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Use of Blood Flow Restriction to Treat and Rehabilitate Patients Ages 18 to 40 Year Old from Postoperative Anterior Cruciate Ligament Reconstruction

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USE OF BLOOD FLOW RESTRICTION TO TREAT AND REHABILITATE PATIENTS AGES 18 TO 40 YEAR OLD FROM POSTOPERATIVE ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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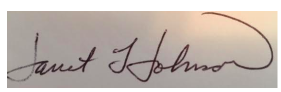
Project Advisor Signature: 

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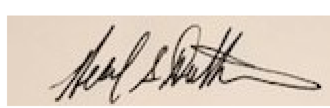

Abstract

Background: Blood flow restriction (BFR) is being shown to have many positive applications for the medical, and strength and conditioning fields. Recently, researchers and physical therapists have been applying these same concepts to patient populations of all ages and are using BFR to assist patients who have undergone major surgeries. A main goal for the use of BFR in rehabilitation is to increase quadricep strength in the rehabilitating patient, while also decreasing stress loads on the knee joint, whether it be the tibiofemoral joint or the patellofemoral joint. This decrease in stress helps the repairing tissue to recover strength without repetitive high compression forces, which can cause unwanted damage and slow down the recovery processes.

Purpose: The purpose of this paper is to evaluate whether or not BFR is effective in the treatment and rehabilitation of postoperative anterior cruciate ligament reconstruction (ACLr) patients within the ages of 18-40 years old.

Results: It was found that BFR is an effective treatment in the rehabilitation of postoperative ACLr patients within the ages of 18-40 years old. The effectiveness is defined by the patient outcomes on strength, function, and patient reported outcome measures (PROMs).

Conclusion: Though the research on the topic of post-surgical ACLr patient's rehabilitation with BFR has only a small sample size, from what we know about conventional and BFR rehabilitation with other post-surgical knee protocols, we can conclude the same benefits with BFR for ACLr patient will be effective.

Implications for Research and Practice: The main implication for this research is that BFR allows practitioners to start patient's rehabilitation sooner, resulting in similar, if not greater,

strength gains. This also decreases the stress on the regenerating tissues, and therefore decreases pain during the patient's rehabilitation experience.

Keywords: Anterior Cruciate Ligament, Blood Flow Restriction, Rehabilitation, Knee, Reconstruction

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Chapter I: Introduction

In recent years a new approach to exercise has made its way into the Western cultures and has begun a paradigm shift in the way medical professionals are thinking about rehabilitation and strength and conditioning. Blood flow restriction (BFR) is a method of vascular restriction which causes a cascade of physiological effects in the body while a person is contracting their muscles. This idea is not new as it has evolved from an Eastern civilization practice termed, KAATSU (Sato, 2005). KAATSU uses vascular occlusion as well, but it differs in thought slightly from the Westernized practices of blood flow restriction. KAATSU causes a reduction in venous blood flow, and BFR aims to achieve limb vascular occlusion. BFR has most recently been introduced into the United States and is one of only a few United States Food and Drug Administration approved medical devices. The most well-known device is from a Canadian company, Delphi Medical Innovations Inc., called the PTS Personal Tourniquet System for BFR (Delphi Medical Innovations, 2018). This unit has made its way into many medical facilities around the United States and it has been shown to improve strength gains in populations from young adults to the elderly (Scott et al., 2014).

The theory behind BFR is the reduction of oxygen supply to the muscles, mimicking a state of hypoxia, similar to what results from high intensity exercise where the oxygen supplies are not able to keep up with the demands of the work the muscles are performing, causing an increased flow of blood and nutrients to the hypoxic state muscles (Patterson et al., 2019). With the restriction of blood flow to the muscles, fatigue sets in much more quickly requiring fewer repetitions to exhaust the muscles to the point of not being able to do more work. The theory is that the body is being "tricked" into thinking the muscles are working hard and lifting large amounts of weight, when in reality the muscles are lifting very small amounts of weight and creating less overall stress on the body, especially major joints. There is research that has shown the similar physiological responses between using light load resistance training with blood flow restriction and heavy load resistance training without blood flow restriction for patients participating in lower limb rehabilitation programs (Ladlow et al., 2018). There has also been recent research in rehabilitation settings showing that blood flow restriction resistance training can bring about greater results of strength gains than that of heavy load resistance training for patients participating in lower limb postsurgical programs (Bowman et al., 2019).

As more research is being performed on BFR, evidence suggests it can have many positive applications for the medical, and strength and conditioning fields. Currently, many different forms of BFR in use have stemmed from the original KAATSU practices, especially with body builders, which are not regulated by a governing body and can be potentially harmful to their systems. Some of these practices include using traditional BFR cuffs, elastic bands, and ACE bandage wraps. The risk in using devices that are not FDA approved includes a difficulty in knowing how much occlusive pressure is being placed on the limb. The newest technology, especially the Delphi Medical models, are being used in Physical Therapy practices to help elderly patients to regain their strength post-surgically with a decrease in joint pain and a decrease in the loads placed on their joints (Scott et al., 2014). The use of BFR is practical for the elderly population because it allows their muscles to do light loads of work without increasing the stress placed on their bodies (Scott et al., 2014). More recently, researchers and physical therapists have been applying these same concepts to patient populations of all ages and have been using BFR to assist patients who have undergone major surgeries and the results have been shown to be positive by multiple studies (Hughes et al., 2019; Bowman et al., 2019; Tennent et al., 2017). These studies have mainly been focused on lower limb injuries with an emphasis on the knee joint. Multiple studies have researched effects on anterior knee pain rehabilitation (Korakakis et al., 2018); meniscal injury rehabilitation (Ladlow et al., 2018); and anterior cruciate ligament repair rehabilitation (Hughes et al., 2018; Hughes et al., 2019; Ohta et al., 2002). These studies have one main goal in common for rehabilitation and that is to increase quadricep strength in the rehabilitating patient, while also decreasing stress loads on the knee joint, whether it be the tibiofemoral joint or the patellofemoral joint. This decrease in stress helps the repairing tissue to recover strength without the repetitive high compression forces, which can cause unwanted damage and slow down the recovery processes. Other positive side effects include decreasing time spent in pain and the presence of effusion in the joint (Hughes et al. 2019).

During the first stage of most knee rehabilitation programs it is crucial for the patient to regain full range of motion and to begin partial weight bearing during the first few weeks (Hoglum, 2016). As stresses are increased so does the progression of isometric and isotonic exercises based on the patients' reports of pain (Houglum, 2016). From there the progression will include quadricep strengthening with weights usually in an open-kinetic chain (OKC) or closed-kinetic chain (CKC) (Hoglum, 2016). Then, exercises progress to only CKC which increases the amount of stress placed on the knee joint (Houglum, 2016). Studies have shown that BFR may be used at any point during the open or closed kinetic chain exercises progression (Lu et al., 2020).

Statement of Purpose

The purpose of this paper is to evaluate whether or not BFR is effective in the treatment and rehabilitation of postoperative anterior cruciate ligament reconstruction (ACLr) patients within the ages of 18-40 years old. To determine the effectiveness, the outcome measures to be assessed will be total strength gains, functional outcome measures, and patient reported outcome measures.

Need for Critical Review

The need for this critical review is based on the principle that today we are seeing higher levels of lower body overuse injuries and especially traumatic injuries involving structures of the knee (McGuine, 2017). Athletes now are specializing in one sport due to the demand of perfection and are only working muscles in a certain way that is specific to their sport. This specializing is causing athletes to see high rates of injuries specifically in the lower body (McGuine, 2017). Once these athletes move from high school into college many of them are bringing their overuse injuries into their schools' athletic training rooms where they are evaluated for the first time. It is fair to assume that at some point during their high school years, collegiate career, or even into adulthood, they will need major surgery for some type of traumatic injury such as an anterior cruciate ligament reconstruction (ACLr) or a meniscectomy or repair. Rehabilitation for these injuries are now being treated in physical therapy (PT) clinics with the use of BFR to allow patients to start the rehabilitation process sooner (Lu et al., 2020). This critical review will focus on what is currently known about BFR training with patients in rehabilitation clinics and also focus on where future research will be needed.

Significance to Athletic Training

In the athletic training setting, BFR appears to be significant in the rehabilitation of athletes. Athletes who obtain lower body injuries of any kind can use BFR to reduce the stress placed on joints during normal protocols of rehabilitation programs and progress into strength training more quickly (Ladlow et al., 2018). This will allow athletes to begin their rehabilitation protocol stages sooner as well as having positive effects on the reduction of effusion and pain, which are significant contributors to slowing down rehabilitation (Hughes et al., 2019; Hoglum, 2016). BFR is also a significant factor in the athletic setting because it can be used by an athletic trainer as a prophylactic measure to reduce stresses of heavy-load resistance training placed on the bodies of athletes when lifting every day (Scott et al., 2015). This modality can be a useful tool in the athletic trainer’s repertoire for patients recovering from injuries and will be well worth the investment in equipment and training required for its use on patients. The research provided and evaluated will show BFRs usefulness and its ability to provide positive rehabilitation outcomes in the athletic training and rehabilitation setting.

Chapter II: Methods

The following chapter provides the details to which this Critical Review of the Literature was performed. This section will include the search strategies used, the inclusion and exclusion criteria used to determine what articles were deemed worthy of using, how studies were selected, how the most important data was extracted from those studies included, how the pertinent information from the studies was organized, how the studies were evaluated, and how that evaluation was reported.

Literature Search Strategies

The literature search was done under the standards of a Critical Review of the Literature (Bethel University, 2021). This was completed largely by a CLICsearch based out of the online library from Bethel University in Minnesota. Through the CLICsearch the majority of the articles were found via the PubMed database with several articles found through SCOPUS and Google Scholar. Not all of the articles that were found were available as free access resources through the Bethel University library so professors who had greater access to desired studies were consulted and used to help obtain those articles which encompassed pertinent information regarding the topic of BFR. There were also systematic review articles that were used in the research in efforts to obtain more sources. The inclusion criteria for the systematic reviews were determined based on the appraisal value of each article which they included in their own research. To complete the search, keywords used included “Blood,” “Flow,” “Restriction,” “Blood Flow Restriction,” “BFR,” “KAATSU,” “Vascular Occlusion,” “Anterior Cruciate Ligament,” “ACL,” “Anterior Cruciate Ligament Reconstruction,” “ACLr,” “Knee,” “Athlete,” “Adult,” “Rehabilitation,” and “Perioperation.” Several of these search terms or phrases were not found to be important because they did not yield any results with their inclusion, but were main focuses of the initial search. Some of the terms were then found to be useful again after reviewing several of the systematic reviews, randomized controlled trials (RCTs) and quasi-experimental studies (QES). The words “and” and “or” were included in the search terms because they were able to help narrow the search fields and the scope of the articles identified. The initial literature searches yielded 105-145 articles. From these search terms, different databases were used to find articles. All databases had functions to be able to narrow the searches by identifying only peer-reviewed journals and articles that were RCTs, QES and systematic reviews. From these searches, the narrowing of the search fields and with the use of the reference pages of the systematic reviews, a total of 33 articles were found. Of those 33 articles, 18 met the criteria that would pertain to specific parts of the critical review of the literature and were used and evaluated for quality.

Inclusion and Exclusion Criteria

Eligible studies found through the critical review of the literature, were included if they had the following criteria: provided a history of BFR or KAATSU, BFR was used on a lower limb, BFR used in training of healthy individuals, BFR in training of a population from 18-40 years of age, BFR used in training of athletes, and BFR was used in rehabilitation of knee pathologies including: (ACLr, Anterior Knee Pain, Patellofemoral Pain Syndrome, Meniscal injury). The inclusion criteria also included that the article was in the English language and was published in a peer-reviewed journal. The range of time of publication for these articles was from January 1, 1999 to September 20, 2020. The reason that the search range was fairly broad was because Blood Flow Restriction is a newer form of practice and it stems from the traditional form of the idea called KAATSU which was studied in great detail from the mid-1990s into the early 2000s. Eighteen articles were assessed for their quality and studies ranking from level 1 to level 3 were included.

