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Case Series

Low-Load Blood-flow Restriction Training for Medial Tibial Stress-Syndrome in Athletes: A Case Series

Anders F. Brekke[1,2,3a], Johanne Bjørklund[4], Rosa C. Holse[4], Christian Larsen[4], Mikkel H. Hjortshoej[4]

[1] Department of Physiotherapy, Centre for Health and Rehabilitation, University College Absalon, Denmark, [2] Department of Orthopaedics and Traumatology, Odense University Hospital, Denmark, [3] Department of Clinical Research, University of Southern Denmark, Denmark, [4] Department of Physiotherapy, Centre for Health and Rehabilitation, University College Absalon

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Background

Medial tibial stress syndrome (MTSS) is a common overuse injury characterized by activity-induced pain along the distal medial tibial border. Current best practice includes rest and progressive resistance training. However, some patients with MTSS may be unable to tolerate the loading during exercise. Blood-flow restriction training using low loads (LL-BFR) may induce similar physiological and structural adaptations as heavy resistance training but without peak loads. This could potentially allow the athlete to continue sports activities during rehabilitation.

Purpose

The purpose of this case series was to describe an exercise program utilizing LL-BFR training for athletes with running-related MTSS.

Study design

Case series

Methods

Six recreational athletes (one handball player, one soccer player, and four runners) with MTSS were recruited. Inclusion criteria included pain along the distal two-thirds medial tibial border occurring during or after activity. Exclusion criteria were symptoms of compartment syndrome, tibial stress fracture, or contraindications for BFR training. Participants underwent a progressive six-week home-based LL-BFR training intervention with three sessions per week and were allowed to continue sports activities if pain was ⩽ NRS 5. Outcome measures included change in standardized running performance (distance and pain level), pain pressure threshold (algometry), and self-reported physical function.

Results

Five athletes experienced improvements in running performance (pain and/or distance) and self-reported function. One athlete sustained an injury unrelated to the LL-BFR training, and therefore the running post-test could not be completed. Adherence to exercise was high, and post-test interviews revealed positive feedback on the training method, with no side effects reported.

a Corresponding Author
Anders Falk Brekke
Address: University College Absalon, Parkvej 190, 4700 Næstved, Denmark
Phone: +45 7248 2626
Email: afr@pha.dk

Conclusion

This case series demonstrated that following a therapeutic exercise program utilizing LL-BFR training improvements in pain and function were seen in athletes with MTSS. BFR may allow clinicians to prescribe lower-load exercises, facilitating continued sports participation. Future research should compare the effectiveness of exercise programs for MTSS with and without LL-BFR training.

Level of Evidence

Level V

INTRODUCTION

Medial tibial stress syndrome (MTSS) is characterized as activity-induced pain located at the distal two-thirds of the posteromedial tibial border, with recognizable pain reproduced with palpation with an extent larger than 5 cm in length.[1] MTSS is one of the most frequent overuse injuries of the lower extremities related to sports that involve running or jumping.[2,3] MTSS is the most frequent running-related musculoskeletal injury, accounting for an incidence of 13.6-20% and a prevalence of 9.5%.[3] The severity of MTSS can range from brief suspensions from activity to career-ending.[4]

The etiology of MTSS is unclear; however, different mechanisms have been proposed. MTSS has been characterized as micro-damage of the tibia due to repeated bending (absorption of energy) during weight-bearing activities, leading to osteopenia, with decreased bone mineral density at the injury site.[5,6] It has also been suggested that MTSS is related to muscular traction-induced periostitis.[7]

Current best practice for treatment of MTSS includes rest and discontinuing activities that provoke symptoms.[8] An additional recommended treatment for MTSS is a progressive training intervention divided into three phases.[9] The three phases include rest and modified activity levels, isometric and concentric resistance training, and eccentric and plyometric exercises. There is, however, no high-quality evidence for the effect of any intervention in treating MTSS.[5,10]

