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Utilization of Vascular Restriction Training in post-surgical knee rehabilitation: a case report and introduction to an under-reported training technique

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Introduction: *The objective of this paper is to introduce a new and reportedly safe training technique, utilizing a vascular restriction stimulus during low intensity rehabilitative exercise and provide a case example within a post-surgical rehabilitation scenario. A brief review of the most commonly reported mechanisms of action behind the purported success of the training stimulus is included.*

Methods: *19-year-old athlete presented for an accelerated post-operative knee rehabilitation program. She received a commonly utilized rehabilitation program that was supplemented with vascular restriction stimulus.*

Results: *The patient maintained muscle cross-sectional area and had improved function at a 12-week follow-up.*

Conclusion: *Low intensity exercise supplemented with vascular restriction may prove to be an efficient and effective means of maintaining post-surgical muscle size and subjective knee function.*
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KEY WORDS: knee, rehabilitation, post surgical, vascular restriction

Introduction: *ce document a pour objet de présenter une nouvelle technique d'entraînement supposément sécuritaire, qui a recours à un stimulus de restriction vasculaire durant les exercices de réhabilitation à faible intensité, et un exemple de cas faisant partie d'un scénario de réhabilitation post-opératoire. Le document comprend une brève évaluation des mécanismes d'action communément jugés comme étant à l'origine du succès du stimulus d'entraînement.*

Méthodes : *une athlète de 19 ans s'est présentée afin de suivre un programme de réhabilitation post-opératoire accéléré pour son genou. On lui a prescrit un programme de réhabilitation communément utilisé, avec comme ajout un stimulus de restriction vasculaire.*

Résultats : *la patiente a maintenu la section transversale du muscle et la fonction du genou s'était améliorée après 12 semaines.*

Conclusion : *l'exercice à faible intensité, auquel s'ajoute une restriction vasculaire, pourrait s'avérer une méthode efficace et efficiente pour maintenir la taille du muscle suite à une opération, ainsi que la fonction du genou.*
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MOTS CLÉS : genou, réhabilitation, post-opératoire, restriction vasculaire

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Introduction

Thigh muscle weakness and dysfunction secondary to an acute knee injury or surgical reconstruction procedure has been well established and has been linked to poor functional outcomes.[1–3]

From a muscular standpoint, post-injury/surgical care initially focuses on proper quadriceps activation and prevention of muscle atrophy. Common training paradigm states that in order to promote the most optimal muscle hypertrophy and strength gains, one has to work at a moderate to high intensity level – in the range of at least 60–70% of 1 repetition maximum (1RM).[4] Early application of this principle in the rehabilitation setting is often hindered due to the compromised nature of the affected limb. However, a growing amount of evidence gathered over the past decade suggests that low intensity resistance exercise (20–50% of 1RM) under the stimulus of blood flow restriction can result in greater strength and muscle cross sectional area (CSA) gains when compared to exercise at the same intensity with normal flow,[5–8] and comparable to the gains seen with traditional high intensity resistance exercise.[5]

Training with vascular restriction (VRT), aka "KAATSU Training,"[9] is accomplished using an instrument such as a blood pressure (BP) cuff placed around the base of an extremity and pumped up to a desired level to produce restricted vascular flow while exercise is performed. Restrictive pressures as low as 100 mmHg have been shown to produce significant strength gains when combined with low intensity resistance exercise.[5,7]

This educational case report will briefly highlight a case of post-arthroscopy knee rehabilitation with the implementation of VRT. More importantly, the objective of this paper is to introduce the reader to an under-reported training technique and discuss the commonly proposed mechanism associated with it by reviewing the relevant literature. It is not the purpose of this article to educate the reader regarding all domains relevant to training with vascular restriction or to provide a structured protocol for its use within a rehabilitative setting.

Figure 1 *Demonstration of vascular restriction stimulus application. Blood pressure cuff was applied at the base of the thigh in the affected lower limb.*

Case

A 19-year-old female provincial level soccer player presented 3 days following a hamstring tendon autograft ACL arthroscopic reconstructive surgery. Twenty-three weeks prior to surgery, the athlete sustained an on-field injury, which yielded the unhappy triad of a right ACL rupture, a grade 3 medial collateral ligament sprain and a large bucket-handle tear of the medial meniscus. Prior to surgery the athlete completed a Knee Injury and Osteoarthritis Outcome Score (KOOS), a Lower Extremity Functional Scale (LEFS), and thigh muscle girth measurements were taken using a standard tape measure at 3.9 in (10 cm) proximal to the superior portion of the patella and at the thickest portion of the leg. Muscle girth measurements were compared to the unaffected side and were deemed equal on both sides.