Number and Types of Articles

Of the final 18 articles selected all of them have been reviewed for quality using the Johns Hopkins Nursing Evidence-Based Practice Manual: Research Evidence Appraisal Tool, (See Appendix B) . The Johns Hopkins Nursing Evidence-Based Practice Manual: Research Evidence Appraisal Tool was used because it covers all types of research and has a methodical review process which identifies a process based on the article's analytical type; quantitative, qualitative, or mixed methods. None of the articles included in this review were from a mixed methods study, so it is deemed to be outside the scope of this review to explain the mixed methods appraisal sections of the Johns Hopkins Nursing Evidence-Based Practice Manual: Research Evidence Appraisal Tool. From there the Research Evidence Appraisal Tool will inform the assessor which section to proceed to and guide them through the necessary order of steps for an accurate appraisal. If the article is quantitative the assessment starts in section 1 based on the level of evidence and study design. It first asks if the report is on a single research study. Next, it asks if there was a manipulation of an independent variable, if there was a control group, and if the study participants were randomly assigned to the intervention and control groups. Following that is an explanation as to which level that particular study can be identified. Based on the answers, the article is assigned either levels 1 (a RCT), 2 (a QES) or 3 (a nonexperimental study). The Research Evidence Appraisal Tool then determines whether the article is an evidence level of 1, 2 or 3. Also in this section it determines if the level 1 evidence is either an appraisal of a single research study or a systematic review. If a study is a systematic review, to be considered level 1 evidence, the reviewed articles must only be RCTs. If there is a combination of RCTs and QES or only QES the systematic review is deemed to be level 2 evidence. If the systematic review has RCTs, QES, and nonexperimental studies or only nonexperimental studies it is determined to be level 3 evidence. Section 1B also includes a field where the assessor can include study findings that help answer their evidence based practice question. Once section 1B is completed the tool instructs the assessor to move to the appraisal of the systematic review portion of the appraisal tool.

In the two appraisal sections there are a number of “yes” or “no” and in some questions a “N/A” field that are to be answered. In the appraisal of quantitative research studies there are 15 questions to be answered, with 7 of those questions having a field of “N/A.” In the appraisal of systematic review section there are 11 questions to be answered, and all of those questions only use a “yes” or “no” field. At the end of the appraisal of quantitative research studies and the appraisal of systematic review sections it instructs the assessor to complete the quality rating for quantitative studies. The quality rating for the quantitative studies section gives the assessor the information to evaluate the level of quality for each article. A grade “A”, high quality study is one which has: “consistent, generalizable results; sufficient sample size for the study design; adequate control; definitive conclusions; consistent recommendations based on comprehensive literature review that includes thorough reference to scientific evidence.” A grade “B”, good quality study is one which has: “reasonably consistent results; sufficient sample size for the study design; some control, and fairly definitive conclusions; reasonably consistent recommendations based on fairly comprehensive literature review that includes some reference to scientific evidence." A grade "C", low quality study with major flaws is one which has: "little evidence with inconsistent results; insufficient sample size for the study design; conclusions cannot be drawn."

The next section in the Johns Hopkins Nursing Evidence-Based Practice Manual: Research Evidence Appraisal Tool is section 2: qualitative studies. Section 2 starts with the "yes" or "no" question of: is this a report of a single research study? If the answer is yes the study is level 3 evidence. The assessor then completes a field where they can write in study findings that helps answer their evidence based practice question. Once that is completed the assessor is directed to complete the appraisal of a single qualitative research study section. In the appraisal of a single qualitative research study section there are 13 "yes" or "no" questions. Once those questions are answered the assessor is asked to proceed to the quality rating for qualitative studies. If the report was not a single research study, the assessor is instructed to proceed to section 2B, wherein the tool asks if the article is: for summaries of multiple qualitative research studies, was a comprehensive search strategy and rigorous appraisal method used? If the answer is "yes" the article is level 3 evidence. Next in section 2B there is a field where the assessor can write study findings that help answer their evidence based practice question. Once that is completed the tool directs the assessor to complete the appraisal of meta-synthesis studies. In the appraisal of meta-synthesis studies section there are 9 "yes" or "no" questions to be answered and then the assessor is asked to complete the quality rating for qualitative studies section. With the answers from either section 2A or 2B the quality level of the article is determined based on several factors. For level A: high quality rating the article must have all of the following found in the report: transparency, diligence, verification, self-reflection and self-scrutiny, participant-driven inquiry and insightful interpretation. For level B: good quality rating the article must include some of the following: transparency, diligence, verification, self-reflection and self-scrutiny, participant-driven inquiry and insightful interpretation. For level C: lower-quality the articles "contribute little to the overall review of findings and have few, if any, or the features listed for high/good quality."

Of the articles that were assessed using the Johns Hopkins Nursing Evidence-Based Practice Manual: Research Evidence Appraisal Tool the differentiation of the quality is presented in Table 1, which provides a clearer understanding of the level and quality of the articles used in this critical review.

Table 1: Level of Evidence and Quality of Included Articles

Level of Evidence	High Quality (A)	Good Quality (B)	Low Quality (C)	Total Number of Articles
Level I	10	0	0	10
Level II	4	3	0	7
Level III	0	1	0	1
Total				18

Information Extraction

Eighteen articles were assessed and placed into a Matrix for organizational purposes. The Matrix that was used to sort the information from each of the assessed articles was based on the Evidence Based-Practice Literature Matrix (Fineout-Overholt et al., 2010). Information was placed into seven or eight categories based on the type of article. RCTs and QES articles had eight categories and systematic reviews usually had seven with an occasional exception. The categories used in the Matrix were: Citation, Purpose, Sample, Study Design, Methods of Measurements, Results/Conclusions, Recommendations and Level/Quality. For the systematic review articles the Results/Conclusions and the Recommendations columns were combined.

Summary

The articles used for this Critical Review of the Literature based on BFR and its use in a rehabilitation setting for ACL reconstruction patients were found from multiple databases. Thirty-three articles were evaluated and found to be fitting of the inclusion criteria. Of those, 18 were eventually used and placed in an Evidence-Based Literature Matrix. Each article was assessed for a level of evidence and a quality value.

Chapter III: Literature Review & Analysis

Synthesis of Matrix

The basis of this chapter is to review and analyze the 18 scholarly articles found during the research and compare their findings to one another. The end goal is to be able to answer the question that was presented in chapter one of this paper. A literature matrix was used to sort and store data gathered from each of the 18 scholarly articles, along with assessing them for level of evidence and quality. These standards were assigned using the Johns Hopkins Nursing Evidence-Based Practice: Research Evidence Appraisal Tool. The criteria for which the Research Evidence Appraisal Tool assessed articles on, yielded nine categories; four levels of evidence categories are represented in the following chapter. The four level of evidence categories contain the following types of research which are not restricted to a specific category: systematic review, systematic review & meta-analysis, randomized control trial (RCT), and quasi-experimental study (QES). The matrix and analyzed data can be found in Appendix A.

Synthesis of Major Findings

Level I, Quality High (A) Evidence: The evidence at this level consists of RCTs and systematic reviews. The systematic reviews in this section only consist of RCT studies. There are ten articles which fall under this category and are summarized in the following pages.

Hughes et al. (2019) conducted a parallel-group, two-arm, single assessor blinded, RCT to discern the effectiveness of blood flow restriction versus traditional heavy load resistance training in the post-surgery rehabilitation of ACLr patients. The research group used a total of 28 participants. Fourteen of them were randomly assigned to the control group, heavy load resistance training (HL-RT), and 14 of the participants were randomly assigned to the experimental group, blood flow restriction resistance training (BFR-RT). The team assessed seven different categories of function and ability. The research team assessed participants' scaled 10-repetition maximum (10RM) for muscle strength on a leg press MED. The participants' scaled isokinetic strength was also measured via a Biodex System 4 Isokinetic Dynamometer. Muscle thickness and fascicule length was measured using a B-mode ultrasonography with a LOGIQ-E ultrasound device. The patients were asked to fill out surveys which included the International Knee Documentation Committee (IKDC), Lower Extremity Functional Scale (LEFS), Lysholm Knee-Scoring Scale (LKSS) and Knee Osteoarthritis Outcome Score (KOOS) and were all used to measure patients' perception of physical function. The team assessed the participants with a modified SEBT test, which was used to determine anterior, posteromedial and posterolateral reach scores on the injured limb. They used a standard goniometer to assess knee ROM, and also measured mid-patella joint circumference to the nearest 0.1 cm with a cloth tape measure. The final measure the research team assessed was knee ligament laxity with a KT-1000 knee ligament arthrometer.

The results from this study found that "scaled 10RM strength significantly increased in the injured limb and non-injured limb with BFR-RT and HL-RT, respectively, with no group differences" (Hughes et al., 2019). They also found that "significant increases in knee extension and flexion peak torque were observed at all speeds in the non-injured limb with no group differences" (Hughes et al., 2019). The authors did not find any difference in the muscle thickness and size as stated by "significant and comparable increases in muscle thickness ($5.8 \pm 0.2\%$ and $6.7 \pm 0.3\%$) and pennation angle ($4.1 \pm 0.3\%$ and $3.4 \pm 0.1\%$) were observed with BFR-RT and HL-RT, respectively, with no group differences. No significant changes in fascicle length were observed" (Hughes et al., 2019). The group did find two categories which produced significant differences as stated by their finding as follows: "Significantly greater attenuation of knee extensor peak torque loss at 150°/s and 300°/s and knee flexor torque loss at all speeds was observed with BFR-RT. No group differences in knee extensor peak torque loss were found at 60°/s;" and "significantly greater and clinically important increases in several measures of self-reported function, Y-balance performance, ROM, and reductions in knee joint pain and effusion were observed with BFR-RT compared to HL-RT, respectively" (Hughes et al., 2019).

From these findings the group concluded that "BFR-RT can improve skeletal muscle hypertrophy and strength to a similar extent to HL-RT with a greater reduction in knee joint pain and effusion, leading to greater overall improvements in physical function" (Hughes et al., 2019). The authors suggest, "...BFR-RT may be more appropriate for early rehabilitation in ACLR patient populations" (Hughes et al., 2019).

Bowman et al. (2019) conducted a RCT to study the proximal, distal, and contralateral effects of BFR training on the lower extremities. This study included 26 participants that were randomly assigned into two groups, 10 patients in the control group, and 16 patients in the experimental, BFR group. The group assigned the participants into three different categories. The first group outcome assessed consisted of isokinetic strength for knee extension and flexion. The second group outcome assessed was dynamometer strength of hip abduction, hip extension, and ankle plantarflexion. The final group outcome assessed was limb circumference, which was measured 10 cm proximal to the superior pole of the patella and 10 cm distal to the inferior pole of the patella.

The results of this study found that the BFR group had statistically significant differences of increase compared to the non-injured limb and the control group. "A statistically greater increase in strength was seen proximal and distal to the BFR tourniquet when compared with both the non-tourniquet extremity and the control group," (Bowman et al., 2019) and "isokinetic testing showed greater increases in knee extension peak torque (3% vs 11%), total work (6% vs 15%), and average power (4% vs 12%) for the BFR group" (Bowman et al., 2019). The research group also found that "limb circumference significantly increased in both the thigh (0.8% vs 3.5%) and the leg (0.4% vs 2.8%) compared with the control group," (Bowman et al., 2019) and that "additionally, a significant increase occurred in thigh girth (0.8% vs 2.3%) and knee extension strength (3% vs 8%) in the non-tourniquet BFR extremity compared with the control group" (Bowman et al., 2019).

From these findings the research team concluded that "low-load BFR training led to a greater increase in muscle strength and limb circumference," (Bowman et al., 2019) "BFR training had similar strengthening effects on both proximal and distal muscle groups," (Bowman et al., 2019) and that "gains in the contralateral extremity may corroborate a systemic or crossover effect" (Bowman et al., 2019).

Hughes et al (2018) conducted a between-subjects, partially randomized study, of which the focus was to compare the acute perceptual and blood pressure response to heavy load versus light load blood flow restriction resistance exercise in ACLr patients and non-injured populations. In this study there were 30 total participants which were partially-randomly assigned into three groups. The first group consisted of 10 non-injured BFR (NI-BFR) participants, the second group consisted of 10 ACLr-BFR participants, and the third group consisted of 10 ACLr heavy load (ACLr-HL) participants. The participants were assessed using three different tools. The first was for pre- and post-exercise blood pressure which was assessed using a Mobil-O-Graph ambulatory blood pressure monitor, the second was Rating of Perceived Exertion using the Borg's Scale and the final measure was a pain scale on a rating from 1-10.

The results of this study found that "RPE was higher in the ACLR-BFR group compared to the non-injured BFR group, but similar to the ACLR-HL group,muscle pain was higher in both BFR groups compared to the ACLR-HL group, session knee pain and 24 hr post-exercise knee pain was lower in the ACLR-BFR group compared to the ACLR-HL group, and there were no differences in pre- and post-exercise 10 blood pressure between the groups" (Hughes et al, 2018). From these results the research team concluded that the "hemodynamic and perceptual responses of light load BFR-RE in ACLr patient should not be a limiting factor for clinician concern in a rehabilitation setting" (Hughes et al., 2018).