Low-load blood-flow restriction (LL-BFR) training utilizes low loads of 20-40% of 1-repetition maximum (1-RM), and is accomplished by the use of a strap or an inflated cuff that restricts the arterial inflow and occludes the venous outflow to an extremity during exercise.[11] Despite the low load, LL-BFR training has been demonstrated to induce similar structural outcomes, such as muscle hypertrophy and improved muscle strength compared to traditional heavy-load resistance training (HL-RT) (70-80% of 1RM).[12] LL-BFR has been used in clinical rehabilitation of various musculoskeletal conditions (i.e. anterior cruciate ligament injuries, knee osteoarthritis, patellofemoral pain) and has demonstrated superior physical function and structural outcomes compared to intensity-matched resistance training[13] and comparable outcomes to those of HL-RT.[14] A potential mechanism is that LL-BFR training seems to induce increased levels of hormone (i.e. growth hormone) and immune responses of similar magnitude compared to conventional HL-RT.[15] Increased growth hormone has been reported to positively influence Type I collagen synthesis[16] which is a key component in bone cell activity via the effect on osteoblasts. Furthermore, LL-BFR training has also been demonstrated to induce similar increases in bone metabolism compared to traditional strength training.[17] Therefore, athletes rehabilitating with a LL-BFR training program may increase bone mass and connective tissue healing without exposing the body to the same amount of physical stress as would occur during HL-RT.[18] The purpose of this case series was to describe an exercise program utilizing LL-BFR training for athletes with running-related MTSS.

CASE DESCRIPTION: PATIENT HISTORY, PHYSICAL EXAMINATION, AND OUTCOME SCORES

PATIENT HISTORY

One handball player, one soccer player, and four runners, all recreational athletes with symptoms corresponding to MTSS, were recruited through posters, social media, friends, and fellow athletes in Region Zealand Denmark. Included athletes were aged 15-50 years with a history of pain at the distal two-thirds medial border of the tibia during or after activity. Their pain had to have been reproduced with palpation in a continuous area larger than 5 cm in length. Athletes with history and symptoms corresponding to compartment syndrome, tibial stress fracture, or contraindication for LL-BFR training were excluded.

Athlete 1 (runner) was a 22-year-old male with symptoms corresponding to right-sided MTSS for two months. The pain was present when running but not at rest. He had a history of anterior lateral stress syndrome one year ago in the same leg. Due to MTSS, he reduced his running level to three times a week for a total of 2-3 hours. He had not tried structured treatment for MTSS, provided by a healthcare professional.

Athlete 2 (runner) was a 21-year-old female with bilateral symptoms corresponding to MTSS for more than five years. The pain was present primarily when running but not at rest. She had stopped running and walked for 45 min twice a day instead. She also felt pain in the lower extremities during resistance training. She used to play badminton years ago but had to stop this, too. She was advised by a physician to do muscle stretching exercises, use analgesics, and reduce activity, but with no effect.

Athlete 3 (soccer) was a 22-year-old male with bilateral symptoms corresponding to MTSS for the prior year. The pain was present during activities related to soccer but not at rest. He played soccer and ran 5 km twice a week, respectively. Despite experiencing pain during exercise, he did not discontinue or use analgesics. He had not tried structured treatment for MTSS, provided by a healthcare professional.

Athlete 4 (runner) was a 24-year-old female with bilateral symptoms corresponding to MTSS for more than five years. The pain was present during activities related to running but not at rest. She was running two times per week for approximately 30 min despite experiencing pain during running; she did not discontinue or use analgesics. She had not tried structured treatment for MTSS, provided by a healthcare professional.

Athlete 5 (handball) was a 16-year-old female with bilateral symptoms corresponding to MTSS for the prior four years. The pain was present primarily during activities related to handball but not at rest. She played handball twice a week and participated in gymnastics once a week. She had not tried structured treatment for MTSS, provided by a healthcare professional.

Athlete 6 (runner) was a 24-year-old female with bilateral symptoms corresponding to MTSS for more than five years. The pain was more intense in the left leg. The pain was present primarily during activities related to running but not at rest. Due to MTSS, she reduced her running level. She was running one time per week for 30 min and participating in CrossFit training three times per week, respectively. She was using analgesics in connection with running. She had not tried structured treatment for MTSS, provided by a healthcare professional.

