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In-Season Rehabilitation Program Using Blood Flow Restriction with Therapy for Two Decathletes with Patellar Tendinopathy: A Case Report

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IN-SEASON REHABILITATION PROGRAM USING BLOOD FLOW RESTRICTION THERAPY FOR TWO DECATHLETES WITH PATELLAR TENDINOPATHY: A CASE REPORT

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ABSTRACT

Background and Purpose: Patellar tendinopathy is an overuse injury experienced primarily by athletes; especially athletes who participate in sports that involve frequent jumping. Therapeutic exercise is the primary conservative treatment for patients with this condition. However, some patients with patellar tendinopathy may be unable to tolerate the loading that occurs during exercise. The use of blood flow restriction (BFR) therapy for patients with patellar tendinopathy may allow the athlete to exercise with a lower load while still experiencing the physiological benefits associated with training at a higher intensity. The purpose of this case report was to detail the outcomes from a rehabilitation program utilizing BFR for two collegiate decathletes with patellar tendinopathy.

Study Design: Case Report

Case Descriptions and Interventions: Two NCAA Division III freshmen collegiate decathletes with a history of left knee pain prior to college and who had been complaining of increasing pain during the initial month of track practices. Findings from the musculoskeletal examinations included left sided lower extremity weakness, pain during functional testing, pain when palpating the left patellar tendon, and VISA-P scores less than 80. Ultrasound imaging at baseline revealed thickened tendons on the left with hypoechoic regions. Both athletes participated in 20 therapy sessions consisting of therapeutic exercises performed with BFR.

Outcomes: Both athletes experienced improvements in pain scores, increases in lower extremity strength, improved functional test performance, higher VISA-P scores, and improvements in tendon size and appearance as measured by diagnostic ultrasound.

Conclusion: Both athletes experienced improvements with the BFR-based therapeutic exercise program and were able to compete throughout the track season. The use of BFR may allow patients who are unable to tolerate exercise due to pain an alternative approach during rehabilitation. Future research should compare therapeutic exercise programs for this condition with and without BFR.

Level of Evidence: Level V

Key Words: college, decathlon, jumper's knee, rehabilitation, track and field

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BACKGROUND AND PURPOSE

Patellar tendinopathy is an overuse injury marked by histopathological changes.[1-9] This condition is experienced primarily by athletes; especially athletes who participate in sports that involve frequent jumping (e.g., basketball and volleyball).[4,5,10-14] Athletes with patellar tendinopathy (also known as jumper's knee) report pain during sport, may experience functional deficits, and may have to miss time from sport participation.[15-18] Numerous conservative and surgical treatment options have been reported for this condition.[19-32]

The primary conservative treatment option for patients with patellar tendinopathy is therapeutic exercise.[20-24,29,33-37] A 12-week treatment program consisting of the unilateral squat performed on a 25 degree squat board has demonstrated success in improving pain and function in subjects with patellar tendinopathy.[33-36] A 12-week heavy slow resistance (HSR) exercise program, consisting of the squat, hack squat, and leg press (each exercise performed bilaterally) has also demonstrated improvements in pain, function, and fibril morphology in patients with patellar tendinopathy.[29,37]

Many athletes with jumper's knee experience success with conservative treatment; however, some do not.[15,38,39] Kettunen et al reported 53% (9 of 17) of athletes (mean age 27.2 ± 6.2 y) had retired from their sport due to their symptoms.[15] Exercise treatment may also not be effective when the athlete is concurrently competing in sport. Visnes et al reported no change in Victorian Institute of Sport Assessment – Patella (VISA-P) scores after a 12-week eccentric training program in volleyball players who were simultaneously training and competing in their sport.[39] Several medical procedures for jumper's knee have been reported in the literature including extracorporeal shockwave therapy, ultrasound-guided intra-tissue percutaneous electrolysis, medication, platelet-rich plasma injections, and sclerosing injections, or ultimately, surgery.[24-32,38] Medical procedures are considered if a patient still has symptoms after failing to improve with a therapeutic exercise program; however, some patients are still symptomatic or worse after surgery.[38]

One potential reason why a patient with patellar tendinopathy may fail to fully recover with conservative measures is due to the pain experienced by the athlete during exercise. In both of the aforementioned therapeutic exercise protocols significant loading, which may be accompanied by pain during exercise, is applied to the patient's knee.[40-42] On one hand this loading appears necessary for tendon remodeling; however, for some patients this may not be tolerable. The use of blood flow restriction (BFR) therapy may allow an athlete with jumper's knee to exercise with a lower applied load while experiencing physiological benefits associated with high intensity training. BFR therapy utilizes a tourniquet, applied to the proximal portion of an extremity, to occlude blood flow during exercise. Performing exercises under occlusion allows a patient to train with lower loads while experiencing benefits associated with high intensity training (i.e., increases in strength and muscle and tendon cross-sectional area). There are several proposed mechanisms for the strength gains observed during BFR training: metabolite accumulation, mammalian target of rapamycin complex 1 (mTORC1) activation, cellular swelling, and growth hormone release.[43-52] Several authors have demonstrated increases in strength and cross-sectional area of the quadriceps when performing exercise(s) with BFR at low loads [e.g., 30% of 1-repetition max (1RM)].[53-65] Recent evidence indicates that low-load training with BFR has the ability to produce comparable morphologic and mechanical adaptations of the Achilles tendon when compared to subjects who perform high-load training without BFR.[66] The purpose of this case report is to describe an in-season rehabilitation program, utilizing BFR therapy, for collegiate decathletes with patellar tendinopathy.

CASE DESCRIPTION: PATIENT HISTORY AND PHYSICAL EXAMINATION

Two NCAA Division III freshmen collegiate decathletes were referred to the university's physical therapy clinic in early February 2019 by their coach. Both athletes had a history of knee pain prior to college and had complaints of increasing pain during the initial month of track practices (January 2019). A musculoskeletal examination was performed for each athlete, including ultrasound imaging of the patellar tendons. Ultrasound imaging was performed with the athletes positioned supine on a treatment table with their knees flexed to approximately 110 degrees.[67] Ultrasound images (a longitudinal view and three transverse views) were collected for each patellar tendon. An Affinity 50 ultrasound machine (Phillips Healthcare, Andover, MA) fitted with a 50-mm linear array probe was used at a depth of 2.5 cm for each image. The reliability of diagnostic ultrasound images of the patellar tendon is excellent.[68-70]

A diagnosis of patellar tendinopathy for each athlete was based on patient history, pain during activity/loading (e.g., pain during jumping/landing or pain during single-leg squat), pain with palpation to the patellar tendon at the inferior pole (pain may also be elicited from other locations along the tendon), with the diagnosis confirmed by diagnostic ultrasound imaging.[8,17,20,39,71-73]

ATHLETE 1

Athlete 1, a 19-year old male freshman (height 1.85 m; weight 73.93 kg; body mass index 21.60 kg/m^2) presented to physical therapy with a recurring history of pain in his left patellar tendon during sport. He reported a history of intermittent left knee pain during sport since his freshmen year of high school (4 years prior) with symptoms worsening during May of 2018. This subject reported no other history of knee injury or surgery. He experienced a return of symptoms when track and field practice began in January 2019.