Tennet et al. (2017) completed a randomized controlled pilot study to understand and evaluate the adding of BFR exercise to traditional methods of physical therapy to improve strength, hypertrophy, functional outcomes, and patient self-reported outcomes after postoperative non-reconstructive knee arthroscopy. Twenty-two participants were randomly assigned to the control group, n=11, and the experimental group, BFR group, n=11. In the control group, one participant withdrew from the study prior to initiating therapy, and the control group finished the study, completed and analyzed, with n=10 participants. In the BFR group, four participants withdrew from the study prior to initiating therapy, and the BFR group finished the study, completed and analyzed, with n=7 participants. The research team assessed four different categories of which two had multiple criteria. The first was a measurement of thigh muscle girth at 6 cm and 16 cm proximal to the superior patellar pole, which was measured using a standard tape measure. The second assessment was of Physical Performance Outcome Measures which included the self-selected walking score (SSWV), the Sit-to-stand 5 times (STS5), the 4 square step test (FSST), and the Timed Stair Ascent (TSA). The third assessment was the Patient-Reported Outcome Measures which included the KOOS and the Veterans RAND 12-Item

Health Survey (VR-12). Lastly, the research team assessed the participants muscular strength using a Biodex System 3 Dynamometer.

The results of the study included "significant improvements in thigh girth @ both 6-cm & 16-cm in BFR group, not seen in control group, significant improvements in control group in only the KOOS subscales of pain, symptoms and sport subscales, and significant improvements in all KOOS subscales for the BFR group" (Tennet et al., 2017). "VR-12 (PCS) showed significant improvements in both BFR & control groups. VR-12 (MCS) only showed significant improvements in the BFR group, the BFR group showed significant improvements in all physical functional outcome measures, when the control group only showed significant improvements in the SSWV, RSST & STS5, plus the BFR group showed generally greater improvements, and quadricep extension strength in the BFR group was 2x more improved compared with the control group" (Tennet et al., 2017).

Based on these results the research team shared the following recommendations: that this was "a pilot study for future studies evaluating BFR intervention in more complex postoperative patients," (Tennet et al., 2017) "using a subocclusive tourniquet in the control group to help alleviate bias in the future," (Tennet et al., 2017) and "with this small study providing promising results, it is in need of "further investigation in more powerful, larger clinical trials investigating preoperative and postoperative surgical patients with a high level of initial disability."

Yasuda et al., (2011) completed a RCT based on the efforts to investigate the combined effects of high-intensity resistance training (HI-RT) and BFR training on muscle size and strength. This study consisted of only male subjects ages 22-32. The total number of participants was 40 and they were divided into four groups: the control group, non-training n=10, HI-RT n=10, LI-BFR n=10, and combined HI-RT and LI-BFR (CB-RT) n=10. The participants were assessed on four different outcomes: isometric strength testing with an Isokinetic Dynamometer from Biodex System 3, maximal muscle activation via electromyography using Bipolar electrodes, muscle cross-sectional area (CSA) using an MRI with a 0.2-T scanners, and Ratings of Perceived Exertion using Borg's Scale.

The results of the study demonstrated that the 1-RM was similar in the HI-RT and the CB-RT groups and lower in the LI-BFR group (Yasuda et al., 2011). The CSA increased in all training groups, but much greater increases were observed in the HI-RT and CB-RT groups (Yasuda et al., 2011). With these results the researchers concluded that muscle improvements were greater with the combination of LI-BFR and HI-RT, than with just LI-BFR intervention alone (Yasuda et al., 2011).

Ladlow et al., (2018) conducted a single-blinded RCT to evaluate the efficacy and feasibility of LL-BFR training versus conventional high mechanical load resistance training on the clinical outcomes of patients undergoing inpatient multidisciplinary team (MDT) rehabilitation. The study was conducted with active British military males ages 19-49, with a total of n=28 participants. The control group, conventional RT, had n=14 participants, and the experimental group, LL-BFR, had n=14 participants. The session adherence rate for the conventional group was >90% and the rate for the LL-BFR was 100%. The participants were assessed in six different categories: muscle CSA and volume assessed with an MRI 1.5-T scanner, 5-RM muscle strength using machines from Pulse Fitness, isometric hip extension strength which was tested with a wireless handheld dynamometer, endurance testing was measured with the multistage locomotion test (MSLT), balance was measured with a Y-Balance test kit, and lastly pain was measured with 100 mm horizontal visual analog scale (VAS) to measure pain and physical discomfort every five treatment sessions.

The results of this study are as follows "at 3-weeks both groups significantly increased quadricep & thigh CSA & volume in their injured limb," (Ladlow et al, 2018) "LL-BFR at 3-weeks showed greater quadriceps CS & volume over the conventional group. Thigh results were within a 1% difference between the groups," (Ladlow et al., 2018) the "conventional group showed greater strength improvements in leg press strength, where LL-BFR group showed greater strength improvements in knee-extension strength," (Ladlow et al., 2018) and the "LL-BFR group showed significant improvement in MSLT distance & Y-balance test than the conventional group" (Ladlow et al., 2018). Based on these results the researchers concluded that "both conventional RT and LL-BFR can safely be used to improve clinical outcomes; however LL-BFR training is a rehabilitation tool that has the potential to induce positive adaptations in the absence of high mechanical loads" (Ladlow et al., 2018). The team also suggested that "further studies using randomized designs examining the effects of LL-BFR training in patients with greater levels of impairment are needed" (Ladlow et al., 2018). The research team recommends that LL-BFR training is an excellent rehabilitative tool for patients who are "suffering from significant functional deficits," and "from whom conventional training is contraindicated" (Ladlow et al., 2018).

Ohata et al., (2002) conducted a RCT to determine the effects of introducing low-load muscular training with moderate restriction of blood flow during the first 16 weeks after reconstruction of the ACL. The study had a total of 44 subjects of which the control group (N), trained without BFR had 22 subjects, and the experimental group (R), BFR trained had 22 subjects. The subjects were assessed by the research team in three different categories which included: muscular torque of the knee extensor and flexor muscles (measured with an Isokinetic Myodynamometer Biodex System 3), CSA of femoral group muscles (measured with MRI imaging), and single muscle fiber diameter (assessed by fiber type with Myosin and ATPase staining and analyzed using a Kontron Imaging System KS-400).

The results of this study found there to be "no significant difference in anterior knee instability between the N and R groups, 16 weeks postoperatively," (Ohata et al., 2002) "similar cross-sectional area of the knee flexor and adductor muscles 16 weeks after surgery between the N and R groups," (Ohata et al., 2002) "after 16 weeks postoperatively the R group showed significant increases in knee extensor and hip flexor torques compared to the N group," (Ohata et al., 2002) and "significant increases were found in cross-sectional area of the knee extensor muscles when comparing the ratios from peri-operation/16 weeks postoperational from the R group compared to the N group" (Ohata et al., 2002). In the second quote the research team is stating they found the differences from before surgery, to a point 16 weeks after surgery was completed. Based on these findings the researchers concluded that "training during moderate restriction of blood flow is effective in rehabilitation after ACL reconstruction" (Ohata et al., 2002). Also they suggest the "findings show the possibilities of this mode of training not only in rehabilitation after ACL reconstruction, but also in training of atrophied muscles in general" (Ohata et al., 2002). Lastly they state that "various problems remained unsolved, such as discomfort or pain during training due to the tourniquet, and the possible effects on the circulation including thrombosis and edema."

Korakakis et al., (2018) conducted a RCT to evaluate if the application of LLRT-BFR would cause a noticeable reduction in anterior knee pain compared to LLRT alone. The study included 40 males that were divided into the control group of LLRT n=20, whose ages ranged from 29.7∓7.6 years; and the experimental group of LLRT-BFR n=20, whose ages ranged from

29.1∓6.6. The participants were evaluated by the research team based only on their pain which was taken by an 11-point Numeric Rating Scale for pain.

The results of the study found that "there were no significant differences observed between the LLRT-BFR group and the LLRT group for any variables assessed at baseline," (Korakakis et al., 2018) there was a "significant immediate pain reduction were found in the LLRT-BFR group in the SLS_S, SLS_D and SDT, but no significant differences were found in the LLRT group," (Korakakis et al., 2018) and lastly "large to very large effects were found in the LLRT-BFR group in both immediately post intervention and post physiotherapy session, compared to LLRT group, but no statistical significance was found" (Korakakis et al., 2018). From these results the researchers concluded that "the pain reduction induced by LLRT-BFR could indicate this intervention as a pre-conditioning process prior to the rehabilitation of anterior knee pain" (Korakakis et al., 2018).

Marissa, F. R. (2018) conducted a RCT to compare the effectiveness of BFR training against traditional training, to increase strength and muscle mass in patients with a history of ACL surgery. The study vetted 20 individuals and 10 were excluded due to not meeting the inclusion criteria. The participant cohort consisted of 10 individuals, n=5 who were in the control group with no BFR training, and n=5 who were in the experimental group with BFR training. The participants were assessed in three different categories which included: muscular strength with a dynamometer, muscular hypertrophy at 10 cm and 20 cm above the patella with a measuring tape, and lastly 1-RM to measure maximal strength.

The results of this study found that both groups had improvements; the BFR group had greater improvement in dynamometer and 1RM evaluation, and the control group had greater improvement in mass volume measurement (Marissa, 2018). The BFR combined with low-load resistance training is an effective method to treat the common consequences of ACL post-surgical procedures without the harms related to high intensity load training (Marissa, 2018). BFR is also an effective way to decrease pain and instability sensation that often appear with high load resistance training after ACL surgery procedures (Marissa, 2018). From this the researcher recommended that “further research is needed to determine if a higher volume of the population with a controlled lab evaluation and different compressions adapted to their initial stage will produce the same positive effects,” (Marissa, 2018) and “patients should also be evaluated for long-term effects comparing both training methods” (Marissa, 2018).

Lipker et al. (2019) conducted a systematic review aimed at understanding if BFR is more effective than standard care for reducing quadriceps atrophy after ACLr. In this systematic review the authors evaluated three RCTs which fit their inclusion criteria. The researchers concluded that “future research should consider muscle volume rather than CSA as the former may be more accurate for evaluating muscle size,” along with “Future research should consider measuring muscular torque or force output before and after therapy” (Lipker et al., 2019). They also concluded that “data is needed on short- & long-term effects of BFR in patient populations" (Lipker et al., 2019). The team makes the clear observation of which “very little research has been produced in this field of study” (Lipker et al., 2019). Lastly, they made the suggestion that “there are many variables to conducting BFR research and continuity of clinical practices and procedures need to be established” to ensure safe and effective uses of BFR (Lipker et al., 2019). The study found that the longer the rehabilitation time frame was set, about 15 weeks, there were greater improvements in results compared to short term use of only a few weeks (Lipker et al., 2019).

Level II, Quality High (A) Evidence: The evidence at this level consists of a QESs, systematic reviews, along with a systematic review & meta-analysis. The systematic reviews in this level of evidence include studies that are not just RCTs, as they include QESs and experimental studies as well. This level of evidence contains four articles and are summarized in the following pages.

Lu et al. (2020) conducted a systematic review to determine the effects of blood flow restriction rehabilitation before and after surgery of patients undergoing ACLr. Their review consisted of results from six studies which collected data based on 154 total patients across those six studies. The statistical analysis of the study was based on the comparison of blood flow restriction rehabilitation results in patients undergoing ACLr, pooling, and statistically analyzing them using a custom spreadsheet and assuming independence of the samples.

The results of this systematic review showed that “two studies examined low-load BFR as a preoperative intervention, one of which observed a significant increase in muscle isometric endurance, surface electromyography of the vastus medialis, and muscle blood flow to the vastus lateralis at final follow- up as compared with patients undergoing sham BFR” (Lu et al., 2020). The analysis also brought forth that “four studies investigated low-load BFR as a postoperative intervention, and they observed significant benefits in muscle hypertrophy, as measured by cross-sectional area; strength, as measured by extensor torque; and subjective outcomes, as measured by subjective knee pain during session, over traditional low- load resistance training” (Lu et al., 2020). From these observations the researchers concluded that “this systematic review found evidence on the topic of BFR rehabilitation after ACLr to be sparse and heterogeneous likely because of the relatively recent onset of its popularity” (Lu et al., 2020). The team also suggested that “while a few authors have demonstrated the potential strength and hypertrophy benefits of perioperative BFR, future investigations with standardized outcomes, long-term follow-up, and more robust sample sizes are required to draw more definitive conclusions" (Lu et al., 2020).

Scott et al. (2015) conducted a systematic review to study recent evidence in regard to the efficacy of various BFR strategies for well-trained athletes, and to determine how those strategies could be implemented with well-trained athlete populations. This review included 11 different investigative searches of athletes participation assessing for acute and adaptive response to BFR. From those searches 12 articles were found and analyzed. The inclusion criteria for this article was based on the following: the "study specifically states that the population investigated was comprised of athletes," (Scott et al., 2015) "BFR was implemented during resistance or aerobic exercise to examine acute or adaptive responses," the "full text of the study was available in English," and the "study was published in a peer-reviewed scientific journal" (Scott et al., 2015).