Upon post-surgical presentation, the patient began an accelerated post-surgical ACL rehabilitation program as proposed by Wilk et al. (1999).[10] The protocol included joint and soft tissue mobilizations, cryotherapy, electro-

Table 1 *Application of the vascular restriction stimulus*

Period	Vascular Restrictive Protocol	Exercise
Days 1–3	• Application of BP cuff to the proximal thigh • Inflation of BP cuff to 100 mm Hg for 5 min • 5 repetitions (3 min rest) • 2x/day	Rest
Days 4–7	• Application of BP cuff to the proximal thigh • Inflation of BP cuff to 100 mmHg • 20 reps/fatigue, 2 sets (30 sec rest b/w sets) • Deflate cuff @ completion of 1st exercise • Rest 5 mins • Repeat with 2nd exercise	1) Knee extensions from 90–40° (hip @ 90°) 2) Heel Slides
Week 2	• Same as above	1) Knee extensions from 90–40° (with extra-light Theraband™) 2) Heel slides (with extra-light Theraband™)
Week 3	• Same as above	1) Front step-ups (height = 1′ 6″) 2) Lateral step-ups (height = 1′ 6″)
Week 4–12	• Same as above	1) Lateral lunges 2) Vertical squat

***Immediately deflate BP cuff upon any of the following:** Pain, burning, tingling, loss of sensation, bruising or anything else that feels different then exercise-induced fatigue.

modalities, electrical muscle stimulation, proprioceptive exercises, as well as stretches and active range of motion exercises. VRT was also included in the regimen. This was implemented via the use of a standard 6-inch (15.2 cm) wide blood pressure cuff. The cuff was inflated to maintain 100 mmHg at the base of the affected lower limb. Although the amount of vascular restriction was maintained at 100 mmHg throughout the rehabilitation program, the exercises used under the stimulus changed periodically with phases, as outlined in Table 1.

During the first phase, days one to three (days four to seven post-surgery), the vascular restriction stimulus was applied without coupled exercises and modeled after a previous study attempting to use vascular restriction to prevent post-surgical quadriceps atrophy.[11] The subsequent phases incorporated a coupling of vascular restriction with low intensity resistance exercise that were already part of the original program as proposed by Wilk et al. (1999). Readers are encouraged to refer to the above reference for the full and detailed rehabilitation protocol. Rehabilitation exercises were performed four to five times per week.

The vascular restrictive stimulus was well tolerated. Rapid onset of fatigue and some associated transient discoloration of the restricted lower limb were the only reported symptoms. The patient reported no pain, paresthesia or other symptoms.

Re-assessment three months after the surgery yielded LEFS scores that were similar to the pre-operative values. Some improvements in KOOS scores were made when

Table 2 *Outcome measures and results*

Outcome Measure	Prior to Surgery		12 Weeks Post-Surgery	
LEFS	66/80		65/80	
KOOS • Pain: • Symptoms: • ADLs: • Sports & recreation function: • Knee-related quality of life:	92 82 97 68 43		100 85 99 78 56	
Muscle Girth (tape measure) • Thigh • Leg	Unaffected: 14.2in (36cm) 12.6in (32cm)	Affected: 14.2 in (36cm) 12.6in (32cm)	Unaffected 14.2in (36cm) 12.6in (32cm)	**Affected:** **14.4in (36.5cm)** **12.8in (32.5cm)**
	***Girth maintained when measured every 3 weeks**			

comparing the pain, symptoms, activities of daily living, sport and recreational function, and knee-related quality of life domains of the pre-operative and post-operative assessment. Muscle girth was measured periodically (every 3 weeks) over the 3-month post-surgical period. When compared to the unaffected lower limb, the girth measurements of the thigh and leg remained identical and at no point did they decrease suggesting atrophy. These remained a stable 14.2 in (36 cm) and 12.6 in (32 cm) measured at the thigh and calf respectively. At 3 months following surgery, the subject exhibited a 0.2 in (0.5 cm) greater thigh and leg circumference on the affected limb. Please refer to Table 2 for result details.

The patient and parent gave informed consent and agreed to allow the use of their medical information without disclosing personal identifiers for this case report.

Discussion

The study design is the inherent limitation of this paper as well as the lack of strength measures and more valid measurements of girth. However, it was not the intention of the authors to provide the readers an in-depth look at training with vascular restriction or to outline a specific utilization protocol. Such information does not exist. It was our intention to simply educate health-care professionals on an innovative training stimulus and to highlight how this may be utilized within a clinical setting to help prevent post-surgical atrophy and secondarily to maintain and improve function.