Table 1 presents pertinent findings from the musculoskeletal examination for both athletes. Ultrasound imaging was performed prior to other examination tests (TC performed all ultrasound studies for this case; JB performed all other tests). Figure 1 demonstrates a thickened left tendon, in relation to the right tendon, and a hypoechoic region (Figures 1a & 1b). At the first visit the left patellar tendon thickness of Athlete 1 was 0.391 cm whereas the right patellar tendon thickness was 0.303 cm (Figures 1a and 1b respectively). Strength measures were collected using traditional manual muscle testing positions (i.e., make test) using a microFET 2 dynamometer (Hoggan Scientific, Salt Lake City, UT) (MMT).[73,74] Hand held dynamometry is a reliable and valid tool for measuring lower extremity strength in a clinical setting.[75-77] Athlete 1 demonstrated left lower extremity weakness in four of the five muscle groups tested. Pain was elicited when palpating the left tendon at the inferior pole of patella. Pain was also reproduced during single leg squat and single leg hop (SLH) testing. The subject was able to squat to 150 degrees of knee flexion on the right but was limited to 125 degrees on the left due to pain. Pain, as measured by a visual analog scale (VAS), was reported as a 2/10 when at rest and an 8/10 during sport. The Victorian Institute of Sport Assessment – Patellar Tendon (VISA-P) questionnaire was administered to each athlete.[78] The VISA-P is not a diagnostic tool; rather it is used to evaluate the severity of tendinopathy and to track progress during rehabilitation.[17] Athlete 1's VISA-P was a 45/100 at baseline.

ATHLETE 2

Athlete 2 was a 19-year old male freshman (height 1.93 m; weight 82.83 kg; body mass index 22.24 kg/m^2) who presented to physical therapy with an approximate 14 month history of left knee pain at the patellar tendon. Onset of pain occurred during the winter of 2017. The condition worsened during his high school track and field season (Spring 2018). He was able to continue with sport by reducing the number of jumps performed during practice. He reported that he did seek treatment from his primary medical doctor who diagnosed him with "tendinitis". The only treatment that was prescribed was to "rest it" after the season ended. He reported a return of pain in January 2019 when practices for the spring track season started. He also reported working with a university athletic trainer who had him perform exercises for his hip and knee and treated him with various modalities. He reported no prior history of any other lower extremity injury and no history of prior surgery.

Ultrasound imaging of the left patellar tendon was performed prior to other components of the musculoskeletal examination. Figure 2a demonstrates a thickened left tendon (0.365 cm) with several hypoechoic regions whereas the right patellar tendon was 0.358 cm (Figure 2b). Handheld dynamometry using the microFET 2 dynamometer (Hoggan Scientific, Salt Lake City, UT) (MMT) was used to collect measures of lower extremity strength. Four of the five muscle groups tested were weaker on the left. Patient reported pain when the left tendon was palpated at the inferior pole of the tendon. Pain was

Table 1. *PreTest and PostTest Strength, Flexibility, Functional Test, Pain, and Outcome Scores for Each Athlete with Patellar Tendinopathy.*

	Athlete 1 (R) Lower Extremity			Athlete 1 (L) Lower Extremity			Athlete 2 (R) Lower Extremity			Athlete 2 (L) Lower Extremity		
	Pretest	Posttest	(% Δ)	Pretest	Posttest	(% Δ)	Pretest	Posttest	(% Δ)	Pretest	Posttest	(% Δ)
Handheld Dynamometry (N)												
Hip Flexion	180.60	235.76	(30.54)	189.05	206.40	(9.18)	169.03	203.28	(20.26)	181.49	191.72	(5.64)
Hip Extension	157.47	282.91	(79.66)	151.68	289.60	(90.93)	130.78	162.80	(24.48)	112.98	161.92	(43.32)
Hip Abduction	198.39	338.51	(70.63)	160.14	303.81	(89.72)	197.50	194.39	(-1.57)	157.91	169.92	(7.61)
Knee Extension	190.38	229.08	(20.33)	177.48	213.51	(20.30)	210.40	217.07	(3.17)	185.93	197.50	(6.22)
Knee Flexion	171.70	208.62	(21.50)	161.03	228.64	(41.99)	206.84	250.43	(21.07)	194.83	195.28	(0.23)
Flexibility (degrees)												
Straight Leg Raise	70	70	(0)	70	70	(0)	70	70	(0)	70	70	(0)
Functional Testing (mean of 3 hops)												
Single-Leg Hop (inches)	75.7	74.0	(-2.25)	76.0	78.3	(3.03)	78.0	80.7	(3.46)	42.3	66.0	(56.03)
Single-Leg Hop (% ht.)	1.04	1.01	(-2.88)	1.04	1.07	(2.80)	1.02	1.06	(3.92)	0.56	0.87	(56.36)
Single-Leg Squat (degrees)	150	150	(0)	125*	150	(20)	120	120	(0)	55*	90*	(63.64)
Pain (VAS)												
At Rest	na	na		2/10	0/10		na	na		2/10	0/10	
During Sport	na	na		8/10	0/10		na	na		8/10	3/10	
VISA-P	na	na		45	82	(82.22)	na	na		60	71	(18.33)

(R) = right; (L) = left; N = newtons; h = height; VAS = visual analog scale; VISA-P = Victorian Institute of Sport Assessment Questionnaire – Patellar Tendon; na = not applicable

*pain limiting motion

ǂReported pain during pretest single-leg squat test at 55° 5/10

‡Reported pain during posttest single-leg squat test at 90° 4/10

reproduced during the single leg squat and single leg hop (SLH) testing. The patient was able to squat to 120 degrees of knee flexion on the right but was limited to 55 degrees on the left due to pain. SLH measures were substantially shorter on the left when compared to the right. Pain, as measured by a visual analog scale (VAS), was reported as a 2/10 when at rest and at 8/10 during sport. Athlete 2's VISA-P was a 60/100 at baseline.[79]

