, 2018). Attention should be given to the material chosen, as certain materials can affect the BFR treatment. For example, the use of elastic or nylon wraps does not allow the clinician to apply a particular amount of pressure to the patient, causing an unknown physiological effect.

Cuff Pressure

When using BFR, it is imperative to use adequate pressure, as each individual patient will require different pressures to receive a beneficial effect. If the restrictive pressure is too low,

muscular responses may not occur. Additionally, extremely high pressures that occlude arterial inflow during rest and/or exercise may not improve muscular development and may be a safety concern (Scott et al, 2015). The cuff pressure should be higher than the patient's systolic blood pressure. The arterial pressure is attenuated because there is a dissociation between the cuff pressure and the underlying soft tissue pressure (Manini et al, 2009). Manini et al found that the cuff pressure occludes venous return and causes arterial blood flow to become turbulent. This causes a decrease in blood viscosity distal to the cuff (Manini et al, 2009).

When exercising with BFR, higher intensities require less cuff pressure, while lower intensities require more cuff pressure (Mattocks et al, 2018). A patient with a larger limb will require a higher cuff pressure (Hughes et al, 2017). Pressure levels appear to vary depending on the clinician. Cook et al found benefit when applying pressures of 150 ± 10 mmHg. Hughes et al applied pressures between 60-270mmHg. Loenneke et al found that higher restrictive cuff pressures (200 mmHg) are more effective at increasing intramuscular metabolites than moderate pressures (150 mmHg). Pope et al found beneficial effects when applying pressure >250 mmHg, while some studies showed beneficial effects when using pressures as low as 50 mmHg (Pope et al, 2013). Therefore, BFR should not be universally applied at an absolute pressure and should vary between each individual patient's limb size and the cuff width (Scott et al, 2015).

Complications and Safety Concerns Regarding Blood Flow Restriction

Blood flow restriction has been shown to have minor side effects and rarely occur (Hughes et al, 2017). Hughes et al showed that a large majority of studies did not report any adverse effects of blood flow restriction, conditions were not worsened, pain was not caused, and risk was no greater than traditional exercise. An incidence rate of 0.008% (over 30,000 participants) of rhabdomyolysis was found in their research. The illness occurred in an obese

Japanese man after three sets of twenty repetitions with blood flow restriction. Hughes et al explained that the man had been sedentary for years, hypothesizing that the cause of rhabdomyolysis was due to unaccustomed exercise. Loenneke et al found that the peripheral blood flow response to blood flow restriction is similar to regular exercise and coagulation does not appear to increase after low-intensity blood flow restriction (Loenneke et al, 2011). He also found that the responses to stroke volume and cardiac output were generally lower than traditional resistance training, oxidative stress is not increased, and tissue plasminogen activator (tPA) was enhanced with blood flow restriction, as it is with traditional exercise. Therefore, it appears that using blood flow restriction at low-intensities causes no greater risk than traditional exercise (Loenneke et al, 2011).

On the contrary, severe restrictions or complete occlusion of blood flow may cause thrombus formation and cause microvascular occlusions after releasing the cuff pressure, resulting in muscle cell damage and necrosis (Yasuda et al, 2011). Using a surgical tourniquet (135 mm width for thighs) may cause a serious amount of pain to the patient due to neural impairment and suppression of lactate clearance (Yasuda et al, 2011).

Continued research of blood flow restriction and its physiological effects are recommended at this time. Potential research on competitive athletes, along with the best time to use blood flow restriction during injury rehabilitation, is recommended in order to help practicing athletic trainers make the best evidence-based decisions when utilizing this modality with their patient.

Methods

Project Design

This project consisted of two parts. Part A is a narrative case report of one Athletic Trainer's experience implementing BFR with collegiate football players. Part B is an article submission about BFR targeting publication in the NATA News (www.nata.org).

Methodology

Part A

The case report elaborated on one Athletic Trainer's experiences with BFR at Virginia Tech from July 2018 to May 2019. The following information were included in the case report: the motivation to use BFR, certification process, set-up/practice/training, and sample cases. Notes kept during the above timeframe were used to inform the case report. No identifying information will be provided about athletes. The format was a journal entry using the following format:

Date/ Time Frame	Action	Notes

Protection of Human Rights

The Institutional Review Board (IRB) of Virginia Tech determined that this project is exempt from IRB approval (Appendix 1). Since we did not conduct research and rather, compiled notes about clinical treatment that was not completed as part of a research study, IRB approval was not required.