Advanced measurements of muscle cross-sectional area and strength were unavailable in this case. Alternatively, common clinical measurements (i.e. tape measure and a subjective functional scale) were utilized. Although the validity of clinical muscle girth measurements is questionable, our results in this case suggest that post-surgical atrophy was prevented. There was evidence of some improvement in subjective functional impairment as demonstrated in all of the KOOS subscales. It should be noted that the previously determined minimal detectable change was not reached for any of the domains (pain: 13.85, symptoms: 9.97, activities of daily living: 11.92, sports and recreational function: 22.96, knee-related quality of life: 15.45).[12] This could easily be attributed to the high baseline scores prior to surgery. Interestingly, when the scores at the 3 month follow up in this case are compared to a previous study including a comparable subject pool, the scores for each domain are similar and in some cases supersede the average KOOS scores of subjects assessed at 6 months post-reconstructive surgery.[13] It is possible that similar results could have been achieved without the additional implementation of VRT within the rehabilitation regimen. Unfortunately the design of this study does not allow for any conclusions to be made regarding the efficacy of VRT in this scenario.

The lack of more significant subjective functional improvements after 3 months of the proposed rehabilitation protocol could be attributed to the fact that the patient suffered a significant injury involving more then the one repaired anatomical structure. Secondly, with the follow-up being only 12 weeks after the surgery, it is clear that the rehabilitation process is not complete. In this case however, the clinical decision to terminate VRT at 12 weeks was made based on the finding that the girth measurements in the affected extremity were already surpassing those of the control limb.

Evidence supporting favourable muscular adaptations secondary to vascular restriction exercise is well established.[5–7,14,15] Application of vascular restriction within the rehabilitative setting has also showed promise. The first report of implementation of vascular restriction post-operatively, was by Takarada et al. (2000).[11] Here the authors utilized repeated bouts of transient vascular restriction with no resistance exercise in post-surgical ACL reconstructed limbs. This type of protocol showed promise as the associated disuse atrophy was markedly diminished (MRI CSA) in the vascular restriction group compared to a control at a 14-day follow-up. Kubota et al. (2008)[16] later reproduced the above protocol in a design that immobilized healthy volunteer lower limbs for two weeks. In this study, the vascular restriction group was compared to a group of subjects performing isometric exercises (knee extensor/flexor and plantar flexors) 2 times per day for two weeks, and a control group (no intervention). The results showed that only the vascular restriction group demonstrated a relative maintenance of strength, as well as thigh and leg circumference.

The first (and only) randomized control trial utilizing vascular restriction in conjunction with post-surgical rehabilitation was by Ohta and collegues (2003).[17] To test the efficacy of low-load resistance training with moderate vascular restriction following ACL reconstruction, the authors randomized a group of post-surgical patients (n = 22) to a 16-week VRT rehabilitation regimen. Another group of patients acted as controls, performing the exact same regimen without the vascular restriction stimulus. Although several study limitations were present, many significant differences were found in favour of VRT. Specifically, the VRT group demonstrated significantly superior knee flexor/extensor muscle strength and knee extensor muscle CSA over the control, as measured by isokinetic dynamometry and axial magnetic resonance imaging slices respectively. The vascular restriction stimulus was maintained for up to 15 minutes at 180 mmHg, as the subjects were performing their assigned exercises. Many subjects reported a deep ache associated with the VRT as they reached the end of the 15-minute application. No serious side effects to VRT were reported in this study. In the present case, the estimated average that the blood pressure cuff remained inflated was roughly 5 minutes per set.

The gains associated with VRT are substantial, yet utilization is low. This is most likely due to the lack of knowledge about the safety surrounding this training technique, as well as knowledge outlining concrete mechanisms of action. VRT has been practiced for decades in Japan. Although side effects have been reported, a study looking at utilization and safety amongst its users has suggested that even though training with vascular restriction is widely used amongst all age groups in Japan, the incidence of serious complications seems rare.[18] In this retrospective study, the most common side effects included transient bruising and paresthesia that occurred in roughly 13 and 1.3 percent of the cases respectively. Other more serious side effects were also reported but were extremely rare. It is worthwhile to mention that out of the ~12.6 thousand individuals who were reportedly receiving VRT, roughly 29% of them were seniors (60+).

The authors of the present study were unable to find any scientific literature studying VRT that reported any serious side effects. The decision to use VRT in this case was strictly based on the similarity of the present case with previous reports of utilization in a rehabilitation setting and patient consent. The patient reported no significant side effects related to the treatment and was at no point hesitant about complying with the planned protocol even though she was advised she could withdraw at any time.

The following two subsections of this discussion relate to the two most commonly reported mechanisms of action pertaining to the effects seen with VRT.

