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Research Article

Blood Flow Restriction Effects on Amateur Soccer Player: More than Just Strength and Mass Gains?

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Abstract

Objective: To investigate effects of blood flow restriction (BFR) in pain modulation beyond other well-established effects on muscle gains after anterior cruciate ligament (ACL) surgery in a soccer player.

Design: Case study examining BFR training in a clinical rehabilitation setting.

Methods: BFR was utilized in a strength training protocol of the lower limbs after ACL surgery. Pain values on a visual analogue scale (VAS) were collected before and after the strength protocol's execution. The cross-sectional area of the thigh and isometric mean and peak force output during a squat were measured before the protocol execution.

Results: Minimal clinical important difference (MCID) of 20 mm on a 1 - 100 mm VAS was reported in both pre- and post-training values between the first data collection (T0) and the last one (T3). No improvements were reported in CSA values on the injured limb between T0-T3. Inconsistent values were reported in the isometric squat test: an increase of both mean and peak from T0 were reported in T1 and T2. Both values then decreased again in T3, below T0 values.

Conclusion: BFR may play an essential role in pain modulation after ACL surgery.

Keywords: ACL; Pain; Rehabilitation; Soccer

Introduction

Anterior cruciate ligament (ACL) injuries are common in sports, especially in those that apply severe stress to the knee joint, such as soccer, where a change of direction, jumping, landings and high speed running occur with and without contact [1]. The impact of these injuries on athletes is significant, considering it takes between 8 - 12 months before the potential to return to play (RTP) [2]. Furthermore, only 65% of the players who suffer an ACL rupture can return to their previous level of performance after 3 years from injury [3] and that different clinical consequences, such as arthritis, are often observed [4]. Specifically in football, or soccer, studies by the Union of European Football Association (UEFA) showed an increase number of ACL injuries on matchdays vs. practice which may be due to higher physical demand of competition [5]. The player's position can play a significant role in developing such an injury. The two positions at highest risk of suffering an ACL injury are the defender (43% incidence) and the midfielder (31% incidence) [6].

Non-contact injuries are the most common injuries found in football: pressing the opponent being the first scenario for the

number of cases reported, followed by regaining balance and landing after heading the ball, while contact injuries in football occur typically due to tackle situations, which create a valgus momentum of the knee, leading to ACL rupture [7].

Long-term symptoms at the knee joint are may be present after an ACL tear [8]. Pain is one of the most frequently reported symptoms after surgery [9]. During the rehabilitation process, pain is often still present and can significantly delay the achievements needed in the rehab's first phases. There is a lack of literature about pain management after surgery through exercise, however several interventions have been described including transcutaneous electrical nerve stimulation (TENS), cryotherapy and systemic pharmacologic therapies [10].

According to the American College of Sports Medicine, muscular strength and hypertrophy can be achieved through exercising 2 - 3 times a week with intensities higher than 65% of one's individual one-repetition maximum (1RM) [11]. It may be challenging to reach these training intensities when people are recovering from surgery due to pain and inability to tolerate loads, which can be a limiting factor in the strength and hypertrophy gains, especially during a long-term rehabilitation process. ACL tears in people who underwent surgery tend to demonstrate muscle weakness, especially in the quadriceps [12,13], reduced quality of life [14] and lower RTP rate [15]. To avoid such conditions and create better outcomes from rehabilitation, Blood Flow Restriction (BFR) training can be implemented in the early stages, right after surgery [16].

BFR training consists of using a tourniquet on a proximal limb during low-intensity exercise to reduce 80% of arterial blood flow while blocking the venous outflow completely. The block that the tourniquet creates on the limb stimulates the creation of an anaerobic system, similar to the one needed to perform training at high intensities over 65% 1RM, despite working with lower mechanical loads [17]. Therefore, BFR can lead to similar results as traditional high mechanical training through physiological effects.

