Ministry of Defence

Chronic exercise-related leg pain:
Diagnosis and treatment in the armed forces

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Chronische inspanningsgebonden onderbeenklachten: *Diagnose en behandeling bij militairen*

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This thesis was prepared at the University of Utrecht, department of Rehabilitation, Physical therapy science and Sport, Utrecht, The Netherlands, in collaboration with the Ministry of Defense.

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Chronische inspanningsgebonden onderbeenklachten: diagnose en behandeling bij militairen

(met een samenvatting in het Nederlands)

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During my first days as physician on base I saw several recruits with exercise-related leg pain (ERLP) in my office. Coming from aquatic sports I had little clinical experience with the treatment of this group of overuse injuries. So, I walked into the office of a senior colleague and asked him what the treatment protocol for ERLP was. His answer was simple:

1. rest;
2. gradual resumption of walking and running;
3. back to active duty or
4. medical discharge.

It was believed that ERLP in the military was a fact of life and that no treatment approach could truly make a difference for the patient or the armed forces.
I have been on a quest ever since....

Opportunities arise

One of the assignments of the department of Military Sports Medicine is to improve the treatment protocols for overuse injuries in the Royal Netherlands Armed Forces. In 2011, the Chief Inspector of all Military Medical Services ordered that special attention be directed toward the improvement of the treatment of ERLP and that better cooperation occur between the three centers for secondary care. I was given the honor to lead the project and was allowed to spend the majority of working hours towards this ERLP project.
In 2012, I gave a lecture on ERLP in the Royal Netherlands Armed Forces at the Uniformed Services University of the Health Sciences in Bethesda, Maryland, USA. By kind invitation of Professor Reamy, Associate Dean for Faculty, I was given the opportunity to join the academic advancement program, which provides researchers a chance to grow from assistant professor, to associate professor and finally to full professor, in the course of about eight years. At USUHS, many experienced military medical scholars are available to assist with the design of clinical studies and the writing of scientific papers.

By kind invitation of Professor Backx, University of Utrecht, The Netherlands, I was asked to bundle my research efforts into a thesis that could lead to the award of a PhD title by the University in (sports) medicine. This provided the opportunity to sharpen my scientific thinking and writing further under expert guidance.

This thesis is the culmination of many years of hard work and the support of many learned people.

Contents

Chapter 1

General introduction

1. Exercise-related leg pain in the armed forces

Exercise-related leg pain (ERLP) is a regional pain syndrome described as pain between the knee and ankle which occurs with physical exercise. Medial Tibial Stress Syndrome (MTSS), Chronic Exertional Compartment Syndrome (CECS), tibial and fibular stress fractures, tendinopathy, nerve entrapment, and vascular pathology are the diagnoses that are usually included in the ERLP group. [1] ERLP is strongly associated with military activities and military physicians have been in the lead to develop treatment concepts. In fact, Reneman, in the military hospital in Utrecht, The Netherlands, was one of the first worldwide to clearly describe CECS patients in a PhD thesis and he introduced diagnostic criteria and a surgical treatment procedure around 1968. [2-4]

2. Epidemiology

In the military, especially in recruits and infantry soldiers, a high prevalence of overuse injuries of the lower leg is reported. [5-7] Young soldiers tend to develop complaints on the anterior side of the lower leg, such as MTSS or CECS. [8] Older service members are more prone to develop overuse injuries to the posterior side of the lower leg, such as non-specific calf complaints and Achilles' tendinopathy. [8] The highest reported incidence of MTSS in a military setting was 35% of 124 naval recruits participating in basic military training in Australia. [5] An estimation of the incidence of CECS in the US military is approximately one in 2000 persons per year. [9]

There is a lack of longitudinal epidemiologic data regarding lower leg injuries in the Netherlands Armed Forces. However, several cohort studies have shown that ERLP is in the top three of overuse injuries that result in termination of a training course and that soldiers with ERLP remain longer in remedial platoons than those with other overuse injuries. [10,11] In the Netherlands Armed Forces, MTSS and CECS, or a combination of the two, are the two most common diagnoses in the ERLP group. [11] In contrast to American and British military literature, stress fractures to the tibia are extremely rare in the Netherlands Armed Forces. [12,13] A study among British recruits reconfirmed that MTSS has a high incidence and a long rehabilitation time, making it the overuse injury with the greatest impact on military training. [14]

3. Anatomy

Figure 1 illustrates the anatomy of the lower leg. The lower leg contains two bones, tibia (medially) and fibula (laterally). The transverse section shows that the leg is divided into four compartments (I – IV), separated by tight muscle coverings, named fasciae (green lines). The trajectory of neurovascular bundles is closely associated with the fascia. Table 1 describes the main structures in each compartment and their motor and sensory actions.

Figure 1.
Anatomy of the lower leg and preferred routes for elective surgery (incision). Note the four compartments are demarcated by green lines: I = Anterior compartment; II = Lateral or Peroneal compartment; III = Superficial posterior compartment; IV = Deep posterior compartment.
Source: *Nederlands Tijdschrift voor Geneeskunde* 2004;148(45):2205-2209.

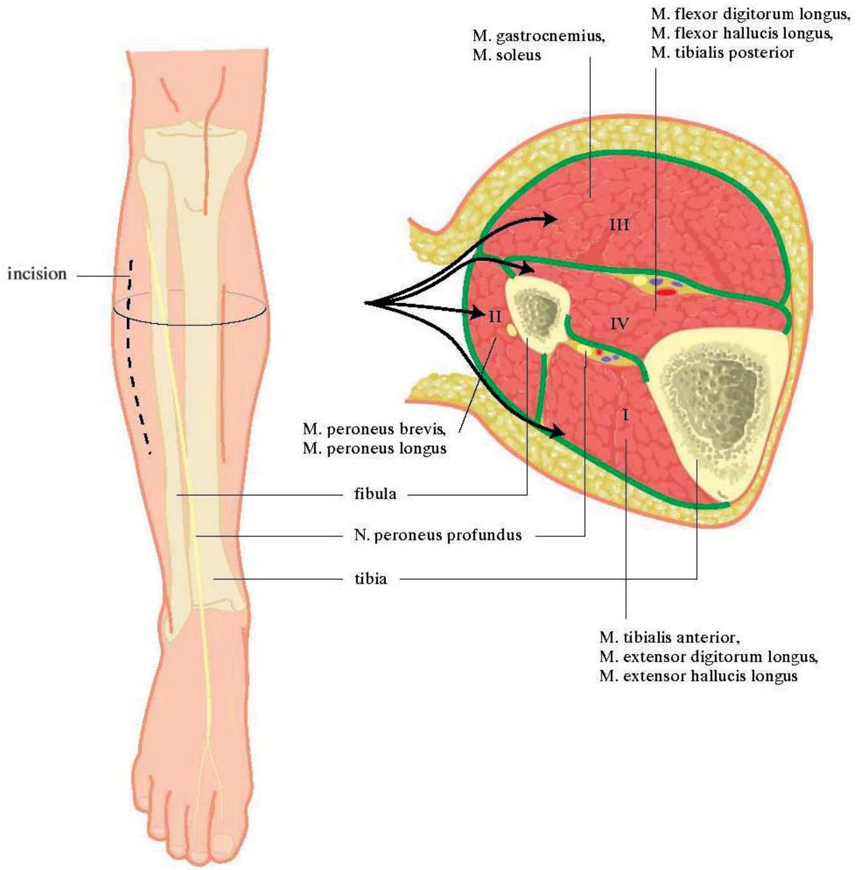

Table 1.
Four compartments of the leg, structures and actions.
(I-IV, see corresponding numbers in Figure 1)

Compartment	Anterior (I)	Lateral (II)	Superficial posterior (III)	Deep posterior (IV)
Muscles	m. tibialis anterior	m. peroneus brevis and longus	m. gastrocnemius and m. soleus	m. tibialis posterior
Nerves	n. peroneus profundus	n. peroneus superficialis	n. suralis	n. tibialis
Motor actions	dorsal flexion	eversion	plantar flexion	inversion / plantar flexion
Sensory areas	1st web space of foot	dorsum of foot	lateral foot and distal calve	plantar surface of foot

4. MTSS and CECS, clinical presentation

MTSS is an overuse injury involving the interface of the tibial bone and the soft tissue. [15,16] In this case, the soldier reports pain during running and jumping activities over the posterior medial tibial border, by definition an area of 5 cm or more is tender on palpation. In the early stages of overuse, the pain will disappear after warming up, allowing relatively pain-free participation in the main athletic event. However, in later stages of overuse, any walking, running and/or jumping is severely limited by pain, which can last into the next day(s). The natural tendency to heal is favorable. Prolonged rest with targeted stretching and strengthening of leg musculature are associated with activity resumption in most cases. [7]

The soldier with CECS reports a cramping or burning sensation on the anterolateral side of the leg (anterior or lateral compartments) or deep in the calf (deep posterior compartment). The pain is most often related to running or marching, begins at a predictable point after exercise initiation and disappears quickly at cessation of activities, usually within 15 minutes, although in severe cases the pain can persist longer. The natural tendency to heal is poor. Without adequate therapy, patients will remain unable to run or march for many years and are forced to permanently reduce their sporting activities. [2,15-17]

5. MTSS and CECS, etiology

The etiology of both MTSS and CECS is not completely understood.
Two theories explaining the pathophysiology of MTSS exist. The first theory suggests that MTSS is caused by traction at the origin of the attaching muscles. [18] Recent anatomic studies reconfirm that musculus soleus and musculus flexor digitorum longus, both very active in running and jumping activities, attach to the tibial sites most involved in MTSS. [19] The second theory suggests that bending forces on the tibia cause bony overload in which resorption outpaces bone formation, and argues that MTSS may be a precursor to stress fractures. [18] Recent histological evidence shows that accumulation of unrepaired microdamage may indeed underlie the pathophysiology of

MTSS.[20] Probably the "traction" and the "bending" theory of MTSS pathogenesis are relevant in combination.[21]
CECS is traditionally characterized by elevated pressure in a muscular compartment during exercise, which returns to normal with cessation of exercise. Some researchers claim that the increased intracompartmental pressure leads to disrupted local tissue perfusion,[22,23] but others doubt this.[24-26] Pressure in a muscular compartment can rise acutely (acute compartment syndrome, ACS) or repeatedly with exercise (CECS). ACS is usually caused by trauma. ACS caused by exercise is a very rare condition,[27,28] and thought to develop in patients with preexisting CECS.[2,4,29] CECS can be present in any muscular compartment of the human body, but is most prevalent in the anterior compartment of the lower leg and the symptoms of CECS depend on structures located in the affected compartment, particularly nerves (see Table 1).[2,30]

6. MTSS and CECS, diagnosis and treatment until the year 2013

The first clinical study for this thesis was initiated in 2013. Therefore, in this introduction the international literature until 2013 is summarized.
The diagnosis of MTSS may be confirmed with history and physical examination alone. When in doubt, other diagnoses can be excluded by additional investigations (e.g. stress fracture by advanced imaging, such as MRI).[18]

Figure 2.
The Stryker pressure monitor.
Note: the patient is supine (not depicted), the legs are hanging over the edge of the table.

To confirm the diagnosis of CECS, an Intracompartmental Pressure Measurement (ICPM) is necessary. In the Central Military Hospital (CMH), Utrecht, The Netherlands, the Stryker pressure monitor is used to perform the ICPM in the first minute after exercise (Figure 2). The local criterion for surgery is 35 mm Hg post exercise, established by Verleisdonk, for the anterior compartment. [31] In the CMH, usually two compartments are tested (anterior right and left); rarely more compartments are tested.
Several treatments for MTSS have been described in the literature, including: reduction of running and jumping, icing, massage, stretching and strengthening exercises, attention to biomechanical factors such as over-pronation, ultrasound therapy, sports compression stockings, lower leg braces, pulsed electromagnetic fields, and extracorporeal shockwave therapy (ESWT). [32,33] There is no hard evidence for the effectiveness of any of these interventions in treating MTSS and none of the studies are sufficiently free from methodological bias to recommend any of the treatments investigated. Therefore, the optimal management of MTSS remains unclear. [33] Of those treatments examined, ESWT appears to have the most promise. [33]
Treatment for CECS has traditionally been surgical. Several authors have proposed that non-operative treatment of CECS rarely leads to complete resolution of symptoms or return to previous levels of athletic or military activity; thus, surgery (fasciotomy) has been strongly recommended as a first line of treatment and been termed the gold standard of treatment. [34-36] In the CMH, every patient with anterior CECS and a positive pressure test received fasciotomy without delay until 2013, following the protocol by Verleisdonk. [31] Figure 1 illustrates the preferred route for incision for elective fasciotomy. The principle goal of fasciotomy is pressure reduction in the compartment and it is proposed that an incision along 90% of the length of the compartment is necessary to achieve optimal results. [37]

Unfortunately, it also has been recognized that the results of fasciotomy and return to former activity level are less favorable in the military population. [38] In The Netherlands, a two-year follow-up of 44 anterior CECS patients after surgery in the CMH showed that only 15 patients (34%) had returned to their original military jobs, 28 patients (64%) had left the military, and 25 patients (57%) still had symptoms of exercise-related leg pain. [39]

Diebal, et al. were the first to report that gait retraining for running was effective in reducing complaints and intramuscular compartment pressure in military personnel with CECS. [40] Their study population was homogeneous concerning young and fit officers in training with CECS of the anterior compartment only.

7. Organization of care in the armed forces until the year 2013

In the Royal Netherlands Armed Forces, the physician on base is responsible for starting the treatment of ERLP. There is no specific treatment protocol for ERLP; each physician works according to clinical experience, using available on-base resources. The physician can refer the patient to a physical therapist on base and may invite the patient to return for monthly visits to discuss treatment progress. In general, treatment programs on base should lead to return to full duty and are divided into four phases: 1. Physical therapy phase I; 2. Physical therapy phase II; 3. Sports phase; 4. Military specific phase. The transfer from one phase to the next is based on objective test results, such as a pain free 12-minute run, which is one of the requirements to enter phase 3 (the sports phase) of rehabilitation. The physician on base may refer the military patient to secondary care if clinical progress is insufficient. Three centers for referral are available for military personnel: 1. The CMH, department of general surgery, for advanced diagnostic procedures and surgical care; 2. The department of Military Sports Medicine, for outpatient rehabilitation programs and 3. The Military Rehabilitation Center (MRC) for inpatient rehabilitation programs. All three centers have distinct treatment approaches.

8. Aims of the thesis

As described before, new elements in the conservative treatment of ERLP, presented in the literature around 2013, were extracorporeal shockwave therapy (ESWT) for MTSS and gait retraining for CECS. The principle aim of this thesis was to investigate the usefulness of these two new treatments, ESWT and gait retraining, for service members with chronic ERLP and to report the overall treatment results of our comprehensive treatment programs for MTSS and CECS, with a follow up. During the years of exploration additional sub-questions were raised, specific to our patient population, such as: Can the same gait retraining cues be used for running in shoes and running in military boots?
In summary, the following studies were undertaken: a review of the Dutch and English literature on ERLP in the military (Chapter 2); a description and evaluation of a new diagnostic protocol for ERLP in the CMH, department of surgery (Chapter 3); an evaluation of the immediate effects of ESWT on MTSS (Chapter 4); the effect of gait retraining on intracompartmental pressures in patients with CECS (Chapter 5); the effectiveness of a comprehensive treatment program, incorporating ESWT and gait retraining, for patients with MTSS, with a one year follow-up (Chapter 6); can the same gait retraining cues be used for running in shoes and running in military boots? (Chapter 7); which gait retraining cue reduces vertical ground reaction forces the most? (Chapter 8); the effectiveness of a comprehensive gait retraining program, incorporating gait retraining, for patients with CECS, with a two year follow-up (Chapter 9).
Studies were planned for the years 2013-2018.

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Chapter 2

Prevention and treatment of exercise-related leg pain in young soldiers

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A review of the literature and current practice in the Royal Netherlands Armed Forces

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ABSTRACT

Overuse injuries of the leg are a common problem for young soldiers. This article reviews the literature concerning the prevention and treatment of exercise-related leg pain in military settings and presents the latest developments in proposed mechanisms and treatments. Current practice and treatment protocols from the Royal Netherlands Armed Forces are reviewed, with an emphasis on the most prevalent conditions of medial tibial stress syndrome and chronic exertional compartment syndrome. The conclusion is that exercise-related leg pain in the military is an occupational problem that deserves further study.

KEYWORDS

- exercise related leg pain
- medial tibial stress syndrome
- chronic exertional compartment syndrome
- military
- expert opinion.

INTRODUCTION

In the military, especially in recruits and infantry soldiers, a high prevalence of overuse injuries of the lower legs is reported. [1-4] Young soldiers tend to develop complaints on the anterior side of the leg. Older soldiers are more prone to develop overuse injuries to the posterior side of the leg. [5]
There is a lack of longitudinal epidemiologic data regarding lower leg injuries in the Dutch military, however, several cohort studies have shown that exercise-related leg pain (ERLP) is one of the three most common overuse injuries that result in termination of a training course and that soldiers with ERLP remain longer in remedial platoons than those with other overuse injuries. [6,7] A recent study among British recruits reconfirmed that Medial Tibial Stress Syndrome (MTSS) has a high incidence and a long rehabilitation time, making it the overuse injury with the greatest impact on military training. [8]

MTSS and CECS

MTSS and Chronic Exertional Compartment Syndrome (CECS) are the two most common types of ERLP of young soldiers in the Dutch military. [7] In contrast to American and British military literature, stress fractures to the tibia are extremely rare in the Royal Netherlands Armed Forces. [9,10] It is assumed that American and British recruits do more running, in shorter training courses, whereas Dutch recruits do more marching and their training courses are, on average, longer. The highest reported incidence of MTSS in a military setting was 35% of 124 naval recruits participating in basic military training in Australia. [4] CECS occurred in US Army soldiers at a rate of 0.49 cases per 1000 person-years (4100 cases diagnosed in six years). [11] The relative risk for young female soldiers to sustain an overuse injury is 2.5 in the Dutch military and the relative risk for young female soldiers to sustain an overuse injury in the ERLP category has been reported between 1.11 and 3.1 (Table 1). [6]

MTSS is an overuse injury involving the interface of the tibial bone and the soft tissue. [31,32] The young soldier reports pain with running and jumping activities over the (posterior) medial tibial border. By definition an area of 5 cm or more is tender on palpation. In the early stages of overuse, the pain will disappear after warming up, allowing relatively pain-free participation in the main athletic event, however, in later stages of overuse, any walking, running and/or jumping is severely limited by pain, which can last into the next day(s). The natural tendency to heal is favorable. Prolonged rest with targeted stretching and strengthening of leg musculature are associated with activity resumption in most cases. [1]

CECS is traditionaly characterized by elevated pressure in a muscular compartment during exercise, which returns to normal with cessation of exercise. Some researchers claim that the increased intracompartmental pressure leads to disrupted local tissue perfusion, [33,34] but others doubt this. [35-37] Pressure in a muscular compartment can rise acutely (acute compartment syndrome, ACS) or repeatedly with exercise (CECS). ACS is usually caused by trauma. ACS caused by exercise is a very rare condition. [38,39] thought to develop in those who already had CECS. [40-42] ACS demands immediate surgical treatment (fasciotomy) to maintain viability of the structures in the muscular compartment. [39,42,43] CECS can present in any muscular compartment of the human body, but is most prevalent in the anterior compartment of the leg and the symptoms of CECS depend on structures located in the affected compartment, particularly nerves. [42,44]

The young soldier with CECS reports a cramping or burning sensation on the anterolateral side of the leg (anterior or lateral compartments) or deep in the calf (deep posterior compartment). The pain is most often related to running or marching, begins at a predictable point after exercise initiation and disappears quickly at cessation of activities, usually within 15 minutes, although in severe cases the pain can stay on longer. The natural tendency to heal is poor. Without adequate therapy, patients will remain unable to run or march for many years and are forced to permanently reduce their sporting activities. [42, 45-47]

METHODS

This article reviews the literature concerning the prevention and treatment of ERLP in military settings and describes the current practice of ERLP care in the Dutch military. A comprehensive search was conducted that included MEDLINE (PubMed) for articles in English that were related to ERLP in the military, using the following (truncated) search terms in different combinations: MTSS, CECS, ERLP and military. The latest consultation of Pubmed was December 2015. The intention of this article is to assist healthcare professionals to better help military patients.

RESULTS

Prevention

Initial medical assessment and intrinsic risk factors

The initial medical assessment before employment in the military provides the first opportunity to prevent ERLP as the screening physician can look for intrinsic risk factors for ERLP (Table 1), although these risk factors for the development of ERLP in a military setting are often based on small sample sizes with conflicting results. In a review and meta-analysis, it is suggested that addressing body mass index (BMI), navicular drop, ankle plantarflexion range of motion and hip external rotation range of motion may be a good starting point for preventing and treating MTSS. [1]

There are no prospective studies that determine which of the risk factors for ERLP reported in Table 1 are most relevant in the Dutch military. Based on a consensus meeting of senior physicians the following five risk factors are deemed most important in the Dutch military setting: current status (injured at the time of medical examination), a history of ERLP, technique of running and marching, female gender and little prior weight bearing physical training (defined as: several years of participation in a sport with leg loading such as soccer, track and field, basketball, etc.).

If a recruit has several risk factors for the development of ERLP, particularly the five identified above, the physician performing the initial medical assessment can take the following preventative measures: (1) the recruit will be assigned a military job where running and marching is of less importance. (2) the recruit is temporarily denied access to the military to heal and to work on modifiable risk factors or (3) the recruit is denied access to the military permanently when the risk profile for ERLP is very unfavorable.

Following the initial medical assessment, the most important factor to prevent injury in military training is a carefully graded increase in physical loading as the literature clearly shows a relationship between weekly training volume (especially running and marching) and the number of injuries to the lower extremity. [48-53] The training load must agree with the physical properties of the recruit.

Changing training programs and extrinsic risk factors

It is known that incorporating moments of extra rest,[54] incorporating extra stretching exercises, [55-57] or assigning running shoes based on plantar shape do not reduce the number of overuse leg injuries in military settings. [58-60] In addition, daily supplementation of calcium or prophylactic treatment with bisphosphonate (risedronate) do not reduce the risk of bone stress injuries to the leg. [61,62] Conversely, there is evidence that calcium plus vitamin D supplementation does reduce the number of lower extremity stress fractures in female recruits with insufficient calcium intake. [63] In contrast to all the negative findings, one recent study showed that gait retraining during Basic Military Training (BMT), including biofeedback on risk factors and a battery of exercises to improve neuromuscular condition, can reduce the incidence of MTSS. [64]

The role of shoe inlays in the military setting to prevent injury has been controversial for many years.