PHYSICAL EXAMINATION

All participants underwent a thorough examination to ensure they were eligible for participation. The potential for compartment syndrome was assessed by history using the algorithm suggested by Winters,[19] which included the following symptoms: *cramping, burning pain over the posterior compartment*, and *numbness, pins, and needles in the foot during exercise*. Indications of tibial stress fracture were: known palpation pain less than 5 cm in length, a positive percussion test of the medial and lateral malleolus with referred pain to the tibia or fibula bone, respectively, or a local pain to the tibia or fibula by a jump test.[20-22] Participants would also be excluded if there was a history of diseases related to blood circulation, e.g., swelling or varicose veins.[11]

Written informed consent was obtained from all participants. The study conformed to the standards set by the Declaration of Helsinki as well as by the procedures stated by The Danish National Center for Ethics. The study was approved by the local research ethics committee, University College Absalon, Region Zealand Denmark. In addition, all participants gave written informed consent that the data concerning the case would be submitted for publication.

OUTCOME SCORES

A standardized and individualized running test was developed with inspiration from a protocol described by Schütte et al. 2018.[23] The running test took place at a 400 m athletic track. The test was standardized by having the participants stop running after a maximum of eight laps, equivalent to 3200 m, or if they experienced a perceived level of pain of NRS=7 (numeric rating scale; from 0: *no pain* to 10: *maximum pain*). A change in NRS pain score by 2 points is considered the minimal clinically important difference (MCID) in chronic pain conditions.[24] The test was individualized and reproducible by the participants, who were instructed to maintain a consistent self-chosen speed throughout the test, measured with a GPS watch. The running distance covered and pain level before and after running were recorded.

Figure 1. Handheld digital algometer

The participants' local pressure pain threshold (NRS 0: *no pain* to 10: *maximum pain*) was measured using a handheld digital algometer (Figure 1: Commander™ Algometer, JTECH Medical, Midvale, Utah, USA) following a standardized protocol with inspiration from Aweid et al. 2013.[25]

The pressure surface was 1 cm^2, and the pressure threshold was a maximum of 30 Newton (N) or when stopped before that level by the participant. By testing healthy individuals before the study, it was determined that 30 N was the threshold for experiencing discomfort by standardized algometry at the area of MTSS. Aweid et al. reported intrarater reliability from moderate to excellent (ICC 0.53–0.90) and concluded that pain pressure threshold algometry could be incorporated into MTSS clinical assessment to assess pain and monitor progress objectively. The participants were supine on the examination table with support under both feet; thus, the calf muscles did not touch the surface. Algometry was assessed bilaterally at the most tender point located by palpation, in a horizontal and posterior-lateral direction, for evaluating the periosteum and muscle tissue, respectively. The distance from the most tender point to the apex of the medial malleolus was recorded to ensure the exact location for the post-test.

Change in self-reported physical function was assessed by the Lower Extremity Functional Scale (LEFS) questionnaire[26] and the Patient Specific Functional Scale (PSFS).[27] LEFS has a total score ranging from 0: *extreme difficulty or inability to perform activity* to 80: *no difficulty*. LEFS is valid and reliable for assessing change in persons with chronic conditions.[26] The MCID for LEFS is 9 points.[26] The PSFS was used accordingly to an individual running-related ac-

Figure 2. The LL-BFR training calf raise exercise for Levels 1 and 2 from A) standing with flat feet on the floor to B) heel-lift. The Level 3 exercise was carried out on one leg. The occlusion band is visible proximally on the right thigh.

tivity. The scoring scale (NRS) ranges from 0: *unable to perform the activity* to 10: *able to perform the activity as before the problem arose*. PSFS is valid, reliable, and responsive in individuals with a limited number of acute, subacute, and chronic conditions.[27] The MCID for PSFS is 2-3 points across various conditions.[27]

Pre-tests were collected on the day of the beginning of the intervention, and post-tests took place one week after the last training session to avoid possible influence from the previous training session.