INTERVENTION

The subjects attended physical therapy two times a week during the 2019 season for a total of 20 sessions [sessions were scheduled to avoid competition days and travel]. The physical therapy program consisted of therapeutic exercises performed with BFR. The Delfi Personalized Tourniquet System (Delfi Medical; Vancouver, BC, Canada) was used for each therapy session. BFR is achieved by applying a tourniquet cuff to the proximal lower extremity. A standard limb occlusion pressure (LOP) was utilized each session restricting 80% of lower extremity arterial inflow.[65,80] To date there has been no reported treatment protocol utilizing exercise with BFR for patients with patellar tendinopathy. The athletes performed two exercises with BFR; however, the

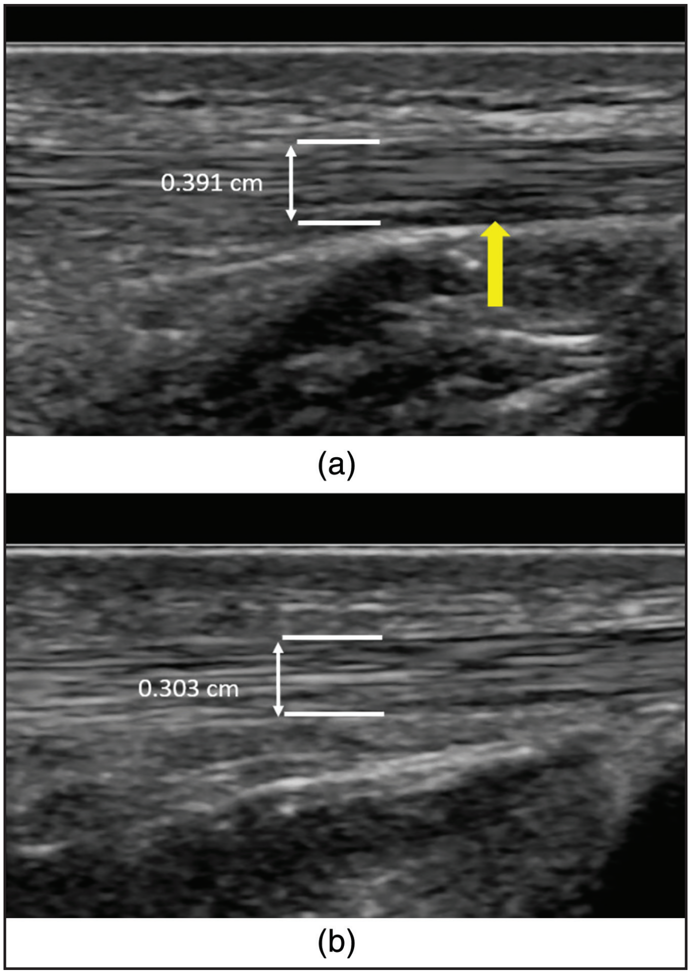

Figure 1. *(a) Sonographic Image of Athlete 1's Left Patellar Tendon (Baseline). Arrow pointing to hypoechoic region. Tendon thickness 0.391 cm. (b) Sonographic Image of Athlete 1's Right Patellar Tendon (Baseline). Tendon thickness 0.303 cm.*

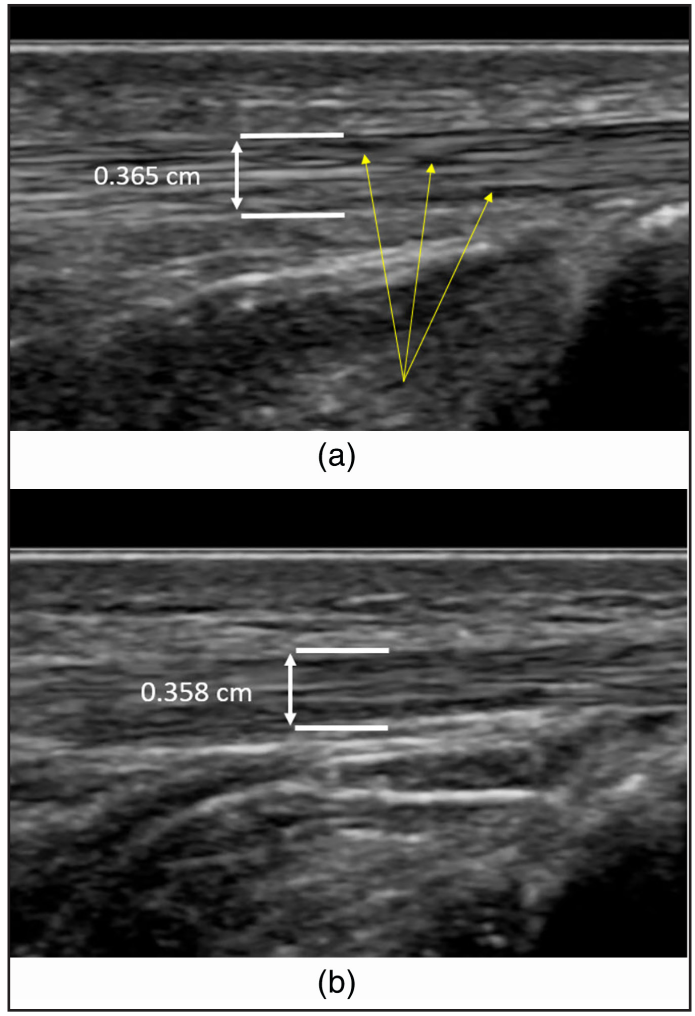

Figure 2. *(a) Sonographic Image of Athlete 2's Left Patellar Tendon (Baseline). Arrows pointing to hypoechoic region. Tendon thickness 0.365 cm. (b) Sonographic Image of Athlete 2's Right Patellar Tendon (Baseline). Tendon thickness 0.358 cm.*

authors gradually progressed the treatment program's intensity (Table 2). The first exercise that was prescribed was the single-leg leg press (MD 117 Super Leg Press, Body Masters, Hauppauge, NY) (Figure 3). Prior to initiating the exercise program each athlete established their 1RM for the single-leg leg press. The athletes were instructed to select a weight that was one-half of their typical heaviest load performed during the bilateral leg press. The athlete would next attempt one repetition at that weight. Weight was adjusted up or down, with repeated one repetition tests, until a one repetition maximum (1RM) was identified. The initial training load was set at 30 percent of 1RM. The 1RM for Athlete 1 was 104.33 kg (230 lbs.) and his initial load during the single-leg leg press was set at 31.75 kg (70 lbs.). The 1RM for Athlete 2 was 58.97 kg (130 lbs.); his initial load during the single-leg leg press was set at 18.14 kg (40 lbs.). The subjects were not restricted by the physical therapists from participating in any of their track and field training.