The results of this study found that "significant muscular development is possible in well trained athletes following low-load resistance training with BFR" (Scott et al., 2015). The research team also found that "low-load resistance training with BFR (LL-BFR-RT) does not provide the neural stimulus that heavy-load resistance training provides" (Scott et al., 2015). Lastly they found that "adaptive responses are found with BFR training that translate to improved performance in sport-specific fitness tests" (Scott et al., 2015). From these results the researchers concluded that it would be "a useful strategy to combine these two training methods is to use LL-BFR-RT exercise as supplemental exercise following a HL-RT session" (Scott et al., 2015). By this the authors meant that the main focus of an athlete's strength training should be HL-RT, but on lighter exercise days it is beneficial to use LL-BFR-FT.

Takarada et al. (2000) conducted a QES "to investigate the effects of vascular occlusion on the size of thigh muscles in patients who underwent an operation for the reconstruction of the ACL to see whether it attenuates the disuse muscular atrophy without any exercise combined." This study included 16 participants, eight of which were in the control group, four males and four females, and eight of which were in the experimental group, four males and four females. The research team assessed the participants with a measurement of muscle CSA by MRI 0.5T, and then the images were gray-scaled so the measurements could be made.

From this study the researchers found the results that the "CSA of knee extensors decreased by 20.7 ± 2.2% for the control group and 9.4 ± 4.6% for the experimental group, which is statistically significant" (Takarada et al., 2000). They also found that the "CSA of the knee extensors also decreases significantly less in the experimental group when split between males and females and then compared to the control group" (Takarada et al., 2000). From these results the researchers concluded that "the present occlusive stimuli can effectively diminish the disuse atrophy of thigh muscles, although the effect may be specific to muscle types. Therefore, it would be potentially highly useful in the post-operation rehabilitation and also for improving muscular function in bed-ridden old people" (Takarada et al., 2000).

Hughes et al. (2017) completed a systematic review and meta-analysis of the current literature to systematically analyze the evidence regarding the effectiveness of this novel training modality in clinical musculoskeletal (MSK) rehabilitation. The initial investigation yielded 1,502 articles, and of those 1,502 articles, 171 were evaluated for eligibility. Of those 171 articles evaluated 30 articles were deemed eligible, and 20 were used for the systematic review and 13 were used for the meta-analysis, with a few articles participating in both parts.

From this systematic review and meta-analysis the research team found multiple main conclusions, results and recommendations. The first of which was "augmentation of low-load rehab training with BFR can produce greater responses in muscular strength compared to low-load training alone" (Hughes et al., 2017). The second of which was "strength gains appear to be smaller in magnitude to those achieved with heavy-load training" (Hughes et al., 2017). The third was "LL-BFR training may be used as a progressive clinical rehab tool in the process of returning to heavy-load exercise" (Hughes et al., 2017). The fourth of which was "many studies are not adjusting & individualizing the occlusive stimulus training load," and that this "emphasizes the need for an individual approach to BFR training when selecting cuff pressure for both safety and effectiveness" (Hughes et al., 2017). Next the group recognizes that "in premature situations when individuals suffering from muscle weakness are not able to begin even low-load exercise (postoperative immobilization), BFR alone can be used as an early rehab intervention" (Hughes et al., 2017). Lastly the team suggests that "less pain in affected areas with LL-BFR compared to heavy-load resistance training, likely attributed to lower exercise load, while still producing similar muscular gains as heavy-load resistance training" (Hughes et at., 2017).

Level II, Quality Good (B) Evidence: The evidence at this level consists of a QES, and systematic reviews. There are three articles in this level of evidence and are summarized in the following pages.

Takarada et al. (2002) conducted a QES comparing the effects of resistance exercise combined with vascular occlusion on muscle function in highly trained athletes. This study is included due to the theory that if BFR can show improvements in the musculature of athletes who have been completing HL-RT for their entire carriers, BFR will be able to yield results in patient populations who have very little resistance training at all. This study included 17 participants, five of which were in the control, untrained, group, six were in the low-intensity with vascular occlusion training (LIO), and six were in the low-intensity training without vascular occlusion training (LI). The participants were evaluated on four criteria which included: MRI to evaluate muscle size, Isokinetic Dynamometer to evaluate muscular strength, muscle mechanical work production, and lastly electromyography from bipolar surface electrodes to assess total muscle activation speed.

From these evaluations of the participants the research team found "the results indicated that low-intensity resistance exercise causes, in almost fully trained athletes, increases in muscle size, strength and endurance, when combined with vascular occlusion" (Takarada et al., 2002). Also "low intensity resistance exercise combined with vascular occlusion causes increases in muscles size, strength and endurance," (Takarada et al., 2002) and that neural, hormonal and metabolic factors would have been involved in these combined effects" (Takarada et al., 2002).

Vopat et al. (2020) conducted a systematic review in which 32 articles were chosen to be reviewed. The studies were RCTs or QESs that pertained to BFR. The following conclusions were made after analyzing the studies. "Rehabilitation patients may use BFR in a progressive manner increasing from BFRT alone to low-load BFRT in combination with traditional training routines in an effort to optimize and shorten the recovery process" (Vopat et al., 2020). The second was that "BFR-RT has not been shown to recruit the degree of muscle units as high-load training methods. However, it has shown promise as an adjunct to traditional training routines" (Vopat et al., 2020). Finally, they suggested that "High-load training routines can have potential negative effects on athletes through increased stress on connective tissues and muscular fatigue. The use of BFRT to supplement athletic performance training has the potential to counter negative effects of high-load routines" (Vopat et al., 2020). This demonstrates that a decrease in stress causes a decrease in micro-trauma to the tissues inside the post-surgical knee, allowing it to heal in a more efficient process.

Wernbom et al. (2008) conducted a systematic review of 152 articles review and assess the current knowledge regarding the physiology of ischemic strength training and to discuss some of the training and health aspects of this type of exercise. The research team gave two main conclusions that pertained to BFR. The first was that "It may be difficult to induce relative ischemia in muscles at low loads by exercise alone, due to factors such as insufficient intramuscular pressure developed during exercise" (Wernbom et al., 2008). The second was "low-load ischemic training should be used as an addition to heavy-load resistance exercise, due to the need for nervous stimulus to recruit more motor neurons in the muscles to be worked. The combination of LL-RT with ischemia and HL-RT will reduce stresses on the connective tissues as well" (Wernbom et al., 2008).

Level III, Quality Good (B) Evidence: This level of evidence includes one systematic review that is summarized in the paragraph below.

Scott et al. (2014) conducted a systematic review of 91 RCTs and QES articles. The goal of this study is to provide an evidence-based approach to implementing BFR exercise. From the research teams analyses of the 91 articles they provided these conclusions and recommendations. "The addition of BFR to low-load resistance exercise enhances hypertrophic and strength responses" (Scott et al., 2014). "BFR alone can stop muscle atrophy during periods of disuse" (Scott et al., 2014). The last was "well trained athletes can benefit from low-load BFR training, either as an independent training method, or more substantially in combination with traditional high-load resistance training" (Scott et al., 2014).

Critique of Strengths and Weaknesses

Throughout the appraisal of all studies, there were many strengths and weaknesses identified. One of the main strengths of the 18 articles assessed was that all but one of them fell into the category of high or good evidence. Another strength of the 18 articles was that all but one of them fell in the level 1 or 2 evidence. All of the RCTs or QESs that were evaluated stated what equipment was used to assess their subjects, most of which was the same from study to study. A strength of the systematic reviews was that most of them identified their inclusion and exclusion criteria, as well as included the sources from which they obtained their articles.

Despite several areas of strengths among the studies, there were some weaknesses as well. It seemed that in most of the RCTs and QESs the occlusive pressure of the BFR cuff was not changed throughout the process of the experiment. This occurs because the research teams are trying to eliminate the amount of variables that change, which can then cause changes in results or the inability to directly correlate where a specific outcome derived from. Also, most of the time the research teams in the RCTs and QESs did not state the cuff sizes of which they used during their studies. One of the main weaknesses and variables between the studies was the timing on when the pain measurements were taken leading to inconsistencies with PROMs.

Summary

Eighteen articles were critically reviewed and assessed for their ability to help evaluate whether or not BFR is effective in the treatment and rehabilitation of postoperative anterior cruciate ligament reconstruction (ACLr) patients within the ages of 18-40 years old. The articles were then assessed for their level of evidence which was placed into a level 1, 2, or 3. Within each of those levels of evidence they were given a grade of A, B, C, or D. The articles were assessed and placed into these categories based on the Johns Hopkins Nursing Evidence-Based

Practice Manual: Research Evidence Appraisal Tool. Takarada et al. (2000) found that BFR would be influential in the immediate stages of post-operative time to slow the progression of muscle atrophy. Lastly, there were four articles (Vopat et al., 2020; Hughes et al., 2017; Marissa, 2018; Ladlow et al., 2018) stated BFR can be used as an initial exercise intervention when resistance training begins to occur, as the LL-BFR-RT can produce less stress forces on the knee, while still producing a similar physiological effect as HL-RT.

Chapter IV: Discussion, Implications, Conclusion

The purpose of this paper is to evaluate whether or not BFR is effective in the treatment and rehabilitation of postoperative anterior cruciate ligament reconstruction (ACLr) patients between the ages of 18-40 years old. To determine the level of effectiveness, the outcome measures to be assessed will be total strength gains, functional outcome measures, and patient reported outcome measures. Upon completion of the critical review of 18 articles in chapter three, chapter four will discuss the need for the practical application of BFR in the clinical rehabilitation setting. Along with the discussion of application to the clinical rehabilitation setting, this chapter will discuss common trends and gaps in the current literature, applications to the athletic training setting, and recommendations for further research.

Literature Synthesis

The main purpose behind this Critical Review of the Literature is to examine and answer the question: Can BFR be effective in the treatment and rehabilitation of postoperative ACLr patients between the ages of 18-40 years old? In this review, 18 articles were analyzed and categorized according to how BFR affected the following outcomes: strength gains, functional outcomes, and patient reported outcome measures (PROMs). Of the 18 articles, 12 of them reported on the effects of strength gains from BFR use. Not all of the articles discussed BFR use in direct conjunction with ACLr rehabilitation; rather, these studies were included because of their rehabilitation goals of returning muscle strength and proper function to normal levels. All of the studies mentioned used a dynamometer to test isokinetic strength. Of the studies that reported on strength gains, four articles (Bowman et al., 2019; Tennet et al., 2017; Ohta et al., 2002; Marissa, 2018) found that BFR training was more effective in obtaining greater strength gains. Three articles found that these strength gains were with post-surgery rehabilitation patients and the article by Bowman et al. (2019) found their results with healthy, non-rehabilitating patients. This implies that if BFR is able to elicit even minor gains in healthy patients, BFR will be able to produce results of an even greater magnitude on individuals who are in a weakened state such as those who are post-surgery. For the two articles that did not find a difference between the use of BFR training and traditional training methods, the research teams found strength gains in one type of training tested including knee extension, leg press, leg extension, leg flexion and knee flexion. Their results did not have statistical significance in showing that BFR rehabilitation was any better or worse than traditional protocols in their capabilities to gain strength.

Three more systematic reviews showed that there were strength gains from the research of which they reviewed. Two of them were based on BFR for rehabilitation purposes and the other focused on BFR in the training of professional athletes in their normal training regimens Lu et al. (2020) and Hughes et al. (2017) recognized that BFR has its purpose as an early rehabilitation exercise modality that is more effective than LL-RT alone, and also found that once the patients had progressed far enough through the rehabilitation process, the effects of HL-RT are much greater than that of BFR-LL-RT alone. The research by Scott et al. (2015) was used to exemplify that most patients who are between the ages 18-40 years old who undergo ACLr surgery are also athletes; therefore, BFR can still be beneficial to those individuals who are not at a deficit for strength training.

All four of the remaining level 2, good quality and level 3, good quality articles (Takarada et al., 2002; Vopat et al., 2020; Wernbom et al., 2008; Scott et al., 2014) investigated

BFR and strength gains. Takarada et al. (2002) is the only experimental study which found that LL-RT, in combination with BFR, can cause strength and endurance gains in highly trained athletes just as Scott et al. (2015) had shown in their systematic review. The other three studies found that as BFR is most beneficial during the beginning stages of rehabilitation, and then to progress to a combination of BFR and LL-RT. The research teams found that at a certain point in the rehabilitation process, the patient will need to begin heavier loaded workouts with BFR in order for strength improvements to develop into the patient's ability of being capable of effectively performing daily activities and sport-specific functional capabilities.

Of the 18 articles, three reported on functional movement screening, and all of them found a significant increase in functional movement screening tool outcomes with BFR-RT compared to traditional rehabilitation training (Hughes et al., 2019; Tennet et al., 2017; Ladlow et al., 2018). The researchers speculated that the patient's ability to place weight bearing loads on the injured limb allowed for neural stimulus to begin to reintegrate after surgical disruption.