Several facts regarding shoe inlays are known. Cushioning insoles in the boots can reduce maximal pressure to the heel and forefoot by 37% and 24%, respectively, and users report comfort when wearing them, [65-67] but there is limited evidence that the use of shock absorbing insoles reduces the number of injuries. [66-70] Providing custom made biomechanic shoe orthoses shows promising results in some studies, [69,71] but three systematic reviews all conclude that more research is necessary to underpin an evidence based policy for providing customized shoe orthoses for asymptomatic military recruits. [68,72,73] To provide every soldier with such orthoses as a prevention strategy is too costly; [69] A possible compromise is providing prefabricated orthoses. [74]
The military instructor plays a key role in the prevention of overuse injuries. Experienced instructors who can prevent overexertion in their training groups have less drop out with injuries and better graduation percentages. [42,75]

Primary care: the medical unit on base

Diagnosis of ERLP

A list of most common diagnoses in young Dutch soldiers with ERLP is: 1. MTSS; 2. CECS and 3. a combination of the two. Pain from fascial herniae, tibial stress fractures, peripheral nerve impingement (e.g., the superficial peroneal nerve) and ACS caused by exercise are all much rarer. The diagnosis of MTSS may be confirmed with history and physical examination alone. When in doubt, other diagnoses can be excluded by additional investigations (e.g. stress fracture by advanced imaging). [31] The diagnosis of CECS is confirmed by an intracompartmental pressure measurement (ICPM). Fascial herniae of the anterior and lateral compartments of the leg are often found as comorbidity of CECS, [5,42,76] but the pathophysiology of CECS and the relationship of CECS to symptomatic and asymptomatic fascial herniae are not fully understood. [2]

MTSS and CECS are two different diseases. However, based on history and physical examination the distinction may be difficult to make, particularly between MTSS and CECS of the deep posterior compartment. [77-79] In addition, many soldiers have complaints compatible with both MTSS and CECS and the clinical presentation may change over time: often initial complaints fit the diagnosis MTSS, but over time CECS may develop. [10]
To diagnose ERLP correctly, it is necessary to provoke the complaints with an exercise test and repeat the physical examination immediately after exercise. [76,80-84] In the Royal Netherlands Armed Forces the 'Running Leg Pain Profile" (RLPP) has been developed as a pain scoring tool for ERLP. [80] During a standardized treadmill test (increasing speed and incline) performed in running shoes, a patient is asked to give a pain score of 0 -10 for four (or six) regions of the legs, Figure 1. The test contains running and marching and is designed to reproduce symptoms in the military patient group. CECS symptoms may be reproduced best by marching. [85,86] The RLPP assists in pinpointing an accurate diagnosis and also provides information on the severity of symptoms. In addition, during the test the investigator can judge running biomechanics. [80]

Table 1.
Risk factors for ERLP in a military setting.

factor	unfavorable characteristic	Ref	year	country	cohort	participants	Outcome statistics
sex	female	4	2004	Australia	navy	84 M; 40 F	RR for MTSS 2.03
		11	2013	USA	all forces	4100	RR for CECS 1.11; 95% CI 1.05-1.14
		12	2013	NED	pre-military	1478 M; 115 F	ERLP 9.3% of M; 16.5% of F
		13	2004	Australia	cadets	122 M; 36 F	OR for medial tibial pain 3.1
		14	2012	Australia	cadets	288 M; 96 F	OR for MTSS 2.97; 95% CI 1.66-5.31
		15	1993	USA	army BMT	124 M; 186 F	OR for lower extr. 2.1; 95% CI 1.5-3.1
current status	tenderness to palpation medial tibial border	14	2012	Australia	cadets	288 M; 96 F	OR for MTSS 4.63; 95% CI 2.5-8.5
	edema (very unfavorable)	14	2012	Australia	cadets	288 M; 96 F	OR for MTSS 76.1; 95% CI 9.6-602.7
foot shape	increased navicular drop > 0.5 cm	16	2010	NED	recruits	35 M	univariate regr 12.7; 95% CI 1.3-121.5
	reduced navicular drop < 0.422 cm	17	2015	Iran	recruits	181	p = 0,015
	pronated foot (foot posture index ≥ +6)	4	2004	Australia	navy	84 M; 40 F	RR for MTSS 1.70
	high footarch (bony arch index > 0.23)	18*	1999	USA	navy	449 M	RR 1.71; 95% CI 0.74-3.95
	>0.27	19	1993	USA	infantry	246 M	OR 6.12; 95% CI 2.17-17.30
	low footarch (bony arch index < 0.20)	18*	1999	USA	navy	449 M	RR 1.86; 95% CI 0.82-4.25
hip function	large exorotation > 64^0, only in men	13	2004	Australia	cadets	122 M; 36 F	Right hip p = 0.026; Left hip p = 0.042
	> 60^0	20*	1991	Israel	army	289 M	p < 0.001
	restricted exorotation < 41^0	17	2015	Iran	recruits	181	p = 0.000
	large endorotation > 48^0, only in men	13	2004	Australia	cadets	122 M; 36 F	Right hip p = 0.014; Left hip p = 0,000
	restricted endorotation < 40^0	16	2010	NED	recruits	35 M	univariate regr 1.1; 95% CI 1.0-1.2
	< 37^0	17	2015	Iran	recruits	181	p = 0.004
leg circumference	lean calf girth < 34 cm, only in men	13	2004	Australia	cadets	122 M; 36 F	right leg only, p = 0.040
	narrow tibial bone width < 25 mm	20*	1991	Israel	army	289 M	p < 0.001
ankle function	dorsal flexion ≥ 21^0	21	2010	USA	marine corps	748 F	OR for shin splints 3.4; 95% CI 1.4-8.4
	plantar flexion > 52^0	16	2010	NED	recruits	35 M	univariate regr 0.8; 95% CI 0.7-1.0
other biometrics	iliospinal height > 53cm	17	2015	Iran	recruits	181	p = 0,017
	lateral trochanter-tibia height > 44.69cm	17	2015	Iran	recruits	181	p = 0,022
target job	soldier (lower rank)	11	2013	USA	all forces	4100	RR for CECS 8.54; 95% CI 7.04-10.36
		22	2011	GB	infantry	660 M	HR officer 0.26; 95% CI 0.14-0.49

Table 1, continued.

factor	unfavorable characteristic	Ref	year	country	cohort	participants	Outcome statistics
target force	army	11	2013	USA	all forces	4100	RR for CECS 2,72; 95% CI 2.45-3.04
walking technique	overpronation (foot balance concept)	23	2011	GB	infantry	468 M	OR for MTSS 9.16; 95% CI 4.32-19.42
	foot pressure measurement bare foot, cavus	18*	1999	USA	navy	449 M	RR for stress # 1.7; 95% CI 0.59-4.89
	foot pressure measurement bare foot, planus	18*	1999	USA	navy	449 M	RR for stress # 2.18; 95% CI 0.80-3.98
	foot pressure measurement bare foot	24	2014	GB	navy officers	200 M	OR for OLLI** 5.28; 95% CI 2.88-9.70
	foot pressure measurement shod, cavus	18*	1999	USA	navy	449 M	RR for stress # 1.82; 95% CI 0.63-5.24
	foot pressure measurement shod, planus	18*	1999	USA	navy	449 M	RR for stress # 2.45; 95% CI 0.89-6.70
	heavy heel strike	23	2011	GB	infantry	468 M	OR for MTSS 9.16; 95% CI 4.32-19.42
running technique	overpronation	25	1993				no statistics
blood	low vitamine D intake (<118 IU, <70.0 nmol/L)	26*	2012	Israel	combat recruits	74 M	stress # group 59% of DRI (p<0.05)
	low vitamine D in blood < 75.8 nmol/L	27*	2006	Finland	recruits	756 M	OR for stress # 3.6; 95% CI 1.2-11.1
history	Priveous lower limb injury	23	2011	GB	infantry	660 M	HR for all injuries 1.49; 95% CI 1.19-1.87
	menstrual disfunction > 1 year	28*	2006	USA	marine corps	2962 F	OR for all stress # 5.64; 95% CI 2.2-14.4
	lower extremity stress fracture	29*	2006	USA	marine corps	824 F	OR for stress # 2.1; 95% CI 0.8-5.5
fitness	> 650 seconds on a 1.5 mile run	23	2011	GB	infantry	468 M	OR for MTSS 3.62; 95% CI 1.77-7.38
	average or lower premilitary activity level	30*	1988	USA	marine recruits	3025	RR 2.4; 95% CI 1.26-4.58
	low self rated fitness	29	2006	USA	marine corps	824 F	OR for OLLI** 1.6; 95% CI 1.1-2.5
smoking	smoker	23	2011	GB	infantry	468 M	OR for MTSS 6.54; 95% CI 3.09-13.82

*Risk factor specifically for stress fracture.
BMT = basic military training; CECS = chronic exertional compartment syndrome; ERLP = exercise-related leg pain; GB = Great Britain; MTSS = medial tibial stress syndrome; NED = Netherlands; OLLI = overuse lower limb injury; OR = odds ratio; regr = regression; RR = relative risk; M = male; F = female.

Figure 1.
The Running Leg Pain Profile (RLPP), a pain scoring system used to diagnose patients with ERLP. Patients are asked every minute to give a pain score of 0-10 for four regions of the leg: 1. (Antero-) Lateral side right leg; 2. Medial tibial border right leg; 3. Medial tibial border left leg; 4. (Antero-) Lateral side left leg; calves, regions 5 and 6, not depicted and optional. The vertical line indicates the medial tibial border.

Box 1.
Five components of a comprehensive treatment program for exercise-related leg pain.

1. Significant reduction of symptoms producing activities (running, marching, jumping, etc.);
2. Treatment of local pain in soft tissues and reduction of limitations in joint range of motion of ankle, knee and hip;
3. Improvement of modifiable risk factors for ERLP in a military setting;
4. Gradual return to leg loading activities;
5. Goal evaluation: is it realistic for this service member to return to the intended military training or specialty?

Table 2.
Treatment guideline for ERLP in the Royal Netherlands Armed Forces, version 2017.[10]

week	treatment action	professional	treatment phase	component	literature
0	significant reduction of running, marching, etc.	MD	visit 1	1	31
0	examine ROM of ankle, knee, hip	MD	visit 1	2	
0	reduce BMI if too much	MD	visit 1	3	
0	stop creatine supplements	MD	visit 1	3	87,88
0	stop smoking	MD	visit 1	3	23
0	vitamin D in blood (goal > 78 nmol/L)	MD	visit 1	3	26,27
0-2	nsaid	MD	visit 1	2	57
0-2	ice	MD	visit 1	2	57, 89
2	send patient to physical therapist on base	MD	visit 2	1	
2	place in on base part-time rehab program	MD	visit 2	1	
2	place in off base full-time rehab program	MD	visit 2	1	6, 7
3	judge running shoes and boots	phys ther	phys ther phase 1	3	90
3	examine / issue orthopedic inlays	phys ther	phys ther phase 1	3	31
3	judge walking biomechanics	phys ther	phys ther phase 1	3	
3	judge running biomechanics	phys ther	phys ther phase 1	3	31,8
3	compression stockings (not for CECS)	phys ther	phys ther phase 1	4	5, 91
3-8	massage	phys ther	phys ther phase 1	2	92, 93
3-8	taping (kinesio-)	phys ther	phys ther phase 1	2	94, 95
3-8	dry needling, (neuro)prolotherapy	phys ther, MD	phys ther phase 1	2	96
3-8	improve range of motion (stretching)	phys ther	phys ther phase 1	3	
3-12	improve relevant strength	phys ther	phys ther phase 1 and 2	3	97-99
3-12	maintain / improve cardiovascular fitness	phys ther	phys ther phase 1 and 2	3	31
6-12	gradual transfer from low impact to impact	phys ther	phys ther phase 1 and 2	4	12,1
6-12	gait retraining marching (boots)	phys ther	phys ther phase 1 and 2	3	
6-12	gait retraining running (running shoes)	phys ther	phys ther phase 1 and 2	3	101-104
8-12	extracorporal shockwave therapy (ESWT)	sportsmed dep	phys ther phase 1	2	105,106
12-20	gradual increase marching km	mil instr.	sports- and specific	4	
12-20	gradual increase running km	mil instr.	sports- and specific	4	31
12-20	judge fitness for intended job	MD	evaluation	5	7
8-20	send to regional military hospital	MD	stagnation	5	

ROM = range of motion; BMI = body mass index; CECS = chronic exertional compartment syndrome; ERLP = exercise-related leg pain; ESWT = extracorporeal shockwave therapy; NSAIDs = non-steroidal anti-inflammatory drugs; MD = medical doctor; phys ther = physical therapist; mil instr. = military instructor.

Treatment of ERLP

Table 2 shows the current treatment guideline based on expert consensus for ERLP in the Dutch armed forces. It is not necessary to perform an IMCP measurement before starting conservative treatment for ERLP. The treatment must offer the components presented in Box 1.
In the Dutch military, the base physician is responsible for starting the treatment of ERLP and ensuring the timelines are adhered to (Table 2). The physician refers the patient to the physical therapist if the initial actions of the guideline are insufficient to reduce the symptoms and invites the patient to return for monthly visits to discuss treatment progress. In general, treatment programs on base should lead to return to full duty and are divided into four phases: 1. Physical therapy phase I; 2. Physical therapy phase II; 3. Sports phase; 4. Military specific phase. The transfer from one phase to the next is based on objective test results, such as a pain free 12-minute run is one of the requirements to enter the sports phase of rehabilitation.

Occupational prognosis for MTSS

The average treatment duration for MTSS, when placed in a remedial platoon in the Dutch military, is 4-5 months. [6,7] This is longer than the three months average treatment duration reported in Dutch civilian settings and longer than 82 days, as reported in a large 2015 study of British army recruits. [8,91,107] A possible explanation is that soldiers do not seek medical consultation until their injury has progressed to an advanced stage, [4] or that soldiers are not reported cured until they can return to duty, which requires a high level of fitness. In addition, the 4-5 months in the Dutch remedial platoon placement may include a waiting period. After healing the soldier must wait for an appropriate moment to rejoin a training group. The only factor that has been reported to predict duration of MTSS recovery time is BMI, with a higher BMI predicting a longer recovery time. [16] Wearing a leg brace does not reduce recovery time, the comfort of wear is poor and soldiers find the braces cosmetically displeasing with duty uniform. [108-110]

Referral to secondary care

The physician on base may refer the military patient to secondary care in a regional military hospital if treatment of the service member with ERLP in accordance with the guideline (Table 2) stagnates. Based on consensus of senior physicians, it is recommended to do this after approximately three months of conservative treatment.

Secondary care: a military hospital

Diagnosis

Traditionally Dutch military personnel with overuse injuries of the lower legs and suspected CECS are sent to the out-patient clinic of the department of general surgery of the Central Military Hospital (CMH). Over the last 20 years, the number of new patients visiting the clinic for ERLP has been

Figure 2A, 2B and 2C.
With the Stryker pressure monitor (Figure 2A) the anterior compartment (Figure 2B) and the deep posterior compartment (Figure 2C) can be reached penetrating the skin only once.

Figure 2B

Figure 2C

constant at 250 per year and until recently approximately 150 fasciotomies per year were performed. In the current protocol the soldier with ERLP meets with three physicians in one hospital visit: a surgeon, a primary care sports medicine physician and a physiatrist. The RLPP is recorded and an ICPM is performed in all compartments where the patient has symptoms, in both legs, even if the patient has unilateral symptoms.

To confirm the diagnosis of CECS, an ICPM is necessary. A recent survey among American military orthopedic surgeons showed that 85% of the respondents are of the opinion that the diagnosis CECS should be confirmed with ICPM testing before surgical treatment. However, respondents who were in practice longer and respondents who saw more patients with suspected CECS per year were more likely to recommend surgical treatment based on clinical diagnosis alone. [111] In the Dutch CMH the Stryker measuring device is used to perform the ICPM in the first minute after exercise (Figure 2A). [112] The Dutch criteria for surgery have beenestablished by Verleisdonk et al., but only for the anterior compartment. [112] Currently in most cases with ERLP, at least four compartments are tested (anterior and deep posterior of both legs) and sometimes more. It is necessary to establish criteria for all compartments separately, both in the resting state and post exercise. [113] For the time being in the Dutch CMH, the criterion for the anterior compartment (35 mmHg 1 minute post exercise) is used for all compartments. With the Stryker pressure monitor the deep posterior compartment can be reached through the anterior compartment. The advantage is that the skin is penetrated only once for measurement of both the anterior and the deep posterior compartment (Figures 2B and 2C); [77,114] there is however a risk of touching a neurovascular bundle, [115] but in the CMH, there are no reports of serious complications of the Stryker ICPM tests. In a British paper, one case of bleeding of the arteria tibialis posterior is mentioned after testing 76 patients. [113] Diagnostic utility of the ICPM tests is improved when measured continuously during exercise, [85] which requires insertion of a catheter and one Stryker pressure monitor for each muscle tested. Currently ICPM is still the accepted standard for CECS diagnostics, if performed with local protocols and local reference values. [116-118] There is an ongoing search for non-invasive diagnostic procedures. Near Infrared Spectometry (NIRS) [5] and ultrasound immediately after exercise [119] are promising methods which are relatively easy to perform, but not yet accepted as the new standard, because they only reach the anterior compartment. An exercise test inside a MRI machine may be technically possible, but it is not feasible for large numbers of patients per year. [120] The ankle-brachial index (ABI) in the first minute post exercise may help to differentiate CECS patients from normals. ABI in combination with the RLPP may provide an acceptable diagnostic alternative in the military setting. [121]

Conservative treatment of ERLP

Most treatment actions reported in Table 2 have been in use in the Dutch military for many years and are considered "standard therapy". New elements in the conservative treatment of MTSS in a secondary care setting are extracorporeal shockwave therapy (ESWT) and gait retraining. Two

Figure 3.
Self-application of extracorporeal shockwave therapy, a soldier with Medial Tibial Stress Syndrome.

studies report that MTSS patients who receive a standard treatment program plus ESWT have better outcomes than those who receive the standard treatment only. [91,105] ESWT treatment on the tibia can be quite painful. In the Dutch military setting, ESWT treatment is available in the sports medicine department only, using a protocol adopted from Rompe et al. (1 session per week, 2000 radial shocks, 8 shock per second, 2.5 bars of pressure, 4 or 5 sessions in total). [105] Practical experience has shown that patients strongly prefer self-administration of ESWT on the tibia (Figure 3).

Gait retraining to change running biomechanics can reduce the vertical forces of landing significantly [122] with the most important factors in reducing the impact forces of running being a change from a rear-foot to a mid-foot strike and increasing cadence, usually through decreasing stride length. [103,123] There is no study that reports the results of gait retraining as a treatment for MTSS. In contrast, gait retraining as a treatment for CECS has been described. Diebal et al. were the first to report that gait retraining for running was effective in reducing complaints and intramuscular compartment pressure in military personnel with CECS. [102] Their study population was homogeneous young, fit, officers in training, with CECS of the anterior compartment only. Recently several studies have confirmed the positive effects of gait retraining on the symptoms of CECS of soldiers. [86,101,124]

In addition, shoe type also plays an important role in the amount of force placed on the legs in running. So-called 'low drop/low heel height' shoes can reduce peak forces on the heel by 25%. [90] In earlier studies it was shown that shoes with a negative sole (a slope increase from heel to toe) reduced peak and average pressure in the anterior compartment during running by approximately 20 mm Hg and it was suggested that changing shoe type alone may be sufficient therapy to reduce symptoms in patients with CECS. [125,126] Some authors are of the opinion that pain and increased intramuscular compartment pressure caused by faulty running biomechanics requires new diagnostic terminology: biomechanical overload syndrome. [86]

Surgical treatment of ERLP

In the CMH, no surgical treatment is offered if the diagnosis is MTSS, because the results reported in the literature are poor. [127] Patients report reduction of pain after surgery, but only 41% fully return to the presymptom level of sports participation.

Until a few years ago, fasciotomy of the affected compartments seemed the only useful treatment for CECS. [128-130] In the CMH, Verleisdonk et al. report after minimal invasive fasciotomy of 151 compartments in 81 patients (149 anterior compartments and 2 lateral compartments) that 76% of patients experienced significant reduction of pain six months after surgery. The average compartment pressure was reduced from 57 mmHg preoperatively to 25 mmHg postoperatively. [131] In 10 cases however, pressures were not reduced postoperatively. Four patients (4.9%) had surgical revision. The following complications for all surgeries were mentioned: three neuromas and one seroma. Other studies report complications of fasciotomy in greater detail: perioperative vascular damage, hematoma, neurological complaints, damage to the superficial peroneal nerve, deep venous thrombosis, delayed wound healing, post-surgical hernia, persistent ankle pain and cosmetically unacceptable scars. [33,132-135] The highest reported percentage of complications is 15.7%. [132] The percentage of complications in the CMH is unknown, but the surgeons indicate that the number of complications of surgery rises with the number of compartments opened during one surgical procedure. Long term complications of fasciotomy are not well documented.

There is limited written information on the rehabilitation post elective fasciotomy of the lower leg. [136] In some cases it is possible to return to a physically demanding military job. [137] The duration of rehabilitation will be three months or more. [34]

Occupational prognosis of CECS after surgery

The prognosis for work in the military is unfavorable after fasciotomy. In a 2010 Dutch analysis of 44 soldiers who underwent fasciotomy of the anterior compartment of the legs in the CMH, 15 patients (34%) returned to their original military jobs, 28 patients left the military (64%) and 25 (57%) still reported symptoms two years after surgery (unpublished, R. Nijhoving, department of Occuptional Medicine, Royal Netherlands Army, 2013). In an American analysis of 611 soldiers who underwent fasciotomy between 2003 and 2010, 44.7% of patients had symptom recurrence, 27.7% did not return to full duty and 17.3% were referred for medical discharge. [132] A limitation of this study was that it was a retrospective review of a database including 32 treatment centers. The database did not allow for evaluation of diagnostic criteria, surgical procedures and rehabilitation protocols at the respective centers. [140] Several recent studies confirm that the results of surgical treatment for CECS in the military are inferior to those in civilian athletes. [2,132,138-140]

Based on all aforementioned new insights, the CMH has changed its policy for surgery for CECS. Fasciotomy will only be performed after at least three months of conservative treatment as described in Table 2. Preoperatively it is ensured that patients did receive gait retraining and that creatine supplementation was terminated. [87,88] The number of fasciotomies performed in the CMH is declining.

CONCLUSIONS

The body of knowledge on ERLP in the military is growing and the number of publications is increasing. Despite these recent developments the occupational problem of ERLP in the military is far from solved. These overuse injuries continue to have a high incidence, long recovery time and large impact on training. Proactive preventative and rehabilitative management targeting ERLP is necessary to achieve change. The challenge is to convey the current knowledge and the sense of urgency to all physicians and policy makers involved.

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Chapter 3

Intracompartmental pressure measurements in 501 service members with exercise-related leg pain

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ABSTRACT

Chronic Exertional Compartment Syndrome (CECS) is one of the recalcitrant overuse injuries of the lower legs. CECS is traditionally diagnosed with an intracompartmental pressure measurement (ICPM). The primary objective of this article was to report the relationship between exertional compartment pain and intracompartmental pressure in young service members. This study is a descriptive analysis of patient records from a central military hospital from 2013 to 2016 (study design: historic cohort, level of evidence = 3). A total of 573 young service members with exercise-related leg pain were evaluated. An ICPM of at least one muscular compartment was performed in 501 patients (87%) one minute after a standardized running test. CECS (32%), medial tibial stress syndrome (MTSS) + CECS (27%), and MTSS (21%) were the most common diagnoses. In the CECS category, most patients (68%) had ICPM values >35 mm Hg in both anterior and deep posterior compartments, 22% had isolated CECS of the anterior compartments, and the others had combinations of pressures >35 mm Hg in one or more of the four leg compartments (9%). Comparison of exertional pain scores with the ICPM showed a negligible correlation for the anterior compartments (Spearman rank correlation coefficient = 0.257, confidence interval = 0.191–0.327). Service members rated needle pain of the ICPM procedure as moderate: median pain rating 5 out of 10 (range 0 -10). This score did not significantly differ between men and women (p = 0.409) and was not different if only anterior compartment versus multiple compartments were measured (p = 0.236). There is a negligible correlation between exertional compartment pain level and intracompartmental pressure in the leg. Current advice to avoid or minimize ICPM due to needle pain concerns does not appear warranted.

KEYWORDS:

- chronic exertional compartment syndrome
- medial tibial stress syndrome
- diagnosis
- military.

INTRODUCTION

Exercise-related leg pain (ERLP) is a group of recalcitrant overuse injuries in the armed forces and young athletes. [1] In the Royal Netherlands Armed Forces the most prevalent diagnoses in the ERLP group are Medial Tibial Stress Syndrome (MTSS), Chronic Exertional Compartment Syndrome (CECS) and a combination of these two, whereas stress fractures of the tibia are extremely rare. [2] An estimation of CECS in the US military service is that one in every 2000 members is diagnosed with CECS every year. [3]

A clinical description of CECS is repetitive pain and pathologically elevated pressure in a muscular compartment during physical exercise, which returns to normal with cessation of the activity. CECS can present in any muscular compartment of the human body, but is most prevalent in the anterior compartment of the leg. [4] The gold standard for CECS diagnosis is an intracompartmental pressure measurement (ICPM) in the first minute post-exercise. [5] Previous recommendations to improve the diagnostic accuracy of ICPM, include standardization of the preceding exercise test, [6] and having the patient exercise to the limit of tolerable pain. [7] An accepted criterion for diagnosis and potential surgical treatment of CECS is a pressure of 35 mm Hg, one minute post exercise, measured with a Stryker® pressure measurement device. [8]

It has been reported that there is no statistical relationship between severity of symptoms and resting compartment pressures. [9] However, while a strongly positive statistical relationship is supposed, no previous studies have reported the relationship between exertional pain and ICPM one minute post exercise. Finally, ICPM has been reported to be sufficiently uncomfortable to warrant limiting multiple needle insertions. [10] However, actual needle pain for the procedure has never been reported numerically.