Part B

An article was written and will be submitted for publication in NATA News, a magazine that publishes articles that connects athletic trainers to their profession association. The purpose of the article was to provide an overview and practical perspectives about the use of BFR with athletes for injury rehabilitation. Literature related to mechanisms by which BFR improves injury rehabilitation, evidence of effectiveness, and safety concerns was reviewed. Practical issues such as the certification process, unique athlete considerations, pressure cuff characteristics, and the utilization of BFR with different types of activity were also provided.

Resources for the article were obtained from a literature search on PubMed and Google Scholar. Systematic reviews, meta-analyses, other review articles, original research, professional guidelines, and case reports were reviewed for information most relevant to the article.

The Instructions for Authors from NATA News (www.nata.org) was used to format the article. This magazine has published articles on BFR recently; however, they have not published any that explore the usage in the athletic training setting. This article educated athletic trainers on BFR and how it can benefit them in their practice. An outline of the article is as follows:

What is Blood Flow Restriction (BFR)?

Why isn't BFR Used More Often?

Physiological Effects

How it Works

Parameter Considerations

My Experiences with BFR in the Collegiate Athletics Setting

Conclusion

Summary of Outcomes, Discussions, and Recommendations

Outcomes and Results

The following table shows the progression of BFR used at Virginia Tech:

Date / Time Frame	Action	Notes
September 2016	Introduction to BFR	<p>Entering my second year as an Intern Athletic Trainer at Johns Hopkins University, I came across an article in Training & Conditioning magazine while at work (http://training-conditioning.com/content/all-wrapped). The article was written by an athletic trainer at the University of Florida about his experiences with BFR while working with injured football players on the football team. He explained how BFR was used during rehab – attaching a band filled with a specific air pressure to an athlete’s extremity in order to restrict the blood flow to the area. This restriction changed the environment in the muscle and was very similar to what a muscle experiences when loads of over 75% BW are applied. As a result, the muscle experiences improvements in muscle size and strength.</p> <p>I had never heard of BFR, so the thought of occluding blood flow during therapeutic exercise was new to me. While I was skeptical at first, I found the results to be very encouraging. I did not anticipate working in a setting that would pay for a unit like this, so I quickly moved on from the idea.</p>
February 2018	KAATSU (https://www.kaatsu-global.com/) representative came to Virginia Tech	<p>A representative from RP SPORTS (https://www.rpsports.com/), a company specializing in recovery and BFR, contacted our Director of Sports Medicine/Head Athletic Trainer. The representative knew a former Virginia Tech football player, who recommended he contact our Head Athletic Trainer about potential sales. The representative contacted the Head Athletic Trainer and was given the opportunity to speak to members of the Virginia Tech Sports Medicine staff about recovery modalities and a BFR unit from the KAATSU company.</p> <p>KAATSU is a Japanese word and trademarked term where KA (加) means “additional” and ATSU (圧) means “pressure.” The representative explained the BFR device, stating that it is an exercise modality, not FDA approved, used for ages 9-90 years old, good for non-weight bearing</p>