Acute Hormonal Responses

Acute responses of anabolic hormones such as testosterone, growth hormone(GH) and insulin-like growth factor 1 (IGF) have long been guiding exercise practices. In a recent review, Kraemer & Ratamess concluded that the acute responses of the above hormones are critical for strength gains and muscular growth.[19] These conclusions are based on the observable increases of these hormones in individuals post-exercise. It is suggested that exercise utilizing high intensity loads, low repetitions, short rest intervals and large muscle groups will result in higher acute hormonal responses.[4] Training dogma has long taken this advice and incorporated it. An example of this is the common recommendation of performing high intensity training and mixing large and small muscle group exercises with the intention that small muscles will benefit from the large increases of systemic anabolic hormones stimulated by intense exercise of large muscle groups.[4] Although low intensity exercise does not fit within the specifications of the above guidelines, when combined with the stimulus of vascular restrictions, significant acute hormonal changes are noted.

Several studies have shown significant increases up to ~290-fold in GH following low intensity training with vascular restriction.[20–22] Acute increases in human GH have been considered as one of the primary mechanisms responsible for the observed muscular adaptations associated with VRT. This hypothesis however is based solely on correlation and does not speak well to causation. Recent investigations into the effects of the ostensibly anabolic hormones concludes that physiological increases of such hormones associated with high intensity exercise of large muscle groups does not equate to any differences in strength, hypertrophy and myofibrillar synthesis in general.[23,24] Also, recent investigations into the effects of GH specifically are suggesting that the hormone plays significant role in tendon collagen synthesis as opposed to muscle protein synthesis.[25] The importance of GH should not be understated, however, with respect to the synthesis of contractile proteins in muscle tissue, evidence suggest other factors are responsible for this. Therefore the theory that the demonstrated gains related to VRT are secondary to associated increases in GH is not well supported by recent empirical evidence. This is not however the only proposed mechanism.

Acute Neuromuscular Adaptations

A more likely proposed explanation for the favourable gains in strength and CSA observed with VRT at low loads is rooted in the acute neuromuscular adaptations that occur while it is being performed.

The "size" principle of motor unit activation (MUA) was first proposed by Henneman in 1965.[26] This principle explains motor unit and therefore muscle fibre recruitment patterns. It states that low-load resistance exercise recruits small motor units and their associated slow twitch, low threshold, oxidative muscle fibres. As the exercise intensity increases (load), there is an increase of motor unit recruitment and larger, higher threshold motor units are recruited. These larger motor units are associated with larger, fatigable (glycolytic) Type II muscle fibres. Since type II fibres respond to exercise with more substantial hypertrophy, the goal of modern resistance exercise progressions is to recruit these fibres in order to maximize gains.[27] Due to the size principle, recruitment of type II motor units primarily occurs when lifting substantial loads. This could also be accomplished by maintaining submaximal fatiguing exercise which eventually exhausts smaller oxidative motor-units leading to the recruitment of larger (non-oxidative) ones in order to maintain work.[28]

Training with a vascular restriction stimulus has demonstrated a unique ability to accelerate muscular fatigue at light loads. The transient hypoxia associated with blood flow restriction at light loads demonstrates hastening fatigue through increases in blood lactate concentrations, MUA, and deceases in motor unit firing rate; all of which suggest fatigue.[29]

Moritani et al. (1992),[29] were the first to show all three changes occurring during very low intensity exercise (20% maximum voluntary contraction) with blood flow restriction (200 mmHg). These changes were not seen in the control group (no vascular restriction). Studies utilizing electromyography (EMG) to study MUA via root mean square and integrated EMG (iEMG) analysis have demonstrated on a number of occasions that vascular restriction leads to increases in recruitment.[5,7,29,30] For example, in a study comparing iEMG of the biceps brachii during vascular restriction (40% 1 RM) and a heavy resistance exercise group (80% 1 RM), Takarada et al. (2000)[5] showed almost equal iEMG output values between the groups. These findings indicate a similar amount of MUA and therefore similar effort at drastically different exercise intensities. This highlights the most likely mechanism for the purported gains in strength and CSA seen with VRT.

Conclusions

This case report outlines a supplementation of the typical accelerated post-surgical knee rehabilitation program with low intensity exercises utilizing vascular restriction. The results suggest maintenance of muscle girth and subjective function 3 months after the surgery for this particular patient. It cannot be stated unequivocally that these results were not due to the other, more traditional elements of the post-surgical program. Low intensity exercise supplemented with vascular restriction may prove to be an efficient and effective means of maintaining post-surgical muscle size and subjective knee function. Future studies should aim to further elucidate the efficacy behind such an approach to rehabilitation.

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