During weeks one and two the subjects only performed the single-leg leg press exercise (Figure 3). Athletes were positioned on the leg press with their knee flexed to 90 degrees. Athletes were instructed to take two seconds to complete the concentric and two seconds to complete the eccentric phases of the exercise. Four sets (30/15/15/15 repetitions per set) were performed with the LOP on the BFR

Table 2. *Weekly Exercise Protocol for Athletes with Patellar Tendinopathy.*

Week	Exercise Protocol
Weeks 1-2	Single-leg Leg Press / LOP 80% / 4 sets (30/15/15/15 reps) / 30 sec rest between sets / 8 min total treatment time
Weeks 3-4	Single-leg Leg Press / LOP 80% / 4 sets (30/15/15/15 reps) / 30 sec rest between sets
	Tourniquet removed after 1st exercise and applied to the other athlete
	Tourniquet reapplied to perform the 2nd exercise
	Unilateral Squat performed on 25° Squat Board / LOP 80% / 4 sets (30/15/15/15 reps / 8 min treatment time
Weeks 5-12	Single-leg Leg Press / LOP 80% / 4 sets (30/15/15/15 reps) / 30 sec rest between sets
	Unilateral Squat performed on 25° Squat Board / LOP 80% / 3 sets (15/15/15) 30 sec rest between sets / 15 min treatment time (no removal/reapplication of tourniquet between exercises)

LOP = limb occlusion pressure; sec = seconds; min = minutes

Figure 3. *Single-leg Leg Press with BFR Tourniquet Applied to the Proximal Left Thigh.*

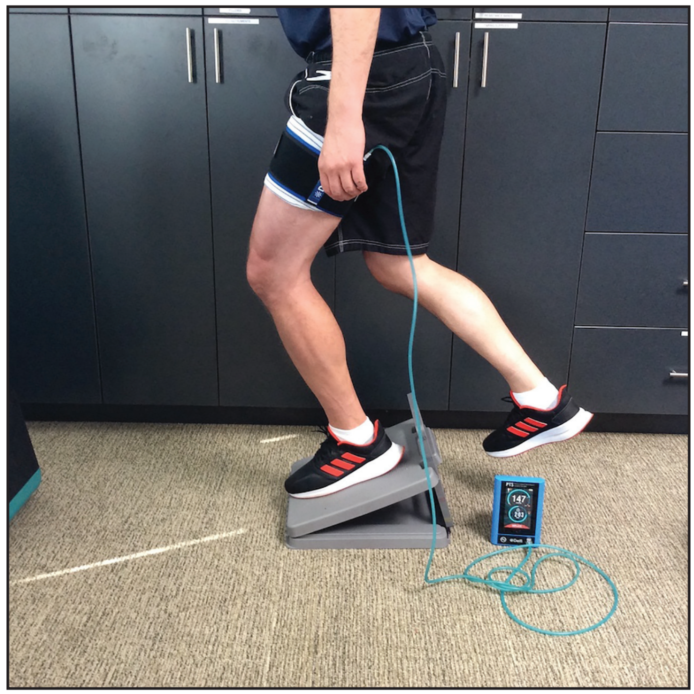

Figure 4. *Unilateral Squat on a 25° Decline Board with BFR Tourniquet Applied to the Proximal Left Thigh.*

device set at 80 percent. Thirty second rest periods were allowed between each set. It took the subjects approximately five and a half minutes to complete the four sets. After completing the final set, the subject would maintain limb occlusion for approximately another two and one-half minutes (total time of limb occlusion = eight minutes). The leg press exercise was the only exercise performed during these initial sessions in order to acclimate the athletes to BFR. Performing exercise with BFR can be uncomfortable and one may experience delayed onset muscle soreness after the initial session.[80-82]

During week three the unilateral squat performed on a 25-degree squat board exercise (Figure 4) was added to the treatment program (Table 2). During weeks three and four the subject would perform the single-leg leg press first (as previously described) followed by removal of the tourniquet. This allowed one athlete to rest (for approximately 5½ minutes) while the second athlete performed the leg press exercise. A rest period during this phase was allowed in order to continue acclimation to the treatment regimen. After the rest period the BFR cuff was reapplied with the athlete performing four sets (30/15/15/15 repetitions per set; 30 second rest between sets) of the unilateral squat on the squat board. The unilateral squat exercise was performed in a manner previously described with emphasis on eccentric loading of the patellar tendon.[33-36] The athlete first squats to 60 degrees of knee flexion with the involved leg, next unloads weight from left lower extremity and shifts bodyweight to the right lower extremity, followed by concentrically extending the right lower extremity to return the athlete to the full upright position. The total time of occlusion during the unilateral squat exercise was eight minutes.

During weeks five through 12 the subjects performed both exercises under BFR conditions without providing the rest break between exercises. The single-leg leg press exercise was performed first each time (4 sets: 30/15/15/15 repetitions; 30 second rest between sets). The subjects were encouraged to increase their working weight, in 10-pound increments, when possible. After completion of the 4th set of the single-leg leg press exercise the athlete was allowed a 30 second rest period prior to performing the unilateral squat exercise. During this phase of the program the subjects performed 3 sets of 15 repetitions (with 30 second rest breaks between sets). The purpose of the first set of 30 repetitions is to facilitate lactate production which ultimately increases motor unit recruitment and the growth hormone release.[51,83] Since there was no removal of the tourniquet between sets the clinicians elected to not have the athletes perform the 30-repetition set during the unilateral squat. The total time of occlusion during both exercises was approximately 15 minutes.

OUTCOMES

Posttesting occurred two days after the last treatment session (and immediately prior to the athletes leaving campus for the summer break). Both subjects demonstrated improvements in pain and VISA-P scores as well as improvements in strength and functional test performance. Ultrasound imaging also demonstrated improvements in tendon size and appearance.

Athlete 1 demonstrated large strength gains in muscle groups proximal and distal to tourniquet application (Table 1). His single-leg leg press 1RM increased from 104.33 kg (230 lbs.) to 167.83 kg (370 lbs.). His single-leg squat depth improved from 125 degrees of knee flexion (with pain) to 150 degrees (without pain). He demonstrated a slight increase in his left lower extremity SLH performance. Pain improved at rest (2/10 to 0/10) and during activity (8/10 to 0/10). His VISA-P score increased from 45/100 to 82/100 well surpassing the minimum clinically important difference [MCID] of 13 points.[85] Posttest ultrasound image of his left patellar tendon demonstrated both improvements in tendon thickness [improving from 0.391 cm (Figure 1a) to 0.280 cm (Figure 5)] and resolution of the hypoechoic region.