The objective of this study was to report the relationship between exertional compartment pain and intracompartmental pressure in young service members suspected of CECS of the legs. In addition we assessed the needle pain of the ICPM procedure, for both men and women.

METHODS

This study has a historic (retrospective) cohort design. It was performed in the Central Military Hospital (CMH), department of General Surgery of the Royal Netherlands Armed Forces, Utrecht, The Netherlands.

Organization of care

The Royal Netherlands Armed Forces has a diagnostic and treatment protocol for ERLP coordinating physicians and physical therapists working in outlying primary care clinics with sports medicine and other specialists in the CMH. This protocol describes that service members with ERLP be referred to the CMH if conservative therapy has not been successful within six months. [2] Since 2011 the CMH has offered a specialty clinic for service members with ERLP. A multidisciplinary team of surgery, sports medicine, and physiatry evaluates patients in a one-stop shop setting. Diagnostic imaging is ordered if stress fractures, malign or vascular disorders are suspected. This is in a small percentage of cases. After medical clearance, a sports medicine physician supervises the patient in a standardized running test on a treadmill to pain tolerance and performs an ICPM of compartments suspected for CECS (see descriptions below). All patient information is stored in an electronic patient record. Based on the evaluations, patients may be referred to any of four treatment arms: surgery in the CMH, outpatient conservative treatment in the Military Sports Medicine department, inpatient conservative treatment in the Military Rehabilitation Center, or referral back to their original military base to re-engage with primary care.

Running Leg Pain Profile

The Running Leg Pain Profile (RLPP) is the pain scoring system used to diagnose military patients with ERLP. Patients are asked every minute, to give a pain score of 0-10 for four (or six) regions of the legs (Figure 1). The RLPP assists in pinpointing an accurate diagnosis and also provides information on the severity of symptoms: MTSS is suspected when pain is reported in regions 2 and 3, and anterior-CECS is suspected with pain in regions 1 and 4. Combined symptoms may indicate concurrence of the two diagnoses. The RLPP is performed with a standardized treadmill protocol (Table 1). This protocol comprises running and marching and is designed to reproduce symptoms to the limit of tolerable pain in the military patient group. The test is performed in running shoes, shorts and a t-shirt. [11]

Intracompartmental Pressure Measurement

Before commencement of the exercise test all locations indicated for pressure measurement are anesthetized with 1-2 cc xylocaine 1.0 %. ICPM is always conducted in the first minute post exercise, with a Stryker pressure measurement device. Pressures are recorded when the device shows a constant number, approximately 10 seconds after introduction of the needle in a particular compartment. The patients are supine, with the knees at the edge of the table and the legs hanging

Figure 1.
The Running Leg Pain Profile (RLPP), a pain scoring system used to diagnose patients with ERLP. Patients are asked every minute to give a pain score of 0-10 for four regions of the leg: 1. (Antero-) Lateral side right leg; 2. Medial tibial border right leg; 3. Medial tibial border left leg; 4. (Antero-) Lateral side left leg; calves, regions 5 and 6, not depicted and optional. The vertical line indicates the medial tibial border.

Table 1.
Treadmill protocol and template to record the Running Leg Pain Profile (RLPP) scores in this study.

velocity km/h	slope %	time	anterior compartm. right	medial tibial border right	medial tibial border left	anterior compartm. left	calf right (optional)	calf left (optional)
5	1	0'55"						
6	1	1'55"						
7	1	2'55"						
8	1	3'55"						
9	1	4'55"						
10	1	5'55"						
11	1	6'55"						
12	1	7'55"						
12	5	8'55"						
12	5	9'55"						
7,5	5	10'55"						
7,5	5	11'55"						
12	1	12'55"						
12	1	13'55"						
finish	time:							

vertically towards the floor. Pressure measurements of the deep posterior compartment are done through the anterior compartment. Thereby the skin is penetrated only once for measurement of both the anterior and the deep posterior compartment. From the first of July 2014 every patient was asked to score ICPM needle pain on a scale of 0-10, immediately after completion of the procedure.

Inclusion

Medical records were searched for all patients with ERLP seen by the CMH from January 1st 2013 – December 31st 2016. From all ERLP patients the following information was obtained from the medical records: sex (male/female), age (years), height (m), weight (kg), most symptomatic activity, number of legs involved, previous treatments, ICPM values, diagnosis, proposed treatments, center of next referral.

Statistics

Demographic characteristics and symptoms were described with appropriate measures of central tendency and dispersion. The measured ICPM values and experienced RLPP were presented graphically by means of a box and whiskers plot. Additionally the Kruskal Wallis test was used to test if the ICPM values in the different groups of pain scores (0-10) were significantly different from each other during the RLPP. The Spearman Rank Correlation Coefficient (rs) was used to determine the correlation between ICPM values and exertional compartment pain. In advance we decided a correlation of .90 to 1.00 is very high, .70 to .90 is high, .50 to .70 is moderate, .30 to .50 is low, and .00 to .30 is a negligible correlation. Needle pain of the ICPM procedure was described with median inter quartile ranges (IQR) and minimum-/maximum values, male and female scores were compared with the Mann Whitney U test. Statistical analysis was performed using SPSS statistical software version 23.0 (IBM Corporation). Alpha level of significance was set at 0.05 for all statistical analyses. International law does not require approval of an ethical board for this study.

RESULTS

In a period of four years, 573 service members with ERLP were seen for a diagnostic intake and treatment suggestions. Table 2 shows selected information from the electronic patient records. Male patients made up 89% (508/573) of the patient group. The median age was 26 years (IQR 7, range 19-58). The average duration of ERLP symptoms upon initial presentation to the CMH was 23.5 months (range 1-240). The most commonly reported exacerbating activity was running (279/452, 62%). The majority of patients (433/533, 78%) reported bilateral symptoms. The most common previously prescribed treatments included: rest (397/424, 94%), physical therapy (300/424, 71%), inlays/orthotics (278/424, 66%), a progressive running schedule (206/424, 49%), and compression stockings (125/424, 30%).

In 451/573 cases (79%) all diagnostic procedures were completed on the same day. Figure 2 shows the clinical diagnoses assigned to these chronic ERLP patients, of which CECS (145/451, 32%), MTSS + CECS (121/451, 27%) and MTSS (95/451, 21%) were the most common diagnoses. In the CECS category most patients (98/145, 68%) had ICPM values > 35 mm Hg one minute after exercise in both the anterior and deep posterior compartments, (32/145, 22%) had isolated CECS of the anterior compartments, the others had combinations of pressures > 35 mm Hg in one or more of the four leg compartments (13/145, 9%). Isolated CECS of the deep compartments or the lateral (peroneal) compartments was very rare, accounting for ~1% of all CECS cases (2/145). After diagnosis in the CMH most patients were referred to the Military Sports Medicine department for additional outpatient conservative treatment (274/376, 73%). Gait analysis and gait retraining (218/320, 68%), a progressive running schedule (174/320, 54%) and extracorporeal shockwave therapy (ESWT) of the medial tibial border (152/320, 48%) were the therapeutic modalities most often suggested by the multidisciplinary clinic.

Figure 3A and 3B show the relationship between the pain score in the last minute of the RLPP versus the pressure measured immediately after exercise in anterior compartments and deep posterior compartments, respectively. Figure 3A shows a statistical relationship between increasing median ICPM value (thick black lines) and increased RLPP anterior compartment pain. The Kruskal Wallis test (p=0.000) revealed that the median pressure values in at least one group varies from the rest. However, figure 3A also illustrates that some individuals with zero or low compartmental pain scores had intracompartmental pressures far above 35 mm Hg (open circles top left). Other individuals had high compartment pain scores (e.g. 8 or above on the RLPP locations 1 and 4), but low intracompartmental pressures (e.g. below 20 mm Hg). Additional statistical evaluation with the Spearman Rank Correlation Coefficient produced a negligible correlation between ICPM scores and compartment pain scores (rs 0.257, with a confidence interval of 0.191-0.327). Figure 3B shows that there is no correlation between pain scores and pressures in the deep posterior compartments (Kruskall Wallis test p=0.115).

An ICPM of at least one muscular compartment of one leg was performed in 501/573 patients (87%). A score for ICPM needle pain was obtained in 316 patients; in the majority of cases (303/316, 96%) an ICPM of both the anterior and deep compartment was performed. The median score for needle pain of the ICPM procedure was 5 (IQR 4, range 1-10). This score did not significantly differ between men and women ($p = 0.409$) and was not different if only the anterior compartments were measured ($p = 0.236$).

Table 2.
Patient characteristics.

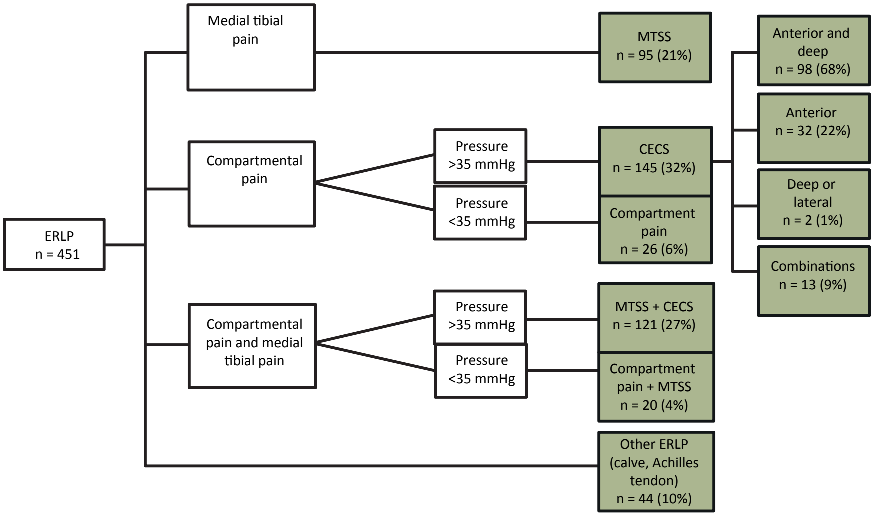
		number	%	average ± SD
All ERLP patients	(n=573)	573	100	
Sex (male)		508	89	
Sex (female)		65	11	
age all		573		28.2 ± 6.7
height (male)	in centimeters	495		181.9 ± 6.7
height (female)	in centimeters	62		169.8 ± 6.3
weight (male)	in kilogram	499		82.8 ± 16.4
weight (female)	in kilogram	63		71.4 ± 10.0
BMI (male)		471		25.7 ± 3.0
BMI (female)		61		24.7 ± 3.2
duration of symptoms	in months	546		23.8 ± 31.5
ICPM in at least 1 compartment		501	87	
Most symptomatic activity	(n=452)			
Running		279	62	
Fast marching		57	13	
Walking		44	10	
Running and marching		13	3	
Other		59	13	
Number of legs involved	(n=553)			
Both legs		433	78	
Left leg		52	9	
Right leg		68	12	
Previous treatments, top 5	(n=424)			
Rest		397	94	
Physical therapy		300	71	
Inlays		278	66	
Progressive running schedule		206	49	
Compression stockings		125	30	
Pain scores of ICPM	(n=316)			
anterior compartment only (M + F)		13		6.0 ± 2.2
anterior + deep compartments (M + F)		303		5.2* ± 2.4

Table 2, continued.

		number	%	average ± SD
Clinical diagnosis in first visit	(n=451)			
CECS (ICPM >35 mm Hg)		145	32	
MTSS + CECS (ICPM > 35 mm Hg)		121	27	
MTSS		95	21	
Other, e.g. myogenic calf pain, achilles tend.		44	10	
Compartment pain (IMCP < 35 mm Hg)		26	6	
MTSS + compartment pain (ICPM < 35 mm Hg)		20	4	
Proposed treatments, top 5	(n=320)			
Observational gait analysis + gait retraining		218	68	
Progressive running schedule		174	54	
Shockwave		152	48	
Evaluate / renew running shoes		133	42	
Video gait analysis + gait retraining		98	31	
Referred to	(n=376)			
Military sports medicine (outpatient)		274	73	
Military rehabilitation clinic (inpatient)		42	11	
Return for treatment on base		34	9	
CMH, surgery		26	7	

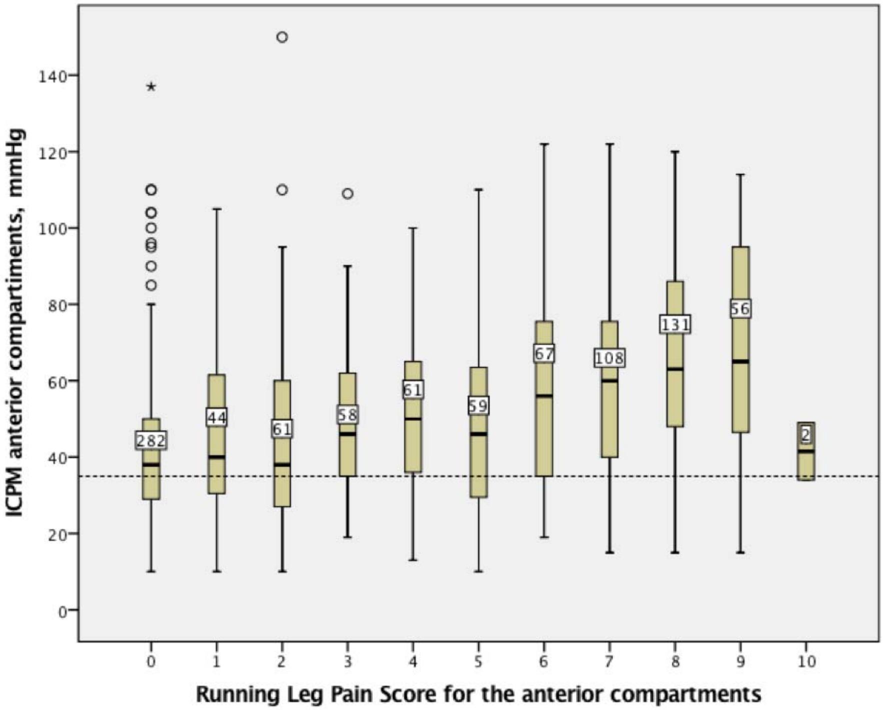
SD = standard deviation; ERLP = exercise-related leg pain; BMI = body mass index; ICPM = intracompartmental pressure measurement; CMH = central military hospital; M+F = male + female; MTSS medial tibial stress syndrome; CECS chronic exertional compartment syndrome.
* no significant difference between men and women, p = 0.418.

Figure 2.
Clinical diagnoses assigned to the chronic ERLP patients (n = 451).



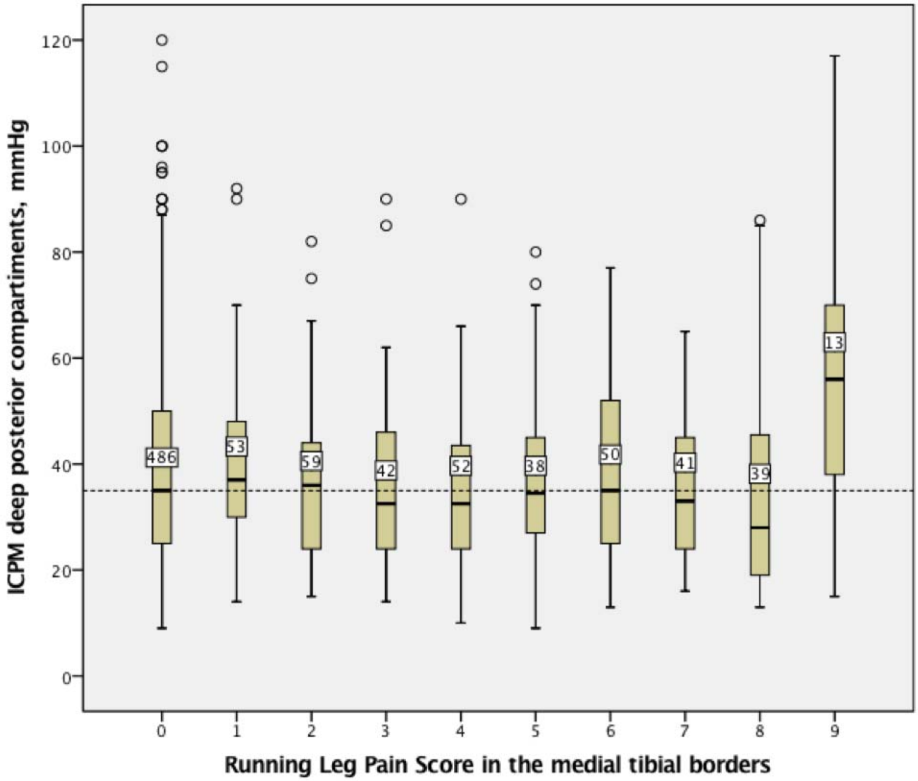
ERLP = exercise-related leg pain; MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; BOS = biomechanical overload syndrome; n = number.

Figure 3A.
Pain scores of patients with ERLP during running (RLPP locations 1 and 4) versus pressure in the anterior compartments in 929 legs.
Note the open circles on top left, indicating individuals with very high pressure measurements, but no (zero) or low anterior compartment pain. Kruskal Wallis test p = 0.000, Spearman Rank Correlation Coefficient rs = 0.257 = negligible correlation.
35 mm Hg is the local diagnostic threshold for CECS.



ERLP = exercise-related leg pain; RLPP = running leg pain profile; CECS = chronic exertional compartment syndrome.

Figure 3B.
Pain scores of patients with ERLP during running (RLPP locations 2 and 3) versus pressure in the posterior deep compartments in 873 legs.
Note the lack of correlation between median pressure (dark lines) and pain score. Kruskal Wallis test p = 0.115.
35 mm Hg is the local diagnostic threshold for CECS.



ERLP = exercise-related leg pain; RLPP = running leg pain profile; CECS = chronic exertional compartment syndrome.

DISCUSSION

This study reports on the relationship between exertional leg pain and intracompartmental pressures in a group of young service members with recalcitrant ERLP, suspected for CECS. The most important findings are that there is no direct correlation between exertional compartment pain level and intracompartmental pressure in the lower leg. Patients with high compartment pain may have high or low intracompartmental pressures and patients without symptoms may have very high pressures. A further finding is that current advice to avoid or minimize ICPM due to needle pain concerns does not appear warranted.

ICPM, a standardized pain assessment tool (i.e. RLPP) and a standardized running protocol are useful in subcategorizing patients with exertional leg pain (figure 2). In particular, the patient group with high anterior compartment pain, but low anterior compartment pressures one minute after exercise (Figure 3A) has not been described before. The patient group with high medial tibial pain, but low deep posterior compartment pressures (Figure 3B) has been described earlier. [12] However, medial tibial scores (2 and 3 of the RLPP) may not reflect pain in the deep compartment, but could also represent pain originating from the medial tibial border, caused by MTSS. The anterior tibial scores (1 and 4 of the RLPP) most likely do reflect pain in the anterior compartment, because of anatomical proximity. Although there is a statistical relationship between the RLPP pain scores of the anterior compartments and ICPM measurements at group level (Figure 3A, $p=0.000$), this does not mean that the physician confronted with an individual patient with exertional anterior compartment pain can assume high intracompartmental pressures. Patients with high anterior pain scores, but low anterior compartment pressures are described as "compartment pain" patients in our five subcategory scale. These findings further challenge our current understanding of CECS. CECS is a multifactorial problem and involves more than just increased ICPM. [13] New diagnostic terminology, like "Biomechanical Overload Syndrome", may be appropriate for those patients with high compartment pain and low pressures. [14] Patients with very high pressures (e.g. >100 mmHg), but no pain at all, bring into question whether we actually know what 'normal' values are. [15]

This study is the first to report scores on ICPM needle pain. On a scale of 0-10, 303 patients scored pain from ICPM of the anterior and deep compartments combined with a median: 5 (range 1-10). This score can be interpreted as "moderate" pain. Hence, the common practice of limiting ICPM to one leg and as few compartments as possible to reduce patient discomfort would seem unjustified. [10]
In four years' time, 501 service members underwent ICPM in one or more compartments of the lower leg. This large number of cases establishes the CMH as a major center for CECS care. Other centers with similar reported cohort sizes include the Maxima Medisch Centrum (Veldhoven, The Netherlands), which frequently publishes research on CECS in civilian patients and has an electronic patient database starting in 2001. [16] In a military setting, the British Defense Medical Rehabilitation Centre near Epsom in Surrey specializes in treating service members with ERLP. [17]

A distinct finding from this study is that the average duration of symptoms for ERLP patients initially presenting to the CMH was nearly two years, despite local military medical protocols dictating that service members with ERLP be referred to the CMH if conservative therapy has not been successful within six months. More effort is necessary to educate base physicians about the ERLP protocol to avoid diagnosis and treatment delay.

Strength of this study is that it reports on a large number of ERLP patients and a large number of ICPMs. In addition, according to our clinical experience, this paper presents an accurate description of the current state of affairs in the treatment of young service members with ERLP in the Royal Netherlands Armed Forces and it adds information that may help to unravel the pathophysiological mechanism of CECS. Limitations of this study include its single center source and the queried database with incomplete records resulting in slightly different numbers for each analysis (see Table 1). Future studies could further examine the best treatment options for patients with high exertional compartment pain, but low intracompartmental pressures. For example, surgical fasciotomy, long considered the gold standard for exertional compartment syndrome, would not seem warranted in this subgroup of patients.

CONCLUSION

In four years' time 573 Dutch service members were referred to secondary care for evaluation of chronic ERLP and treatment suggestions. Almost 59% of these service members were diagnosed with CECS or CECS + MTSS. ICPM, a standardized pain assessment tool (i.e. RLPP) and a standardized running protocol are useful in subcategorizing patients with exertional leg pain. Subsets of patients with ERLP may have high compartment pressures and low compartment pain scores, or vice versa. The clinical treatment ramifications of these categories is still evolving and further research into optimal treatment strategies for all subgroups of patients is warranted. Current advice to avoid or minimize ICPM due to needle pain concerns does not appear warranted.

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Chapter 4

The immediate effect of extracorporeal shockwave therapy for chronic medial tibial stress syndrome

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ABSTRACT

Medial Tibial Stress Syndrome can be a recalcitrant overuse injury in the military.

Objectives: To report the immediate effect and clinical experiences of extracorporeal shockwave therapy as part of a comprehensive treatment program for patients with chronic Medial Tibial Stress Syndrome.

Design: Historic cohort.

Methods: Patients received an individualized treatment program, including radial shockwave therapy, for 16 weeks. The length of tenderness along the posterior medial tibial border was measured in centimeters during the weeks of shockwave therapy. Pain during and after shockwave therapy was recorded. Patients were asked if they would recommend shockwave therapy.

Results: 37 male cases were included, median age 23 (IQR 8) years. On average, shockwave therapy did not reduce the length of tenderness during the weeks of application. All patients (100%) reported shockwave to be painful (≥ 6 out of 10), but tolerable by self-application. After the initial shockwave session 25/37 patients (68%) reported no post treatment hours of pain, after session four 33/37 patients (89%). Thirty patients (81%) would recommend shockwave therapy.

Conclusion: Radial extracorporeal shockwave therapy did not reduce the length of tenderness along the posterior medial tibial border during the weeks of application in patients with chronic Medial Tibial Stress Syndrome. It is a painful treatment, but tolerable by self-application. The majority of patients did not experience post treatment pain. In this group of patients 81% would recommend shockwave therapy. More studies are necessary to establish if extracorporeal shockwave therapy for Medial Tibial Stress Syndrome is clinically effective.

KEY WORDS

- exercise-related leg pain
- chronic exertional compartment syndrome
- military
- occupational.

INTRODUCTION

Medial tibial Stress Syndrome (MTSS) is a common overuse injury in the military. [1] MTSS is a condition involving the interface of the tibial bone and soft tissue. [2] MTSS causes pain along the medial tibial border during and after leg loading activities. [3] Incidence of MTSS varies between 4% and 35% in athletic and military populations. [3] The exact incidence and prevalence of MTSS in the Royal Netherlands Armed Forces are not known. Information from remedial platoons reveals that exercise-related leg pain, including MTSS and Chronic Exertional Compartment Syndrome (CECS), are among the top three overuse injuries leading to dropout from basic and secondary military training. [4] Several treatments for MTSS have been described in the literature, including: reduction of running and jumping, icing, massage, stretching and strengthening exercises, attention to biomechanical factors such as over-pronation, ultrasound therapy, sports compression stockings, lower leg braces, pulsed electromagnetic fields, and extracorporeal shockwave therapy (ESWT). [5,6] The optimal management of MTSS remains unclear.