Lactate production created during the use of BFR leads to the recruitment of larger motor units, the ones that form fast-twitch muscles, which will then be activated to avoid failure even if the subject is working with low resistances (20 - 30% 1RM) [18]. Lactate production will also stimulate the pituitary gland to release growth hormone (GH), which is linked to higher collagen production. Meanwhile, the lower resistances used during the exercise will not result in collagen breakdown, leading to a positive collagen turnover [19]. Insulin growth factor 1 (IGF 1) is a protein linked to muscle growth that activates satellite cells, the precursors of myocytes, and fuses them into the muscle fibers [20] which is activated by GH. BFR, GH, and lactate production also activate the mammalian target of rapamycin complex 1 (MTORC1), a complex responsible for modulating the muscle growth process [21].

Although the effects of BFR on muscular architecture in terms of trophism, has been well established, its effect on pain has barely been investigated. The British National Health Service (NHS) investigated outcomes of BFR application following ACL surgery. Subjects experienced a decrease in pain after a 9-week protocol [22], however, within each session, pre/post pain levels (before-after BFR protocol) were not assessed. The purpose of this case study is to evaluate the immediate impact of BFR in reducing one individual's pain during a strengthening protocol. A secondary purpose is to assess the impact of BFR on strength and mass gains for the same subject.

Materials and Methods

This study will analyze thigh cross-sectional area (CSA), visual analog scale (VAS) and strength output through an encoder, once a week, over four weeks. CSA values will be measured manually in centimeter before the warm-up to verify any previous evaluation changes. Pain values will be evaluated through the VAS scale before the warm-up and 5 minutes after the end of the BFR protocol. Through the use of the encoder, a mean and a peak force will be evaluated during an isometric squat strength test, and this test will also be performed after the warm-up. The subject who participated in the study provided signed informed consent in compliance with the declaration of Helsinki [23].

Blood flow restriction (BFR) unit

In this study, the DELFI© PTS BFR device was used. This device belongs to the third generation of tourniquets which represents the safest for clinical use [24] this is because these devices show a series of features, like self-calibration to establish correct pressure, ability to set limits for pressure, and inflation time and automatic measurement of limb occlusion pressure (LOP) which represents the lowest pressure to reach the target occlusion on a given patient. Cuffs are then placed at the proximal limb to be trained and linked through a tube to the device. DELFI© PTS device comes with

three different "Variable Countour" cuffs that can be adjusted to the shape of the limb to enhance comfort, reduce mechanical shearing, and require lower pressures to occlude the flow [25].

The therapist starts the LOP measurement by having the patient lying as motionless as possible in the supine position. This test calculates the personalized pressure to be used during training, which will be 80% of calculated pressure when training on lower limbs and 50% when training upper limbs. The subject selected for this study performed BFR standard protocol of 30-15-15-15 repetitions divided into four sets performing a squat with the help of TRX© with 30-second rest between every set, in addition to a strengthening protocol.

Encoder device

Measurements of strength output during an isometric squat with knees flexed at 90° were recorded with "Desmotec D.plus pininfarina isoinertial device" (Figure 1). This device has integrated load cells on the ground platform. The Isometric Test consisted of expressing the maximum force from a squat position where both knees and hips were bent at 90°. The patient had to wear a vest that was connected through an adjustable rope to the platform. The therapist adjusted the length of the rope in order to place the person to be tested in the proper starting position. During the test, the patient was asked to push as hard as he could for the full test duration of 15 seconds, as if he was trying to get back to a standing position. The load cell "D.load cells" registered the force applied on them in terms of KG/cm^2, showing a mean value and the max peak force for the 15 second test. "Desmotec D.plus pininfarina" is an isoinertial workstation, with a rotatory encoder installed to perform a different test to evaluate strength, power, and balance outputs in several tasks, like squatting and lunges. Test-retest reliability and validity of a flywheel squat test using the ergomemeter (D11 Full, Desmotec Biella) demonstrated excellent relative reliability with an intraclass correlation coefficient (ICC) score of > 0.9 and an acceptable coefficient of variation (CV) of < 5% between different days in strength outputs [26].