Athlete 2 also demonstrated large gains in both proximal and distal lower extremity muscle groups. His single-leg leg press increased from 58.97 kg (130 lbs.) to 79.38 kg (175 lbs.). His single-leg squat improved from 55 degrees of knee flexion to 90 degrees; however, it had not equalized yet to his opposite side. He had a large increase in single leg hop performance increasing from a normalized to height pretest measure of 0.56 to a posttest measure of 0.87. His pain during rest (2/10 to 0/10) and during activity (8/10 to 3/10) both improved. He had a small increase of 11 points on the VISA-P (two points less than the MCID).[84] Posttest ultrasound image of his left patellar tendon demonstrated an increase in tendon thickness [increasing from 0.358 cm (Figure 2a) to

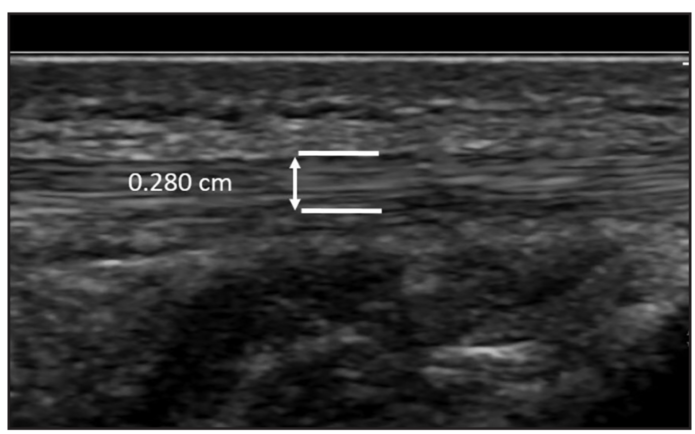

Figure 5. *Sonographic Image of Athlete 1's Left Patellar Tendon (Posttest). Tendon thickness reduced to 0.280 cm from 0.391 cm at baseline.*

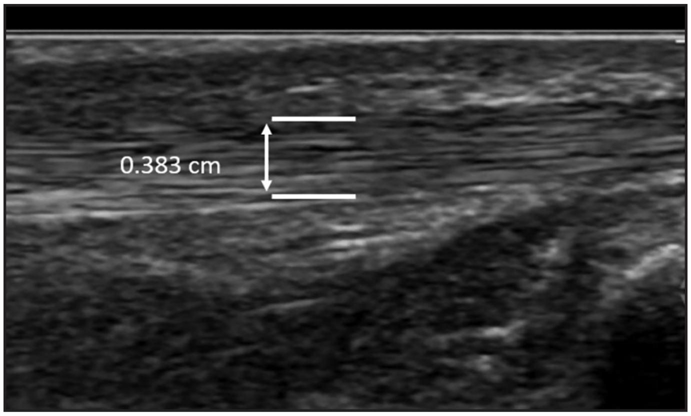

Figure 6. *Sonographic Image of Athlete 2's Left Patellar Tendon (Posttest). Tendon thickness increased to 0.383 cm from 0.358 cm at baseline.*

0.383 cm (Figure 6); see Discussion section] with a reduction of hypechogenicity.

Both subjects were able to compete throughout the track and field season. Supervised therapy sessions were continued until the athletes left campus for the summer break. The athletes were encouraged to continue with strength training exercises once they returned home. They were instructed to perform lower extremity exercises (e.g., squats, leg press) both bilaterally and unilaterally two times per week for a training volume of three to four sets of six to eight repetitions. They were also encouraged to seek treatment from an orthopaedic physician or a physical therapist if their symptoms worsened or if there was a plateau in their symptom improvements.

DISCUSSION

This report presents two cases utilizing BFR therapy to treat patients with patellar tendinopathy. In this report, both athletes were able to demonstrate improvements in pain, strength, and function. In addition, both athletes had improvements with their sonographic images (i.e., decreased hypechogenicity and/or decreased tendon thickness) after treatment. The rehabilitation program detailed in this case report can offer physical therapists and other rehabilitation professionals a potential in-season treatment strategy for athletes with jumper's knee.

This case report details a novel therapeutic exercise program, utilizing BFR, for athletes with jumper's knee. Prior research reports have presented therapeutic exercise strategies either using the single-leg squat on a decline board (exercise program performed twice daily for 12 weeks) or the HSR program (performed three times per week for 12 weeks).[33-36,37,40] The two exercises that were utilized in this case report were selected for three reasons. First, the exercises that were prescribed were selected based on their utilization in prior studies.[33-36,37,40] Second, the two exercises included in this case report were chosen based on available equipment in the clinic. Two of the exercises from the HSR training program that were not included were the barbell loaded squat and hack squat exercises. Equipment for the barbell squat and the hack squat were not available within the clinic. Third, the athletes were also continuing with their daily track practices and training sessions. The exercises prescribed during physical therapy differed from the lower body exercises (lunges, hex squats) that were performed by the athletes as part of their in-season training.

As previously mentioned, both subjects experienced improvements in strength, pain, and function. The training program appeared to have a greater effect on Athlete 1 when compared to Athlete 2. Athlete 1 had large gains (percentage change) in most strength measures, significant reductions in pain during rest and activity, and he was able to demonstrate symmetrical single-leg squat depth (without pain) after the 20 training sessions. His tendon thickness decreased (which is a positive response to training)[85-88] and a decrease in the tendon's hypechogenicity was apparent. He also had a large improvement in VISA-P score (> 13 point MCID).[84] His single-leg hop distance on the left improved; albeit the percentage change was small as his pretest single-leg hop was nearly symmetrical to his uninvolved side.

Athlete 2 also experienced improvements in strength, pain, and function. His strength gains (percentage change) were smaller than those experienced by Athlete 1. His smaller strength gains may have been a result of the total number of rehabilitation sessions that he was able to attend prior to the end of the academic year. Prior research has evaluated improvements in pain and function for patients with patellar tendinopathy after participating in a 12-week program. The single-leg squat exercise program was performed twice a day for 12 weeks (n = 168 training sessions)[33-36] and the HSR program was performed three times a week for 12 weeks (n = 36 training sessions).[37,40] Athlete 2 was only able to participate in 20 sessions with the end of the academic calendar limiting his ability to continue with therapy at the university. He may have benefitted from more frequent supervised rehabilitation sessions based on his disease severity. His disease severity was greater than Athlete 1, as reflected in his functional test performance at baseline (Table 1). He was able to make improvements in both his single-leg squat (able to squat to 90 degrees before pain onset) and his normalized single-leg hop distance (0.87); however, his squat and hop measures were not symmetrical after 20 sessions. His pain also improved; however, his pain during sport had not completely resolved (change from an 8/10 to a 3/10). His VISA-P score was higher at baseline than Athlete 1; however, his improvement was small (+11) and did not meet the MCID (+13). The hypechogenicity improved between his pre- and posttest ultrasounds. It is important to address the increase in tendon thickness at posttest. A decrease in tendon thickness is a common response to training,[85-88] however, in this case there was a slight increase (+0.022 cm). It is possible though that small increase was not an actual change, as changes in patellar tendon size less than 0.07 may be the result of measurement error.[89]

CONCLUSIONS

The outcomes from this case report demonstrate that a therapeutic exercise program, prescribed during the season, utilizing BFR can reduce pain, increase strength, and increase function in two track and field athletes with patellar tendinopathy. Patellar tendinopathy can be a painful condition with pain limiting the ability to participate in a rehabilitation program. The use of BFR may allow clinicians to prescribe exercises at a lower load (which may help decrease the chance of pain during exercise) and showed mainly positive outcomes in the treatment of patellar tendinopathy in these two subjects. Future research should compare the effectiveness of an exercise program for patellar tendinopathy in subjects with or without the use of BFR.