The department of military sports medicine of the Royal Netherlands Army is a secondary care setting. Service members are referred if conservative care on base for at least three months has not produced satisfactory results. Around 100 new patients with exercise-related leg pain, including those with MTSS, CECS, or a combination of MTSS+CECS, receive an individualized treatment program each year. The department has an ongoing research assignment to improve the care for service members with overuse injuries from sports and military training. In response to two studies reporting promising results of Extracorporeal Shockwave Therapy (ESWT) for MTSS, this therapy was introduced in our department as part of the chronic MTSS treatment program in 2011.[7,8] ESWT is a non-invasive treatment in which short burst high intensity sound waves are delivered to targeted tissues to trigger a repair response. [9] Based on their propagation pattern, shockwaves can be focused or unfocused. Studies on bone models reported that ESWT promotes vascularity, enhances osteoblast differentiation and increases chemical mediators of the bone healing process. [10] Assuming that ESWT would support bone healing it was placed in the first weeks of our comprehensive treatment program for service members with chronic MTSS, before initiation of gait retraining.

It is important to investigate the effectiveness of new treatments in our specific patient population. If ESWT is an effective intervention in patients with MTSS, a change in length of the tender medial tibial portion might be an indication of its effectiveness. Previous studies noted that ESWT to the medial tibial border can be painful. [8] The feasibility of a treatment may depend on acceptable levels of pain during and after application. This makes monitoring adverse reactions and patient satisfaction with ESWT important. Therefore, the aims of this observational study were to: 1. determine the effectiveness of ESWT on the bone healing process during the weeks of ESWT application; 2. to monitor pain during and after ESWT and record patient satisfaction with ESWT.

METHODS

This historic cohort was performed in the Department of Military Sports Medicine of the Royal Netherlands Army, Utrecht, The Netherlands. According to the declaration of Helsinki approval of an ethical board for this type of study was not required. All patients gave permission in writing for aggregate, anonymous use of their treatment data.

Inclusion

Service members from all armed forces and all types of military specialties, who were referred to our department for the first time in 2013, were eligible for inclusion. Inclusion criteria were: male sex, diagnosis chronic MTSS, or a combination of MTSS with another overuse injury of the leg. Exclusion criteria were: the patient did not complete the program due to military tasks, the patient had psychological problems or any other affliction that could impede with the treatment program. Chronic was defined as complaints lasting more than six months despite treatment in primary care on base. Patients' diagnosis of MTSS was based on history, physical examination and a standardized running test to provoke symptoms. Diagnostic procedures for other overuse injuries of the leg e.g., CECS, with intracompartmental pressure measurement, were described in detail previously. [4] All patients were initially seen by a single, experienced sports medicine physician (WZ), using a detailed intake, diagnostic and treatment protocol for exercise-related leg pain.

During intake, the following baseline parameters were collected: duration of symptoms (months), repeat episode of MTSS (yes/no), age (years), biometrics (height in meters, weight in kilograms), and diagnosis. The single assessment numerical evaluation (SANE intake) was recorded. This SANE score is a single question instrument evaluating patients' subjective injury status with the following question: "how would you rate your lower leg today as a percentage of normal, on a 0-100 scale, with 100 being normal". The SANE score was developed and validated in a military health care setting. [11]

Individualized conservative outpatient treatment program

Depending on observed risk factors, the following previously-proven helpful components were selected (along with shockwave treatment) to create a custom rehabilitation program for service members: [5,6] stretching and/or strengthening of lower extremity musculature, massage of hypertonic musculature, dry needling of trigger points, prescription of compression stockings, evaluation of running shoes, evaluation / prescription of shoe inlays, maintaining fitness with a low impact training program, gait retraining of running and a progressive running schedule. Massage was performed by a physical therapist; all other modalities were self-administered or administered by the sports physician. For each of the aforementioned interventions local protocol described criteria for application (Appendix 1). Every service member received a 6-week progressive running program building up to a 15-minute uninterrupted run once free of pain in rest. Some service members with a physically demanding specialty, received an additional 6-week progressive running schedule to build to a 30-minute uninterrupted run, beyond the 16-week evaluation point.

Extracorporeal shockwave therapy (ESWT)

ESWT was always the first intervention of the comprehensive treatment program. Patients were instructed to refrain from load bearing exercise, such as running and jumping, during the weeks of ESWT. Patients received four consecutive radial ESWT sessions at one week intervals. If patients were not able to attend four weeks consecutively, they received five sessions over a period of six weeks. Shockwave treatment was performed by self-application, in a sitting position, after initial instruction by the attending physician (Figure 1). At every session, 2000 unfocused (or "radial") shocks were administered per leg, with a frequency of eight shocks per second and intensity set at 2,5 bar (Swiss DolorClast, Nyon, Swiss), copying the machine settings used by Rompe. [8] Local anesthesia was not applied, also conforming to Rompe's protocol. [8] To determine the effectiveness of ESWT, the change in length of the tender area of the medial tibial region was calculated. For this, first patients were instructed to palpate the medial tibial border before each ESWT session and accurately indicate the tender area with a skin marker. Patients were unaware of the primary research objective to minimize the chance of outcome manipulation. Next, the length of the marked tender area was measured in centimeters, rounded to an integer, by the first author (WZ). This procedure was repeated before each next ESWT session.

Figure 1.
Shockwave treatment was performed by self-application, in a sitting position, after initial instruction by the attending physician.

During each ESWT session patients were asked if the treatment was painful, expressed as 6 or more on a 0-10 Numerical Rating Scale (yes/no). In addition, from the second session of ESWT onward, all patients were asked to report any adverse effects of the previous ESWT session, in particular post treatment pain, reported as the number of hours of post treatment leg discomfort in five categories.

Subjective final evaluations

During final evaluation, approximately four months after intake, patients were asked if they would recommend ESWT for MTSS (yes/no).

Statistics

Baseline age, biometrics, and characteristics of the complaints: i.e. duration of symptoms, repeat episode of MTSS, diagnosis and the SANE score at intake, were described with appropriate measures of central tendency and dispersion. Normality of the data was checked visually by means of histograms, boxplots, and QQ-plots. The length of the tenderness measured before each ESWT session was presented in a table, per patient group (four or five ESWT sessions). To determine the effectiveness of ESWT on the bone healing process, the differences in length between first and final ESWT session were tested for statistical significance by means of a paired sample t-test or the Wilcoxon signed-rank test if the parametric assumptions were not met. Pain during (yes/no) and post ESWT (1= no pain; 2 = < 12 hrs; 3 = 12-24 hrs; 4 = 24-48 hrs; 5 = > 48 hrs) was described.
Patient recommendation of ESWT (yes/no) were described. All tests were performed using SPSS version 24.0. The level of significance was set at $p < 0.05$.

RESULTS

In total 37 male cases in the year 2013 met all the criteria for inclusion. Table 1 shows relevant baseline characteristics of the service members in this study.

ESWT

Table 2 shows the length of the tender posterior medial tibial area identified by the patients before all ESWT sessions. 28/37 patients (76%) received four ESWT sessions, 9/37 patients (24%) received five ESWT sessions. There was no significant change in the average length of the posterior medial tibial tender area identified by the patients from the first (27.9 cm, ± 10.4) to the last ESWT session (4-ESWT group: 27.1 cm, ± 11.0 cm), (5-ESWT group: 30.2 cm, ± 14.5 cm), $p < .05$.

All patients (100%) reported ESWT to be a painful treatment (numerical rating scale ≥ 6 out of 10), during all sessions. After ESWT session one, 25/37 patients (68%) reported no post treatment hours of pain/discomfort, after ESWT session four 33/37 patients (89%) reported no post treatment pain.

Subjective final evaluations

Thirty patients (81%) would recommend ESWT for MTSS treatment.

Table 1.
Baseline characteristics of all 37 cases in this study.

	All Cases (n = 37)
Mean age (years) ± SD	24.6 ± 5.6
Mean height (m) ± SD	1.81 ± 0.06
Mean weight (kg) ± SD	82.3 ± 8.7
Mean BMI ± SD	25.2 ± 2.4
Median Duration of symptoms (months) / IQR	7 / 8
Repeat episode of MTSS (yes/no)	24 (65%)
Diagnosis: MTSS	16 (43%)
Diagnosis: MTSS + CECS (ICPM>35 mmHg)	15 (41%)
Diagnosis: MTSS + other ERLP	6 (16%)
Mean SANE intake ± SD	56.3 ± 18.2

n = number; SD = standard deviation; BMI = body mass index: IQR = inter quartile range; MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; ICPM = intra-compartmental pressure measurement; ERLP = exercise-related leg pain; SANE = single assessment numerical evaluation.

Table 2.
Length of the area of tenderness on the posterior medial tibia on both legs, identified by patients, per ESWT session. Column 7 and 9 compare the length of the tender area with the initial situation, expressed as a percentage, in order of increasing values.
Note: reduction of tenderness and increase of tenderness, both in approximately half of all patients, leads on average to insignificant change.

case number	ESWT protocol	ESWT session 1 length of tenderness on 2 legs cm	ESWT session 2 length of tenderness on 2 legs cm	ESWT session 3 length of tenderness on 2 legs cm	ESWT session 4 length of tenderness on 2 legs cm	length of tenderness 2 legs percentage of session 1	ESWT session 5 length of tenderness on 2 legs cm	length of tenderness 2 legs percentage of session 1
1	4 in 4	22	21	15	12	54.5		
2	4 in 4	36	36	30	24	66.7		
3	4 in 4	15	17	14	10	66.7		
4	4 in 4	15	15	12	10	66.7		
5	4 in 4	31	27	27	22	71.0		
6	4 in 4	54	44	42	40	74.9		
7	4 in 4	26	20	21	20	76.9		
8	4 in 4	20	15	18	16	80.0		
9	4 in 4	40	43	37	33	82.5		
10	4 in 4	29	29	26	24	82.8		
11	4 in 4	24	24	23	22	91.7		
12	4 in 4	23	22	18	22	95.7		
13	4 in 4	30	32	30	29	96.7		
14	4 in 4	44	44	44	44	100.0		
15	4 in 4	30	26	30	30	100.0		
16	4 in 4	32	38	34	33	103.1		
17	4 in 4	15	18	13	16	106.7		
18	4 in 4	42	42	45	45	107.1		
19	4 in 4	9	11	12	10	111.1		
20	4 in 4	22	29	26	25	113.6		
21	4 in 4	20	22	22	23	115.0		
22	4 in 4	31	35	33	37	119,4		
23	4 in 4	20	23	19	24	120.0		

Table 2, continued.

case number	ESWT protocol	ESWT session 1 length of tenderness on 2 legs cm	ESWT session 2 length of tenderness on 2 legs cm	ESWT session 3 length of tenderness on 2 legs cm	ESWT session 4 length of tenderness on 2 legs cm	length of tenderness 2 legs percentage of session 1	ESWT session 5 length of tenderness on 2 legs cm	length of tenderness 2 legs percentage of session 1
24	4 in 4	40	45	46	48	120.0		
25	4 in 4	25	35	35	32	128.0		
26	4 in 4	32	38	43	42	131.3		
27	4 in 4	24	33	38	37	154.2		
28	4 in 4	16	22	22	30	187.5		
29	5 in 6	17	14	14	14		8	47.1
30	5 in 6	17	17	14	13		13	76.5
31	5 in 6	24	23	22	24		24	100.0
32	5 in 6	50	50	50	50		50	100.0
33	5 in 6	31	31	28	31		31	100.0
34	5 in 6	27	34	34	31		30	111.1
35	5 in 6	39	46	44	42		44	112.8
36	5 in 6	39	45	50	50		46	117.9
37	5 in 6	21	19	26	24		26	123.8
average		27.9	29.3	28.6	28.1	100.9	30.2	98.8
SD		10.4	10.9	11.6	11.0	29.0	14.5	23.7

4 in 4 = 4x ESWT in 4 weeks; 5 in 6 = 5x ESWT in 6 weeks; ESWT = extracorporeal shockwave therapy; SD = standard deviation.

DISCUSSION

This study evaluated the effect of radial ESWT on the length of the tender area on the posterior medial tibial border in a military population with chronic MTSS. The most important findings were that radial shockwave did not reduce the length of the tenderness during the weeks of application. Despite it being a painful treatment, 81% in this group of patients would recommend ESWT.
The premise of this study was that ESWT would trigger a repair response in bone and reduce the length of the tender area on the posterior medial border during the weeks of application. This did happen in about half of patients, but not in the others, neutralizing an average effect (Table 2). Possibly the positive effects of ESWT on bone in this patient group are delayed into the weeks of running resumption; possibly the effect of ESWT is to reduce the intensity of pain on the medial tibial area first, before the palpable length of the tender area is reduced. This study clearly indicates that the clinical effectiveness of ESWT for MTSS for our specific patient group needs to be established in a randomized trial, such as previously performed in athletes by Moen. [7]

Rompe et al. reported that radial ESWT to the medial tibial border was painful in eight of 47 patients. [8] Our experience was very different. Using the same radial ESWT machine, with the exact same settings (number of shocks, frequency and pressure), all of our patients (100%) reported the treatment to be painful, defined as six or more on a 0-10 scale. In fact, in the preparation phase for this study it was discovered that patients strongly preferred self-application, and this has become the standard way of providing ESWT to the tibia in our department. Self-application offers the patient the opportunity to give more shocks to the most sensitive areas and to interrupt the treatment briefly if pain becomes excessive.

Gomez Garcia is the only other study to report on ESWT for MTSS in a military population. [12] However, the circumstances of the current study and the Gomez Garcia study were quite different. Gomez Garcia gave a single session of focused ESWT to military cadets with a minimum of three weeks of symptoms. All patients returned to activity and running four weeks after treatment. [12] In our study, patients had symptoms on average more than 12 months, received four or five sessions of radial ESWT and not all returned to pain free running. In our study return to active duty was not tracked. Return to active duty, particularly to the same military specialty, is a useful outcome measure in the military. We intend to track this in the future.

This study was not designed to investigate the optimal number of ESWT sessions. However, the extra ESWT session did not yield an additional treatment effect. Given the small number of patients receiving an extra ESWT session, this comparison has low power and should be interpreted with caution. In future studies on ESWT for MTSS, the optimal number of ESWT sessions, the optimal pressure and the optimal distribution of sessions over days or weeks should be further investigated. [9]

This study suffers from the inherent limitations of an analysis of regular care. A heterogeneous group of patients received individualized treatments plans and two different ESWT protocols were used. There was no control group. The study method, measuring the length of the tender medial tibial area with a ruler, has not been described before and has not been validated. Acknowledging these major limitations, we conclude that ESWT did not reduce the length of the tender area on the posterior medial tibial border during the weeks of application and we reveal that self-application of ESWT for MTSS is preferred by patients.

Based upon the positive patient recommendations reported in this study, and positive reports in the literature, [7,8,13] ESWT has remained part of our treatment program for service members with chronic MTSS. Since 2013, promising short- and medium-term treatment results for this particular group of patients have been published by our department. [14] The results are attributed to increased attention to gait retraining in both running shoes and military boots. In our view the combination of ESWT and gait retraining was very important in the treatment of chronic MTSS in the military, but the current study shows the need for further evaluation of the ESWT component of the comprehensive treatment program.

This study also illustrates the impact of MTSS on service members and the military organization. In our patient group 65% suffered from a repeat bout of exercise-related leg pain. In a time where recruiting and retaining young men and women in the military is very difficult, efforts in primary prevention of MTSS are paramount, with continuing emphasis on developing efficient and durable early-stage treatment strategies to prevent chronic and recurrent symptoms. [15]

CONCLUSION

A group of military patients with chronic MTSS received radial ESWT as part of their treatment program. During the weeks of application the length of the tender posterior medial tibial border did not decrease. ESWT to the medial tibial border was a painful treatment, but tolerable when self-applied. The majority of patients did not experience post treatment pain. In this group of patients 81% would recommend radial ESWT.

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Appendix 1

Table 1.
Standard care for chronic exercise-related leg pain: criteria for application (version 2013).

therapeutic intervention	criterion
Stretching	Gastrocnemius tightness = minimal angle compared to a vertical line: 70 degrees or more (Fig. A); Soleus tightness = maximal distance 5 cm from the wall or less (Fig. B).
Strengthening	Calf strength insufficient: not able to perform 30 consecutive calf raises on one leg.
Massage hypertonic m. plantaris	m. plantaris palpation painful (patient in prone position).
Dryneedling of triggerpoints	Medial and lateral gastrocnemius: if the patient identifies the calf as a pain location.
Compression stockings	Not given to patients with proven anterior CECS (ICPM ≥ 35 mm Hg).
Shockwave ESWT	For MTSS only: once a week, 4-5 sessions; each session 2000 radial shocks, frequency 8 per second and intensity 2.5 bar, on the posteromedial tibial border.
New running shoes	Every year or after 500 miles (800 km); If the patient describes a relation between symptoms and shoes; Minimalist shoes are discouraged, low drop shoes are encouraged (± 6-8 mm drop).
Customized anti-pronation inlays	If navicular drop is positive (> 1.0 cm) and if over-pronation is established with slow motion video analysis of barefoot running.
Maintaining fitness with low impact training	Resume three sessions of low impact exercise per week. Keep leg pain scores ≤ 3 (on a Numeric Pain Rating Scale 0-10).
Gait retraining while running in sports shoes	Four cues for running: 1. Change to a ball-of-the-foot strike (when applicable); 2. Increase cadence to 180 steps/min; 3. Stand up tall (don't bend over at the waist); 4. Increase knee lift 1-2 cm.
Progressive running schedule	Week 1-6: run twice a week, end goal = a 15-minute uninterrupted run, pain free with new running technique; Week 7-12: run twice or three times per week, end goal is a 30-minute uninterrupted run, pain free with new running technique.

Figure A.
Gastrocnemius / Achilles stretch (right leg, barefoot), criterion for normal value = maximal angle compared to a vertical line: 70 degrees or less.

Figure B.
Soleus stretch (left leg, barefoot), criterion for normal value = minimal distance 5 cm from the wall or more.

Chapter 5

The effectiveness of a 6-week intervention program aimed at modifying running style in patients with chronic exertional compartment syndrome

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ABSTRACT

Background: Previous studies have reported on the promising effects of changing running style in patients with chronic exertional compartment syndrome (CECS) using a 6-week training program aimed at adopting a forefoot strike technique. This study expands that work by comparing a 6-week in-house, center-based run training program with a less extensive, supervised, home-based run training program (50% home training).

Hypothesis: An alteration in running technique will lead to improvements in CECS complaints and running performance, with the less supervised program producing less dramatic results.

Study Design: Cohort study; level of evidence = 3.

Methods: Nineteen patients with CECS were prospectively enrolled. Postrunning intracompartment pressures (ICP), run performance, and self-reported questionnaires were taken for all patients at baseline and after 6 weeks of running intervention. Questionnaires were also taken from 13 patients (7 center-based, 6 home-based) four months post-treatment.

Results: Significant pre- to postintervention improvements were found for running distance (43%), ICP values (36%), and scores on the questionnaires Single Assessment Numeric Evaluation (SANE, 36%), Lower Leg Outcome Survey (LLOS, 18%), and Patient Specific Complaints (PSC, 60%). The mean post-treatment score on the Global Rating of Change (GROC) was between +4 and +5 ("somewhat better" to "moderately better"). In 14 participants (74%), no elevation of pain was reported post-treatment, compared with three participants (16%) at baseline; in all these cases, the running test was aborted due to a lack of cardiorespiratory fitness. Self-reported scores continued to improve four months after the end of the intervention program, with mean improvements of 48% (SANE), 26% (LLOS), and 81% (PSC). The mean GROC score improved to +6 points ("a great deal better").

Conclusion: In 19 patients diagnosed with CECS, a 6-week forefoot running intervention performed in both a center-based and home-based training setting led to decreased postrunning lower leg ICP values, improved running performances, and self-assessed leg condition. The influence of training group was not statistically significant. Overall, this is a promising finding, taking into consideration the significantly reduced investments in time and resources needed for the home-based program.

KEYWORDS

- chronic exertional compartment syndrome
- lower leg pain
- forefoot running
- conservative treatment.

INTRODUCTION

Lower extremity overuse injuries are common in occupations that involve prolonged weightbearing and repetitive lower-limb activities, such as the military. Army recruits and infantry soldiers typically have a high prevalence of lower extremity overuse injuries, which vary from 15% to 40%.[9,21,23,40] These types of injuries may result in significant lost duty and training time and greatly increased costs of medical care.[28]

Injuries to the leg such as medial tibial stress syndrome (MTSS), chronic exertional compartment syndrome (CECS), and stress fractures are among the most common forms of lower extremity overuse injuries seen in the military. High-impact running activities may particularly lead to increased bone-related injuries such as stress fractures and MTSS, while both running and low-impact marching activities may induce myofascial problems such as CECS. Our study focuses on the latter condition.

CECS is an idiopathic pain condition that is frequently associated with a sudden or significant increase in activities such as walking, (forced) marching, or running—as is often the case when young and relatively untrained military recruits start their basic training. Other speculated risk factors for CECS include muscle hypertrophy from the use of anabolic steroids, creatine supplementation, and biomechanical deviations in running (eg, overstriding, overpronation).[5,8] The classic symptoms of CECS include lower leg pain and tightness during exertion, with a complete absence of physical signs and symptoms at rest.[7] As the symptom producing activity continues, compartment pressures progressively increase, causing increased lower leg pain, sensory abnormalities, and muscle weakness, which eventually results in a premature cessation of the activity.[3,13,16,17,18,24,35] Symptoms normally subside within 15 minutes of activity cessation, but classically return at the same or slightly shorter interval/intensity during the next training session.[7,18]

While several hypotheses exist that explain the development of CECS pain, the exact pathophysiology of CECS is not understood. The primary accepted theory is that exercise increases intracompartmental pressure (ICP), which in turn compromises circulation, prohibits muscular function, and causes pain and disability in the lower leg.[4,7,13,15,31,34] CECS may occur unilaterally or bilaterally and may be present in a single compartment or all four compartments of the lower leg (anterior, lateral, superficial posterior, and deep posterior). The anterior and deep posterior compartments are the most commonly affected (45% and 40%, respectively).[38] Intracompartmental pressure measurement using needle manometer technology is the currently accepted gold standard for confirming the CECS diagnosis, although the validity and reliability of this measurement is not entirely unchallenged.[2,23]

Prior to 2012, conservative treatment for CECS was focused on addressing the extrinsic and intrinsic factors that may contribute to this condition and typically included prolonged rest periods, a decreased level of physical activity, anti-inflammatory agents, orthotics, ultrasound, massage, stretching, and electrical stimulation.[5,17] The efficacy of these conservative treatment options was extremely poor, with no suggestion of consistently positive outcomes. In the absence of effective conservative treatment, recruits and soldiers who were unable to abstain from or modify their problematic activities typically underwent surgical management by means of a fasciotomy. This type of surgery has proven to be an effective treatment modality in CECS, especially in the anterior and lateral compartments.[29,33] While the majority of patients do well after surgery, approximately 3% to 17% experience less than favorable outcomes such as pain, decreased sensation or hypersensitivity to touch at the incision site, paresthesia, infection, and hemorrhage.[7,13,19,30,37] Additionally, even individuals who do well initially may have a risk of symptom recurrence, which is reported to be as high as 50% over 5 years. These less favorable operative outcomes and the morbidity burden that postoperative rehabilitation has on military readiness gives great relevance to discovering alternative strategies for effective nonoperative CECS management.

In two recent studies, Diebal et al[12,13] reported on the promising effects of changing running technique in US military members with CECS indicated for surgical release. A 6-week forefoot running instruction program led to decreased postexercise ICP values, significant reductions in pain and disability, and improved performance outcomes on running tests, and these results were maintained and/or improved after one year of follow-up. Surgical intervention was avoided for all patients at the one year follow-up.