		<p>activities, over 180 clinical studies. He also explained the rules when using it, such as to never occlude the blood flow, apply to the most proximal part of the arms and legs (depending on what area you are targeting), never lift heavy weight while using BFR, and to limit the time with the bands to 20 minutes. Lastly, he explained how to use the unit by stating to pump up the cuffs, un-attach the cords, exercise until fatigue, take them off, and release the pressure in the bands.</p> <p>The total cost was \$2,850 which included the KAATSU unit, two arm bands, two leg bands, two cords, and six certifications. When compared to other companies selling BFR units, such as Owens Recovery and The Occlusion Cuff, the decision was made to purchase the BFR unit from KAATSU because of the ability to use the unit without cords attached. See figures below for visual descriptions.</p>
Spring 2018	BFR was recommended by the surgeon of Patient #1 to be used for Patient #1's rehab	Patient #1 was coming off a left navicular open reduction-internal fixation (ORIF) using a bone marrow aspirate from his left hip. Since the patient was to be partial-weight bearing for the first 4 weeks post-operation, he asked that we use BFR therapy during his rehab process to delay muscle atrophy in his lower extremity.
Spring 2018	Review of evidence	Articles on BFR were identified using Google Scholar, sent to me by colleagues, and sent from the BFR company (KAATSU) from which we were buying. I carefully reviewed the literature on BFR. Information was organized by different categories, such as the physiological effects, parameters to use, safety concerns, etc.
Summer 2018	Online KAATSU certification	<p>In order to use the KAATSU unit with patients, certification is required. The online certification required viewing several videos (self-paced) and successfully completing an exam. The topics covered included the home screen, setting the base pressure, finding the optimal pressure, setting the appropriate pressure, types of exercise to use BFR with, exercise and muscle physiological effects from BFR, how to apply the bands, and maintaining the unit and bands. The exam included 100 questions and was administered in online format; a passing score was 90% or above.</p> <p>Other companies, such as Owens Recovery, require 8 hours of in-person training and education on BFR. The first half of the day typically covers the science and history of BFR, while the second half addresses the application.</p>

Summer 2018	First patient interaction	<p>The first patient was a 5'8", 173 lb, 21 year old Division 1 wide receiver in his redshirt sophomore year who sustained a left ankle injury when attempting to return a punt in a college football game in November of 2016. He was evaluated by the team physician on the sideline and was able to return to play the remainder of the game. For the following four weeks, the patient received treatment to reduce his pain and improve the strength and proprioception in his left ankle. In December of 2016, an MRI was ordered by the team physician to determine the severity of the injury. The MRI revealed diffuse edema in the navicula with a non-displaced partial fracture across the dorsal surface, along with a tear of the anterior talofibular ligament. Since the navicular bone does not have good blood supply, he did not respond well to conservative treatment. Therefore, in February of 2017, the patient underwent surgery for the first time. The surgical procedure consisted of repair and reconstruction of the navicular stress fracture nonunion; takedown of the nonunion with compression and fixation. Two Synthes solid 3.5mm screws (1 medial-to-lateral and 1 lateral-to-medial) were used. A bone graft harvest from the left calcaneus was taken using the Synthes dowel graft system for this autogenous bone grafting of the nonunion.</p> <p>After five months of rehab, the patient continued to have pain, which lead to his second operation in July of 2017. His second operation consisted of a left ankle arthroscopy with debridement of anterior-lateral impingement lesion and synovectomy.</p> <p>Again, his ankle did not respond well to rest and rehab after the surgery, which led him to see an outside physician. In April of 2018, the outside surgeon also performed a navicular ORIF; however, he removed the hardware that was in his navicular bone from the first surgery and used a bone marrow aspirate from his left hip.</p> <p>His new surgeon wanted us to use BFR this time around during his rehab process. Our Director of Sports Medicine bought the unit for us to use on this particular patient and for as many patients necessary in the future. The patient enjoyed using the BFR. He had a close friend, former teammate, and current NFL player who used BFR when he was rehabilitating from a meniscus repair. For the first two weeks, the patient used BFR twice per week. The patient struggled coming in for rehab consistently, reducing his opportunity to use BFR more frequently. The patient initially performed rehab exercises that</p>
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		<p>were non-weight bearing, such as ankle pumps, straight leg raises, isotonic hip and knee movements, and cryotherapy. As time progressed, he was able to begin functional movements, such as squats and lunges, followed by running on an anti-gravity treadmill to gradually introduce stress to his ankle. As training camp approached, the patient continued to rehab his ankle by performing exercises to address muscle endurance, such as seated calf raises, seated toe raises, and 4-way isotonic ankle strengthening using a theraband. Parameters were 1-3 sets of 30 reps. When training camp arrived, the patient was gradually progressed to full activity per the approval of his outside physician. Initially, the patient felt great with his modified activity, orthotics, and ankle taping. However, he was not able to finish the entire football season due to pain in his ankle.</p>
<p>Summer 2018</p>	<p>Second patient interaction</p>	<p>This patient was a 20 year old, 6'2", 222 lb wide receiver in his redshirt freshman year who experienced left hip pain when running during a team workout in late January of 2018. Initially, the patient began conservative treatment to reduce his pain with activity. After conservative treatment failed, an MRI was ordered in February of 2018, revealing a full-thickness tear of the left anterior superior acetabular labrum. In March of 2018, the patient underwent left hip arthroscopic surgery to repair the torn labrum. This surgery is typically a 4-6 month recovery. Since training camp began in August, he had about 5 months to return to play.</p> <p>We used BFR when he was 3 months post-operation to improve his muscle mass and strength. We also used the BFR during plyometric and agility exercises. These exercises typically consisted of 1-2 sets of 20 repetitions or 20 seconds with short rest intervals (30 seconds). The patient enjoyed using the BFR unit because he claimed he could feel his muscles working harder. In return, he came in frequently and was more likely to want to perform his exercises because of the benefits he felt. Before training camp began, we performed a functional test to use objective data when deciding on his return to play. The patient recorded a 39 inch vertical, greatly improving his confidence and reducing his anxiety about returning to football. He was able to return to football one month earlier than expected and had his best season of his college career.</p>