REFERENCES

1. King D, Yakubek G, Chughtai M, et al. Quadriceps tendinopathy: a review-part 1: epidemiology and diagnosis. *Ann Transl Med.* 2019; 7(4): 71.
2. Schwartz A, Watson JN, Hutchinson MR. Patellar tendinopathy. *Sports Health.* 2015; 7(5): 415-420.
3. Peers KH, Lysens RJ. Patellar tendinopathy in athletes: current diagnostic and therapeutic recommendations. *Sports Med.* 2005; 35(1): 71-87.
4. Cook JL, Khan KM, Kiss ZS, et al. Prospective imaging study of asymptomatic patellar tendinopathy in elite junior basketball players. *J Ultrasound Med.* 2000; 19(7): 473-479.
5. Cook JL, Khan KM, Kiss ZS, et al. Patellar tendinopathy in junior basketball players: a controlled clinical and ultrasonographic study of 268 patellar tendons in players aged 14-18 years. *Scand J Med Sci Sports.* 2000; 10(4): 216-220.
6. Scott A, Backman LJ, Speed C. Tendinopathy: update on pathophysiology. *J Orthop Sports Phys Ther.* 2015; 45(11): 833-841.
7. Gisslen K, Alfredson H. Neovascularization and pain in jumper's knee: a prospective clinical and sonographic study in elite junior volleyball players. *Br J Sports Med.* 2005; 39(7): 423-428.
8. Figueroa D, Figueroa F, Calvo R. Patellar tendinopathy: diagnosis and treatment. *J Am Acad Orthop Surg.* 2016; 24(12): e184-e192.
9. Tan SC, Chan O. Achilles and patellar tendinopathy: current understanding of pathophysiology and management. *Disabil Rehabil.* 2008; 30(20-22): 1608-1615.
10. Cassel M, Risch L, Intziegianni K, et al. Incidence of Achilles and patellar tendinopathy in adolescent elite athletes. *Int J Sports Med.* 2018; 39(9): 726-732.
11. Morton S, Williams S, Valle X, et al. Patellar tendinopathy and potential risk factors: an international database of cases and controls. *Clin J Sport Med.* 2017; 27(5): 468-474.
12. Bode G, Hammer T, Karvouniaris N, et al. Patellar tendinopathy in young elite soccer – clinical and songraphical analysis of a German elite soccer academy. *BMC Musculoskelet Disord.* 2017; 18(1): 344.
13. Fazekas ML, Sugimoto D, Cianci A, et al. Ultrasound examination and patellar tendinopathy scores in asymptomatic college jumpers. *Phys Sportsmed.* 2018; 46(4): 477-484.
14. van der Worp H, Zwerver J, Kuijer PP, et al. The impact of physically demanding work of basketball and volleyball players on the risk of patellar tendinopathy and on work limitations. *J Back Musculoskelet Rehabil.* 2011; 24(1): 49-55.

15. Kettunen JA, Kvist M, Alanen E, et al. Long-term prognosis for jumper's knee in male athletes. A prospective follow-up study. *Am J Sports Med.* 2002; 30(5): 689-692.
16. Rosen AB, Ko J, N Brown C. Single-limb landing biomechanics are altered and patellar tendinopathy related pain is reduced with acute infrapatellar strap application. *Knee.* 2017; 24(4): 761-767.
17. Malliaras P, Cook J, Purdam C, et al. Patellar tendinopathy: clinical diagnosis, load management, and advice for challenging case presentations. *J Orthop Sports Phys Ther.* 2015; 45(11): 887-898.
18. Cook JL, Khan KM, Harcourt PR, et al. A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. The Victorian Institute of Sport Tendon Study Group. *Br J Sports Med*. 1997; 31(4): 332-336.
19. Brumitt J, Keefer Hutchison M, Jones N, et al. Employing evidence-based clinical decision-making in physical therapy management of patellar tendinopathy. *Orthop Phys Ther Pract.* 2018; 30(4): 518-526.
20. Woodley BL, Newsham-West RJ, Baxter GD. Chronic tendinopathy: effectiveness of eccentric exercise. *Br J Sports Med.* 2007; 41(4): 188-198; discussion 199.
21. Malliaras P, Barton CJ, Reeves ND, et al. Achilles and patellar tendinopathy loading programmes: a systematic review comparing clinical outcomes and identifying potential mechanisms for effectiveness. *Sports Med.* 2013; 43(4): 267-286.
22. Larsson ME, Kall I, Nilsson-Helander K. Treatment of patellar tendinopathy – a systematic review of randomized controlled trials. *Knee Surg Sports Traumatol Arthrosc.* 2012; 20(8): 1632-1646.
23. Couppe C, Svensson RB, Silbernagel KG, et al. Eccentric or concentric exercises for the treatment of tendinopathies? *J Orthop Sports Phys Ther*. 2015; 45(11): 853-863.
24. Abat F, Gelber PE, Polidori F, et al. Clinical results after ultrasound-guided intratissue percutaneous electrolysis and eccentric exercise in the treatment of patellar tendinopathy. *Knee Surg Sports Traumatol Arthrosc.* 2015; 23(4): 1046-1052.
25. Andriolo L, Altamura SA, Reale D, et al. Nonsurgical treatments of patellar tendinopathy: multiple injections of platelet-rich plasma are a suitable option: a systematic review and meta-analysis. *Am J Sports Med.* 2018; 47(4): 1001-1018.
26. Bahr R, Fossan B, Loken S, et al. Surgical treatment compared with eccentric training for patellar tendinopathy (jumper's knee). *J Bone Joint Surg.* 2006; 88(8): 1689-1698.
27. Dupley L, Charalambous CP. Platelet-rich plasma injections as a treatment for refractory patellar tendinosis: a meta-analysis of randomised trials. *Knee Surg Relat Res*. 2017; 29(3): 165-171.
28. Hoksrud A, Bahr R. Ultrasound-guided sclerosing treatment in patients with patellar tendinopathy (jumper's knee). 44-month follow-up. *Am J Sports Med*. 2011; 39(11): 2377-2380.
29. Kongsgaard M, Kovanen V, Aagaard P, et al. Corticosteriod injections, eccentric decline squat training and heavy slow resistance training in patellar tendinopathy. *Scand J Med Sci Sports*. 2009; 19(6): 790-802.
30. Korakakis V, Whiteley R, Tzavara A, et al. The effectiveness of extracorporeal shockwave therapy in common lower limb conditions: a systematic review including quantification of patient-rated pain reduction. *Br J Sports Med*. 2018; 52(6): 387-407.
31. Steunebrink M, Zwerver J, Brandsema R, et al. Topical glyceryl trinitrate treatment of chronic patellar tendinopathy: a randomised, double-blind placebo-controlled clinical trial. *Br J Sports Med*. 2013; 47(1): 34-39.
32. Thijs KM, Zwerver J, Backx FJ, et al. Effectiveness of shockwave treatment combined with eccentric training for patellar tendinopathy: a double-blinded randomized study. *Clin J Sport Med*. 2017; 27(2): 89-96.
33. Purdam CR, Johnsson P, Lorentzon R, et al. A pilot study of the eccentric decline squat in the management of painful chronic patellar tendinopathy. *Br J Sports Med*. 2004; 38(4): 395-397.
34. Jonsson P, Alfredson H. Superior results with eccentric compared to concentric quadriceps training in patients with jumper's knee: a prospective randomised study. *Br J Sports Med*. 2005; 39(11): 847-850.
35. Young MA, Cook JL, Purdam CR, et al. Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. *Br J Sports Med*. 2005; 39(2): 102-105.
36. Frohm A, Saartok T, Halvorsen K, et al. Eccentric treatment for patellar tendinopathy: a prospective randomised short-term pilot study of two rehabilitation protocols. *Br J Sports Med.* 2007; 41(7): e7
37. Kongsgaard M, Qvortrup K, Larsen J, et al. Fibril morphology and tendon mechanical properties in patellar tendinopathy: effects of heavy slow resistance training. *Am J Sports Med*. 2010; 38(4): 749-756.
38. Bahr R, Fossan B, Loken S, et al. Surgical treatment compared with eccentric training for patellar tendinopathy (jumper's knee). A randomized, controlled trial. *J Bone Joint Surg Am.* 2006; 88(8): 1689-1698.