The rationale behind this intervention is that most runners have a habitual rearfoot strike pattern, which is often accompanied with a long stride length and prominent dorsiflexion of the foot at ground contact. This leads to a marked increase in the eccentric activity of the anterior structures of the lower leg, in particular the tibialis anterior muscle.[32] The running technique concept that was used in the studies by Diebal et al[12,13] focused on a forefoot strike pattern (i.e., landing on the ball of the foot) by applying shorter strides and a significantly increased step rate (180 spm or more). These adaptations reduce ground reaction impact forces by minimizing ground contact time and vertical displacement, but, more importantly, they shift the eccentric loading of the anterior compartment musculature of the leg to the posterior lower leg structures such as the Achilles tendon and the gastroc-soleus muscle complex. These structures have demonstrated higher elastic recoil potential and may be better suited to absorb eccentric impact forces during landing.[1,10,11,25,26]

This study expands the work by Diebal et al. into non–U.S. military members.[12,13] Our primary aim was to evaluate, in three consecutive case series, the effectiveness of a 6-week intervention program aimed at changing running technique in Dutch military service members with CECS of the lower legs. In the first two training iterations, the program was conducted at the Military Sports Medical Center in Utrecht, the Netherlands. In the third iteration, a less extensively supervised treatment program (50% center-based training, 50% home training) was evaluated. We hypothesized that alterations in running technique would lead to improvements in CECS complaints, decreased ICP values, and increased running performance. We, additionally, hypothesized that both extensively and less extensively supervised programs would lead to decreased compartment pressures and improved running performance, but that the less supervised program would produce less dramatic results.

METHODS

Design and study population

A single-group prospective cohort design was used in this study, closely following the study design used by Diebal et al. [13] Members from the Royal Netherlands Army, both recruits and active duty soldiers, diagnosed with CECS by a general surgeon of the Central Military Hospital, were sent to the department of Military Sports Medicine, to be included in the study after providing written informed consent.

To be included in this study, patients had to be active duty service members required to pass the annual 12-minute running test. They had to report a minimum of 2-month history of recurrent anterior and/or lateral leg pain and tightness in one or both legs that worsened with running. Pain had to occur within the first 15 minutes of running and lead to cessation of desired exercise. In addition, all symptoms had to completely resolve within 15 minutes upon cessation of running. The physical examination findings had to be normal at rest (i.e., no tenderness or compartment tightness to palpation and full functional ability to squat and hop without symptoms).

Exclusion criteria included a postexercise ICP in the anterior compartment of the lower leg below 35 mm Hg, a history of previous fasciotomy or other lower extremity surgery, any condition that would cause lower extremity swelling, creatine suppletion in the previous two months, any injury that would affect running tolerance besides CECS, any respiratory issue that could impact running tolerance, and a current use of nonsteroidal anti-inflammatory drugs (NSAIDs) that would interfere with test outcomes. Approval for the center-based intervention program was granted by the Institution Review Board of the University Medical Center Utrecht.

Preintervention measurements

Intracompartmental Pressure Measurements

To objectify and confirm the clinical diagnosis of CECS, 1-minute postexercise ICPs of the anterior compartments were measured, according to Verleisdonk.[36] All measurements were performed by the same sports physician using a Stryker pressure monitor. During ICP measurements, the patient was supine, with the legs dangling over the edge of the table in a free, nearly vertical position. ICPs were measured directly after CECS symptoms forced the individual to cease a running test on a treadmill, following a standardized running protocol with progressive increases in speed and inclination. These postrunning, preintervention ICP values were also used to evaluate the effectiveness of the treatment program. Additionally, after each minute of running, patients scored their “pain profile,” i.e., the level of pain in four lower leg regions (right lateral, right medial, left medial, left lateral) on a 10-point rating of pain scale. The test was aborted at a score of 7 out of 10 in at least one region. This running test design for CECS complaints has been previously described by Zimmermann.[41]

Demographic Measurements

A baseline biometric screening included measurements of body height, body weight, fat percentage (skinfold measurement according to Durnin and Womersley [14]), waist circumference, and blood pressure. Measurements were done by the same practitioner to avoid inter-rater reliability issues. Moreover, sex, age, and duration of complaints were recorded at baseline.

Self-Assessed Leg Condition

Participants filled out three self-report questionnaires, comprised of: (1) the Single Assessment Numeric Evaluation (SANE), [39] a 1-item question rating the lower leg condition on a 0 to 100 scale, with 100 being normal; (2) the Lower Leg Outcome Survey (LLOS),[13] a 20-item scale questionnaire that specifically evaluates leg conditions such as CECS, with a range of scores between 0 and 60, with a score of 60 being normal; and (3) the Patient Specific Complaints (PSC) questionnaire,[6] in which, from a list of different daily activities, patients had to select the one to three most important activities that were hampered by their leg complaints in the past week, and rate them on a 100-mm visual analog scale (VAS).

Running Performance and Kinematic Measurements

At baseline, participants performed a running test on a treadmill at the department of Military Sports Medicine. Prior to the running test, participants were asked to select a speed they thought they could normally maintain for approximately 25 minutes at a steady pace. This self-selected pace was used during the running test. Pain profile scores were asked after every minute of the running test. The test was aborted if one of the following occurred: a pain score of 7 out of 10 in at least two of the lower leg regions, after the participant ran five km without scoring a 7, or when the participant himself asked to stop due to reaching their cardiorespiratory limit. Running distance was used as one of the outcome variables. The Woodway treadmill was equipped with the Optojump Next system (Microgate), which is an optical measurement system consisting of a transmitting and receiving bar for measuring spatiotemporal parameters such as step length, step frequency, contact time, and flight time. At both pre- and postintervention running tests, the participants wore the same running shoes.

Intervention

A team of specialists, consisting of a running specialist, a physical therapist, and two human movement scientists, conducted a 6-week group-training program aimed at altering running technique. The primary aim of the program was to have participants adopt a forefoot strike running gait where they would land on the ball of foot (BOF) and demonstrate principles from the Pose Running Concept (Pose Tech Corp). Key features of this running strategy are to run at a minimum of 180 steps per minute, decrease stride length, and to actively use the hamstring muscle group to pull the support foot from the ground while "falling" forward under a gravitational torque (the center of mass moves in front of the support limb, thereby using gravity to propel movement).[25]

The training program started with a 1-hour theory class in which background information was given about the intervention program. During the 6-week program, subsequent training sessions of approximately 60 minutes each were conducted three times a week at the Military Sports Medical Center for the center-based (CB) group. The home-based (HB) group trained twice a week in the first three weeks and once a week in the last three weeks at the center. For the remaining sessions, one in the first three weeks and two in the last three weeks, participants had to train at their own military base or at home. No other training activities were allowed in both groups during the 6-week intervention period.

A typical training session consisted of the following consecutive elements: head-to-toe joint flexibility exercises, specific running technique drills aimed at specific running movement patterns, running integration drills, running bouts of increasing length, and a cool down. Drills focused on issues such as perception of body weight and pressure on BOF, changing support, leaning forward while running, and pulling the support foot from the ground directly under the hip. Combinations of these elements were applied in the running integration drills. The specific running technique (integration) drills used in our intervention are described elsewhere in detail.[12,13,27] The intensity and duration of the running integration drills and running bouts increased throughout the time frame of the program. For proprioception purposes, all training activities in the first three weeks were performed barefoot. Thereafter, shod running was gradually incorporated into the program. In addition to verbal cues (eg, "shorter strides", "increase step rate", "run quietly"), digital metronomes were used to pace the cadence at 180 steps per minute or over. Individual running performance was videotaped weekly and discussed as a visual feedback tool at the beginning of the next training session. For the home-based group, all videos (including slow-motion replays and coaching cues) were uploaded on the Internet for personal use during home training. The training sessions were all performed indoors. Participants of the home-based group received a training log with information on how to perform each home training session. The training log contained flexibility exercises, drills, and an indoor running program. The content and principles of the delivered running technique program comply with that of the US Army study by Diebal et al.[13]

Postintervention Measurements

One week after the last training session, all baseline measurements (i.e., biometry, questionnaire, ICP, running performance) were repeated. The protocols were identical to those used to obtain the baseline measurements (i.e., running tests were executed using identical speed values, inclinations, and running times). One item was added to the questionnaire: the Global Rating of Change (GROC),[20] a 15-point scale to measure the patients' perceived change and overall improvement, from "a very great deal worse" (score, −7) to "a very great deal better" (score, +7). The postintervention running test prior to the ICP measurements was executed using the same protocol from baseline, i.e., participants ran the same amount of time at the same elevation and speed.

Information on surgical intervention after the 6-week training program was not included in this study since the Central Military Hospital policy on fasciotomy changed during the study period toward a conservative treatment first approach. Four months postintervention, participants were asked to fill in a follow-up questionnaire consisting of the SANE, LLOS, PSC, and GROC.

Statistics

Following the study by Diebal et al,[13] running distance and postexercise ICP values (left-right mean values for the patients with bilateral symptoms) were chosen as the primary outcomes variables of this study. In addition, self-assessed outcome variables (SANE, LLOS, PSC, GROC) and kinematic variables (step length, step rate) were evaluated, the latter to quantify whether running form had indeed changed toward a forefoot striking pattern.

Pre- to postintervention differences in outcomes were checked using paired samples statistics. The assumption of normality was checked by using a Shapiro-Wilks test, as well as by visual inspection of the q-q plots and box plots of the data within the groups. Nonparametric testing was used if the assumption of normality was violated. No random sampling distribution was used because of the small sample size of this study.

The effects of training program (center-based vs home-based) on all outcome measures were examined using a 2-way repeated measures analysis of variance, with training group as the between-subjects variable and pre- to postintervention changes in outcomes as the within-subjects variables. The level of significance was set at $p < .05$. All statistical analyses were performed using SPSS statistics software (version 18; SPSS Inc).

RESULTS

Overall Patient Group

Baseline Characteristics

In total, 22 patients with CECS received an informed consent form for one of three training iterations (January 2013, April 2013, and September 2013). Two patients did not start the program due to logistic reasons (i.e., not available for six consecutive weeks), and one patient was excluded because of additional ankle problems. The number of patients per treatment group was limited to seven patients, both due to logistic constraints (staff capacity, facilities) and because this group size would suit our training purposes best. Baseline demographics and clinical characteristics of the 19 included patients are shown in Table 1. All patients reported a history of CECS symptoms for a minimum of two months, and all but two patients had bilateral CECS symptoms. For those patients with bilateral symptoms, there were no significant differences in postexercise ICPs between left and right legs (not presented). Combined MTSS and CECS symptoms were present in 47% of the overall group, with CECS being the dominant injury. Fourteen patients (11 center-based [CB], three home-based [HB]) chose running as their main PSC-complaint, two patients (HB) chose speedmarching (i.e., a combination of running and marching), two patients (1 CB, 1 HB) chose executing military work, and one patient (CB) chose prolonged standing. Reported earlier treatment modalities included rest, physical therapy, NSAIDs, orthotics and/or modified shoes, and training without running technique instructions specific to the Pose Method. All patients in this study were soldiers with a "remedial" status, i.e., soldiers who were waivered for their regular unit physical training program due to their physical condition. Prior to the initiation of the study, none of the patients were able to successfully complete their mandatory annual military service 12-minute running test due to their lower leg complaints. Baseline running assessments revealed that, in all but two participants, lower leg pain occurred within the first two minutes of running and progressively worsened while running. In the other two participants, both from the CB group, pain emerged after three and five minutes of running, respectively. All participants visually ran with a rearfoot striking gait pattern.

Pre- to Postintervention Results

All patients complied with the 6-week program; no patient had to withdraw due to complications or an inability to tolerate the running intervention. In the overall group of 19 patients, significant differences between pre- and postintervention scores were found for all outcome measurements but step rate. Figure 1 presents the results for the primary outcomes: running distance (mean increase of 43%) and postexercise ICP (mean decrease of 36%). Table 2 presents the results for the self-reported outcomes, with mean improvements in SANE, LLOS, and PSC of 36%, 18%, and 60%, respectively. The mean postintervention GROC score was between +4 and +5, which correspond with "somewhat better" to "moderately better." Step length decreased significantly from pre- to postintervention (mean difference 3.8 cm), while mean step rate remained unchanged. Moreover,

Table 1.
Baseline patient characteristics and scores on outcome measures of the overall group of patients, the center-based (CB) group, and the home-based (HB) group. [a]

	Overall	CB	HB
Total number of participants	19	13	6
Female participants	1	1	0
Mean age, y (SD; range)	24.5 (7.7; 19-53)	26.1 (8.6; 19-53)	21.2 (1.7; 19-24)
Mean body height, cm (SD)	181.5 (7.7)	181.9 (7.5)	180.7 (8.7)
Mean body weight, kg (SD),	85.1 (15.0)	86.6 (16.6)	81.7 (11.3)
Mean Body Mass Index, kg/m²	25.7 (3.6)	26.0 (3.8)	25.1 (3.3)
Mean systolic blood pressure, mm Hg	138.3 (18.5)	143.2 (17.9)	127.7 (16.6)
Mean diastolic blood pressure, mm Hg	81.2 (12.4)	84.5 (12.2)	74.0 (10.4)
Body weight ranges [b]			
Healthy weight	11 (58%)	7 (54%)	4 (67%)
Overweight	3 (16%)	2 (15%)	1 (17%)
Obesity	5 (26%)	4 (31%)	1 (17%)
Waist circumference ranges [c]			
Average health risk	14 (74%)	9 (69%)	5 (83%)
Raised health risk	4 (21%)	3 (23%)	1 (17%)
Strongly raised health risk	1 (5%)	1 (8%)	0 (0%)
Diagnosis			
CECS	9 (47%)	6 (46%)	3 (50%)
Mainly CECS, some MTSS	9 (47%)	7 (54%)	2 (33%)
CECS with MTSS history	1 (5%)	0 (0%)	1 (17%)
Duration of CECS complaints:			
2-3 mo	3 (16%)	2 (15%)	1 (17%)
3-6 mo	9 (47%)	5 (39%)	4 (67%)
6-12 mo	3 (16%)	3 (15%)	1 (17%)
> 12 mo	4 (21%)	4 (31%)	0 (0%)
Previous treatments			
Physical therapy	13 (68%)	6 (46%)	6 (100%)
Rest	5 (26%)	4 (31%)	3 (50%)
NSAID	3 (16%)	2 (15%)	1 (17%)
Orthotics/modified shoes	9 (47%)	8 (62%)	1 (17%)
Running schedule	9 (47%)	6 (46%)	6 (100%)
Reason to abort running test			
Pain score >7	16 (84%)	11 (85%)	5 (83%)
Cardiorespiratory failure	3 (16%)	2 (15%)	1 (17%)
Run for 5 km without scoring a 7	0 (0%)	0 (0%)	0 (0%)

[a]Numbers of individuals are presented, unless otherwise stated. CECS, chronic exertional compartment syndrome, MTSS, medial tibial stress syndrome; NSAID, nonsteroidal anti-inflammatory drugs.
[b]Based on skinfold measurement: healthy weight, up or below norm value; overweight, 5% or less above norm value; obesity, more than 5% above norm value. Age- and sex-adjusted norm values according to Durnin and Womersley.[14]
[c]Average health risk, circumference between 79-94 (men) or 68-80 (women); raised health risk, circumference between 95-102 (men) or 81-88 (women); strongly raised health risk, circumference above 102 (men) or above 88 (women). Norm values according to Lean et al.[22]

biometric measurements and blood pressure measurements did not change over time in the overall group (not presented). In 14 participants (74%), no elevation of pain was reported during the postintervention running test, compared with three participants (16%) whose pain values did not elevate at the baseline running test. In all these cases, the running test was aborted due to a lack of cardiorespiratory fitness. No complications (e.g., stress fractures) were reported in either study group during the intervention period.

Four-Month Follow-up Results

Due to logistic restraints, only participants from the April 2013 group and later (CB group, n = 7; HB group, n = 6) filled out the follow-up questionnaire. Self-reported scores continued to improve four months after the end of the intervention program, with mean improvements of 48% (SANE), 26% (LLOS), and 81% (PSC). The mean GROC score improved to +6, which corresponds with “a great deal better” (Table 2).

Center-based Group vs Home-based Group

Baseline Characteristics

The two training groups demonstrated different baseline values for the primary outcomes: The CB group showed higher mean postexercise ICP values and lower mean running distances than the HB group. Moreover, the CB group included one older participant (53 years of age), and showed a somewhat higher percentage of overweight participants as well as patients with longstanding CECS complaints. Most other baseline patient characteristics were comparable between the two groups (Tables 1 and 2).

Pre- to Postintervention Results

The CB group showed significant differences from pre- to postintervention on all outcome measures except step rate. In the HB group, all outcome measures changed significantly except running distance. We only found a significant interaction between group and pre- to postintervention scores on step rate, which indicates that training group had a significant influence on step rate. None of the other variables showed an interaction effect with group. In the CB group, eight participants (62%) had to abort their postintervention running test due to a lack of cardiorespiratory fitness, versus two participants (15%) at baseline. In the HB group, all six participants (100%) stopped their postintervention running test due to a lack of cardiorespiratory fitness, versus one participant (17%) at baseline. Figure 2 displays the results for the primary outcome measurements; Table 2 includes the results for the other outcomes.

Four-Month Follow-up Results

As in the overall group, both the CB group and the HB group showed larger improvements in the self-reported outcomes four months after the end of program, compared with the postintervention measurements (Table 2).

Table 2.
Analyses of differences (paired-samples test) between preintervention scores (pre) and postintervention scores (post) on self-assessed leg condition and kinematic measurements for the overall group (n = 19), the center-based group (CB, n = 13), and the home-based group (HB, n = 6). [a]

	Overall	P [95% CI]	CB	P [95% CI]	HB	P [95% CI]
SANE, %						
Pre	56.2 (14.9)	.00 [-31.0;-9.8]	54.5 (14.5)	0.01 [-35.3;-5.8]	60.0 (16.4)	.039 [-38.5;-1.5]
Post	76.6 (21.6)		75.0 (24.2)		80.0 (15.8)	
FUb	83.2 (13.6)	-	82.1 (16.8)	-	84.6 (8.8)	
LLOS, %						
Pre	72.0 (11.3)	.00 [-17.6;-7.7]	71.3 (12.8)	0.00 [-16.8;-5.9]	73.6 (7.7)	.036 [-29.0;-1.5]
Post	84.6 (15.5)		82.7 (16.9)		88.9 (12.1)	
FUb	90.4 (12.7)	-	89.0 (15.6)	-	92.3 (8.4)	
PSC, %						
Pre	70.4 (21.1)	.00 [28.6;58.3]	75.5 (18.4)	0.00 [21.2;64.7]	67.4 (23.9)	.023 [8.9;70.7]
Post	28.4 (28.0)		32.5 (29.4)		27.6 (23.1)	
FUb	12.8 (13.3)	-	9.6 (12.9)	-	17.4 (13.8)	
GROC, points						
Post	+4 to +5	-	+4 to +5	-	+6	-
FUb	13.8 (1.2)	-	14.1 (1.1)	-	13.4 (1.3)	-
Step length, cm						
Pre	110.2 (14.6)	.01 [1.4;7.1]	105.4 (14.9)	.04 [0.5;7.1]	120.8 (6.4)	.03 [0.9;11.5]
Post	106.0 (13.2)		102.1 (14.1)		114.6 (4.2)	
Step rate, steps/s						
Pre	2.81 (0.22)	.90 [-0.16;0.14]	2.84 (0.24)	.35 [-0.12;0.30]	2.74 (0.15)	.01 [-0.33;-0.08]
Post	2.82 (0.24)		2.75 (0.27)		2.95 (0.12)	

[a]Mean scores (standard deviations) are presented per group, including 4-month follow-up (FU) scores on a subset of participants (n = 13). GROC, Global Rating of Change (range of scores: -7 to +7); LLOS, Lower Leg Outcome Survey; PSC, Patient Specific Complaints; SANE, Single Assessment Numeric Evaluation.

[b]A follow-up measurement at 4 months postintervention was taken from the two last shifts: April 2013 (CB, n = 7) and September 2013 (HB, n = 6).

Figure 1.
Pre- and postintervention mean scores on the primary outcome measures (running distance, postexercise ICP) for the overall study group (n = 19). Error bars denote 95% CI; *, statistically significant difference between pre- and post-intervention (*P* < .05).

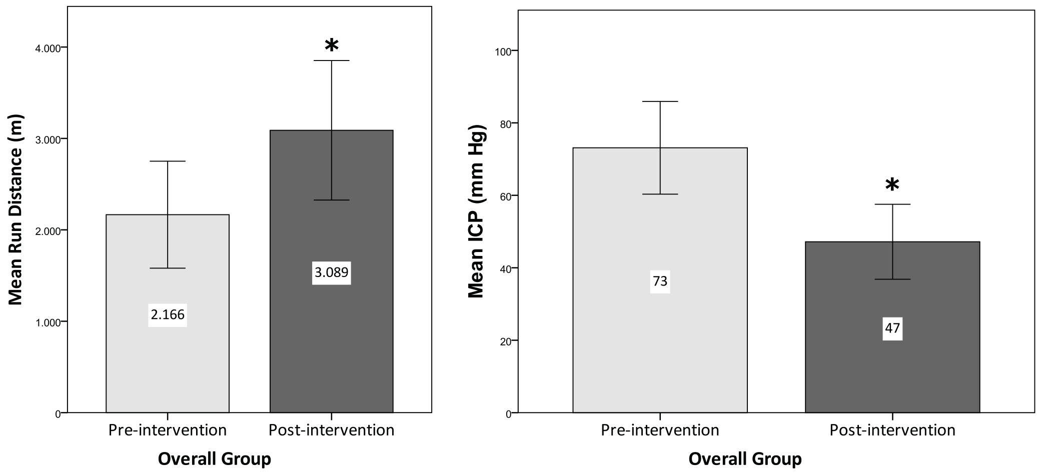
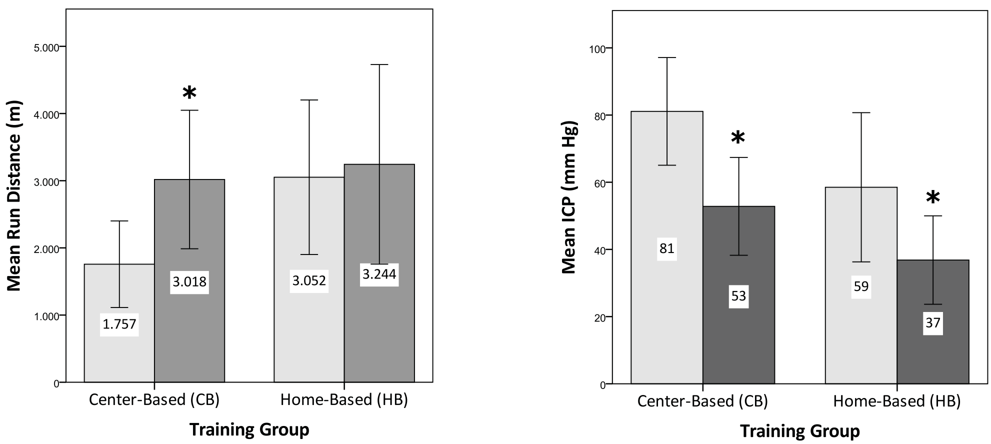


Figure 2.
Pre- and postintervention mean scores of the primary outcome measures for the center-based group (CB, n = 13) and the home-based group (HB, n = 6). Error bars denote the 95% CI; *, statistically significant difference between pre- and postintervention (P < .05).



DISCUSSION

The effectiveness of a 6-week treatment program aimed at changing running technique was studied in Dutch service members with CECS of the lower legs. Our hypothesis was that the running intervention would lead to improvements in CECS complaints in terms of decreased ICP values and increased running performance. Based on the results, this hypothesis can be confirmed. The primary outcomes of running performance and postexercise ICP showed significant improvements over time. Moreover, the patients' self-assessed leg condition improved significantly. We additionally hypothesized that the home-based program (50% center-based training, 50% home training) would lead to less convincing results than the center-based program due to the decreased supervision. Our study demonstrated mixed results here, possibly due to the baseline differences between the two groups with regard to fitness level and leg complaints. Both the CB group and the HB group showed significant improvements in postexercise ICP values and self-assessed leg condition from pre- to postintervention, but only the CB group showed significant improvements in running performance. Our main findings align with those from Diebal et al.[13] Our study is a (partial) replication of their case series conducted at the US Military Academy. Pre- to postintervention running distance significantly increased by 300% in the US study (1400 ± 600 m vs 4800 ± 500 m). Our overall group showed lower improvements in running performance (43%), possibly due to its more heterogeneous character in terms of age, military job function, lower leg symptoms, and duration of complaints. The CB group showed a significant increase in running distance of 72%, whereas the HB group showed a small and statistically insignificant decrease of 6%. This difference may reflect the differences seen at baseline between the two groups: mean running distance was nearly twice as high and the mean postexercise ICP level was somewhat lower in the HB group. It is possible that their CECS complaints did not hamper their running performance as much and/or as soon as it did in the CB group. Consequently, the relatively high baseline level of running performance in the HB group may have given less room for improvement over time in terms of running distance. In terms of pain level, there was a clear improvement in the HB group: no participant of the HB group had to abort their postintervention running test due to pain, compared with 5 participants at baseline.