INTERVENTION

The participants completed a six-week home-based progressive LL-BFR training intervention with three training sessions per week (a total of 18 sessions). A training session consisted of calf raises, given the association between reduced plantar flexor strength and endurance and MTSS (Figure 2).[28] This included four sets of LL-BFR training with a 30-15-15-15 repetition scheme (75 total repetitions) and 30 seconds of rest between sets.[11]

The participants were instructed to keep the standard elastic occlusion band (width 5 cm) tightened throughout all four sets and placed most proximally on the symptomatic leg.[29] The occlusion band was tightened corresponding to NRS=7 (0: *no sensation of tightness* to 10: *maximal sensation of tightness*).[30] Before starting the home-based training, all participants were instructed to tighten the occlusion band under the practical guidance of a physiotherapist, who ensured proper application until the participants felt comfortable and confident in performing the procedure independently. This training ensured the occlusion of venous backflow (visually dilated superficial veins) without causing arterial occlusion (palpable posterior tibial artery pulsation). Regarding participants with bilateral MTSS symptoms, the participant performed the training protocol on each leg separately.

The calf raise exercise was carried out as continuous cyclic movements from standing with flat feet on the floor to the heel(s) being lifted as much as possible for 1-2 seconds and then lowered for 1-2 seconds until the entire foot was placed on the floor again. The exercise was performed wearing training shoes. The participants were allowed to use their hands to support their balance and keep an upright position, with their feet pointing straight forward, hip-width distance apart.

The LL-BFR training progression was developed using table values on load (% of 1RM) and the corresponding number of repetitions.[31] Accordingly, 30 repetitions of one-leg calf raises (Level 3) corresponded to 45% of 1RM and thus deemed acceptable for the 30-15-15-15 repetitions LL-BFR training protocol. The LL-BFR training intervention followed a standardized progression every second week. Level 1 (weeks one and two): both heels were lifted simultaneously with even weight bearing. Level 2 (week three and four): both heels were lifted simultaneously with more weight on the occluded leg. Level 3 (week five and six): the exercise was performed on one leg. Two persons from the author group, one with MTSS, conducted the three levels of LL-BFR training in parallel with the participants for first-hand expression of the progression of the intervention. Data from these persons were not included in the present study.

After three weeks of training, individual mid-term interviews were held with the participants regarding potential side effects, adherence, practical matters (such as correct tightness of the occlusion band), experience of progression from Level 1 to 2, and the opportunity to ask questions. The participants were encouraged to contact the project team by phone or e-mail if they had questions about the training. If deemed necessary, a physical meeting would be arranged. Continuation of training (soccer, handball, and running) was allowed as long as the pain level did not exceed NRS 5. The participants filled in a training diary with a record of all training sessions, the progression of exercises, and any potential side effects of the training.

OUTCOMES

An overview of the individual results is presented in Table 1.

Athlete 1 (runner) had a post-test pain reduction of 2 NRS points in the running test and completed the total distance without pain. Overall, there was no change in pain by algometry in the periosteum or muscle. The self-reported improvement in LEFS was 7 points, and PSFS 6 points.

Athlete 2 (runner) had no post-test pain change in the running test and completed with NRS 7. However, the running distance was increased by 600 m (86%). Overall, the post-test pain by algometry was unchanged (NRS 8) for both periosteum and muscle. The self-reported improvement in LEFS was 13 points, and PSFS 4 points.

Athlete 3 (soccer) had no post-test pain change in the running test and completed with NRS 7. However, the running test was terminated prematurely due to pain caused by a calf muscle strain from playing soccer a few days before the post-test. Overall, the post-test pain by algometry increased with 3 NRS points to NRS 5-7 for both periosteum and muscle. The self-reported change in LEFS was a reduction of 1 point and an improvement in PSFS by 4 points.

Athlete 4 (runner) had a post-test pain reduction of 7 NRS points in the running test and completed the total distance without pain. Additionally, the running distance was increased by 250 m (26%). Overall, the post-test pain by algometry decreased with 1-4 NRS points to approximately NRS 5 for both periosteum and muscle. The self-reported improvement in LEFS was 4 points and PSFS 7 points, respectively. The LEFS post-test score was 77 points, and thus close to the highest possible score of 80 points.

Athlete 5 (handball) had a post-test pain reduction of 1 NRS point in the running test and completed the total distance with NRS 4. Overall, the post-test pain by algometry was unchanged (NRS 6-7) for both periosteum and muscle. The self-reported improvement in LEFS was 21 points, and PSFS 5 points.