September 2018	Third patient interaction	<p>This patient was a 19 year old, 6'2", 202 lb redshirt freshman wide receiver who in August of 2017 suffered from a left knee injury during college football practice. While cutting, his knee went into a varus position, causing him pain at the lateral aspect of his left knee. After two weeks of conservative treatment, the patient's pain persisted. At that time, the team physician ordered an MRI of the left knee, which showed a complex tear of the left lateral meniscus. In September of 2017, the patient underwent a left knee arthroscopy with partial lateral menisectomy.</p> <p>As a redshirt freshman in college, he struggled with time management and consistent commitment to rehab. This lead to lack of muscular strength and size, eventually causing him left knee pain. Although he was able to return to play, he did not feel the same as he did before surgery.</p> <p>The following year, April of 2018, the patient suffered from a right knee injury during the spring football game. An MRI was ordered by the team physician the following week, which revealed a full-thickness and full width radial tear at the junction of the body and anterior horn of the lateral meniscus. For the next two months, the patient rehabilitated his right knee to control the pain and swelling in his knee while also helping support the joint. After two months, his pain had not resolved completely, leading to arthroscopic surgery with a partial lateral menisectomy of his right knee in June of 2018.</p> <p>This time around, we introduced BFR to his rehab process. The BFR, along with his maturity, was a reason he came in for rehab more frequently than he did the year prior and helped him return to participation faster and experienced less issues in his knee. He also experienced greater improvements in muscle mass than he did in the year prior during the rehab of his left knee.</p>
January 2019	Fourth patient interaction	<p>This patient was a 19 year old, 6'4", 246 lb sophomore tight end who sustained a right knee injury during a college football game in September of 2018. The patient was running a route when he caught the ball and attempted to break a tackle by spinning off the defender. At that point, the patient reported his right foot was planted in the ground, causing an axial load mechanism on his right knee. The patient was able to return to play the remainder of the game. The following day, the patient was evaluated by the team physician due to right knee pain and mechanical symptoms. The team physician ordered an MRI of the right knee, which showed a partial tear of the</p>

proximal patellar tendon near the lower pole patella attachment, involving at least 80% of deep fibers. The MRI also revealed free edge blunting at the body of the medial meniscus. The patient was able to continue playing football the remainder of the season.

In January of 2019, when the season ended, the patient underwent right knee arthroscopy with partial lateral menisectomy, along with open debridement of the partial patellar tendon tear and primary repair of the patellar tendon. The patient is currently twelve weeks post-operation and has seen great improvements in his quadriceps muscle and feels like the BFR is helping him throughout his rehab. His improved muscular strength has allowed him to get complete knee extension back, good quad control when walking, and almost bilateral symmetry in quadriceps size.