Lastly, of the 18 articles, seven examined patients' feedback with PROMs. The outcomes measured used by Hughes et al. (2019) and Tennet et al. (2017) focused on patient activities related to daily living (ADLs), with the KOOS used in both of the studies. The KOOS also assessed pain levels in the questionnaire. Another common PROMs tool, the RPE, was used by Hughes et al. (2018) and Yasuda et al. (2011) to determine the rate at which muscles were worked to exhaustion while using and not using BFR during exercise. The last and most utilized PROMs tool was a pain scale that focused on knee pain. In the research conducted by the seven research teams, different pain scales were used, and one study used a pain scale that was incorporated into other PROMs such as the KOOS. Pain rating was assessed before the exercise as well as after the exercise concluded, but one of the main variables between the studies was the timing on which the pain measurement was taken. All of the studies found improvements in PROMs scores as the patients progressed through their rehabilitation process.

The last article (Lu et al., 2020) is a level 2, high quality article that systematically reviewed current research on knee pain; the researchers found four articles of which the results showed significant improvement in subjective outcomes, another version of PROMs.

Current Trends, Gaps in Literature and Future Recommendations

As this research and review of the literature was conducted multiple trends and gaps of the current literature were found. First, most of the current studies have been completed from 2017-2020. A gap in the research was noted from the early 2000's until 2017. Most of the early 2000's research was based out of Asian countries, most likely due to the origins of BFR being found in that region. Research had increased in the mid-2010s as BFR was expanding to western culture across Europe and into the America's. The research from 2017 to current has focused mainly on the rehabilitation of knee surgery patients (Hughes et al., 2019; Hughes et al., 2018; Tennet et al., 2017; Ladlow et al., 2018; Marissa, 2018; Lipker et al., 2019; Lu et al., 2020; Hughes et al., 2017; Vopat et al., 2020). This trend is important because the main goal of BFR is to produce the same physiological results in the musculature as HL-RT while reducing the stresses placed on the surgically repaired structures of the knee. This then leads to less pain and swelling in the knee as a result of less stress placed on the already damaged structures during the healing and remodeling processes. The other major trend that is found in the articles is how BFR can increase functional movement outcomes (Hughes et al., 2019; Tennet et al., 2017; and Ladlow et al., 2018). This trend is positive because it allows healthcare providers to evaluate how well BFR training is suited to give a patient the ability to return to their ADLs without physical limitations.

The systematic review, the experimental research studies, as well as the main consensus amongst the researchers was that the study populations were too small and studies with greater numbers of participants needed to be conducted to be able to better understand how BFR rehabilitation will represent the population as a whole. The majority of the research on BFR rehabilitation is based on elderly individuals or those who are undergoing post-surgical knee rehabilitation and most studies have very small numbers of participants, which can be referenced in the matrix in Appendix A. Another major gap in the literature is that there are not many studies focused solely on BFR rehabilitation interventions with surgical ACLr patients. Of the research completed in this review of the literature only five studies directly focused on the use of BFR rehabilitation in patients who had ACLr surgery (Hughes et al., 2019; Hughes et al., 2018; Ohta et al., 2002; Marissa, 2018). For this reason, the articles utilized for this review was expanded to include patients that had undergone other types of knee surgeries. These surgeries also require rehabilitation with the goals of returning muscle strength and lower extremity function to normal. One of the main recommendations by the authors of the systematic review studies was that research parameters must be more aligned, as the literature that has been published to date shows large variants in all of the variables that can be controlled by the research teams (Lipker et al., 2019; Lu et al., 2020).

Applications to Athletic Training

One of the fastest growing specialties of athletic trainers is that of a rehabilitation specialist. As we have seen the number of overuse injuries in athletes in the past decade increase, mainly due to specialization in sport, athletes are placing greater stresses on their joints

(McGuine, 2017). One of the largest growing injury locations for young athletes is the knee, and more specifically the ACL (McGuine, 2017). With this in mind athletes are in need of pre-habilitation, before surgery occurs, and rehabilitation, after the surgery occurs. This is most important because in a sports specific setting such as a high school, collegiate, or even professional, the athletic trainer is the focal healthcare personnel for those individuals' post-injury, pre-surgery, and post-surgery. BFR is a new intervention tool that can be used with the athletic trainer's repertoire of interventions that allows their patients to have improved strength outcomes, less knee pain, and better functional outcomes. This new intervention into the rehabilitation sphere of Western medicine could be difficult for individuals to see as something that works effectively because most patients believe that in order to gain strength, one must lift something heavy and strain the muscles. The athletic trainer will have to provide patient education and explain the latest research to individuals who are skeptical about the effectiveness of BFR. Many of the current studies such as, Hughes et al. (2019), Hughes et al. (2018), Tennet et al. (2017), Ladlow et al. (2018), and Marissa (2018), have all shown there are definite strength increases amongst the study participants with the use of BFR.

Conclusion

The findings of this critical review of the literature are that BFR can be an effective rehabilitation intervention in patients 18-40 years of age who are undergoing ACLr. This conclusion was based on 18 scholarly articles being analyzed and evaluated by the Johns Hopkins Nursing Evidence-Based Practice Manual: Research Evidence Appraisal Tool and placed into an Evidence Based-Practice Literature Matrix (Fineout-Overholt et al., 2010). The promising research that is coming along with BFR research in the perioperative field shows that this intervention can alleviate pain for the knee, yield strength gains in the early stages of patient rehabilitation similar if not greater to that of traditional rehabilitation methods, as well as producing better functional outcomes for patients than the traditional rehabilitation protocols. Overall, the research that has been conducted over the past decade or so has proven that BFR training in rehabilitation is very effective and can significantly improve patient outcomes without the undue stressors placed on the healing and regenerating structures from surgery.

References

Bethel University. (2021). *Athletic Training Program Capstone Handbook*. Bethel University Graduate Athletic Training Program. https://docs.google.com/document/d/1DOzdgzzXC9xh9U_MmJlg_BUN5MgZBOMLdhYo4FdoyOQ/edit?ts=602bf7cb.

Bowman, E. N., Elshaar, R., Milligan, H., Jue, G., Mohr, K., Brown, P., … Limpisvasti, O. (2019). Proximal, Distal, and Contralateral Effects of Blood Flow Restriction Training on the Lower Extremities: A Randomized Controlled Trial. *Sports Health: A Multidisciplinary Approach*, *11*(2), 149–156. https://doi.org/10.1177/1941738118821929

Fineout-Overholt, E., Melnyk, B. M., Stillwell, S. B., & Williamson, K. M. (2010). Evidence-Based Practice Step by Step: Critical Appraisal of the Evidence: Part I. *AJN, American Journal of Nursing*, *110*(7), 47–52. https://doi.org/10.1097/01.naj.0000383935.22721.9

Hughes, L., Paton, B., Haddad, F., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2018). Comparison of the acute perceptual and blood pressure response to heavy load and light load blood flow restriction resistance exercise in anterior cruciate ligament reconstruction patients and non-injured populations. *Physical Therapy in Sport*, *33*, 54–61. https://doi.org/10.1016/j.ptsp.2018.07.002

Hughes, L., Paton, B., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2017). Blood flow restriction training in clinical musculoskeletal rehabilitation: a systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(13), 1003–1011. https://doi.org/10.1136/bjsports-2016-097071

Hughes, L., Rosenblatt, B., Haddad, F., Gissane, C., McCarthy, D., Clarke, T., … Patterson, S. D. (2019). Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomised Controlled Trial. *Sports Medicine*, *49*(11), 1787–1805. https://doi.org/10.1007/s40279-019-01137-2

Johns Hopkins University. (2017). *Johns Hopkins Nursing Evidence-Based Practice: Appendix E - Research Evidence Appraisal Tool*. Evidence Based Nurse. http://evidencebasednurse.weebly.com/uploads/4/2/0/8/42081989/appendix_e_final_-_research_evidence_appraisal_tool.pdf.

Korakakis, V., Whiteley, R., & Giakas, G. (2018). Low load resistance training with blood flow restriction decreases anterior knee pain more than resistance training alone. A pilot randomised controlled trial. *Physical Therapy in Sport*, *34*, 121–128. https://doi.org/10.1016/j.ptsp.2018.09.007

Ladlow, P., Coppack, R. J., Dharm-Datta, S., Conway, D., Sellon, E., Patterson, S. D., & Bennett, A. N. (2018). Low-Load Resistance Training With Blood Flow Restriction Improves Clinical Outcomes in Musculoskeletal Rehabilitation: A Single-Blind Randomized Controlled Trial. *Frontiers in Physiology*, *9*, 1–14. https://doi.org/10.3389/fphys.2018.01269

Lipker, L. A., Persinger, C. R., Michalko, B. S., & Durall, C. J. (2019). Blood Flow Restriction Therapy Versus Standard Care for Reducing Quadriceps Atrophy After Anterior Cruciate Ligament Reconstruction. *Journal of Sport Rehabilitation*, *28*(8), 897–901. https://doi.org/10.1123/jsr.2018-0062

Lu, Y., Patel, B. H., Kym, C., Nwachukwu, B. U., Beletksy, A., Forsythe, B., & Chahla, J. (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

Marissa, F. R. (2018). Effectivity of blood flow restriction training for gains in strength and trophism in patients with ACL injuries. *MOJ Orthopedics & Rheumatology*, *10*(6), 371–375. https://doi.org/10.15406/mojor.2018.10.00452

Mcguine, T. A., Post, E. G., Hetzel, S. J., Brooks, M. A., Trigsted, S., & Bell, D. R. (2017). A Prospective Study on the Effect of Sport Specialization on Lower Extremity Injury Rates in High School Athletes. *The American Journal of Sports Medicine*, *45*(12), 2706–2712. https://doi.org/10.1177/0363546517710213

Ohta, H., Kurosawa, H., Ikeda, H., Iwase, Y., Satou, N., & Nakamura, S. (2002). Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. *Acta Orthopaedica Scandinavica*, *74*(1), 62–68. https://doi.org/10.1080/00016470310013680

Patterson, S. D., Hughes, L., Warmington, S., Burr, J., Scott, B. R., Owens, J., … Loenneke, J. (2019). Blood Flow Restriction Exercise: Considerations of Methodology, Application, and Safety. *Frontiers in Physiology*, *10*, 1–14. https://doi.org/10.3389/fphys.2019.00533

Sato, Y. (2005). The history and future of KAATSU Training. *International Journal of KAATSU Training Research*, *1*(1), 1–5. https://doi.org/10.3806/ijktr.1.1

Scott, B. R., Loenneke, J. P., Slattery, K. M., & Dascombe, B. J. (2014). Exercise with Blood Flow Restriction: An Updated Evidence-Based Approach for Enhanced Muscular Development. *Sports Medicine*, *45*(3), 313–325. https://doi.org/10.1007/s40279-014-0288-1

Scott, B. R., Loenneke, J. P., Slattery, K. M., & Dascombe, B. J. (2015). Blood flow restricted exercise for athletes: A review of available evidence. *Journal of Science and Medicine in Sport*, *19*(5), 360–367. https://doi.org/10.1016/j.jsams.2015.04.014

Takarada, Y., Sato, Y., & Ishii, N. (2002). Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *European Journal of Applied Physiology*, *86*(4), 308–314. https://doi.org/10.1007/s00421-001-0561-5

Takarada, Y., Takazawa, H., & Ishii, N. (2000). Applications of vascular occlusion diminish disuse atrophy of knee extensor muscles. *Medicine and Science in Sports and Exercise*, *32*(12), 2035–2039. https://doi.org/10.1097/00005768-200012000-00011

Tennent, D. J., Hylden, C. M., Johnson, A. E., Burns, T. C., Wilken, J. M., & Owens, J. G. (2017). Blood Flow Restriction Training After Knee Arthroscopy. *Clinical Journal of Sport Medicine*, *27*(3), 245–252. https://doi.org/10.1097/jsm.0000000000000377

Vopat, B. G., Vopat, L. M., Bechtold, M. M., & Hodge, K. A. (2020). Blood Flow Restriction Therapy: Where We Are and Where We Are Going. *Journal of the American Academy of Orthopaedic Surgeons*, *28*(12), e493–e500. https://doi.org/10.5435/jaaos-d-19-00347

Wernbom, M., Augustsson, J., & Raastad, T. (2008). Ischemic strength training: a low-load alternative to heavy resistance exercise? *Scandinavian Journal of Medicine & Science in Sports*, *18*(4), 401–416. https://doi.org/10.1111/j.1600-0838.2008.00788.x

Yasuda, T., Ogasawara, R., Sakamaki, M., Ozaki, H., Sato, Y., & Abe, T. (2011). Combined effects of low-intensity blood flow restriction training and high-intensity resistance training on muscle strength and size. *European Journal of Applied Physiology*, *111*(10), 2525–2533. https://doi.org/10.1007/s00421-011-1873-8