Diebal et al[13] found that mean anterior ICPs after running showed significant postintervention decreases of 51% (78.4 ± 32.0 mm Hg vs 38.4 ± 11.5 mm Hg), slightly higher than the significant ICP decreases of 37% seen in our overall group. These small differences in ICP improvements between the two studies may reflect the aforementioned differences between the study populations. Differences in the standardized measurement techniques used in both studies (eg, the position of the lower leg during pressure measurement, which was supine and supported in the US group vs hanging in the Dutch group) are less likely to explain the pre- to postintervention differences.

The significant improvements in self-reported outcome measures found in our overall group, ranging from 39% (mean SANE score) to 18% (LLOS) to 60% (PSC), were comparable or somewhat lower than the improvements found in the US study (81% for SANE, 21% for LLOS, 96% for VAS). Self-reported outcomes continued to improve four months after the end of the intervention period, which suggests that the effects of a 6-week program aimed at modifying running technique have longer term potential. The authors chose a follow up period of four months for this study because, together with the injury time and intervention time, this covers a period of at least six months. This 6-month period is a meaningful time frame in the Dutch military setting due to national job security regulations.

The direction of changes in the kinematic parameters step length and step rate demonstrated in both studies were in direct correlation with the imposed running technique alterations, i.e., decreased step lengths and increased step rates. Changes were more prominent in the US study, which suggests that the adaptation to the new running style was somewhat more successful in their population. This may explain the greater improvements in outcomes seen in this group.

In our experience, individuals often suffer from both CECS and MTSS symptoms. To our knowledge, research has yet to be done that investigates the impact of adopting a forefoot running technique in individuals with combined symptoms. Indicatively, our study, with half of the group reporting mixed problems, shows that modifying running style targeting the reduction of CECS complaints coincidentally does not provoke MTSS symptoms and may even result in beneficial symptom changes. Looking into the pain profiles of the overall group during the running test at baseline, nine of 19 patients suffered from combined complaints, i.e., scoring a three or more (out of 10) on the pain profile for the MTSS-related medial regions of the lower legs. At the end of the 6-week training program, this number dropped to four of 19 patients. Research in individuals that have developed CECS symptoms during (forced) marching activities, as opposed to running activities, may also provide an interesting topic for study. Principles derived from the gait retraining techniques that were used in the current study may be applied to changing marching style in this target group. The authors are currently planning another study to confirm this hypothesis.

The main purpose of this study was to replicate the study findings by Diebal et al[13] in a different (military) setting. We have added information to the US case studies by including a home-based intervention program. Evidently, the study design has some weaknesses concerning the relatively small numbers per group (lack of power to determine group difference), short follow-up period, and the lack of a control group. Our study was built around three consecutive case series, for which patients were grouped during different time frames (January 2013, April 2013, September 2013). The number of patients per iteration was limited to seven patients, both due to logistic constraints (staff capacity, facilities) and because we anticipated that this group size would suit our training purposes best. We had to work with eligible patients (referred to us by the surgeon) within a certain time frame to prevent the first patients assigned to each group from waiting too long prior to treatment initiation. This explains why we had seven patients in the second shift and six patients in the other two shifts. We have chosen to neither use a randomized nor a controlled design, since we thought this was not feasible considering the expected numbers of patients that would be referred to our center within a reasonable time frame. We realize that this choice weakens the methodologic power of our study and the intercomparability of the study groups.

CONCLUSION

In 19 patients diagnosed with CECS, a 6-week forefoot running intervention performed in both a center-based and home-based training setting led to decreased postrunning lower leg ICP values and improved running performances. The pain and disability typically associated with CECS were significantly reduced, and scores even improved at four months postintervention. Both training programs showed significant improvements over time, and the influence of training group on all but one of our measurements (step rate) was not statistically significant. Overall, this is a promising finding, taking into consideration the significantly reduced investment in time and resources needed for the home-based program. Considering the small sample size and lack of control group of the study, future research with more power is needed to confirm these results.

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Chapter 6

Gait retraining as part of the treatment program for service members with exercise-related leg pain: Preliminary clinical experiences and retention

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ABSTRACT

Background: Gait retraining as part of a treatment program for exercise-related leg pain was introduced in the sports medicine department of the Royal Netherlands Army in 2013.
Objective: To describe clinical experiences and retention of gait retraining in a military setting.
Methods: Sixty-one cases from the year 2015 were available for analysis of gait and gait retraining. In 2016, 32 patients were available for follow-up survey, 28 of them also for follow-up measurement of running biomechanics in running shoes.
Results: Service members received an outpatient treatment program that lasted on average 129 days (SD 76). They received on average 2.4 gait retraining sessions, leading to significant and lasting changes in running biomechanics, in particular reduction in maximal force (N) and maximal pressure (N/cm^2) on the heels at 317 days follow-up (average, SD 108). Most service members were satisfied with gait retraining. At follow-up 27 service members (84%) attributed some, the majority or all symptom reduction to gait retraining. Seventy percent reported that they had mastered the new running technique within two months. The Single Assessment Numerical Evaluation score increased from 55 to 78 for males and from 45 to 75 for females.
Discussion: This is the first study to report on gait retraining for Medial Tibial Stress Syndrome. In future, prospective studies on gait retraining in the military both running in shoes and running in boots should be investigated.
Conclusion: Soldiers with exercise-related leg pain, among them patients with chronic Medial Tibial Stress Syndrome, respond well to a treatment program that included gait retraining. Ten months post gait retraining, their running biomechanics still showed positive changes from intake.

KEYWORDS

- medial tibial stress syndrome
- chronic exertional compartment syndrome
- gait retraining
- military.

INTRODUCTION

Exercise-related leg pain (ERLP) is a common problem in the military. Healthy young men can have pain in both legs only weeks after starting a training course, leading to them dropping out of the military. The most common diagnoses in the Royal Netherlands Armed Forces are: 1. Medial Tibial Stress Syndrome (MTSS), 2. Chronic Exertional Compartment Syndrome (CECS) or 3. a combination of MTSS+CECS. [1] The highest reported incidence of MTSS in a military setting was 35% of 124 naval recruits participating in basic military training in Australia. [2] An estimation of the incidence of CECS in the military is 1 in every 2000 US military service members per year. [3]

MTSS is an overuse injury involving the interface of the tibial bone and soft tissue. The patient with MTSS reports pain over the tibia during and after leg loading activities. [4] The definition of CECS is pathologically elevated intracompartmental pressure during exercise, which returns to normal with cessation of exercise. [5] The patient with CECS reports a fullness or cramp like sensation over the involved muscular compartment, often after a specific amount of exertion (time, distance, or intensity). [5] If an intracompartmental pressure measurement (ICPM) in the first minute post exercise is above 35 mm Hg and the patient reports pain, the diagnosis CECS is confirmed. [6] If the pressure measurement is below 35 mm Hg, new diagnostic terminology can be applied: Biomechanical Overload Syndrome (BOS). [7]

For both MTSS and CECS the exact pathophysiological mechanism is not known. [1] A previous episode of leg pain and the biomechanics of walking and running are just two of many risk factors identified for these conditions in the military. [1] Gait retraining as a treatment for overuse injuries of the lower extremities, is presumably widely practiced, but until now scarcely reported in the literature. [8] Gait retraining regimens generally focus on a transition from rear foot to midfoot or forefoot strike, increasing cadence, or altering proximal mechanics. [8] The rationale for gait retraining for overuse injuries of the tibia is reduction of vertical impact forces [9] and for gait retraining in CECS is reduction of musculus tibialis anterior activity. [10] Gait retraining as a treatment for CECS shows promising results in the first publications on this topic. [11,12] There are no publications on gait retraining as a treatment for MTSS, but positive effects are assumed by experts. [8]

In the sports medicine department of the Royal Netherlands Armed Forces gait retraining as a part of the treatment program for ERLP has been introduced in 2013, using sophisticated tools, such as high speed cameras and an instrumented treadmill, to analyze walking and running biomechanics. The goal of this study is to evaluate the treatment results and to describe preliminary clinical experiences and retention of gait retraining in a military setting. This study is retrospective in design.

METHODS

The study involved an analysis of provided patient care (patient record analysis), a follow-up survey and a follow-up measurement of running biomechanics. Included were all soldiers with ERLP who received gait retraining as part of their treatment program in the year 2015 with the following diagnoses: 1. MTSS; 2. CECS (ICPM > 35 mm Hg); 3. BOS (ICPM < 35 mm Hg); 4. MTSS+BOS; 5. MTSS+CECS. All patients were initially seen by a single, senior sports medicine physician (WZ), using a detailed intake, diagnostic and treatment protocol for ERLP. Exclusion criteria were a fasciotomy less than one year ago and previous gait retraining elsewhere. Minimal follow-up time was set at three months.

From the patient records the following information was retrieved: patient history, biometrics, pressure measurements of the anterior and deep compartments in the first minute post exercise, diagnosis, kinetics and kinematics of running before gait retraining (T_0) and after a single gait retraining session on the same day (T_1).

The gait retraining intervention in 2015 consisted of four instruction sessions, session one and four by a primary care sports medicine physician (WZ), session two and three by a physical education instructor. The initial gait retraining session consisted of the following three segments: 1) measurement T_0: one minute running in running shoes, i.e. personal mechanics; 2) running on bare feet, with verbal instruction to change to ball-of-the foot landing (when applicable) and preferably 180 steps per minute; 3) Measurement T_1: one minute running in shoes, new mechanics. The speed of running was 9 km/h for females, 10 km/h for males during all running segments and measurements. The running style (type of striker) was determined based on slow motion camera evaluation and treadmill vertical force measurement. A heel striker was defined as a visual heel striker plus a maximum force on the heels > 400 N. During short moments of rest all participants were shown a video recording of their original and new running mechanics and the measurements of the instrumented treadmill to learn the reduction in impact forces. Instruction session two and three were private gait retraining lessons lasting
30-60 minutes. All participants received a 6-week gait retraining schedule, containing two running sessions a week, to ingrain the new running technique, to a continuous running time of 15 minutes. Instruction session four by the physician was limited to a brief visual check of the new running mechanics. Many patients stayed on for a second 6-week gait retraining schedule, containing two to three running sessions a week, to increase running time with the new running technique to 30 minutes. Patients were advised not to run more than prescribed in the schedules, to reduce the chance of symptom recurrence.

Gait retraining was not the only intervention offered in 2015 to patients with ERLP. Each patient received a personalized program with a mix of the following interventions: stretching or strengthening of lower extremity musculature, supplementation with vitamin D if below 50 nmol/l, massage of hypertonic musculature, dry needling of trigger points, neuro-prolotherapy with 10% glucose, extra corporeal shockwave therapy of the medial tibial border (4-5 sessions), prescription of compression stockings, evaluation of running shoes, evaluation/prescription of shoe inlays, maintaining fitness with a low impact training program, radiological imaging. At the end of the treatment program in the sports medicine department many patients, particularly those in physically demanding military specialties, were referred to the physical therapist on base for additional training before returning to full duty.

From the follow-up survey by telephone in the year 2016 the following information was obtained, primarily with multiple choice questions: current military status, current ERLP status, time and effort required to master the new running technique and any additional medical interventions from other medical professionals in the follow-up period.

During the follow-up measurement of running biomechanics (T_2) the treadmill (H/P/Cosmos Sports & Medical, Nussdorf, Germany), the software (Zebris Medical, Isny, Germany) and running speed applied were identical to the initial measurements (T_0 and T_1). The treadmill is serviced yearly. The Zebris software allowed for immediate feedback on running biomechanics in three zones of the foot: rearfoot, midfoot and forefoot.

In this study the single assessment numerical evaluation (SANE) was used to evaluate treatment results. [13] The SANE score is a single question instrument evaluating patients' subjective injury status with the following question: "how would you rate your lower leg today as a percentage of normal, on a 0-100 scale, with 100 being normal". The SANE score was developed and validated in a military health care setting. The SANE score was recorded at intake (SANE in), at the completion of the sports medicine treatment program (SANE out) and at follow-up (SANE follow-up).

All statistical tests were performed using SPSS version 24.0. The level of significance was set at $p < 0.05$. Data gathered included counts, means and standard deviations for continuous variables and counts and frequencies for categorical variables. A Shapiro-Wilk test was performed to test for normality of the data. If normality was assumed, independent sample t-tests and paired t-tests were conducted; if not, non-parametric testing was performed (Wilcoxon signed ranks test).
The study was announced to the medical ethics board Brabant, The Netherlands and approved under number NW2016-41.

RESULTS

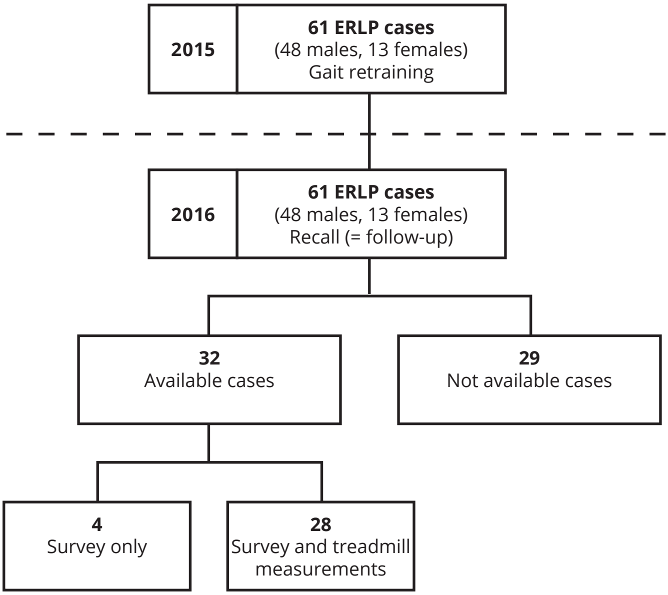
In total 61 cases with ERLP from 2015 were available for record analysis, 48 males and 13 females. Table 1 shows relevant characteristics of these service members. The most common diagnoses were MTSS+CECS (20 males and 7 females) and MTSS (15 males and 5 females). The average duration of the treatment program was 119 days for men (SD = 62.7) and 176 days for women (SD = 103.6). The average SANE score of patients improved during this time from 55 to 78 for males and from 45 to 75 for females. At intake 52 soldiers were classified as heel-strikers (85%).

At recall in 2016, 32 patients were available for follow-up survey (53%), see Flowchart 1. The average follow-up time was 298 days for men (SD = 105.2) and 357 days for women (SD = 82.0), the average follow-up SANE score was 73 for males and 85 for females. In addition, 28 of these 32 patients were available to return to our department for follow-up treadmill measurements (46%). The soldiers not available for follow-up were statistically not different from the soldiers that were available on any of the factors presented in Table 1. Reasons for not participating in the follow-up were: no contact possible (17 cases), no time to participate (8 cases) and follow-up time < three months (four cases).

Table 1.
Characteristics of all cases analysed (n = 61) and follow-up participants (n = 32).

	all gait retraining cases		**follow up participants**	
	male n = 48 + SD	**female n = 13 + SD**	**male n = 22 + SD**	**female n = 10 + SD**
age (years)	24.8 ± 5.2	23.8 ± 5.1	25.1 ± 5.1	23.7 ± 5.5
length (m)	1.82 ± 0.1	1.70 ± 0.1	1.85 ± 0.1	1.7 ± 0.1
weight (kg)	86.9 ± 11.0	70.4 ± 8.0	91.3 ± 9.6	68.1 ± 6.8
BMI	26.3 ± 2.5	24.5 ± 2.8	26.7 ±2.6	23.6 ± 2.2
duration of complaints (months)	12.5 ± 12.3	20.4 ± 32.4	14.0 ± 14.2	18.1 ± 36.1
re-injury	17 (35%)	6 (46%)	6 (27%)	1
heel striker	42 (88%)	10 (77%)	19 (86%)	0,7
navicular drop R (cm)	0.83 ± 0.26	0.77 ± 0.36	0.85 ± 0.29	0.77 ± 0.40
navicular drop L (cm)	0.80 ± 0.31	0.70 ± 0.34	0.80 ± 0.38	0.70 ± 0.39
diagnosis MTSS	15 (31%)	5 (39%)	7 (32%)	5 (50%)
diagnosis CECS	4 (8%)	1 (8%)	1 (5%)	1 (10%)
diagnosis BOS	6 (12%)	0 (0%)	3 (14%)	0 (0%)
diagnosis MTSS + BOS	3 (6%)	0 (0%)	2 (9%)	0 (0%)
diagnosis MTSS + CECS	20 (42%)	7 (54%)	9 (41%)	4 (40%)
SANE in (%) (M n = 47)	55 ± 19	45 ± 22	53 ± 16	42 ± 21
duration of treatment (days)	119.0 ± 62.7	175.8 ± 103.6	132.2 ± 64.7	136.1 ± 50.0
SANE out (%) (M n = 32; F n = 10)	78 ± 19	75 ± 20	82 ± 13	82± 12
moment of follow up (days)			298.0 ± 105.2	357.0 ± 82.0
SANE follow up (%)			73 ± 22	85 ± 14

Flowchart 1.
Study proceedings.



ERLP = exercise-related leg pain.

Table 2.
Kinetics and kinematics of running in sports shoes at T_0 (intake), T_1 (lesson 1) and T_2 (follow up).
The speed of running was 9 km/h for females, 10 km/h for males during all measurements.

Male	T0 (n=48)		T1 (n=43)		T2 (n=19)		T1 vs T0	T2 vs T0	T2 vs T1
	average	SD	average	SD	average	SD	%	%	%
stride length (cm)	204	12.4	192	8.3	197	13.4	94%*	97%*	103%
cadence (steps/min)	161	8.9	173	7.3	169	11.5	107%*	105%*	98%
max force heel (N)	614	159.3	211	89.5	348	227.1	34%*	57%*	165%*
max force midfoot (N)	749	136.2	798	150.3	839	158.4	106%*	112%*	105%
max force forefoot (N)	1023	197.3	887	151.9	956	217.4	87%*	94%*	108%
max pressure heel (N/cm²)	28	7.3	17	5.1	21	8.1	60%*	73%*	120%*
max pressure midfoot (N/cm²)	26	7.9	26	4.3	28	3.5	98%*	107%	109%
max pressure forefoot (N/cm²)	26	5.1	28	5.3	31	4.8	106%*	119%*	112%
Female	**T0 n=13)**		**T1 (n=12)**		**T2 (n=9)**		**T1 vs T0**	**T2 vs T0**	**T2 vs T1**
	average	**SD**	**average**	**SD**	**average**	**SD**	**%**	**%**	**%**
stride length (cm)	189	15.8	178	12.5	182	8.0	95%*	97%	102%
cadence (steps/min)	160	6.6	168	8.5	166	7.9	105%*	104%	99%
max force heel (N)	489	164.1	167	140.3	175	104.5	34%*	36%*	105%
max force midfoot (N)	576	124.0	693	207.3	663	111.1	120%*	115%*	96%
max force forefoot (N)	820	107.8	694	144.3	806	150.3	85%*	98%	116%
max pressure heel (N/cm²)	26	7.6	15	7.5	14	6.9	58%*	54%*	93%
max pressure midfoot (N/cm²)	26	6.2	27	7.0	28	5.5	102%	107%	105%
max pressure forefoot (N/cm²)	27	5.9	29	5.0	32	3.8	105%	118%*	112%

* = significant at $p < 0.05$; n = number; SD = standard deviation.

Table 3A.
Information from the follow up survey (average and SD where applicable).

	male n = 22	female n = 10
currently in military service	22 (100%)	9 (90%)
replaced in a lighter specialty	3 (14%)	1 (10%)
number of gait retaining sessions received	2.4 (1.3)	2.4 (0.8)
was this number adequate (yes)	13 (59%)	7 (70%)
number of gait retraining sessions preferred	3.4 (1.5)	2.8 (1.2)

n = number; SD = standard deviation.

Table 3B.
Patient evaluation of gait retraining at follow up.

	male	female
time required to master new running technique	n = 19	n = 8
1 month	11	5
2 months	2	1
3 months	4	1
> 3 months	2	1
effort required to master new running technique	n = 20	n = 8
very little, it is very easy	2	0
little, it is easy	5	5
intermediate	7	2
a lot, it is hard	6	1
symptom reduction attributed to new running technique	n = 22	n = 10
no symptom reduction	3	2
some symptom reduction	8	3
the majority of symptom reduction	5	2
complete symptom reduction	6	3

n = number.

Table 2 shows selected measurements of the running technique in running shoes at T_0, T_1 and T_2. Comparison of measurements at T_0 and T_1 shows that a single session of gait retraining leads to significant changes in most parameters of running measured. The changes in stride length and cadence are relatively small, the changes in force (N) and pressure (N/cm^2) on the heels are relatively large. Comparison of measurements at T_0 and T_2 shows that participants are still statistically different in most aspects of running technique measured. For females the changes in stride length and cadence are no longer statistically different, but force (N) and pressure (N/cm^2) on the heels remain significantly reduced at T_2 for both males and females. Comparison of measurements at T_1 and T_2 shows that males have lost a significant part of their initial reduction of force (N) and pressure (N/cm^2) on the heels. At follow-up seven soldiers were classified as heel-strikers (25%).

Table 3A and 3B show information from the follow-up survey. On average both males and females received 2.4 gait retraining sessions. The number of gait retraining sessions was called 'adequate' by 59% of the males and 70% of the females, the others would have preferred one or two more sessions (Table 3A). Seven patients received only one session (not presented in table 3A). Most soldiers are positive about gait retraining. At follow-up 27 soldiers (84%) contribute some, the majority or all symptom reduction to it. Mastering the new running technique was reported to be easy or very easy by 12 soldiers (43%) and 19 soldiers (70%) reported they mastered the new running technique within 2 months (Table 3B). After completing the treatment program in the sports medicine department 14 soldiers (44%) received additional training by a physical therapist, two had surgical treatment (fasciotomy).

Table 4 shows treatment duration, follow-up time and SANE scores in chronological order per diagnostic category. In some diagnostic categories, already small at intake, only a few participants could be evaluated at follow-up, therefore no further statistical calculations were performed on the data in Table 4. After 129 days of outpatient treatment and 317 days of follow-up, military ERLP patients report an average SANE score of 77. Patients in the MTSS group have the highest average SANE out scores. Patients in the CECS group have the lowest average SANE out and SANE follow-up scores.

Table 4.
Treatment periods and subjective evaluation per diagnostic category.

	SANE in (%)			duration treatment (days)			SANE out (%)			follow up time (days)			SANE follow up (%)		
	average	SD	n=	average	SD	n=	average	SD	n=	average	SD	n=	average	SD	n=
MTSS	56	18	20	114	43	20	84*	14	15	340	98	12	78*+	19	12
CECS	54	21	5	122	67	4	63	31	3	345	6	2	50	28	2
BOS	56	17	5	89	48	5	70*	17	3	287	80	3	80	13	3
MTSS + BOS	60	10	3	208	135	2	83	4	2	347	263	2	75	35	2
MTSS + CECS	48	22	27	143	92	27	74*	21	18	294	113	13	80*+	20	13
all	52	20	60	129	76	58	77*	19	41	317	108	32	77*+	20	32

* = significant change from SANE in at $p < 0.05$; + = no significant change from SANE out at $p > 0.3$; SD = standard deviation; n = number; MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; SANE = single assessment numeric evaluation score.

DISCUSSION

Gait retraining as a treatment for overuse injuries of the lower extremities is presumably widely practiced, but scarcely reported in the literature. This study is a retrospective evaluation of gait retraining offered in 2015 to 61 service members with ERLP. Of these soldiers 32 were available for a follow-up survey and of them 28 for a follow-up measurement of running technique at 317 days (SD = 108). The service members not available for follow-up were statistically similar to those who were available. To the best of these authors' knowledge, this is the first study to describe the results of gait retraining for MTSS patients.