Visual analogue scale (VAS)

A visual analouge scale (VAS) to assess pain was used before warm-up and after completing the protocol to evaluated if the BFR intervention modifies pain. VAS is formed by a line with numbers written on it ranging from 0 - 100 millimeters, where 0 stands for "No pain sensation" and 100 represented by "Maximum pain you felt since you injured your knee." The VAS scale has been widely used between practitioners, and it has been clinically validated [27].

Figure 1: Desmotec D.Plus Pininfarina device.

To set test-retest reliability and evaluate the intervention's efficacy, an MCID (minimal clinically important improvement) was established. RCTs studies indicate MCID for VAS to be between 11.1 to 19.9 mm [28] without referring to a specific part of the body while 19.9 mm was the MCID indicated for the knee [29]. In this study MCID is defined as 16.9 mm, which is a mean of the 3 values previously mentioned, avaiable in the literature.

Cross-sectional area (CSA)

A cross-sectional area (CSA) is a cross-section of a muscle, perpendicular to its fibers, generally at the largest point. This study analyzed if, through the use of BFR, an increase in CSA could have been reached. There is a contrast to whether a relationship between muscle CSA and force production exists in literature [30]. CSA is usually measured using an MRI scan [31]. Unfortunately, the use of MRI technology is not possible for this case study due to cost and difficult access to repeated MRI scans, especially during the COVID-19 pandemic. The CSA measurements were taken manually

in centimeters (cm) at the distance of 6 cm and 12 cm from the patella's superior board, which took place before the training session. There are flawed findings on MCID relationship to CSA, so a distribution-based method [32] will be used to determine whether or not the intervention produced meaningful changes. Based on this method, a standardized change of 0.8 cm on the CSA will be considered as MCID.

Case Presentation

The subject was a 22 years old male non-professional soccer player. He tore his left knee ACL while performing a sudden change of direction to the right with the left foot planted on the ground during pre-season training (i.e., external rotation of the tibia and the femur's internal rotation creating a valgus momentum). The Injury affected only the ACL as the MRI scan did not find collateral ligament or meniscal tears. The subject did not have a history of previous knee injury and underwent surgery three weeks later. The ACL repair was performed through the use of a Semitendineous graft, and no adverse events were reported during the procedure. The protocol started four weeks after the surgery. During the three weeks prior to starting the protocol, the subject received physiotherapy to restore complete extension of the knee, allowing pain-free range of motion, and cryotherapy was initiated to prepare the athlete for the strengthening program.

The strengthening protocol (Table 1) was performed twice a week for four weeks with a day of rest between sessions. Data acquisition took place during the first session of the week for a total of four data collection periods (T0, T1, T2, T3). CSA measurements and VAS values were recorded before starting the stationary bike warm up and 5 minutes after the last excercise of the session; the 90° isometric squat test on the encoder was only collected after warm up.

Excercise	Sets/Repetitions
Stationary bike	8 Minutes
Leg press (30% 1Rm)	4 sets/8 repetitions
Leg curl isometric holds at 45° knee flexion	4 sets/8 repetitions
Sitting monolateral heel raise	4 sets /8 repetitions
BFR squat to 90° knee flexion TRX (suspension system)	

Table 1: Strengthening protocol performed during the study.

Results

CSA

Regarding cross sectional area, the patient presented linear values through the process, with no change in the measurements between the first evaluation (T0) and the last evaluation (T3), where a CSA value of 43.5 cm was reported in both times on the injured leg (left). On the non-involved right leg, where BFR was not applied, an increase of 1.5 cm was noted from the first evaluation (T0) and the last evaluation at the end of the study (T3), as notable in figure 2.