39. Visnes H, Hoksrud A, Cook J, et al. No effect of eccentric training on jumper's knee in volleyball players during the competitive season: a randomized clinical trial. *Clin J Sport Med.* 2005; 15(4): 227-234.
40. Kongsgaard M, Aagaard P, Roikjaer S, et al. Decline eccentric squats increases patellar tendon loading compared to standard eccentric squats. *Clin Biomech.* 2006; 21(7): 748-754.
41. Zwerver J, Bredeweg SW, Hof AL. Biomechanical analysis of the single-leg decline squat. *Br J Sports Med.* 2007; 41(4): 264-268.
42. Frohm A, Halvorsen K, Thorstensson A. Patellar tendon load in different types of eccentric squats. *Clin Biomech.* 2007; 22(6): 704-711.
43. Abe T, Yasuda T, Midorikawa T, et al. Skeletal muscle size and circulating IGF-1 are increased after two weeks of twice daily "KAATSU" resistance training. *Int J Kaatsu Train Res*. 2005; 1(1): 6-12.
44. Fry CS, Glynn EL, Drummond MJ, et al. Blood flow restriction exercise stimulates mTORC1 signaling and muscle protein synthesis in older men. *J Appl Physiol.* 2010; 108(5): 1199-1209.
45. Gunderman DM, Walker DK, Reidy PT, et al. Activation of mTROC1 signaling and protein synthesis in human muscle following blood flow restriction exercise is inhibited by rapamycin. *Am J Physiol Endocrinol Metab*. 2014; 306(10): E1198-E1204.
46. Laurentino, GC, Ugrinowitsch, C, Roschel, H, et al. Strength training with blood flow restriction diminishes myostatin gene expression. *Med Sci Sports Exerc*. 2012; 44(3): 406-412.
47. Loenneke JP, Abe T, Wilson JM, et al. Blood flow restriction: how does it work? *Front Physiol.* 2012; 3:392.
48. Loenneke JP, Fahs CA, Thiebaud RS, et al. The acute muscle swelling effects of blood flow restriction. *Acta Physiol Hung*. 2012; 99(4): 400-410.
49. Madarame H, Sasaki K, Ishii N. Endocrine responses to upper- and lower-limb resistance exercises with blood flow restriction. *Acta Physiol Hung.* 2010; 97(2): 192-200.
50. Pierce JR, Clark BC, Ploutz-Snyder LL, et al. Growth hormone and muscle function responses to skeletal muscle ischemia. *J Appl Physiol*. 2006; 101(6): 1588-1595.
51. Poton R, Polito MD. Hemodynamic response to resistance exercise with and without blood flow restriction in healthy subjects. *Clin Physiol Funct Imaging*. 2016; 36(3): 231-236.
52. Takarada Y, Nakamura Y, Aruga S, et al. Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *J Appl Physiol.* 2000; 88(1): 61-65.
53. Giles L, Webster KE, McClelland J, et al. Quadriceps strengthening with and without blood flow restriction in the treatment of patellofemoral pain: a double-blind randomised trial. *Br J Sports Med.* 2017; 51(23): 1688-1694.
54. Manimmanakorn A, Hamlin MJ, Ross JJ, et al. Effects of low-load resistance training combined with blood flow restriction or hypoxia on muscle function and performance in netball athletes. *J Sci Med Sport*. 2013; 16(4): 337-342.
55. Ladlow P, Coppack RJ, Dharm-Datta S, et al. Low-load resistance training with blood flow restriction improves clinical outcomes in musculoskeletal rehabilitation: a single-blind randomized controlled trial. *Front Physiol*. 2018; 9:1269.
56. Yasuda T, Fukumura K, Tomaru T, et al. Thigh muscle size and vascular function after blood flow-restricted elastic band training in older men. *Oncotarget.* 2016; 7(23):33595-33607.
57. Segal NA, Williams GN, Davis MC, et al. Efficacy of blood flow-restricted, low-load resistance training in women with risk factors for symptomatic knee osteoarthritis. *PM R*. 2015; 7(4): 376-384.
58. Rodrigues R, Ferraz RB, Kurimori CO, et al. Low-load resistance training with blood flow restriction increases muscle function, mass and functionality in women with rheumatoid arthritis. *Arthritis Care Res.* 2020; 72(6): 787-797.
59. Lipker LA, Persinger CR, Michalko BS, et al. Blood flow restriction therapy versus standard care for reducing quadriceps atrophy after anterior cruciate ligament reconstruction. *J Sport Rehabil.* 2019; epub ahead of print.
60. Vechin FC, Libardi CA, Conceicao MS, et al. Comparisons between low-intensity resistance training with blood flow restriction and high-intensity resistance training on quadriceps muscle mass and strength in elderly. *J Strength Cond Res*. 2015; 29(4): 1071-1076.
61. Hylden C, Burns T, Stinner D, et al. Blood flow restriction rehabilitation for extremity weakness: a case series. *J Spec Oper Med*. 2015; 15(1): 50-56.
62. Tennent DJ, Hylden CM, Johnson AE, et al. Blood flow restriction training after knee arthroscopy: a randomized controlled pilot study. *Clin J Sport Med*. 2017; 27(3): 245-252.
63. Ferraz RB, Gualano B, Rodrigues R, et al. Benefits of resistance training with blood flow restriction in knee osteoarthritis. *Med Sci Sports Exerc*. 2018; 50(5): 897-905.
64. Takarada Y, Sato Y, Ishii N. Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *Eur J Appl Physiol*. 2002; 86(4): 308-314.