Appendix A: Literature Review Matrix

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Hughes, L., Rosenblatt, B., Haddad, F., Gissane, C., Mccarthy, D., Clarke, T., … Patterson, S. D. (2019). Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomised Controlled Trial. *Sports Medicine*, *49*(11), 1787–1805. https://doi.org/10.1007/s40279-019-01137-2	To discern the effectiveness of blood flow restriction versus traditional heavy load resistance training in the post-surgery rehabilitation of ACLr patients.	28 total participants 14 HL-RT 14 BFR-RT	Parallel-group, two-arm, single-assessor blinded, randomized clinical trial	Scaled 10RM Muscle strength tested on a leg press MED. Scaled Isokinetic Strength measured on a Biodex System 4 Isokinetic Dynamometer. B-mode ultrasonography using the LOGIQ E ultrasound device used to measure muscle thickness, pennation angle, and fascicule length. IKDC, LEFS, LKSS and all KOOS used to measure patient perception of physical function. Modified SEBT used to assess anterior, posteromedial and posterolateral reach scores on injured limb. Goniometer used to assess knee ROM. Mid-patella joint circumference to nearest 0.1 cm with cloth tape measure. KT-1000 knee ligament arthrometer used to assess knee ligament laxity.	"Scaled 10RM strength significantly increased in the injured limb and non-injured limb (with BFR-RT and HL-RT, respectively, with no group differences." "Significant increases in knee extension and flexion peak torque were observed at all speeds in the non-injured limb with no group differences." "Significantly greater attenuation of knee extensor peak torque loss at 150°/s and 300°/s and knee flexor torque loss at all speeds was observed with BFR-RT. No group differences in knee extensor peak torque loss were found at 60°/s." "Significant and comparable increases in muscle thickness (5.8 ± 0.2% and 6.7 ± 0.3%) and pennation angle (4.1 ± 0.3% and 3.4 ± 0.1%) were observed with BFR-RT and HL-RT, respectively, with no group differences. No significant changes in fascicle length were observed." "Significantly greater and clinically important increases in several measures of self-reported function, Y-balance performance, ROM and reductions in knee joint pain and effusion were observed with BFR-RT compared to HL-RT, respectively."	"BFR-RT can improve skeletal muscle hypertrophy and strength to a similar extent to HL-RT with a greater reduction in knee joint pain and effusion, leading to greater overall improvements in physical function." "Therefore, BFR-RT may be more appropriate for early rehabilitation in ACLR patient populations."	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Bowman, E. N., Elshaar, R., Milligan, H., Jue, G., Mohr, K., Brown, P., … Limpisvasti, O. (2019). Proximal, Distal, and Contralateral Effects of Blood Flow Restriction Training on the Lower Extremities: A Randomized Controlled Trial. Sports Health: A Multidisciplinary Approach, 11(2), 149–156. https://doi.org/10.1177/1941738118821929	To find out the proximal, distal, and contralateral effects of blood flow restriction training on the lower extremities.	26 patients 16 BFR patients 10 control patients	Randomized Control Trial	Isokinetic Strength Testing for knee extension and flexion Dynamometer Strength Testing for hip abduction, hip extension, ankle plantarflexion Limb circumference measured 10 proximal to superior pole of patella and 10 cm distal to inferior pole of patella.	"A statistically greater increase in strength was seen proximal and distal to the BFR tourniquet when compared with both the non-tourniquet extremity and the control group." "Isokinetic testing showed greater increases in knee extension peak torque (3% vs 11%), total work (6% vs 15%), and average power (4% vs 12%) for the BFR group." "Limb circumference significantly increased in both the thigh (0.8% vs 3.5%) and the leg (0.4% vs 2.8%) compared with the control group." "Additionally, a significant increase occurred in thigh girth (0.8% vs 2.3%) and knee extension strength (3% vs 8%) in the non-tourniquet BFR extremity compared with the control group."	"Low-load BFR training led to a greater increase in muscle strength and limb circumference." "BFR training had similar strengthening effects on both proximal and distal muscle groups." "Gains in the contralateral extremity may corroborate a systemic or crossover effect."	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Hughes, L., Paton, B., Haddad, F., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2018). Comparison of the acute perceptual and blood pressure response to heavy load and light load blood flow restriction resistance exercise in anterior cruciate ligament reconstruction patients and non-injured populations. Physical Therapy in Sport, 33, 54–61. https://doi.org/10.1016/j.ptsp.2018.07.002	To compare the acute perceptual and blood pressure response to heavy load versus light load blood flow restriction resistance exercise in ACLr patients and non-injured populations.	30 total participants 10 NI-BRF 10 ACLR-BFR 10 ACLR-HL	Between-subjects, partially-randomized	Mobil-O-Graph ambulatory blood pressure monitor for pre and post exercise blood pressure. RPE tested using Borg's scale Pain scale from 1-10	"RPE was higher in the ACLR-BFR group compared to the non-injured BFR group, but similar to the ACLR-HL group." "Muscle pain was higher in both BFR groups compared to the ACLR-HL group." "Session knee pain and 24 hr post-exercise knee pain was lower in the ACLR-BFR group compared to the ACLR-HL group." "There were no differences in pre- and post-exercise 10 blood pressure between the groups."	"Hemodynamic and perceptual responses of light load BFR-RE in an ACLr patient should not be a limiting factor for clinician concern in a rehabilitation setting."	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Tennent, D. J., Hylden, C. M., Johnson, A. E., Burns, T. C., Wilken, J. M., & Owens, J. G. (2017). Blood Flow Restriction Training After Knee Arthroscopy. *Clinical Journal of Sport Medicine*, *27*(3), 245–252. https://doi.org/10.1097/jsm.0000000000000377	To evaluate the adding of BFR exercise to traditional methods of physical therapy to improve strength, hypertrophy, functional outcomes, and patient self-reported outcomes after postoperative non-reconstructive knee arthroscopy.	Assessed for eligibility: n=56 Excluded n=32 due to screening fail, declined participation, or unable to attend therapy. BFR group: Randomized: n=11 -Patients withdrawing prior to initiating therapy n=1 -Completed & Analyzed n=10 Control Group: Randomized: n=11 -Patients withdrawing prior to initiating therapy n=4 -Completed & Analyzed n=7	Randomized Controlled Pilot Study	BFR -Delphi Medical PTS ii portable tourniquet system -Delphi Medical Easy-Fit Tourniquet Cuff Standard Tape Measure to measure thigh girth @ 6-cm & 16-cm proximal to the superior patellar pole Physical Performance Outcome Measures *Self-selected walking score (SSWV) *Sit-to-stand 5 times (STS5) *4 square step test (FSST) *Timed stair ascent (TSA) Patient-Reported Outcome Measures *Knee Osteoarthritis Outcome Score (KOOS) *Veterans RAND 12-Item Health Survey (VR-12) Strength Testing *Biodex System 3 Dynamometer	Significant improvements in thigh girth @ both 6-cm & 16-cm in BFR group, not seen in control group. Significant improvements in the control group in only the KOOS subscales of pain, symptoms and sport subscales. Significant improvements in all KOOS subscales for the BFR group. VR-12 (PCS) showed significant improvements in both BFR & control groups. VR-12 (MCS) only showed significant improvements in the BFR group. BFR group showed significant improvements in all physical functional outcome measures, when the control group only showed significant improvements in the SSWV, RSST & STS5, plus the BFR group showed generally greater improvements. Quadricep extension strength in the BFR group was 2x more improved compared with the control group.	"A pilot study for future studies evaluating BFR intervention in more complex postoperative patients." Using a subocclusive tourniquet in the control group to help alleviate bias in the future. With this small study providing promising results, it is needed for "further investigation in more powerful, larger clinical trials investigating preoperative and postoperative surgical patients with a high level of initial disability.	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Yasuda, T., Ogasawara, R., Sakamaki, M., Ozaki, H., Sato, Y., & Abe, T. (2011). Combined effects of low-intensity blood flow restriction training and high-intensity resistance training on muscle strength and size. *European Journal of Applied Physiology*, *111*(10), 2525–2533. https://doi.org/10.1007/s00421-011-1873-8	To investigate the combined effects of HI-RT and BFR training on muscle size and strength.	Males only: Ages: 22-32 n=40 Non-training Control n=10 HI-RT: n=10 LI-BFR: n=10 CB-RT: n=10	Randomized Controlled Trial	BFR with Kaatsu-Master cuffs by Sato Sports Plaza Isometric strength with Isokinetic Dynamometer from Biodex System 3 Electromyography with Bipolar electrodes from Nihon Kohden, Differential amplifier from Nihon Kohden, signals rectified and integrated with PowerLab Chart 4 software from ADInstruments, done on a Macintosh Power PC 750. MRI images using 0.2-T scanner from GE Signa, Image analysis software by Tomo-Vision Inc. Ratings of perceived exertion using Borg Scale	1-RM were similar in HI-RT and CB-RT groups and lower in LI-BFR group. Cross-sectional area increased in all training groups, but much greater in HI-RT and CB-RT groups.	Muscle improvements are greater with combination of LI-BFR and HI-RT, than with just LI-BFR alone.	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Ladlow, P., Coppack, R. J., Dharm-Datta, S., Conway, D., Sellon, E., Patterson, S. D., & Bennett, A. N. (2018). Low-Load Resistance Training With Blood Flow Restriction Improves Clinical Outcomes in Musculoskeletal Rehabilitation: A Single-Blind Randomized Controlled Trial. *Frontiers in Physiology*, *9*, 1–14. https://doi.org/10.3389/fphys.2018.01269	To evaluate the efficacy and feasibility of LL-BFR training versus conventional high mechanical load resistance training on the clinical outcomes of patients undergoing inpatient MDT rehabilitation.	Active British Military Males Ages: 19-49 n=28 Conventional RT: n=14 LL-BFR: n=14 Session Adherence Rates: Conventional RT = >90% LL-BFR =100%	Single-Blind Randomized Controlled Trial	BFR with Delphi Medical Innovations PTSii portable tourniquet system Muscle CSA and Volume assessed with MRI 1.5T scanner from GE Signa 5-RM Muscle strength using machines from Pulse Fitness Isometric Hip Extension strength tested with Wireless Digital microFET2 hand-help dynamometer from Hoggan Scientific LLC Endurance measured with multistage locomotion test (MSLT) Balance measured with Y-Balance Test kit based off study from (Plisky et al., 2009) Pain measured with 100 mm horizontal visual analog scale (VAS) to measure pain and physical discomfort every five treatment sessions of the 3 week period.	At 3-weeks both groups significantly increased quadricep & thigh CSA & volume in their injured limb. LL-BFR at 3-weeks showed greater quadriceps CS & volume over the conventional group. Thigh results were within a 1% difference between the groups. Conventional group showed greater strength improvements in leg press strength, where LL-BFR group showed greater strength improvements in knee-extension strength. LL-BFR group showed significant improvement in MSLT distance & Y-balance test than the conventional group.	"Both conventional RE and LL-BFR can safely be used to improve clinical outcomes; however LL-BFR training is a rehabilitation tool that has the potential to induce positive adaptations in the absence of high mechanical loads." "Further studies using randomized designs examining the effects of LL-BFR training in patients with greater levels of impairment are needed."	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Ohta, H., Kurosawa, H., Ikeda, H., Iwase, Y., Satou, N., & Nakamura, S. (2002). Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. *Acta Orthopaedica Scandinavica*, *74*(1), 62–68. https://doi.org/10.1080/000164703100013680	To determine the effects of introducing low-load muscular training with moderate restriction of blood flow during the first 16 weeks after reconstruction of the anterior cruciate ligament.	Total Subjects: n=44 Group R: BFR trained n=22 Group N: Trained without BFR n=22	Randomized Controlled Trial	Muscular Torque of knee extensor and flexor muscles measured with Isokinetic Myodynamometer Biodex System 3 Cross-sectional area of femoral muscle group measured with Visart MRI from Toshiba Corp. and analyzed with NIH Image 1.61 software Single muscle fiber diameter assessed by fiber type with Myosin ATPase staining with Wako Pure Chemical Industries Ltd. Substrate and analyze with Kontron Imaging System KS-400.	No significant difference in anterior knee instability between the N and R groups, 16 weeks postoperatively. Similar cross-sectional area of the knee flexor and adductor muscles 16 weeks after surgery between the N and R groups. After 16 weeks postoperatively the R group showed significant increases in knee extensor and hip flexor torques compared to the N group. Significant increases were found in the cross-sectional area of the knee extensor muscles when comparing the ratios from perioperation/16 weeks post-operational from the R group compared to the N group.	"Training during moderate restriction of blood flow is effective in rehabilitation after ACL reconstruction." The "findings show the possibilities of this mode of training not only in rehabilitation after ACL reconstruction, but also in training of atrophied muscles in general." "Various problems remained unsolved, such as discomfort or pain during training due to the tourniquet, and the possible effects on the circulation including thrombosis and edema."	