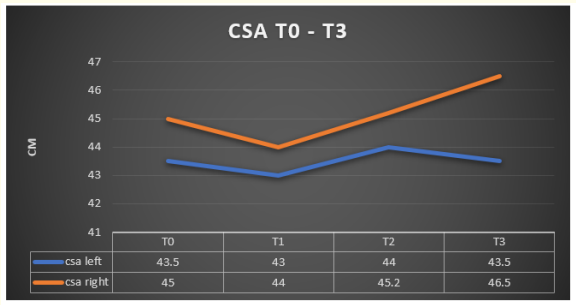

Figure 2: CSA left= Cross-Sectional Area left leg, CSA right= Cross-Sectional Area right leg, T0= first data acquisition, T1= second data acquisition, T2= third data acquisition, T3= fourth and last data acquisition.

Isometric squat strength test- Encoder

The test records the mean value of force expressed in Kilograms (Kg) during the whole test and the maximum force peak reached in the test. An increase of force production while the program was carried on was showed in mean strength outputs between (T0) 416.2 Kg and (T2) 446 Kg while a decrease in the values is shown in the last test performed (T3) 407.9 Kg. The peak force reached was inconsistent between the sessions, with the highest peak of force produced being recorded in the second session (T1), as notable in figure 3.

Balance asymmetries in strength outputs between the two legs are also reported from the encoder while performing the test. This variable measures in percentage (%) which of the two limbs is producing more force. As shown, in figure 4, the patient was able to improve the ratio of force production from the left (injured) leg to

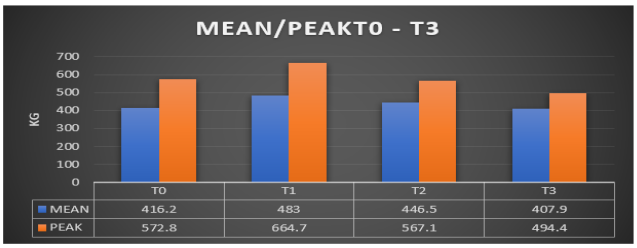

Figure 3: Compares mean force production, the peak reached, and the trend of these values during the study. Mean= mean of force values produced during the whole duration of the test, Peak= peak of maximum force output registered during the test, T0= first data acquisition, T1= second data acquisition, T2= third data acquisition, T3= fourth and last data acquisition.

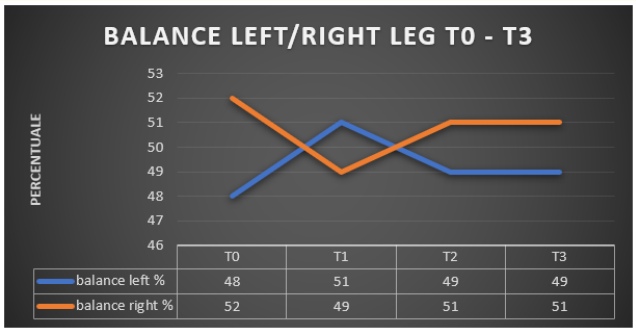

Figure 4: Balance between left and right leg in generating force during the 90° isometric squat strength test. Balance left %= percentage of force output generated by the left limb, balance right %= percentage of force output generated by the right leg. T0= first data acquisition, T1= second data acquisition, T2= third data acquisition, T3= fourth and last data acquisition.

49% (T3) from the starting value of 48% recorded at the first test (T0).

Visual analogue scale (VAS)

Patient reported pain VAS scores between the first evaluation (T0) and the last treatment (T3) resulted in a 20 mm decrease. As reported in figure 5 if we consider the values after using BFR, pain sensation is reduced up to 50% from the first training session (T0) and the last evaluation (T3). It is of relevance to underline that the pain senstaion recorded through the VAS scale has been constantly decreasing from the second evaluation (T1) to the last one (T3) has shown in figure 5.