Athlete 6 (runner) had a post-test pain reduction of 2 NRS points in the running test and completed the total distance without pain. Overall, the post-test pain by algometry decreased with 1-5 NRS points to NRS 2-6 for both periosteum and muscle. The self-reported improvement in LEFS was 7 points, and PSFS 5 points. The LEFS post-test score was 80 points, and thus, the highest possible score.

MID-TERM INTERVIEWS

The participants expressed that it required practice to find the correct tightness of the occlusion band, but after a few attempts, it worked well. Athlete 1 felt the first level of progression was too easy. Athlete 2 had experienced cramps in the feet during the first week of Level 1 LL-BFR training. Consequently, an expert in LL-BFR training was consulted (MHH). The athlete was advised to do calf raises without the occlusion band to test if the cramping was related to the restriction in blood flow. The cramping of the feet continued without the use of the occlusion band. After a short period of treatment of the plantar muscles of the foot in week two of the intervention, the symptoms stopped, and the LL-BFR training continued.

POSTINTERVENTION INTERVIEWS

Individual interviews were conducted one week after the last training session, on the same day as the post-tests. The athletes were asked about their experiences with the LL-BFR training intervention. All expressed that they were generally positive about the training method.

Athletes 1 and 4 found the training challenging but did not experience severe muscle fatigue or subsequent muscle soreness. Athlete 1: "*It has been hard, but I haven't felt it afterward. I also haven't had muscle soreness during the process*." Athlete 4: *"... I only had a bit of muscle soreness the first few times after training."*

Athletes 4 and 6 highlighted the sensation of training with restricted blood flow. Athlete 4: "*You just have to get used to it. The way the lactic acid builds up. It is a little surprising if you are not used to it.*" Athlete 6: "*The lactic acid buildup with occlusion feels much stronger than regular strength training, but it disappears as soon as the band is loosened*." Athlete 5: "*It was nice that it wasn't 30 all the way through. It was a bit of a relief that you only had to do 15 repetitions afterward*."

The participants agreed that Level 1 (week one and two) was easy to complete, and the following weeks, especially the last two (Level 3), were challenging. Athlete 1: "*The first two weeks were easy when standing on both legs. I wasn't tired in my calves afterward. Weeks 3-4 and 5-6 were hard. During the last two weeks of training, I was on the verge of needing a little help with the other foot for the last two sets' last repetitions.*" Only Athlete 2 had difficulties completing the number of repetitions. "*The only thing I have considered is whether there were too many sets. It has always been those last two sets where I have thought, now I can't do it anymore*."

There was a consensus that it was easy to do LL-BFR training at home and not time-consuming, making it easier to complete the training. Athlete 6: "*You can train at home, and you don't need a lot of weights or machines to do the training*." One participant expressed that training with the occlusion band could sometimes be uncomfortable on the thigh as it fits very tightly. Athlete 3: "*... you have to be willing to do it because it can be uncomfortable that it tightens*."

All participants, except for athlete 2, completed all 18 training sessions as prescribed. Athlete 2 did not train in week two of the intervention and, thus, completed 15 training sessions. No side effects were reported to the LL-BFR training. Athlete 3 did not report difficulties in conducting the training despite the strained calf muscle.

DISCUSSION

This report presents six cases utilizing LL-BFR training to treat running-related MTSS. The athletes had chronic MTSS symptoms for 4-5 years, except for athlete 1, who had symptoms for two months.

Five athletes improved their running performance after completing the six-week LL-BFR training intervention, except for athlete 3, who sustained an acute calf muscle strain during the intervention period while playing soccer. Thus, the results from athlete 3 are not included in the following summary of change in the pre- to post-test outcomes scores. Three athletes achieved an MCID decrease in pain of 2 NRS from pre- to post-test and completed the total running distance with no pain (no. 1, 4, and 6). Athlete 2 did not change pain level but increased the running distance, and athlete 5 reduced pain slightly.