Figure 1A
Menu Screen

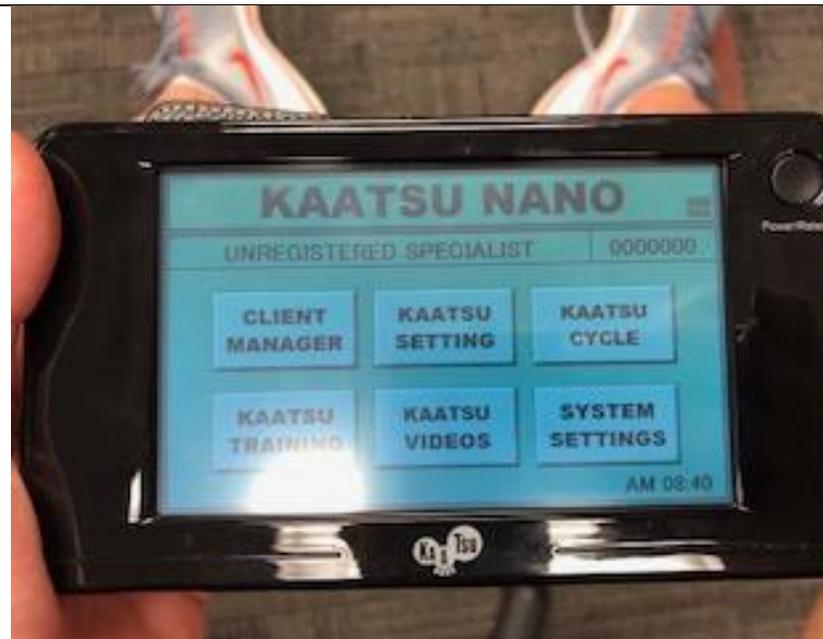


Figure 1B
Checking the Base SKU
(pressure)



Figure 1C
Parameter Selection



Figure 1D
Training Time Entry



Figure 1E
Capillary Refill Time Entry



Figure 1F
Parameter Selection



Figure 1G
Beginning of Cycle



Figure 2A
Cord Attachment from Unit to
Cuff



Figure 2B
Cuff Positioning



Figure 3A
Capillary Refill Check for
Lower Extremity



Figure 3B
Capillary Refill Check for
Lower Extremity
(immediately after release)



Figure 3C
Capillary Refill Check for
Lower Extremity
(3 seconds after release)



Figure 4A
Patient Positioning (Lower
Extremity)



Figure 5A
Capillary Refill Check
(upper extremity)



Figure 5B
Capillary Refill Check
(upper extremity) Immediately
After Release



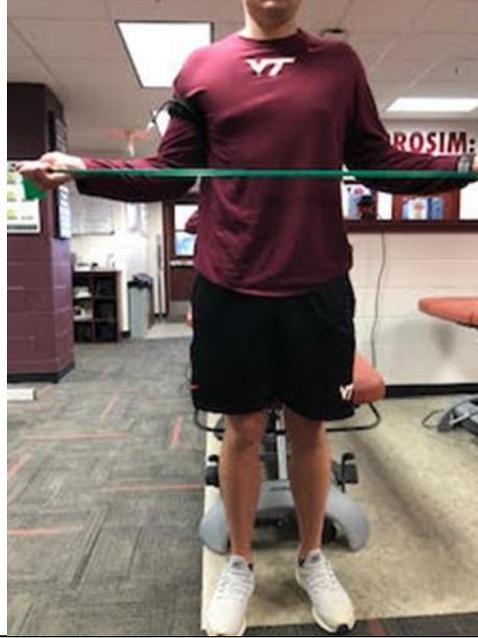
Figure 5C
Capillary Refill Check
(upper extremity) 3 Seconds
After Release



Figure 6A
Patient Positioning
(upper extremity)



Figure 6B
Rehabilitation with BFR
(upper extremity)



The following is an article prepared for the NATA News magazine:

Article Title: Implementing BFR for Injury Rehab in the Athletic Training Setting

What is Blood Flow Restriction (BFR)?

Blood flow restriction (BFR) involves using specialized bands filled with air to a specific pressure that are applied to a person's extremities in order to occlude venous return. The bands are kept inflated during the duration of exercise, typically for no longer than 20 minutes. The pressure from the bands decreases arterial pressure and occludes the venous blood flow of the muscle, causing an increase in growth hormones to the muscle³. While it has been used in Japan for hundreds of years, it was first used in the United States approximately 40 years ago, and it is more frequently used by clinicians today. There is an extensive amount of research supporting the numerous beneficial effects of BFR, such as improvements in muscle size, strength, endurance, bone health, and the cardiovascular system^{2,3,4,5,7,11}. Athletic training facilities may be a setting where BFR can promote physiological benefits that can expedite an athlete's return to competition.