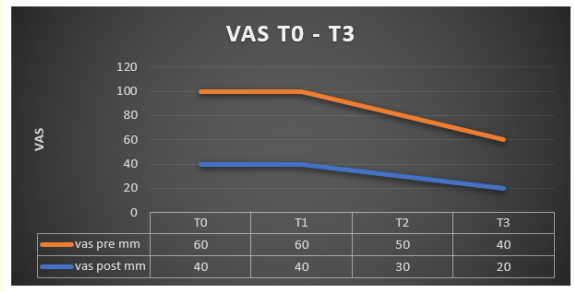

Figure 5: VAS trend during the study. VAS post= pain sensation score given by the patient after the intervention, VAS pre= pain sensation score given by the patient before the intervention, T0= first data acquisition, T1= second data acquisition, T2= third data acquisition, T3= fourth and last data acquisition.

Discussion

The CSA outcomes showed no difference from T0 to T3 on the injured limb (left); the MCID threshold (0.8 cm) was not met. Thus, unlike a previous study [33] there was no increase in muscle hypertrophy following BFR application.

The encoder 90° isometric squat strength test data was not consistent with expected outcomes. An increase of both mean power and peak output was recorded at T1 when compared to T0. However, T2 showed a decrease in both mean and peak values when compared to T1, but still an increase when compared to T0. Furthermore, T3 showed a decrease of both mean and peak values to the lowest levels measured during the intervention.

This could be biased from several factors (tiredness, sleep routine, work routine) on the day of the test. If a comparison with the literature is made, other studies shown an increase of strength output evaluated through 10RM strength on a leg press over a study period of 8 weeks [34]. In this case study, data evaluation occured

over a period which was 50% shorter (4 weeks vs 8 weeks). Furthemore, measurements were taken in a standing position by an encoder, and this may represent a more functional position relating to a sport, soccer, which is played in a standing position rather than an non-functional position like a sitting leg press.

Lower limb symmetry was assessed using the 90° isometric squat strength test. Through this parameter, it is possible to see how the involved left leg gained strength during the intervention resulting in improved limb symmetry, reaching a 49% at T3 while at T0 the balance reported was 48%. The aspect of force output symmetry using the standing encoder with the same test position has not been investigated in previous studies.

BFR intervention for pain modulation has not been fully elicidated in the literature, especially the influence of BFR has on pain values within the same sessions. The study conducted by the NHS [35] shows a decrease in pain values after 8 weeks of intervention, which could also be linked to normal physiological reduction in pain after the inflammatory phase or due to a significant passage of time (8 weeks). In this case study, every time the subject was asked to report his pain sensation on the VAS scale, the values were lower after the intervention than the one he reported before the protocol was performed. When considering the VAS data, the MCID threshold of a 20 mm decrease was met in each session and at the end of the study (T3). This could be due to effects of exercise on cortical activation/inhibition pathways [36] however, the pain pathways through which BFR may influences pain sensations still needs to be investigated.

Limitations of the Study

The subject's working routine and the uncontrolled aspect of the subject's regular life such as sleeping, emotional side, and diet were not controlled. They could have played a significant role in the outcomes evaluated, especially in the isometric squat strength test. Another limit present in the study was the lack of access to more accurate evaluation instruments like MRI, which is considered the goal standard when evaluating CSA.

Conclusion

BFR is an emerging technology in the rehabilitation setting. Its efficacy for strength gains and muscle mass are well established [37]; however, there is a gap in the literature in regarding any immediate effect BFR might have on pain modulation, especially after ACL reconstruction. To the author's knowledge, prior BFR studies have not investigated or reported immediate within-session pain modulation following BFR treatment. This case study indicates BFR may decrease pain sensation after application duirng early management of post surgical ACL, where pain is a limiting factor for progress during rehabilitation. A randomized clinical trial is suggested in order to verify this outcome on a wider population and to study if there may be connections between the increase in strength values and reduced perceived pain.

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