There was no difference in pain pressure algometry between the periosteum and muscle. Thus, this case series found no tendency regarding whether MTSS pain originated from one or the other tissue. Furthermore, the relation between performance in the running test and pain

Table 1. Pre-test and post-test outcome scores for each athlete with MTSS

	Athlete 1 Female, 22 yr. Runner MTSS right, 2 mo.			Athlete 2 Female 21 yr. Runner MTSS bilat., 5 yr.			Athlete 3 Male 22 yr. Soccer MTSS bilat., 1 yr.		
	Pre	Post	(Δ)	Pre	Post	(Δ)	Pre	Post	(Δ)
Running test (NRS-pain 0-10)									
Before running	4	1	(-3)	2	5	(3)	4	2	(-2)
After running	2	0	(-2)	7	7	(0)	7	7	(0)
Distance completed (m)	3200	3200	(0)	700	1300	(600)	3200	2500*	(-700)
Algometry periosteum (NRS-pain 0-10)									
Right leg	1	1	(0)	8	8	(0)	5	7	(2)
Left leg	NA	NA	NA	8	8	(0)	3	6	(3)
Algometry muscle (NRS-pain 0-10)									
Right leg	0	0	(0)	8	8	(0)	0	0	(0)
Left leg	NA	NA	NA	5	8	(3)	2	5	(3)
PROMS									
LEFS (Score 0-80)	66	73	(7)	57	70	(13)	60	59	(-1)
PSFS running (NRS 0-10)	3	9	(6)	1	5	(4)	2	6	(4)
	Athlete 4 Female 24 yr. Runner MTSS bilat., 5 yr.			**Athlete 5 Female 16 yr. Handball MTSS bilat., 4 yr.**			**Athlete 6 Female 24 yr. Runner MTSS bilat., 5 yr.**		
	Pre	Post	(Δ)	Pre	Post	(Δ)	Pre	Post	(Δ)
Running test (NRS-pain 0-10)									
Before running	2	0	(-2)	0	0	(0)	0	0	(0)
After running	7	0	(-7)	5	4	(-1)	2	0	(-2)
Distance completed (m)	2950	3200	250	3200	3200	(0)	3200	3200	(0)
Algometry periosteum (NRS-pain 0-10)									
Right leg	9	5	(-4)	7	6	(-1)	7	4	(-3)
Left leg	9	6	(-3)	8	7	(-1)	8	6	(-2)
Algometry muscle (NRS-pain 0-10)									
Right leg	6	4	(-2)	6	6	(0)	7	2	(-5)
Left leg	7	6	(-1)	7	7	(0)	7	6	(-1)
PROMS									
LEFS (Score 0-80)	73	77	(4)	53	74	(21)	73	80	(7)
PSFS running (NRS 0-10)	2	9	(7)	3	8	(5)	3	8	(5)

NA: Not applicable
PROMS: Patient-reported outcome measures
LEFS: Lower extremity functional scale. 0: *Extreme difficulty to perform activity* to 80: *No difficulty to perform activity*
PSFS: Patient specific functional scale. 0: *Extreme difficulty to perform the specific activity* to 10: *No difficulty to perform the specific activity*
*The running test was terminated prematurely due to pain in the lower extremity other than MTSS

pressure algometry was inconsistent. Regarding athletes 1, 2, and 5, there was a relation between low (NRS 0), high (NRS 7), and moderate pain (NRS 4) after the running test and low (NRS: periosteum 1 and muscle 0), high (NRS: periosteum 8 and muscle 8), and moderate pain (NRS: periosteum 6-7 and muscle 6-7) by the pressure algometry test, respectively. This relation is supported by evidence suggesting a relationship between increased muscle pain by pressure algometry and decreased physical performance.[32] Conversely, athletes 4 and 6 experienced no pain (NRS 0) after the running test but had moderate pain (NRS: periosteum 4-6 and muscle 2-6) by the pressure algometry test. However, However, both athletes experienced reduced post-test pressure pain (NRS: periosteum -2 to -4 and muscle -1 to -5), which potentially influenced the running test positively (NRS reduction of -7 and -2, respectively). This inconsistent finding may indicate that running is a function that involves many muscles and can be performed with individual techniques, which involve muscles differently. Overall, the evidence is sparse on the effect of LL-BFR training in patients with chronic musculoskeletal conditions related to the connective tissue, such as tendinopathies and MTSS.[33]

All five athletes improved their self-reported level of function by 4-21 points, and two athletes reported a MCID of ⩾ 9 points, with final LEFS scores between 70 and 80 points (80 points= *No difficulty to perform activity*). There was a ceiling effect when using the LEFS for athletes 4 and 6. The pre-test score was 73 points; thus, achieving a MCID of 9 points was impossible. All five athletes improved their self-reported running-related activities by 4-7 NRS points (exceeding the MCID of 2-3 points), with final PSFS scores between 5 and 9 points (10 points= *Able to perform the activity as before the problem arose*). This result is consistent with all participants' improvement in the standardized running test.