At first measurement 85% of service members with ERLP were identified as heel-strikers. This is similar to previous findings on strike pattern among service members. [14] One gait retraining session offered by a primary care sports medicine physician changing strike pattern and introducing relatively small changes in stride length and cadence can produce a statistically significant change in most parameters of running, but in particular in maximal force (N) and maximal pressure (N/cm^2) on the heels. This reconfirms that the biomechanical parameters of running can be readily modified with deliberate instruction. [15] Measurement at follow-up shows that participants lose a percentage of the changes that were made after the first gait retraining session, but a statistically significant reduction in force and pressure at the heels remains (Table 2). At 317 days follow-up 25% of the soldiers were still heel strikers, indicating perhaps an individual variation in susceptibility to gait retraining.

At follow-up the average SANE score of ERLP patients was 77 (Table 4). This shows that many soldiers with ERLP experience persistent difficulty with running even after a comprehensive conservative sports medicine outpatient treatment program and 317 days. In The Netherlands Armed Forces, as in the British and American forces, ERLP is a major cause of decreased readiness. [1] Continued effort is warranted in both the primary prevention and treatment of these injuries. In previous studies, positive results were reported with gait retraining in the treatment of service members diagnosed with CECS. [11,12] In this study patients with MTSS also responded well to a treatment program which included gait retraining. This is a novel finding and should encourage health care workers to introduce gait retraining as part of the treatment of MTSS patients.

In controlled study settings gait retraining has been executed with eight instruction sessions in two weeks, or 18 sessions in six weeks. [9,11,12] Short term clinical success with only three gait retraining sessions has been reported. [10] This retrospective analysis shows that some patients had a high SANE follow-up score with as little as a single gait retraining session, however most soldiers would have preferred three to four sessions. On average patients received 2.4 gait retraining sessions, where four sessions were intended. Stimulating attendance at all four gait retraining sessions more stringently may improve treatment results in the authors' department and may reduce the number

of treatments sought after completing our program.
This study reports on gait retraining of soldiers running in running shoes. Many patients in this study indicated that their symptoms induced by running in running shoes were enhanced when running in military boots. In the authors' lab effects of similar magnitude have been observed with gait retraining of running in boots (Meindl, Germany). No studies are available on gait retraining of running in military boots.

This study has several of the inherent limitations of a retrospective analysis: incomplete patient records, different follow-up times per case analyzed, patients unavailable for follow-up, and no control group. In addition, patients with different diagnoses in the ERLP group were included and they received different treatment programs of different duration. It is important to recognize that the benefits of the treatment provided cannot be attributed to gait retraining alone. However, accepting these major limitations, the strength of this study is that it presents new and practical information on gait retraining and it's retention as part of a treatment program for soldiers with ERLP. The follow-up period, 317 days, is long compared to most published studies [15] and contact with 53% of the patients, on average after ten months, is a fair recall result in a military setting. It is also an instructive precursor for a prospective study on gait retraining of the same patient population. In future studies, it is advisable to measure running mechanics both in running shoes and in military boots at intake and at the completion of the gait retraining intervention. Follow-up measurements could be planned at six and 12 months respectively.

CONCLUSION

This study is a retrospective analysis of patient care, with a follow-up, among Dutch service members with ERLP. The ERLP patients received on average 2.4 gait retraining sessions. Significant and lasting changes were achieved in running biomechanics, in particular in maximal force (N) and maximal pressure (N/cm^2) on the heels at 317 days follow-up. Soldiers with ERLP are satisfied with gait retraining as part of their treatment program. Patients with MTSS responded well to the treatment program that included gait retraining as reflected by the increase of their SANE scores. It is suggested that four gait retraining instruction sessions, spread over two-three months, with homework exercises, can be sufficient to produce lasting positive clinical results. In future, prospective studies on gait retraining in the military, both running in running shoes and running in boots should be investigated, because both shod conditions are relevant for the military patient.

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Chapter 7

Gait retraining reduces vertical ground reaction forces in running shoes and military boots

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ABSTRACT

Gait retraining can lead to persistent changes in vertical ground reaction forces while running in shoes. No studies describe gait retraining in military boots.

The aim of this prospective cohort study was to evaluate the difference between running in sports shoes and boots, before and after gait retraining, for selected biomechanical parameters, in service members with chronic exercise-related leg pain. Measurements of interest were: stride length, cadence, maximal force (N) and maximal pressure (N/cm^2) in three sections of the foot.

Forty one cases were analyzed. At intake maximal force at the heel and maximal pressure in all sections of the foot were greater in boots. The median duration of the outpatient treatment program was 143 days (IQR 95), containing five gait retraining sessions (range 4-6), with four gait retraining cues repeated in all training sessions. These cues produced reduction in stride length, increase in cadence, reduction of force and pressure in the heel, and force reduction and pressure increase in the fore foot. However, in boots maximal force and pressure in the mid foot increased.

We concluded that the same gait retraining cues can be used to optimize ground reaction forces in running shoes and in military boots.

KEY WORDS

- medial tibial stress syndrome
- chronic exertional compartment syndrome
- conservative treatment
- military
- occupational.

INTRODUCTION

Exercise-related leg pain (ERLP) is a regional pain syndrome described as pain between the knee and ankle which occurs with exercise. Medial Tibial Stress Syndrome (MTSS), Chronic Exertional Compartment Syndrome (CECS), tibial and fibular stress fractures, tendinopathy, nerve entrapment, and vascular pathology are the diagnoses that are usually included in the ERLP group. [1] The diagnosis Biomechanical Overload Syndrome (BOS), used in patients with chronic exertional anterior compartment pain with low intramuscular pressures, is a new edition to the ERLP group. [2] In the military ERLP is a common complaint and MTSS is considered to be the overuse injury with the largest impact on basic military training. [3]

The evidence for an association between ground reaction forces and musculoskeletal injuries in runners from both retrospective and prospective data is now considered "compelling". [4] Gait retraining as a treatment for ERLP is presumably widely practiced, but reports in the literature were sparse until recently. [5] The goal of gait retraining can be reducing vertical ground reaction forces (e.g., for MTSS) or to reduce muscular activity of a symptomatic muscle group (e.g., for anterior CECS). Cues commonly recommended by experts to reduce vertical ground reaction forces while running are: 1. change from heel strike to a fore foot strike landing; 2. Increase cadence to 180 steps/min; 3. Stand up taller, don't bend over at the waist (trunk and pelvic position). [5]

Two military studies have shown that service members with MTSS can benefit from gait retraining when given as part of a comprehensive treatment program. [6,7] These studies have been performed in running shoes. Both running in shoes and running in military boots are common occupational tasks for service members. Among other factors, military boots differ from running shoes in design (shaft), weight (heavier) and sole flexibility (stiffer). [8] In studies comparing running in shoes versus running in military boots at 10 km/h on a treadmill, conflicting results were presented; one research group found no significant differences in stride length, cadence and maximal vertical ground reaction forces, [9,10] but in one other study, running at 14,4 km/h in army boots was associated with significantly greater loading impact compared with cross-trainer and running type shoes. [11] The goal of conservative treatment of ERLP in military patients is to help them return to military duties, including running in boots, without re-injury. Reduction of ground reaction forces while running in military boots may contribute to treatment effectiveness. No study reports on retraining of running technique in military boots. It is not known whether the same cues used to retrain biomechanics of running in running shoes can also lead to reduction in vertical ground reaction forces while running in military boots. Increased knowledge on gait retraining in boots could improve conservative treatment results for military ERLP patients. The objectives of this study were: 1. to determine the difference in stride length, cadence and vertical ground reaction forces while running in sports shoes versus running in military boots before gait retraining and 2. to determine the same differences after gait retraining, provided as part of a comprehensive treatment program.

MATERIALS AND METHODS

Prospective cohort study, performed at the Department of Military Sports Medicine, Royal Dutch Army, Utrecht, The Netherlands. This study was presented to the medical ethics board Brabant, The Netherlands, and approved under number NW2017-01. All subjects gave permission in writing for aggregate, anonymous use of their treatment data.

Organization of care

The Royal Netherlands Armed Forces have a diagnostic and treatment protocol for ERLP coordinating physicians and physical therapists working in outlying primary care clinics with sports medicine and other specialists in the Central Military Hospital (CMH). This protocol describes that service members with ERLP be referred to the CMH if conservative therapy has not been successful within six months. [2] Since 2011 the CMH has offered a specialty clinic for service members with ERLP. A multidisciplinary team of surgery, sports medicine, and physiatry evaluates patients in a one-stop shop setting. All patients are screened using a detailed intake template for history, physical examination, diagnostic testing and treatment prescription. All patients are asked to run on a treadmill and score their ERLP symptoms according to the Running Leg Pain Profile and all patients receive diagnostic intracompartmental pressure measurements in the first minute post exercise, as described previously in detail. [2] Appendix 1 shows the diagnostic flowchart used in this study and the five potential diagnoses in the ERLP group: 1. MTSS; 2. CECS; 3. BOS; 4. MTSS + BOS; 5. MTSS + CECS. Based on the evaluations, patients may be referred to any of four treatment arms: surgery in the CMH, outpatient conservative treatment in the Military Sports Medicine department, inpatient conservative treatment in the Military Rehabilitation Center, or referral back to their original military base to re-engage with primary care.

Subjects

Potentially all patients with chronic ERLP, who were assigned to a comprehensive outpatient treatment program in the Military Sports Medicine department, who received gait retraining both in running shoes and military boots between September 2017 and September 2018, were eligible for analysis in this study. Exclusion criteria for analysis were: 1. age > 30 years; 2. previous gait retraining; 3. fasciotomy of a leg less than one year ago; 4. concurrent psychological treatment or other lower extremity injury with a potential impact on gait retraining; 5. incomplete gait retraining measurements in running shoes and military boots, at intake or at evaluation.

Measurements at intake (T_{in})

As part of the intake procedure (T_{in}), age (years), height (meter), weight (kilogram), duration of symptoms (months), repeat ERLP episode (yes/no) were collected. In addition, two running conditions were recorded on an instrumented treadmill, running in shoes and running in military boots, each for a 30-seconds segment and at a speed of 10 km/hour and an incline of 1%, without any corrective instruction and with a very short accommodation time (± 15 seconds) to prevent onset of symptoms.

The treadmill used in this study (H/P/Cosmos Mercury, Nussdorf-Traunstein, Germany) was serviced yearly. The gait analysis software (Zebris Medical, Isny, Germany, version 2013) allowed for measurements of stride length, cadence, forces and pressures in three zones of the foot: heel (rear foot), mid foot and fore foot. Both the treadmill and the gait analysis software have been certified according to European standards for sports, fitness, medical and rehabilitation equipment.

Patients' running strike technique (heel, mid foot, or fore foot striker) was determined based on visual evaluation of slow motion camera images and treadmill vertical force measurement. A heel striker was defined as a visual heel striker at initial contact, plus a maximal force on the heels > 400 N. [7,12] Objective outcome measurements were stride length (centimeter), stride length was defined as the distance covered from initial contact to initial contact of the same foot and equal to the sum of the lengths of two steps, cadence (steps/minute), maximum force (N) and maximum pressure (N/cm^2) per segment of the foot. The Single Assessment Numeric Evaluation score (SANE) was used to describe patient's subjective evaluation of treatment progress. [13] The SANE score is a single question instrument evaluating patients' subjective injury status with the following question: "how would you rate your lower leg today as a percentage of normal, on a 0-100 scale, with 100 being normal". The SANE score was developed and validated in a military health care setting.

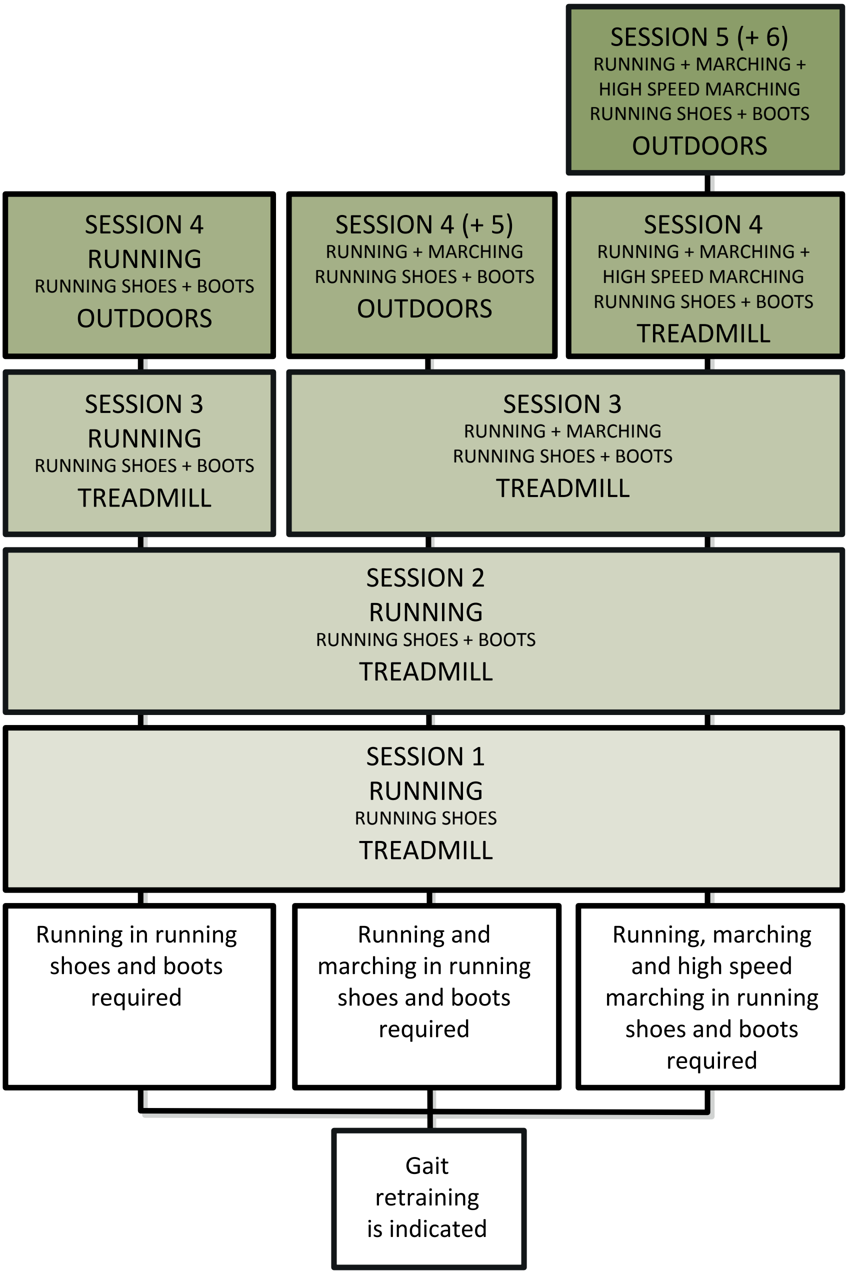
Gait retraining and standard care

Gait retraining was introduced on the treadmill, by a senior sports medicine physician and two medical students, all with ample experience with the study protocol and gait retraining for this particular group of patients. Four basic verbal instructions were repeated throughout the gait retraining sessions: [5]

1. change from heel strike to a ball-of-the foot landing (when applicable);
2. increase cadence to 180 steps/min (at a constant training speed of 10 km/h);
3. stand up taller, don't bend over at the waist or look down;
4. increase knee-lift by 1-2 cm and relax the foot that is in the air, so that it points towards the floor.

Patients received at least four and maximally six individual gait retraining sessions during a training period of minimally six weeks. Figure 1 shows the gait retraining sessions offered in this study. Depending on the military specialty, and therefore the goals of rehabilitation, training also addressed marching in military boots and high speed marching in gait retraining session four through six.
For feedback, during short moments of rest, all participants were shown a video recording of their

Figure 1.
Gait retraining sessions offered in this study.



original and new running mechanics and the measurements of the instrumented treadmill to learn the reduction in impact forces they achieved. In addition, patients received written information, to perform self-controlled training assignments, two to three training sessions a week, to acquire the new running technique.
Gait retraining was not the only intervention offered to these patients with ERLP. Each patient received standard care, i.e. an individualized treatment program (appendix 2).

Measurements at evaluation (T_{out})

When the treatment program for chronic ERLP in the sports medicine department was completed, the same two running conditions on the treadmill were measured again, recording stride length (cm), cadence (steps/min), maximum Force (N) and maximum Pressure (N/cm^2) per segment of the foot (10 km/h; 1% incline), during 30-second periods, without additional corrective instruction and with a very short accommodation time (± 15 seconds). Patients' post intervention running technique in running shoes (type of striker) was determined with the same criteria as used at T_{in}. Subjective evaluation of leg injury status at T_{out} was the SANE score.

Statistics

Baseline characteristics were described with appropriate measures of central tendency and dispersion. The SANE score at T_{out}, duration of treatment, number of gait retraining sessions received and type of striker at T_{out} were presented to describe the studied population. Normality of the data was checked visually by means of histograms, boxplots, and QQ-plots. The biomechanical measurements of running in sports shoes and in military boots at intake (T_{in}) and (T_{out}) were described with averages and 95% confidence intervals. The delta scores were calculated ($T_{out} – T_{in}$) to determine the changes in running biomechanics for running shoes and military boots. These scores were also presented with averages and 95% confidence intervals. All statistical tests were performed using SPSS version 24.0.

RESULTS

Subjects: In total 41 cases with chronic ERLP were available for analysis. Table 1 shows characteristics of these service members.

Running biomechanics at intake (T_{in}): Table 2 shows measurements of the running technique in running shoes and military boots at T_{in}. Average stride length, cadence and maximum force (N) on the mid foot and fore foot were similar for running shoes and military boots. Maximum force on the heel and maximum pressure (N/cm^2) on the heel, mid foot and fore foot were larger in military boots. At intake, before gait retraining, 39/41 (95.1%) of the service members were classified as heel strikers.

Running biomechanics after gait retraining (T_{out}): The median number of gait retraining sessions patients received was 5.0 (minimum 4.0, maximum 6.0). Table 2 shows measurements of the running technique in running shoes and military boots at T_{out} and the change in measurements between T_{out} and T_{in}. The changes in running biomechanics achieved at T_{out} show similar tendencies for running shoes and military boots: reduction in stride length, increase in cadence, reduction of force and pressure on the heel, force reduction and pressure increase in the fore foot. However, in boots the new running technique increased maximal force and pressure in the mid foot by 44.9 and 7.3 percent respectively for men and 61.3 and 11.3 percent for women. Changes in selected biomechanical parameters achieved by gait retraining are similar for men and women (Figure 2). At T_{out} one of the 41 patients was categorized as a heel striker (2.4%), a difference of 92.7 % compared with intake.

Table 1.
Characteristics of patients analyzed.

	men	SD / %	women	SD / %
	33		8	
age (years)	23.0	2.9	22.9	3.3
height (m)	1.79	0.07	1.69	0.04
weight (kg)	82.6	10.0	74.4	4.8
BMI	25.8	3.2	26.0	2.2
duration of complaints (months) *	9.0	13.0	6.0	4.8
re-injury (yes/no)	15	45.5%	1	12.5%
diagnosis MTSS	5	15.2%	4	50.0%
diagnosis CECS	12	36.4%	0	0.0%
diagnosis MTSS + BOS	3	9.1%	1	12.5%
diagnosis MTSS + CECS	13	39.4%	3	37.5%
treatment duration (days) *	133	77	180	98
SANE in	50	15	51	16
SANE out	77	16	77	21

*Median and interquartile range; BMI = body mass index, MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; BOS = biomechanical overload syndrome; SANE = single assessment numeric evaluation score; SD = standard deviation.

Table 2A and 2B.
Selected biomechanical parameters of two running conditions at T_{in} (intake) and T_{out} (exit); all measurements at 10 km/h and 1% incline on an instrumented treadmill; 2A men, 2B women.

Table 2A.

Men (n=33)	T_{in}		T_{out}		T_{out} - T_{in}	
	average	95% CI	average	95% CI	average	95% CI
Running Shoes						
stride length (cm)	207.1	(203.1, 211.1)	186.1	(182.8, 189.3)	-21.0	(-25.0, -17.0)
cadence (steps/min)	160.1	(157.2, 163.1)	178.2	(175.2, 181.3)	18.1	(14.8, 21.4)
max force heel (N)	656.2	(622.1, 690.2)	241.8	(213.3, 270.4)	-414.3	(-463.4, -365.3)
max force mid foot (N)	640.0	(596.0, 683,9)	629.5	(583.0, 676.0)	-10.5	(-47.6, 26.7)
max force fore foot (N)	1101.9	(1034.7, 1167.0)	1073.04	(1017.9, 1128.2)	-27.8	(-69.7, 14.2)
max pressure heel (N/cm²)	30.3	(27.3, 33.3)	17.6	(15.5, 19.7)	-12.7	(-15.4, -10.0)
max pressure mid foot (N/cm²)	29.5	(25.8, 33.3)	25.1	(23.0, 27.1)	-4.5	(-8.2, -0.7)
max pressure forefoot (N/cm²)	26.7	(25.3, 28.2)	30.5	(28.5, 32.5)	3.8	(2.2, 5.3)
Military boots						
stride length (cm)	208.3	(204.5, 212.1)	187.9	(184.5, 191.3)	-20.4	(-24.0, -16.8)
cadence (steps/min)	159.9	(156.8, 162.9)	176.9	(173.7, 180.1)	17.0	(13.7, 20.3)
max force heel (N)	753.0	(716.6, 789.4)	265.2	(232.1, 298.4)	-487.7	(-542.1, -433.4)
max force mid foot (N)	554.4	(510.5, 598.4)	803.2	(749.5, 856.9)	248.8	(185.1, 312.4)
max force fore foot (N)	1150.0	(1082.8, 1217.2)	990.9	(928.8, 1053.0)	-159.1	(-217.9, -100.3)
max pressure heel (N/cm²)	49.2	(46.6, 51.8)	28.0	(24.7, 31.3)	-21.2	(-25.3, -17.1)
max pressure mid foot (N/cm²)	45.6	(42.7, 48.5)	48.9	(46.1, 51.8)	3.3	(1.2, 5.5)
max pressure fore foot (N/cm²)	48.60	(45.2, 52.0)	49.8	(46.5, 53.1)	1.2	(-1.3, 3.7)

n = number; 95% CI = 95% confidene interval.

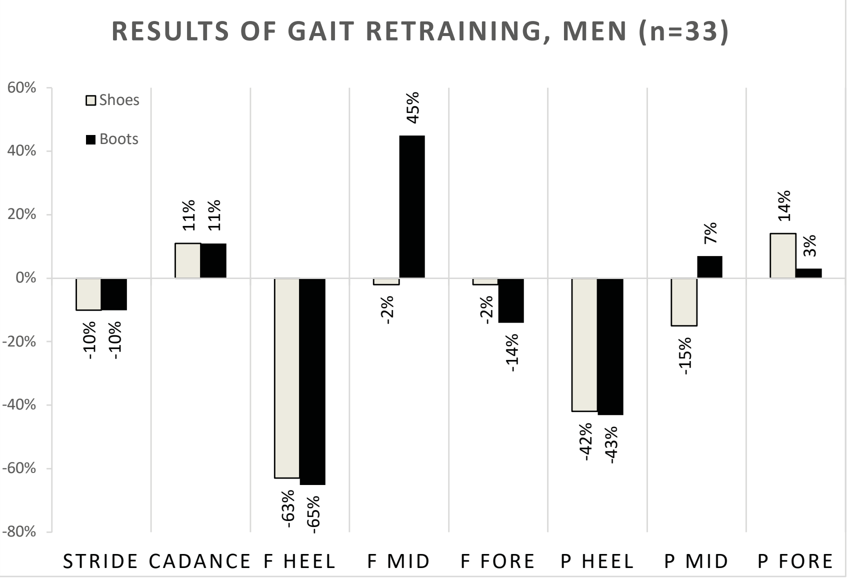
Table 2B.