How is it Set-Up?

To use a KAATSU blood flow restriction unit, it is important that the clinician is certified through the KAATSU company. The KAATSU BFR unit comes with a manufacturer's manual. When using BFR on a patient, follow the instructions per the manufacturer's manual Appendix A).

What are the Physiological Effects of BFR?

When the specialized band is inflated, it causes a decrease in arterial blood flow and occlusion of venous blood flow of the muscle³. In 2015, Farup et al suggested that a reason for muscle hypertrophy from BFR came from an increase in intracellular or extracellular water retention, causing an increased strain on the sarcolemma, which stimulates protein synthesis⁵. Hughes et al found that an ischemic and hypoxic muscle environment causes high levels of metabolic stress⁶. This environment caused an increase in systemic vascular endothelial growth factor (VEGF) production, cell swelling, production of reactive oxygen species (ROS), and fast-twitch muscle fiber recruitment^{3,6}. Pope et al found that this ischemic and hypoxic intramuscular environment caused a greater role of ATP hydrolysis, exaggerated PCr depletion, decreased pH levels, and increased blood lactate concentrations¹⁰. Additional potential physiological effects include increased motor unit recruitment and cellular signaling events from the mechanical changes of the muscle fibers, causing an increase in similar muscle fiber recruitment found in traditional high-intensity exercise^{1,4}.

Effects of Blood Flow Restriction on Muscle Hypertrophy and Strength

When a muscle is not used for a long period of time, it undergoes atrophy. The lack of muscle activation results in less protein synthesis, cross-sectional area (CSA), and neuromuscular impairments due to lack of voluntarily recruiting motor units and decreased transmission of neural impulses⁴.

Rebuilding muscle mass (hypertrophy) is a major goal when rehabilitating an injury after an operation involving joints and bones. However, hypertrophy occurs when training at loads above 75% 1-repetition maximum⁴. When rehabilitating from an injury, it is unsafe to train at a

load that high. Blood flow restriction in conjunction with low-load resistance training has shown to have a positive effect on hypertrophy, as it increased protein synthesis and improved neuromuscular function^{4,5}. Farup et al found that lifting weights with blood flow restriction at 30% 1RM produced equal muscle hypertrophy compared to lifting weights without blood flow restriction at 80% 1RM⁵.

Effects of Blood Flow Restriction on Cardiovascular Endurance & Bone Health

One of the most difficult areas to address during surgical rehabilitation can be cardiovascular endurance. Early in the healing process, it is difficult to address this area, particularly if resources are not available because of restrictive budgets. Therefore, clinicians may neglect this area and focus mainly on getting full range of motion, muscle girth, strength, and proprioception back to the involved area. Research has shown that walking with blood flow restriction twice daily for two weeks increases endurance capacity due to an increase in oxidative enzymes, capillary density, stroke volume, and glycogen stores¹⁰.

Bone healing is another major goal, especially after a fracture. Weight-bearing activity may be beneficial to stimulate bone growth; however, many patients are prohibited from bearing weight on the involved bone after surgery to allow the bone to heal. Blood flow restriction has been shown to improve bone remodeling without the need for high-intensity training by increasing circulating bone-specific alkaline phosphate (BAP) and growth hormone (GH) levels².

Parameter Considerations

In athletic training facilities, it is common for an athlete to complete their rehabilitation exercises 5 times per week. Depending on the case, some athletes may come in to the athletic training facility for rehabilitation two times per day. Since a training intensity of 20% of 1RM

produces minimal muscle damage, less recovery time is necessary, allowing the training frequency to be increased¹³. Cook et al found that rehabilitation with BFR twice daily for two weeks caused a 24% increase in IGF-1, leading to an anabolic response due to the increased levels of growth hormone⁴. The researchers also found that rehabilitation with BFR twice per week for 8 weeks caused a significant increase in strength, cross-sectional area, and muscular endurance⁴. Scott et al found that 6 weeks of low-load BFR bench press training (3 days each week at 30% 1RM) increased the CSA of the triceps brachii (4.9%) as well as the pectoralis major (8.3%)¹². The researchers also found that 8 weeks of low-load knee extension training (twice per week using three sets of 15 repetitions) at 20% 1RM resulted in a large increase in knee extension 1RM (40.1%) in addition to a substantial increase in quadriceps CSA (6.3%)¹².