In the interviews, the six athletes said they were generally positive about the training method. They found the progression easy at the beginning and strenuous at the end. The training was easy to perform once they gained experience in tightening the occlusion band optimally. There were no side effects or adverse events from the training. All participants continued their sport throughout the intervention period.

This case series details a novel therapeutic home-based progressive exercise program utilizing LL-BFR training for athletes with running-related MTSS along with a standardized and individualized running test, which has some methodological strengths and weaknesses.

LL-BFR training was evaluated as a novel treatment method for athletes with running-related MTSS in a clinical practice setting. The study presents the process beginning with the systematic differential diagnostic examination, which minimizes the potential risk associated with LL-BFR training. Then, continuing with an intervention tailored to each participant's body weight, facilitating a pragmatic approach to load progression without the need for additional strength training equipment. The intervention consisted of a progressive single, technically simple exercise, which enhanced participant adherence. The LL-BFR training was sufficiently manageable, considering the athletes' MTSS, allowing them to continue their sports activities. The standardized running test was individualized based on each athlete's natural running speed and monitored with a GPS watch, enabling reproducibility of the running speed during the post-test. This approach allowed for the assessment of changes in pain and running distance.

There are some limitations to the study. Firstly, this is a case series with a low number of participants which limits the generalizability to a broader population.[34] The findings may be specific to the particular cases and not applicable to other people with the same condition. Thus, there is a higher risk of bias and random chance. Due to the non-randomized, non-controlled, and non-blinded design, the results cannot infer a causal effect, and the results of this case series should be interpreted with caution. Additionally, there was no follow-up after the intervention post-test, so it remains uncertain if the changes in MTSS are permanent. Therefore, a future high-quality randomized controlled trial, with a long-term follow-up period on the level of function and pain, is needed in testing the effectiveness of an exercise program utilizing LL-BFR training for athletes with running-related MTSS. Further, it is unclear what impact limiting the participants to practice their sport only up to a pain level of a maximum of NRS 5, thereby reducing their activity during the intervention period, has had on pain reduction and improved function. Since this study did not monitor and record the participants' sporting activities the potential variability between cases could have influenced the results of this case series. There is no consensus on the duration (weeks) and frequency (sessions per week) of LL-BFR training, but a training volume of three training sessions per week for six weeks is frequently reported.[15,33] Therefore, it is unclear if the applied intervention for this study is optimal, and how extra practices or exercise (dose-response) could affect the findings. As a result of the pragmatic choice of an occlusion band instead of an inflatable thigh cuff with an attached sphygmomanometer, it is not known to what extent blood flow was restricted.[35] However, there are wide variances in occlusion pressures throughout studies, with recommended pressures typically ranging between 40–80% of total arterial occlusion pressure.[33] Furthermore, with the approach presented in the present study with very tight occlusion bands (NRS 7), visually dilated superficial veins, and the statements from the participants regarding training intensity, it must be assumed that all athletes have performed LL-BFR training and not only performed calf raises. Nonetheless, the use of non-standardized occlusion pressures is a less reliable method compared to an inflatable thigh cuff with an attached sphygmomanometer. The intervention was carried out as unsupervised home-based training. Although participants completed an exercise diary and reported good adherence, there is potentially greater variability compared to supervised exercise.

CONCLUSION

This case series presents a therapeutic exercise program utilizing LL-BFR training, implemented in conjunction with sports activities, that reduced pain and increased function in some of the athletes with running-related MTSS. MTSS is a condition with pain potentially limiting the ability to participate in a rehabilitation program. LL-BFR training may allow clinicians to prescribe exercises at a lower load, decreasing the chance of pain during exercise. Future research should investigate the effectiveness of an intervention program with and without the use of LL-BFR training.

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