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Korakakis, V., Whiteley, R., & Giakas, G. (2018). Low load resistance training with blood flow restriction decreases anterior knee pain more than resistance training alone. A pilot randomised controlled trial. *Physical Therapy in Sport*, *34*, 121–128. https://doi.org/10.1016/j.ptsp.2018.09.007	To evaluate if the application of LLRT-BFR would cause a noticeable reduction in anterior knee pain compared to LLRT alone.	n=40 males LLRT-BFR: n=20 (age: 29.1 ± 6.6) LLRT: n=20 (age: 29.7 ± 7.6)	Randomized Controlled Trial	11-point Numeric Rating Scale for pain	There were no significant differences observed between the LLRT-BFR group and the LLRT group for any variables assessed at baseline. Significant immediate pain reduction was found in the LLRT-BFR group in the SLS_S, SLS_D and SDT, but no significant differences were found in the LLRT group. Large to very large effects were found in the LLRT-BFR group in both immediate post intervention and post physiotherapy session, compared to LLRT group, but no statistical significance was found.	The pain reduction induced by LLRT-BFR could indicate this intervention as a pre-conditioning process prior to the rehabilitation of anterior knee pain.	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Marissa, F. R. (2018). Effectivity of blood flow restriction training for gains in strength and trophism in patients with ACL injuries. MOJ Orthopedics & Rheumatology, 10(6), 371–375. https://doi.org/10.15406/mojor.2018.10.00452	To compare the effectiveness of BFR training against traditional training, to increase strength and muscle mass in patients with a history of ACL surgery.	20 individuals originally, 10 excluded due to not meeting inclusion criteria n=10 BFR training n=5 Control no BFR training n=5	Randomized Controlled Trial	Dynamometer to measure muscle strength Measuring tape to measure hypertrophy of the thigh @ 10 cm & 20 cm above the patella 1 RM to measure maximal strength repetition	*Both groups had improvements, --BFR group had greater improvement in dynamometer and 1RM evaluation --Control group had greater improvement in mass volume measurement *BFR combined with low-load resistance training is an effective method to treat the common consequences of ACL post-surgical procedures without the harms related to high intensity load training. *Also an effective way to decrease pain and instability sensation that often appear with high load resistance training after ACL surgery procedures.	*Further research is needed to determine if a higher volume of the population with a controlled lab evaluation and different compressions adapted to their initial stage will produce the same positive effects. *Patients should also be evaluated for long-term effects comparing both training methods.	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion/Recommendations	Level & Quality
Lipker, L. A., Persinger, C. R., Michalko, B. S., & Durall, C. J. (2019). Blood Flow Restriction Therapy Versus Standard Care for Reducing Quadriceps Atrophy After Anterior Cruciate Ligament Reconstruction. Journal of Sport Rehabilitation, 28(8), 897–901. https://doi.org/10.1123/jsr.2018-0062	Is BFR more effective than standard care for reducing quadriceps atrophy after ACLr?	3 RCTs	Systematic Review	Sorting for articles that pertain to the purpose.	Results/Conclusion/Recommendations *Future research should consider muscle volume rather than CSA as the former may be more accurate for evaluating muscle size. *Future research should consider measuring muscular torque or force output before and after therapy. *Data is needed on short- & long-term effects of BFR in patient populations. *Very little research has been produced in this field of study. *There are many variables to conducting BFR research and continuity of clinical practices and procedures need to be established.	Level I, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Lu, Y., Patel, B. H., Kym, C., Nwachukwu, B. U., Beletksy, A., Forsythe, B., & Chahla, J. (2020). Perioperative Blood Flow Restriction Rehabilitation in Patients Undergoing ACL Reconstruction: A Systematic Review. Orthopaedic Journal of Sports Medicine, 8(3). https://doi.org/10.1177/2325967120906822	To determine the effects of blow flow restriction rehabilitation before and after surgery of patients undergoing ACL reconstruction.	Data from 6 studies which collected data based on 154 patients.	Systematic Review	Comparison of blood flow restriction rehabilitation results in patients undergoing ACLr pooling the study results and statistically analyzing them using a custom spreadsheet and assuming independence of samples.	"2 studies examined low-load BFR as a preoperative intervention, 1 of which observed a significant increase in muscle isometric endurance, surface electromyography of the vastus medialis, and muscle blood flow to the vastus lateralis at final follow- up as compared with patients undergoing sham BFR." "Four studies investigated low-load BFR as a postoperative intervention, and they observed significant benefits in muscle hypertrophy, as measured by cross-sectional area; strength, as measured by extensor torque; and subjective outcomes, as measured by subjective knee pain during session, over traditional low- load resistance training."	"This systematic review found evidence on the topic of BFR rehabilitation after ACLr to be sparse and heterogeneous likely because of the relatively recent onset of its popularity." "While a few authors have demonstrated the potential strength and hypertrophy benefits of perioperative BFR, future investigations with standardized outcomes, long-term follow-up, and more robust sample sizes are required to draw more definitive conclusions."	Level II, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Scott, B. R., Loenneke, J. P., Slattery, K. M., & Dascombe, B. J. (2015). Blood flow restricted exercise for athletes: A review of available evidence. *Journal of Science and Medicine in Sport*, *19*(5), 360–367. https://doi.org/10.1016/j.jsams.2015.04.014	Study was used to gather recent evidence in regard to the efficacy of various BFR strategies for well-trained athletes, and to determine how those strategies could be implemented with well-trained athlete populations.	12 papers from 11 different investigative searches of athlete participation assessing for acute and adaptive responses to BFR.	Systematic Review	(Inclusion Criteria) *Study specifically states that the population investigated was comprised of athletes *BFR was implemented during resistance or aerobic exercise to examine acute or adaptive responses *Full test of the study was available in English *Study was published in a peer-reviewed scientific journal	Significant muscular development is possible in well trained athletes following low-load resistance training with BFR. Low-load resistance training with BFR does not provide the neural stimulus that heavy-load resistance training provides. Adaptive responses are found with BFR training that translate to improved performance in sport-specific fitness tests.	"A useful strategy to combine these two training methods is to use LL-BFR-RT exercise as supplemental exercise following a HL-RT session."	Level II, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Takarada, Y., Takazawa, H., & Ishii, N. (2000). Applications of vascular occlusion diminish disuse atrophy of knee extensor muscles. *Medicine and Science in Sports and Exercise*, *32*(12), 2035–2039. https://doi.org/10.1097/00005768-200012000-00011	"To investigate the effects of vascular occlusion on the size of thigh muscles in patients who underwent an operation for the reconstruction of the ACL to see whether it attenuates the disuse muscular atrophy without any exercise combined."	n=16 Control Group: n=8 *Males: n=4 *Females: n=4 Experimental Group: n=8 *Males: n=4 *Females: n=4	Quasi-experimental	Measurement of Muscle Cross-Sectional Area by MRI *0.5T superconducting system, Gyroscan T5 II, Philips Medical Systems International Images were gray-scaled and then measurements were made by using NIH image (ver. 1.25)	CSA of knee extensors decreased by 20.7 ± 2.2% for the control group and 9.4 ± 4.6% for the experimental group, which is statistically significant. CSA of the knee extensors also decreases significantly less in the experimental group when split between males and females and then compared to the control group.	The present occlusive stimuli can effectively diminish the disuse atrophy of thigh muscles, although effect may be specific to muscle types. Therefore, it would be potentially highly useful in the post-operation rehabilitation and also for improving muscular function in bed-ridden old people.	Level II, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion/Recommendations	Level & Quality
Hughes, L., Paton, B., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2017). Blood flow restriction training in clinical musculoskeletal rehabilitation: a systematic review and meta-analysis. British Journal of Sports Medicine, 51(13), 1003–1011. https://doi.org/10.1136/bjsports-2016-097071	To systematically analyze the evidence regarding the effectiveness of this novel training modality in clinical MSK rehabilitation.	Originally 1502 articles found. 171 evaluated for eligibility 30 articles deemed eligible 20 for the systematic review 13 for meta-analysis -15 were randomized trials -3 Controlled Trials -2 Quasi-experimental studies	Systematic Review & Meta-Analysis	Sorting for articles that pertain to the purpose statement.	*Augmentation of low-load rehab training with BFR can produce greater responses in muscular strength compared to low-load training alone. *Strength gains appear to be smaller in magnitude to those achieved with heavy-load training. *LL-BFR training may be used as a progressive clinical rehab tool in the process of return to heavy-load exercise. *Many studies are not adjusting & individualizing the occlusive stimulus training load --Emphasizes the need for an individual approach to BFR training when selecting cuff pressure for both safety and effectiveness. *IN premature situations when individuals suffering from muscle weakness are not able to begin even low-load exercise (postoperative immobilization), BFR alone can be used as an early rehab intervention. *Less pain in affected areas with LL-BFR compared to heavy-load resistance training, likely attributed to lower exercise load, while still producing similar muscular gains as heavy-load resistance training.	Level II, Quality High (A)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion	Recommendations	Level & Quality
Takarada, Y., Sato, Y., & Ishii, N. (2002). Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. European Journal of Applied Physiology, 86(4), 308–314. https://doi.org/10.1007/s00421-001-0561-5	To compare the effects of resistance exercises combined with vascular occlusion on muscle function in highly trained athletes.	17 total participants Control untrained: n=5 Experimental Groups: LIO: n=6 LI: n=6	Quasi-Experimental	MRI using Gyroscan T5 II by Philips Medical Systems International Isokinetic Dynamometer by Myoret, Kawasaki Industry, Co. Ltd. Mechanical Work Production calculated by computer using Macintosh 8100/100AV Electromyograph from bipolar surface electrodes fed through a full-wave rectifier through both low (time constant, 0.03s) and high (1kHz) cut filters and stored in a Macintosh 8100/100AV.	"The results indicated that low-intensity resistance exercise causes, in almost fully trained athletes, increases in muscle size, strength and endurance, when combined with vascular occlusion."	"Low intensity resistance exercise combined with vascular occlusion causes increases in muscles size, strength and endurance." "Neural, hormonal and metabolic factors would have been involved in these combined effects."	Level II, Quality Good (B)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion/Recommendations	Level & Quality
Vopat, B. G., Vopat, L. M., Bechtold, M. M., & Hodge, K. A. (2020). Blood Flow Restriction Therapy: Where We Are and Where We Are Going. *Journal of the American Academy of Orthopaedic Surgeons*, *28*(12), e493–e500. https://doi.org/10.5435/jaaos-d-19-00347	To review and give an overview on the current stances on BFR and how it pertains to the medical world.	32 Articles Referenced	Systematic Review	Sorting for articles that were RCTs or Quasi-experimental that pertained to BFR	*Rehabilitation patients may use BFR in a progressive manner increasing from BFRT alone to low-load BFRT in combination with traditional training routines in an effort to optimize and shorten the recovery process. *BFRT has not been shown to recruit the degree of muscle units as high-load training methods. However, it has shown promise as an adjunct to traditional training routines. *High-load training routines can have potential negative effects on athletes through increased stress on connective tissues and muscular fatigue. The use of BFRT to supplement athletic performance training has the potential to counter negative effects of high-load routines.	Level II, Quality Good (B)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion/Recommendations	Level & Quality
Wernbom, M., Augustsson, J., & Raastad, T. (2008). Ischemic strength training: a low-load alternative to heavy resistance exercise? *Scandinavian Journal of Medicine & Science in Sports*, *18*(4), 401–416. https://doi.org/10.1111/j.1600-0838.2008.00788.x	To summarize current opinion and knowledge regarding the physiology of ischemic strength training and to discuss some of the training and health aspects of this type of exercise.	152 Articles Referenced	Systematic Review	Sorting for articles that pertain to the purpose.	*It may be difficult to induce relative ischemia in muscles at low loads by exercise alone, due to factors such as insufficient intramuscular pressure developed during exercise. *Low-load ischemic training should be used as an addition to heavy-load resistance exercise, due to the need for nervous stimulus to recruit more motor neurons in the muscles to be worked. The combination of LLRT with ischemia and HLRT will reduce stresses on the connective tissues as well.	Level II, Quality Good (B)