When using BFR, it is important to prescribe appropriate sets and repetitions. The most commonly used protocol is 1 set of 30 repetitions, followed by 3 sets of 15 repetitions⁹. However, beneficial effects are also seen when the patient completes between 15-30 repetitions, followed by short rest intervals of 30 seconds¹⁰. Scott et al found that BFR research typically either use training volumes ranging from 45-75 repetitions of each exercise per session or exercise to volitional fatigue; however, low-load BFR training can significantly increase muscle size and strength without the need to train to failure. Extended periods of training to failure may lead to increased physiological markers of over-training¹². It is important to implement short rest intervals, and assess the patient for proper technique. If the patient begins using improper technique, they should stop that particular movement and begin their rest.

The majority of research studies on low-load resistance exercise with BFR show that using relatively brief inter-set rest periods of 30-60 seconds are associated with an increase in metabolic stress¹². The general consensus appears to be that the restriction should be maintained

during the rest periods to increase the metabolic stress¹². If applied appropriately, venous outflow will be occluded, and the clearance of metabolites between sets will be diminished drastically¹². In addition, the venous pooling occurring during the rest interval will increase cellular swelling, which is considered to be an important factor in the hypertrophic response. This phenomenon is thought to be a primary reason for the beneficial physiological responses to BFR with resistance exercise.

Concerns and Risks

Blood flow restriction is an intimidating modality by nature. However, blood flow restriction has been shown to only have minor negative effects that rarely occur⁶. Hughes et al showed that a large majority of studies did not report any adverse effects of blood flow restriction, conditions were not worsened, pain was not caused, and risk was no greater than traditional exercise. An incidence rate of 0.008% (over 30,000 participants) of rhabdomyolysis was found in their research. Loenneke et al found that the peripheral blood flow response to blood flow restriction is similar to regular exercise, and coagulation does not appear to increase after low-intensity blood flow restriction^{7, 8}. Therefore, it appears that using blood flow restriction at low-intensities causes no greater risk than traditional exercise^{7, 8}. On the contrary, severe restrictions or complete occlusion of blood flow may cause thrombus formation and promote microvascular occlusions after releasing the cuff pressure, resulting in muscle cell damage and necrosis¹⁴. Using a surgical tourniquet (135 mm width for thighs) may cause a serious amount of pain to the patient due to neural impairment and suppression of lactate clearance¹⁴. If BFR is used in conjunction with cardiovascular activity, an increase in heart rate and blood pressure during exercise may occur because of the compromised venous return; therefore, it is important to monitor the patient and avoid high-intensity activity⁹. In addition,

blood flow restriction units can be very expensive for athletic training departments, depending on their budget.

Preliminary Experiences with BFR in the Collegiate Athletics Setting

During our short time working with BFR in the collegiate athletics setting, we have found it to be helpful during the rehabilitation process. We feel that it is very easy to set up and have not experienced any negative side effects. When we explain the benefits and safety to the athletes, they are more excited to complete their therapeutic exercises and have a greater desire to complete their treatment.

In one case, a collegiate football player came in to the athletic training facility more frequently than usual because he wanted to use the BFR unit. This particular patient had the same surgery on the contralateral side the year prior and struggled to come in for rehabilitation consistently. Introducing BFR helped get him in to the athletic training facility more often and improve his muscle strength and size.

Just like any other modality, it should not be the only tool utilized during the recovery process. However, we have found it to improve patient outcome and help our patients increase muscle strength and size more quickly while they have weight-bearing restrictions.

Conclusion

Unfortunately, objective data on muscle strength and size were not documented throughout the rehabilitation process. However, we have found that college football players enjoy using BFR as the continuous pressure causes an increase in perceived exertion during treatment. The current athletes who are returning to play after using BFR have had no set-backs in the rehabilitation process, and continue to progress without pain. Over the past year, we have not experienced any

negative side effects after using BFR on an athlete. Although a sample size of 4 athletes is not significant, the athletic trainers and athletes have had positive experiences with the use of BFR and will continue using it during post-operative rehabilitation.