65. Bowman EN, Elshaar R, Milligan H, et al. Proximal, distal, and contralateral effects of blood flow restriction training on the lower extremities: a randomized controlled trial. *Sports Health.* 2019; 11(2): 149-156.

66. Centner C, Lauber B, Seynnes OR, et al. Low-load blood flow restriction training induces similar morphological and mechanical Achilles tendon adaptations compared with high-load resistance training. *J Appl Physiol.* 2019; 127(6): 1660-1667.

67. Keefer Hutchison M, Houck J, Cuddeford T, et al. Prevalence of patellar tendinopathy and patellar tendon abnormality in male collegiate basketball players: a cross-sectional study. *J Athl Train.* 2019; 54(9): 953-958.

68. McCreesh KM, Anjum S, Crotty JM, et al. Ultrasound measures of supraspinatus tendon thickness and acromiohumeral distance in rotator cuff tendinopathy are reliable. *J Clin Ultrasound.* 2016; 44(3): 159-166.

69. van Ark M, Rabello LM, Hoevenaars D, et al. Inter- and intra-rater reliability of ultrasound tissue characterizations (UTC) in patellar tendons. *Scand J Med Sci Sports.* 2019; 29(8): 1205-1211.

70. Black J, Cook J, Kiss ZS, et al. Intertester reliability of sonography in patellar tendinopathy. *J Ultrasound Med*. 2004; 23(5): 671-675.

71. Zwerver J, Bredeweg SW, van den Akker-Scheek I. Prevalence of jumper's knee among nonelite athletes from different sports: a cross-sectional survey. *Am J Sports Med*. 2011; 39(9): 1984-1988.

72. Mendonca Lde M, Ocarino JM, Bittencourt NF, et al. The accuracy of the VISA-P questionnaire, single-leg decline squat, and tendon pain history to identify patellar tendon abnormalities in adult athletes. *J Orthop Sports Phys Ther*. 2016; 46(8): 673-680.

73. Cook JL, Khan KM, Kiss ZS, et al. Reproducibility and clinical utility of tendon palpation to detect patellar tendinopathy in young basketball players. Victorian Institute of Sport tendon study group. *Br J Sports Med*. 2001; 35(1): 65-69.

74. Palmer ML, Epler ME. *Fundamentals of Musculoskeletal Assessment Techniques.* 2nd ed. Philadelphia, Penn: Lippincott; 1998.

75. Stratford PW, Balsor BE. A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. *J Orthop Sports Phys Ther*. 1994; 19(1): 28-32.

76. Mentiplay BF, Perraton LG, Bower KJ, et al. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study. *PLoS One*. 2015; 10(10): e0140822.

77. Chopp-Hurley JN, Wiebenga EG, Gatti AA, et al. Investigating the test-retest reliability and validity of hand-held dynamometry for measuring knee strength in older women with knee osteoarthritis. *Physiother Can*. 2019; 71(3): 231-238.

78. Stark T, Walker B, Phillips JK, et al. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. *PM R*. 2011; 3(5): 472-479.

79. Visentini PJ, Khan KM, Cook JL, Kiss ZS, Harcourt PR, Wark JD. The VISA score: an index of severity of symptoms in patients with jumper's knee (patellar tendinosis). Victorian Institute of Sport Tendon Study Group. *J Sci Med Sport.* 1988; 1(1): 22-28.

80. Fatela P, Reis JF, Mendoca GV, et al. Acute effects of exercise under different levels of blood-flow restriction on muscle activation and fatigue. *Eur J Appl Physiol*. 2016; 116(5): 985-995.

81. Umbel JD, Hoffman RL, Dearth DJ, et al. Delayed-onset muscle soreness induced by low-load blood flow-restricted exercise. *Eur J Appl Physiol.* 2009; 107(6): 687-695.

82. Brandner CR, Warmington SA. Delayed onset muscle soreness and perceived exertion after blood flow restriction exercise. *J Strength Cond Res.* 2017; 31(11): 3101-3108.

83. Gosselink KL, Grindeland RE, Roy RR, et al. Skeletal muscle afferent regulation of bioassayable growth hormone in the rat pituitary. *J Appl Physiol*. 1998; 84(4): 1425-1430.

84. Hernandez-Sanchez S, Hidalgo MD, Gomez A. Responsiveness of the VISA-P scale for patellar tendinopathy in athletes. *Br J Sports Med*. 2014; 48(6): 453-457.

85. Arampatzis A, Karamanidis K, Albracht K. Adaptational responses of the human Achilles tendon by modulation of the applied cyclic strain magnitude. *J Exp Biol.* 2007; 210 (Pt 15): 2743-2753.

86. Chaudhry S, Morrissey D, Woledge RC, Bader DL, Screen HR. Eccentric and concentric loading of the triceps surae: an in vivo study of dynamic muscle and tendon biomechanical parameters. *J Appl Biomech*. 2015; 31(2): 69-78.

87. Beyer R, Kongsgaard M, Hougs Kjaer B, et al. Heavy slow resistance versus eccentric training as treatment for Achilles tendinopathy: a randomized controlled trial. Am J *Sports Med.* 2015; 43(7): 1704-1711.

88. Kjaer M, Langberg H, Heinemeier K, et al. From mechanical loading to collagen synthesis, structural changes and function in human tendon. *Scand J Med Sci Sports*. 2009; 19(4): 500-510.

89. Skou ST, Aalkjaer JM. Ultrasonographic measurement of patellar tendon thickness – a study of intra- and interobserver reliability. *Clin Imaging*. 2013; 37(5): 934-937.