Citation	Purpose	Sample	Design	Measurement	Results/Conclusion/Recommendations	Level & Quality
Scott, B. R., Loenneke, J. P., Slattery, K. M., & Dascombe, B. J. (2014). Exercise with Blood Flow Restriction: An Updated Evidence-Based Approach for Enhanced Muscular Development. *Sports Medicine*, *45*(3), 313–325. https://doi.org/10.1007/s40279-014-0288-1	To provide an evidence-based approach to implementing BFR exercise.	91 articles referenced	Systematic Review	Sorting for articles that were RCTs or Quasi-experimental	*The addition of BFR to low-load resistance exercise enhances hypertrophic and strength responses. *BFR alone can stop muscle atrophy during periods of disuse. *Well trained athletes can benefit from low-load BFR training, either as an independent training method, or more substantially in combination with traditional high-load resistance training.	Level III, Quality Good (B)

Appendix B: Quality Assessments and Level of Evidence Chart

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Appendix E
Research Evidence Appraisal Tool

Evidence level and quality rating:	
Article title:	Number:
Author(s):	Publication date:
Journal:	
Setting:	Sample (composition and size):

Does this evidence address my EBP question?

☐ Yes
☐ No-*Do not proceed with appraisal of this evidence*

Is this study:

☐ **QuaNtitative** (collection, analysis, and reporting of numerical data)
Measurable data (how many; how much; or how often) used to formulate facts, uncover patterns in research, and generalize results from a larger sample population; provides observed effects of a program, problem, or condition, measured precisely, rather than through researcher interpretation of data. Common methods are surveys, face-to-face structured interviews, observations, and reviews of records or documents. Statistical tests are used in data analysis.

➡ Go to ***Section I: QuaNtitative***

☐ **QuaLitative** (collection, analysis, and reporting of narrative data)
Rich narrative documents are used for uncovering themes; describes a problem or condition from the point of view of those experiencing it. Common methods are focus groups, individual interviews (unstructured or semi structured), and participation/observations. Sample sizes are small and are determined when data saturation is achieved. Data saturation is reached when the researcher identifies that no new themes emerge and redundancy is occurring. Synthesis is used in data analysis. Often a starting point for studies when little research exists; may use results to design empirical studies. The researcher describes, analyzes, and interprets reports, descriptions, and observations from participants.

➡ Go to ***Section II: QuaLitative***

☐ **Mixed methods (**results reported both numerically and narratively)
Both quaNtitative and quaLitative methods are used in the study design. Using both approaches, in combination, provides a better understanding of research problems than using either approach alone. Sample sizes vary based on methods used. Data collection involves collecting and analyzing both quaNtitative and quaLitative data in a single study or series of studies. Interpretation is continual and can influence stages in the research process.

➡ Go to ***Section III: Mixed Methods***

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Section I: QuaNtitative		
Level of Evidence (Study Design)		
A Is this a report of a single research study?	☐ Yes	☐No **Go to B**
1. Was there manipulation of an independent variable?	☐ Yes	☐ No
2. Was there a control group?	☐ Yes	☐ No
3. Were study participants randomly assigned to the intervention and control groups?	☐ Yes	☐ No
If **Yes to questions 1, 2, and 3,** this is a randomized controlled trial (RCT) or experimental study.		**LEVEL I**
If **Yes to questions 1 and 2 and No to question 3** or **Yes to question 1 and No to questions 2 and 3,** this is quasi-experimental. *(Some degree of investigator control, some manipulation of an independent variable, lacks random assignment to groups, and may have a control group).*		**LEVEL II**
If **No to questions 1, 2, and 3,** this is nonexperimental. *(No manipulation of independent variable; can be descriptive, comparative, or correlational; often uses secondary data).*		**LEVEL III**
Study Findings That Help Answer the EBP Question		
Skip to the **Appraisal of QuaNtitative Research Studies** section		

Appendix E
Research Evidence Appraisal Tool

Section I: QuaNtitative (continued)		
B Is this a summary of multiple sources of research evidence?	☐ Yes *Continue*	☐ No **Use Appendix F**
1. Does it employ a comprehensive search strategy and rigorous appraisal method? *If this study includes research, nonresearch, and experiential evidence, it is an integrative review (see Appendix F).*	☐ Yes *Continue*	☐ No **Use Appendix F**
2. For systematic reviews and systematic reviews with meta-analysis (see descriptions below):		
a. Are all studies included RCTs?		**LEVEL I**
b. Are the studies a combination of RCTs and quasi-experimental, or quasi-experimental only?		**LEVEL II**
c. Are the studies a combination of RCTs, quasi-experimental, and nonexperimental, or non- experimental only?		**LEVEL III**
A **systematic review** employs a search strategy and a rigorous appraisal method, but does not generate an effect size. A **meta-analysis**, or systematic review with meta-analysis, combines and analyzes results from studies to generate a new statistic: the effect size.		
Study Findings That Help Answer the EBP Question		
Skip to the **Appraisal of Systematic Review** (With or Without a Meta-Analysis) section		

Appendix E
Research Evidence Appraisal Tool

Appraisal of QuaNtitative Research Studies			
Does the researcher identify what is known and not known about the problem and how the study will address any gaps in knowledge?	☐ Yes	☐ No	
Was the purpose of the study clearly presented?	☐ Yes	☐ No	
Was the literature review current (most sources within the past five years or a seminal study)?	☐ Yes	☐ No	
Was sample size sufficient based on study design and rationale?	☐ Yes	☐ No	
If there is a control group: • Were the characteristics and/or demographics similar in both the control and intervention groups?	☐ Yes	☐ No	N/A
• If multiple settings were used, were the settings similar?	☐ Yes	☐ No	N/A
• Were all groups equally treated except for the intervention group(s)?	☐ Yes	☐ No	N/A
Are data collection methods described clearly?	☐ Yes	☐ No	
Were the instruments reliable (Cronbach's α[alpha] $\geq$ 0.70)?	☐ Yes	☐ No	N/A
Was instrument validity discussed?	☐ Yes	☐ No	N/A
If surveys or questionnaires were used, was the response rate $\geq$ 25%?	☐ Yes	☐ No	N/A
Were the results presented clearly?	☐ Yes	☐ No	
If tables were presented, was the narrative consistent with the table content?	☐ Yes	☐ No	N/A
Were study limitations identified and addressed?	☐ Yes	☐ No	
Were conclusions based on results?	☐ Yes	☐ No	
Complete the **Quality Rating for QuaNtitative Studies** section			

Appendix E
Research Evidence Appraisal Tool

Appraisal of Systematic Review (With or Without Meta-Analysis)		
Were the variables of interest clearly identified?	☐ Yes	☐ No
Was the search comprehensive and reproducible? • Key search terms stated	☐ Yes	☐ No
• Multiple databases searched and identified	☐ Yes	☐ No
• Inclusion and exclusion criteria stated	☐ Yes	☐ No
Was there a flow diagram that included the number of studies eliminated at each level of review?	☐ Yes	☐ No
Were details of included studies presented (design, sample, methods, results, outcomes, strengths, and limitations)?	☐ Yes	☐ No
Were methods for appraising the strength of evidence (level and quality) described?	☐ Yes	☐ No
Were conclusions based on results?	☐ Yes	☐ No
• Results were interpreted	☐ Yes	☐ No
• Conclusions flowed logically from the interpretation and systematic review question	☐ Yes	☐ No
Did the systematic review include a section addressing limitations **and** how they were addressed?	☐ Yes	☐ No
Complete the **Quality Rating for QuaNtitative Studies** section (below)		

Quality Rating for QuaNtitative Studies

Circle the appropriate quality rating below:

A High quality: Consistent, generalizable results; sufficient sample size for the study design; adequate control; definitive conclusions; consistent recommendations based on comprehensive literature review that includes thorough reference to scientific evidence.

B Good quality: Reasonably consistent results; sufficient sample size for the study design; some control, and fairly definitive conclusions; reasonably consistent recommendations based on fairly comprehensive literature review that includes some reference to scientific evidence.

C Low quality or major flaws: Little evidence with inconsistent results; insufficient sample size for the study design; conclusions cannot be drawn.

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Research Evidence Appraisal Tool

Section II: QuaLitative		
Level of Evidence (Study Design)		
A Is this a report of a single research study?	☐ Yes **this is Level III**	☐ No **go to II B**
Study Findings That Help Answer the EBP Question		
Complete the **Appraisal of Single QuaLitative Research Study** section (below)		

Appraisal of a Single QuaLitative Research Study		
Was there a clearly identifiable and articulated: • Purpose?	❑Yes	❑No
• Research question?	❑Yes	❑No
• Justification for method(s) used?	❑Yes	❑No
• Phenomenon that is the focus of the research?	❑Yes	❑No
Were study sample participants representative?	❑Yes	❑No
Did they have knowledge of or experience with the research area?	❑Yes	❑No
Were participant characteristics described?	❑Yes	❑No
Was sampling adequate, as evidenced by achieving saturation of data?	❑Yes	❑No
Data analysis: • Was a verification process used in every step by checking and confirming with participants the trustworthiness of analysis and interpretation?	❑Yes	❑No
• Was there a description of how data were analyzed (i.e., method), by computer or manually?	❑Yes	❑No
Do findings support the narrative data (quotes)?	❑Yes	❑No
Do findings flow from research question to data collected to analysis undertaken?	❑Yes	❑No
Are conclusions clearly explained?	❑Yes	❑No
Skip to the **Quality Rating for QuaLitative Studies** section		

Appendix E
Research Evidence Appraisal Tool

B For summaries of multiple quaLitative research studies (meta-synthesis), was a comprehensive search strategy and rigorous appraisal method used?	☐Yes **Level III**	☐No go to **Appendix F**
Study Findings That Help Answer the EBP Question		
Complete the **Appraisal of Meta-Synthesis Studies** section (below)		

Appraisal of Meta-Synthesis Studies		
Were the search strategy and criteria for selecting primary studies clearly defined?	☐Yes	☐No
Were findings appropriate and convincing?	☐Yes	☐No
Was a description of methods used to: • Compare findings from each study?	☐Yes	☐No
• Interpret data?	☐Yes	☐No
Did synthesis reflect:	☐Yes	☐No
• New insights?	☐Yes	☐No
• Discovery of essential features of phenomena?	☐Yes	☐No
• A fuller understanding of the phenomena?	☐Yes	☐No
Was sufficient data presented to support the interpretations?	☐Yes	☐No
Complete the **Quality Rating for QuaLititative Studies** section (below)		

Appendix E
Research Evidence Appraisal Tool

Section III: Mixed Methods

Level of Evidence (Study Design)

You will need to appraise both the quaNtitative and quaLitative parts of the study independently, before appraising the study in its entirety.

1. Evaluate the quaNitative part of the study using **Section I**.	**Level**	**Quality**
Insert here the level of evidence and overall quality for this part:		
2. Evaluate the quaLitative part of the study using **Section II**.	**Level**	**Quality**
Insert here the level of evidence and overall quality for this part:		

3. To determine the level of evidence, circle the appropriate study design:

- **Explanatory** sequential designs collect quaNtitative data first, followed by the quaLitative data; and their purpose is to explain quaNtitative results using quaLitative findings. The level is determined based on the level of the quaNtitative part.
- **Exploratory** sequential designs collect quaLitative data first, followed by the quaNtitative data; and their purpose is to explain quaLitative findings using the quaNtitative results. The level is determined based on the level of the quaLitative part, and it is always Level III.
- **Convergent** parallel designs collect the quaLitative and quaNtitative data concurrently for the purpose of providing a more complete understanding of a phenomenon by merging both datasets. These designs are Level III.
- **Multiphasic** designs collect quaLitative and quaNtitative data over more than one phase, with each phase informing the next phase. These designs are Level III.

Study Findings That Help Answer the EBP Question

Complete the **Appraisal of Mixed Methods Studies** section (below)

Appendix E
Research Evidence Appraisal Tool

Appraisal of Mixed Methods Studies[3]			
Was the mixed-methods research design relevant to address the quaNtitative and quaLitative research questions (or objectives)?	❑Yes	❑No	❑N/A
Was the research design relevant to address the quaNtitative and quaLitative aspects of the mixed-methods question (or objective)?	❑Yes	❑No	❑N/A
For convergent parallel designs, was the integration of quaNtitative and quaLitative data (or results) relevant to address the research question or objective?	❑Yes	❑No	❑N/A
For convergent parallel designs, were the limitations associated with the integration (for example, the divergence of quaLitative and quaNtitative data or results) sufficiently addressed?	❑Yes	❑No	❑N/A
Complete the **Quality Rating for Mixed-Method Studies** section (below)			

3 National Collaborating Centre for Methods and Tools. (2015). Appraising Qualitative, Quantitative, and Mixed Methods Studies included in Mixed Studies Reviews: The MMAT. Hamilton, ON: McMaster University. (Updated 20 July, 2015) Retrieved from http://www.nccmt.ca/ resources/search/232

Quality Rating for Mixed-Methods Studies

Circle the appropriate quality rating below

A **High quality:** Contains high-quality quaNtitative and quaLitative study components; highly relevant study design; relevant integration of data or results; and careful consideration of the limitations of the chosen approach.

B **Good quality:** Contains good-quality quaNtitative and quaLitative study components; relevant study design; moderately relevant integration of data or results; and some discussion of limitations of integration.

C **Low quality or major flaws:** Contains low quality quaNtitative and quaLitative study components; study design not relevant to research questions or objectives; poorly integrated data or results; and no consideration of limits of integration.