Implications, Impacts, and Recommendations

Rehabilitation after an injury in athletics is a major concern for athletes and an athletic trainer. The athletic trainer is responsible for returning the injured athlete back to participation as fast and safely as possible. Since it is typically unsafe to apply heavy loads, such as weights, to an extremity after an injury, atrophy tends to occur to the injured area. Blood flow restriction is a modality that is fairly new in the United States. Research has shown that blood flow restriction used during low-intensity (20-30% 1RM) loads has significant increases in muscular strength and hypertrophy compared to high-intensity loads (>70% 1RM) without blood flow restriction.¹⁰

This project documented preliminary experiences with blood flow restriction in a collegiate athletics setting with hopes to disseminate practical information about blood flow restriction to practicing athletic trainers at Virginia Tech and across the United States. Blood flow restriction is easy to operate and appears to be a safe and effective resource for clinicians when helping a patient rehabilitate from surgery and return to participation faster.

Although this is anecdotal evidence, continued research of blood flow restriction and its physiological effects are recommended at this time. Potential research of the best time to use blood flow restriction during injury rehabilitation is recommended in order to help practicing athletic trainers make the best evidence-based decisions when utilizing this modality with their patient.

Dissemination Plan

The purpose of the publication in NATA News magazine will be to provide an overview and practical perspectives about the use of BFR with athletes for injury rehabilitation. It will briefly review literature related to mechanisms by which BFR improves injury rehabilitation,

evidence of effectiveness, and safety concerns. Practical issues such as the certification process, unique athlete considerations, pressure cuff characteristics, and the utilization of BFR with different types of activity will also be provided. Target audience for the article is practicing athletic trainers in the United States to educate on BFR and how it can benefit them in their practice.

In addition, a comprehensive presentation of BFR will be reported to the Sports Medicine Staff at Virginia Tech. The purpose of the presentation will be to provide an overview and practical perspectives about the use of BFR with athletes for injury rehabilitation. It will briefly review literature related to mechanisms by which BFR improves injury rehabilitation, evidence of effectiveness, and safety concerns. Practical issues such as the certification process, unique athlete considerations, pressure cuff characteristics, and the utilization of BFR with different types of activity will also be provided.

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Appendices (A)

KAATSU MASTER & NANO Quick Start Guide

Thank you for your purchase of a KAATSU MASTER or Nano and KAATSU Air Bands.

Enclosed you will find your

- KAATSU MASTER or Nano
- 2 translucent connector tubes
- Power adapter
- Micro SD card
- A set of 4 KAATSU Air Bands (2 arm and 2 leg bands)

The default PASSCODE is 0000.

Before you begin, please charge the KAATSU MASTER or Nano for at least 3 hours. The unit has a lithium ion battery that will keep the unit charged for approximately 2½ hours of continuous use. There is a 4-step battery power indicator located on the upper right corner of the screen. Occasionally, if the unit runs too low on battery power and shuts off, you may need to reset the unit. To reset the KAATSU Nano, gently insert the end of a paper clip or a similarly sized pin into the reset hole on the side of the unit. This will reset the device so the unit can be recharged.

USAGE

Insert the translucent air tubes into the left and right holes on the KAATSU MASTER or Nano. Then connect the left white connector at the end of the translucent air tube to the Left KAATSU Air Band and the right white connector at the end of the translucent air tube to the Right KAATSU Air Band. Each KAATSU Air Band is marked either left or right with its size indicated with an S (small), M (medium), or L (large).

Place the KAATSU Air Bands on the arms or legs with the connector tubes pointing down, towards either the wrist on the arms or the ankles on the legs. The KAATSU Air Bands should be placed as high up on the arms or legs as possible in order to capture enable as much blood pooling in the limbs as possible below the Air Bands.

PRESSURES

There are 2 types of pressures used with KAATSU: the Base SKU and the Optimal SKU. SKU stands for Standard KAATSU Units.

BASE SKU

The Base SKU is the initial tightness of the KAATSU Air Bands when they are first manually placed on the limbs. Base SKUs for the KAATSU MASTER or Nano are recommended to be between 20-25 SKUs for competitive athletes, 15-20 SKUs for healthy adults, and 10-15 SKUs for older or weaker individuals.

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