Women (n=8)	T_{in}		T_{out}		T_{out} - T_{in}	
	average	95% CI	average	95% CI	average	95% CI
Running Shoes						
stride length (cm)	203.6	(197.2, 210.0)	185.4	(182.6, 188.2)	-18.3	(-24.9, -11.6)
cadence (steps/min)	163.0	(157.8, 168.2)	179.00	(176.1, 181.9)	16.0	(10.6, 21.4)
max force heel (N)	495.9	(444.0, 547.8)	200.2	(143.9, 256.4)	-295.7	(-368.1, -223.4)
max force mid foot (N)	507.2	(419.7, 594.7)	553.6	(467.8, 639.3)	46.3	(-44.4, 137.1)
max force fore foot (N)	1027.5	(918.1, 113.9)	973.7	(878.7, 1068.6)	-53.8	(-210.0, 102.4)
max pressure heel (N/cm²)	25.1	(20.0, 30.3)	17.1	(13.9, 20.2)	-8.1	(-16.3, 0.1)
max pressure mid foot (N/cm²)	30.9	(26.1, 35.7)	27.1	(23.2, 31.0)	-3.8	(-9.7, 2.1)
max pressure forefoot (N/cm²)	29.7	(26.2, 33.3)	33.4	(30.1, 36.8)	3.7	(0.7, 6.7)
Military boots						
stride length (cm)	202.8	(196.8, 208.7)	186.8	(183.3, 190.2)	-16.0	(-22.9, -9.1)
cadence (steps/min)	163.1	(158.7, 167.6)	177.6	(174.3, 180.9)	14.5	(9.1, 19.9)
max force heel (N)	646.5	(582.0, 711.1)	224.7	(165.8, 283.6)	-421.8	(-490.0, -353.6)
max force mid foot (N)	486.8	(430.9, 542.7)	785.0	(688.3, 881.7)	298.3	(184.9, 411.5)
max force fore foot (N)	1040.9	(956.5, 1125.3)	829.6	(757.0, 902.2)	-211.3	(-350.5, -72.2)
max pressure heel (N/cm²)	49.3	(44.1, 54.5)	29.0	(23.5, 34.6)	-20.3	(-28.1, -12.4)
max pressure mid foot (N/cm²)	42.7	(39.1, 46.30	47.5	(42.3, 46.3)	4.8	(-3.4, 13.0)
max pressure fore foot (N/cm²)	46.7	(41.0, 52.4)	48.0	(43.6, 52.3)	1.2	(-5.7, 8.1)

n = number; 95% CI = 95% confidene interval.

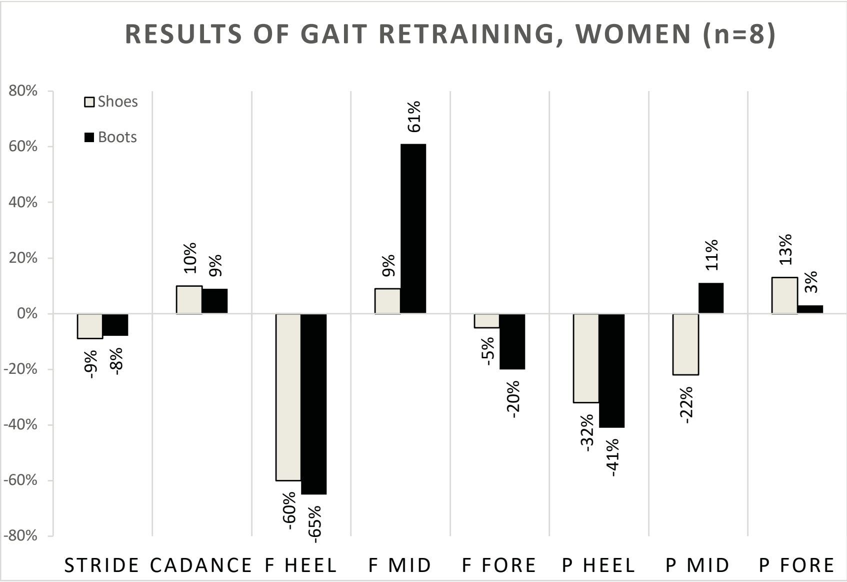
Figure 2A and 2B.
Results of gait retraining (T_{out}) for shoes and boots, expressed as a percentage change from intake (intake = 0%, on y-axis).
Note reductions in force (F) and pressure (P) in the heel; note increase in force (F) and pressure (P) in the mid foot in boots; note similarity of changes between men and women (Figure 2B).

Figure 2A.



n = number; F = force; P = pressure; MID = mid foot; FORE = fore foot.

Figure 2B.



n = number; F = force; P = pressure; MID = mid foot; FORE = fore foot.

DISCUSSION

To the best of our knowledge this is the first study to report on gait retraining in military boots for patients with chronic ERLP. Our most significant finding is that the same gait retraining cues can be used in shoe or boot shod runners to achieve similar optimizations in stride length (reduction), cadence (increase), force and pressure on the heel (reduction) and in the fore foot (force reduction, pressure increase). However, in military boots the new running technique increased maximal force and pressure in the mid foot.

Comparing intake measurements (before gait retraining) to the literature, our results confirmed the findings by Paisis et al. that stride length, cadence and maximal vertical ground reaction forces do not differ significantly between running shoes and military boots when running at 10 km/h. [9,10] In their studies, using the same treadmill, participants were running at a 5% incline, in the current study 1% incline was used. However, in our study, force (N) on the heel and pressure (N/cm²) on all sections of the foot were significantly greater in military boots. This finding was not reported in previous work, [10] but may be explained by the different shape, materials and composition of the sole between running shoes and military boots. [14]

Comparing measurements after gait retraining to the literature, this study reconfirmed that biomechanical parameters can be altered by running modification training programs, even in military boots. [15] Changes in stride length and cadence achieved by gait retraining in military boots were similar to the changes in running shoes. [7] However, changes in vertical ground reaction forces in the mid foot were elevated for boots compared to shoes. This novel finding may be causal in explaining why running in military boots is less comfortable than running in running shoes. [10]

In this study 39/41 (95.1%) of service members with ERLP presented with a heel strike running technique. This percentage is even higher than previously reported by Warr, who observed that 83% of service members were heel strikers. [12] A possible explanation is that our cases were chronic ERLP patients and his cases were healthy. Encouragingly, in our study only one of the 41 patients who completed the treatment program was still categorized as a heel striker (2.4%) at post-testing; in our previous study 25% of ERLP patients were still heel strikers post intervention. [7] One possible explanation for the increased percentage of strike change is an increase in the number of training sessions offered, from average 2.4 to average 5.0 sessions per patient.

One of the limitations of this study is that patients received a different number of gait retraining sessions (four - six), over a different number of treatment days. In a gait retraining study with healthy subjects these variable factors could be equalized, however the overall goal of this study was to improve conservative treatment procedures for military patients with ERLP and this can best be

Figure 3.
Standard issued military boots (Meindl), The Netherlands, 2018.

done by working with that particular group of patients. An omission and recommendation for future study is that body weight was not measured at T_{out}. If patient's body weight changed significantly during the rehabilitation period, vertical ground reaction forces while running may have been influenced. Another potential limitation is that several different brands of military boots were used. 26/41 subjects (63.4%) wore the standard issued military boots (Meindl), the rest wore individually acquired boots from other brands (i.e., Lowa, Bates, Magnum and Alt-berg). However, comparison of results showed that different brands of military boots demonstrated similar changes in running parameters, including the increased force and pressure in the mid foot. Women make up a small proportion of our study population, as is frequently observed in military studies. Women make up approximately 10% of the Royal Netherlands Armed Forces. In our study 8/41 (19.5%) injured warrior athletes were women. This may reflect the fact that women have a higher relative risk of developing ERLP in the Royal Netherlands Armed Forces. [16] Although not an objective of our study, our findings indicate that the effects of gait retraining are not different for men and women. Finally, this study reports the results of gait retraining in a controlled indoor setting, mostly on an instrumented treadmill and under full-time supervision. Running on a treadmill is biomechanically not the same as running outdoor and the kinetics/kinematics of observed running may be quite different from habitual, unobserved running. However, for the sake of research, the laboratory setting is considered acceptable and widely used, as long as results are interpreted with caution. [17] As reflected by Figure 1, every patient received at least one gait retraining session outdoors, to facilitate the transfer from the lab environment (treadmill) to over ground running. We look forward to future studies using wearable technology to more accurately characterize changes in the natural running state.

Accepting the aforementioned limitations, the strength of this study is that it presents new and practical information on gait retraining in military boots. Additionally, the number of included subjects is large compared to most gait retraining studies and completely composed of a patient group for whom gait retraining would be particularly recommended. In addition to using wearable technology to document changes in natural running state, future research is warranted to identify which gait retraining cues contribute most to beneficial gait changes, both in athletic shoes and in military boots.

CONCLUSION

Gait retraining in military boots achieved similar changes in stride length (reduction), cadence (increase), force and pressure in the heel (reduction) and in the fore foot (force reduction, pressure increase) compared to running shoes. However, in boots mid foot maximal force and pressure increased.

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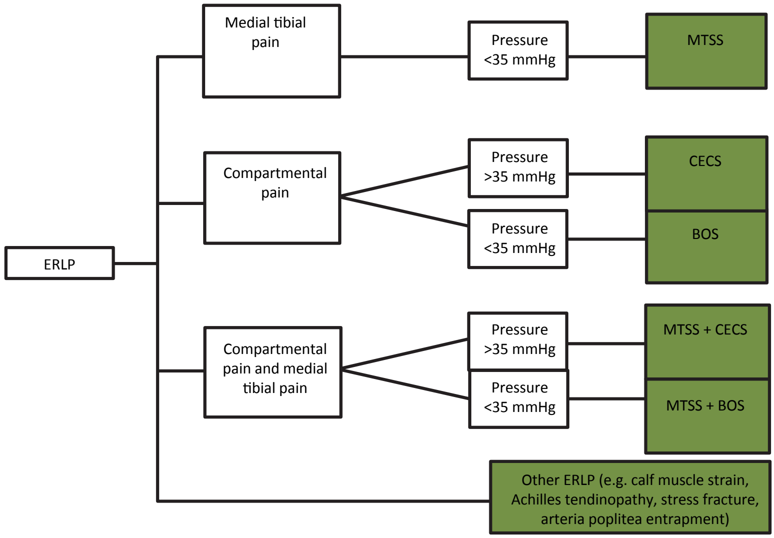
Appendix 1
Diagnostic flowchart for ERLP in the Royal Netherlands Armed Forces.



ERLP = exercise-related leg pain; MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; BOS = biomechanical overload syndrome.

Appendix 2

Standard care for chronic exercise-related leg pain: criteria for application (version 2017).

Therapeutic intervention	**criterion**
Therapeutic intervention	criterion
Stretching	Gastrocnemius tightness = minimal angle compared to a vertical line: 70 degrees or more (Fig. A); Soleus tightness = maximal distance 5 cm from the wall or less (Fig. B).
Strengthening	Calf strength insufficient: not able to perform 30 consecutive calf raises on one leg.
Massage hypertonic m. plantaris	m. plantaris palpation painful (patient in prone position).
Dryneedling of triggerpoints	Medial and lateral gastrocnemius: if the patient identifies the calf as a pain location.
Compression stockings	Not given to patients with proven anterior CECS (ICPM ≥ 35 mm Hg).
Shockwave (ESWT)	For MTSS only: once a week, 4-5 sessions; each session 2000 radial shocks, frequency 8 per second and intensity 2.5 bar, on the posteromedial tibial border.
Vitamin D supplementation	If MTSS is present. Criterion: < 50 nmol/l = insufficient, supplementation required; optimal 75 nmol/l.
New running shoes	Every year or after 500 miles (800 km); If the patient describes a relation between symptoms and shoes; Minimalist shoes are discouraged, low drop shoes are encouraged (± 6-8 mm drop).
Customized anti-pronation inlays	If navicular drop is positive (> 1.0 cm) and if over-pronation is established with slow motion video analysis of barefoot running
Maintaining fitness with low impact training	Resume three sessions of low impact exercise per week. Keep leg pain scores ≤ 3 (on a Numeric Pain Rating Scale 0-10).
Gait retraining while running in sports shoes	Four cues for running: 1. Change to a ball-of-the-foot strike (when applicable); 2. Increase cadence to 180 steps/min; 3. Stand up tall (don't bend over at the waist); 4. Increase knee lift 1-2 cm.
Progressive running schedule	Week 1-6: run twice a week, end goal = a 15-minute uninterrupted run, pain free with new running technique; Week 7-12: run twice or three times per week, end goal is a 30-minute uninterrupted run, pain free with new running technique.

Appendix 2, Figure A.
Gastrocnemius / Achilles stretch (right leg, barefoot), criterion for normal value = maximal angle compared to a vertical line: 70 degrees or less.

Appendix 2, Figure B.
Soleus stretch (left leg, barefoot), criterion for normal value = minimal distance 5 cm from the wall or more.

Chapter 8

Reducing vertical ground reaction forces: The relative importance of three gait retraining cues

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ABSTRACT

Background: Previous studies in our department demonstrated that gait retraining as part of a conservative treatment program for service members with exercise-related leg pain can lead to persistent changes in vertical ground reaction forces while running in shoes and boots. It is not known which gait retraining cue has the largest effect and whether a combination of cues is advantageous.

Methods: During a single gait retraining session, 12 male heel striking patients were given three cues in isolation: Cue 1, change to a ball-of-foot strike; Cue 2, increase cadence to 180 steps per minute; Cue 3, stand up taller; and finally all three cues combined. Runs were performed on an instrumented treadmill at 10 km/h, 1% incline and in running shoes. The three cues were randomly introduced. Measurements, taken during 30-second episodes, were stride length, cadence, and six force variables: maximum force (N) and maximum pressure (N/cm^2) on the heel, mid-foot and fore-foot.

Findings: Each cue, i.e. each change in running technique, caused a different pattern of changes among the six force variables, mostly reductions. In isolation, cue 1 produced the largest reduction of force and pressure on the heel, 54% and 33% respectively. Overall, the combination of cues 1+2+3 ranked first in reducing forces for four of the six force variables.

Interpretation: Three commonly used gait retraining cues, when applied in isolation, all resulted in a reduction of most vertical ground reaction forces. The combination of the three cues is advantageous.

KEYWORDS

- medial tibial stress syndrome
- chronic exertional compartment syndrome
- conservative treatment
- military
- occupational.

INTRODUCTION

Exercise-related Leg Pain (ERLP) is a regional pain syndrome described as pain between the knee and ankle which occurs with exercise. Medial Tibial Stress Syndrome, Chronic Exertional Compartment Syndrome, tibial and fibular stress fractures, tendinopathy, nerve entrapment, and vascular pathology are the diagnoses that are usually included in the ERLP group. [1] In the military, ERLP is a common complaint and Medial Tibial Stress Syndrome is considered to be the overuse injury with the largest impact on basic military training. [2]

The evidence for an association between vertical ground reaction forces (vGRF) and musculoskeletal injuries in runners from both retrospective and prospective data is considered "compelling". [3] Gait retraining as a treatment for ERLP is presumably widely practiced, but reports in the literature were sparse until recently. [4] The goal of gait retraining can be reducing vertical ground reaction forces (e.g., for Medial Tibial Stress Syndrome) or reducing muscular activity of a symptomatic muscle group (e.g., for anterior Chronic Exertional Compartment Syndrome). [4] Cues commonly recommended by experts to reduce vGRF while running are: 1. Change from a heel strike to a fore foot strike; 2. Increase cadence to 180 steps per minute; 3. Stand up taller, don't bend over at the waist (trunk and pelvic position). [4] Changing from a heel strike to a fore foot strike while running at 9 km/h on a treadmill reduced average loading rate and maximal loading rate of vGRF significantly, both in shod and bare foot running conditions. [5] Manipulating cadence in isolation has shown that a 5% increase in cadence reduced force (N) and pressure (N/cm^2) variables in the heel and metatarsal regions. [6] An increase in cadence around 15% may be the optimal dosage to reduce vertical impact peak, vertical instantaneous loading rate and vertical average loading rate. [7,8] All these studies were performed in healthy volunteer runners, running in sports shoes. In a clinical setting the goal is to optimize treatment results for a particular group of patients, i.e. service members running in sports shoes and in military boots. Previous studies in our department demonstrated that gait retraining as part of an outpatient comprehensive treatment program for service members with ERLP can lead to persistent changes in vGRF while running in shoes and boots and clinical improvements for chronic ERLP patients were encouraging. [9,10] The aforementioned three cues were used in all our gait retraining programs. It is not known which cue in isolation achieves the largest reduction in vertical ground reaction forces and whether a combination of all three cues reduces vertical ground reaction forces more than the cues in isolation. Insight in this could be helpful to further improve treatment results of military ERLP patients. Therefore the objectives of this study were to determine the reduction in vGRF per gait retraining cue: 1. in isolation and 2. when the three cues are combined.

METHODS

During a single, 30-minute gait retraining session, biomechanical measurements were performed at the Department of Military Sports Medicine, Royal Dutch Army, Utrecht, The Netherlands. The procedures were part of regular care for patients at the institute. National law does not require approval of an ethical board for this study. All subjects gave written informed consent for anonymous use of collected data. All study procedures were performed by a single senior sports medicine physician.

Participants

Twelve consecutive male patients with chronic ERLP, who were assigned to a comprehensive treatment program with gait retraining in the spring of 2018, were asked to participate in this study. The program was previously described in detail. [11] In short, all patients were initially screened using a detailed local intake template for history, physical examination, diagnostic testing and treatment prescription. As part of the diagnostic procedures all patients were asked to run on a treadmill and score their ERLP symptoms according to the Running Leg Pain Profile and all patients received intracompartmental pressure measurements in the first minute post exercise. Appendix 1 shows the diagnostic flowchart used in our department. Further inclusion criteria were: 1. Personal cadence < 170 steps per minute; 2. Heel striker.

Measurements

From the medical records the following information was taken: age (years), height (meter), weight (kilogram) and body mass index. Each study participant performed eight 30-second runs, with a very short accommodation time (maximal 15 seconds) to prevent onset of symptoms, on an instrumented treadmill. All runs were performed in a t-shirt, shorts and personal running shoes, at a speed of 10 km/hour and an incline of 1%.

The three gait retraining cues of interest in this study were: 1. Change from heel strike to a ball-of-the foot landing; 2. Increase cadence to 180 steps per minute (at a constant running speed of 10 km/h); 3. Stand up taller, don't bend over at the waist or look down. Table 1, the study protocol, shows how these three running cues were randomly introduced in isolation per patient (Run 2, Run 4, Run 6) and how they were interspersed by returning to the personal running technique (Run 1, Run 3, Run 5, Run 7). Finally, in Run 8, participants were asked to apply all three cues simultaneously.

Biomechanical parameters of interest were stride length in centimeters (stride length was defined as the distance covered from initial contact to initial contact of the same foot and equal to the sum of the lengths of two steps), cadence (steps/minute), maximum force (N) and maximum pressure (N/cm^2) in three segments of the foot: heel, mid foot, fore foot.

Table 1.
Study protocol: twelve participants performed eight 30-second runs. The order of the gait retraining cues was randomized.

case	R1	R2	R3	R4	R5	R6	R7	R8
1	0	1	0	2	0	3	0	1+2+3
2	0	1	0	2	0	3	0	1+2+3
3	0	1	0	3	0	2	0	1+2+3
4	0	1	0	3	0	2	0	1+2+3
5	0	2	0	1	0	3	0	1+2+3
6	0	2	0	1	0	3	0	1+2+3
7	0	2	0	3	0	1	0	1+2+3
8	0	2	0	3	0	1	0	1+2+3
9	0	3	0	1	0	2	0	1+2+3
10	0	3	0	1	0	2	0	1+2+3
11	0	3	0	2	0	1	0	1+2+3
12	0	3	0	2	0	1	0	1+2+3

R1-R8 = Run 1 through Run 8; 0 = no cue, personal running technique; 1 = cue 1: change to ball-of-foot strike (only); 2 = cue 2: increase cadence to 180 steps per minute (only); 3 = cue 3: stand up taller, don't bend over at the waist (only); 1+2+3 = apply all three cues simultaneously.

All measurements were obtained with an instrumented treadmill (H/P/Cosmos Mercury, Nussdorf-Traunstein, Germany), which was serviced yearly. The combination of instrumented treadmill with the gait analysis software (Zebris Medical, Isny, Germany, version 2013) allowed for collection of all biomechanical parameters of interest. Both the treadmill and the gait analysis software were certified according to European standards for sports, fitness, medical and rehabilitation equipment.

Patients' personal running strike technique (heel, mid foot, or fore foot striker) was determined based on visual evaluation of slow motion camera images and treadmill vertical force measurement. A heel striker was defined as a visual heel striker at initial contact, plus a maximal force on the heels > 400 N. [9] Patients were assisted in keeping the prescribed cadence per run with a digital metronome on a smart phone. Measurements were accepted for analysis if cadence deviation was within three steps per minute (< 2%) and heel strike was confirmed according to the above mentioned criteria. For analysis measurements from the right legs only were used.

Based on previous work in our department, it was expected that changing gait would lead to reduction of some vGRF variables (e.g., force and pressure on the heels), but could lead to an increase in other variables (e.g., pressure on the fore foot). [9]

Statistics

Participants' characteristics were described with appropriate measures of central tendency and dispersion. Normality of the data was checked visually by means of histograms, boxplots, and QQ-plots.

The biomechanical measurements of running before introduction of cues (Run 1) were described with averages, standard deviation and 95% confidence interval. The measurements per gait retraining cue introduced were presented with averages and 95% confidence interval, expressed as a percentage from Run 1 and presented graphically (with box and whiskers plots).

RESULTS

Participants: 12 male service members, diagnosed with ERLP, median age 24 years (IQR 5.75), mean height 1.78 m (SD 0.07), mean weight 84.0 kg (SD 13.9), mean body mass index 26.4 (SD 3.4).

Measurements: In all measurements used for analysis, cadence deviation was within three steps per minute (< 2%) and heel strike was confirmed according to the previously described criteria. Table 2 shows the measurements when participants performed their personal running style (Run 1). Table 3 shows measurements when participants applied one gait retraining cue in isolation and all three cues combined. Each change in running technique produced a different pattern of changes in vGRF. Table 4 shows the relative importance of the gait retraining cues: resulting vGRF, expressed as a percentage from Run 1 (personal running style). In isolation, cue 1 produced the largest reduction of force and pressure on the heel, 54% and 33% respectively. Overall, the combination of cues 1+2+3 ranked first in reducing forces for four of the six force variables. Figures 1A and 1B graphically summarize information from tables 2, 3 and 4.

Table 2.
Participants' personal preferred running style at intake (=100%), selected biomechanical parameters.

Run 1, preferred running style (100%)	mean	SD	95% CI
stride length (m)	206.8	6.6	203.1-210.6
cadence (steps/min)	160.3	5.0	157.5-163.2
fore-foot max Force (N)	1114.4	189.5	1007.2-1221.6
mid-foot max Force (N)	645.3	118.4	578.3-691.6
heel max Force (N)	648.3	76.4	605.1-691.6
fore-foot max Pressure (N/cm²)	29.0	7.9	24.5-33.5
mid-foot max Pressure (N/cm²)	31.4	8.4	26.7-36.2
heel max Pressure (N/cm²)	29.5	7.6	25.2-33.8

SD = standard deviation; 95% CI = 95 % confidence interval.

Table 3.
Selected biomechanical parameters, when participants applied one gait retraining cue in isolation, and all three cues combined.

	cue 1 only mean	95% CI	cue 2* only mean	95% CI	cue 3 only mean	95% CI	cues 1+2+3 mean	95% CI
stride length (m)	205.9	202.8-209.1	183.9	183.3-184.5	205.4	200.7-210.1	183.9	183.3-184.5
cadence (steps/min)	161.0	158.6-163.4	179.9	179.5-180.3	160.4	157.7-163.2	180.0	179.8-180.2
fore-foot max Force (N)	1123.4	1025.6-1221.3	966.7	855.2-1078.2	1095.8	965.8-1225.8	944.2	853.7-1034.6
mid-foot max Force (N)	565.7	521.1-610.2	584.8	524.2-645.4	611.6	558.7-664.5	588.3	530.3-646.2
heel max Force (N)	296.7	190.2-403.2	553.5	511.9-595.0	586.0	553.4-618.6	197.0	127.6-266.4
fore-foot max Pressure (N/cm^2)	31.1	27.0-35.1	25.6	21.9-29.4	27.4	23.6-31.2	29.8	25.9-33.8
mid-foot max Pressure (N/cm^2)	25.9	22.7-29.2	30.2	25.2-35.2	30.6	26.2-35.0	25.4	22.5-28.3
heel max Pressure (N/cm^2)	19.8	16.3-23.4	27.1	22.2-32.0	27.8	23.8-31.7	17.9	15.1-20.7

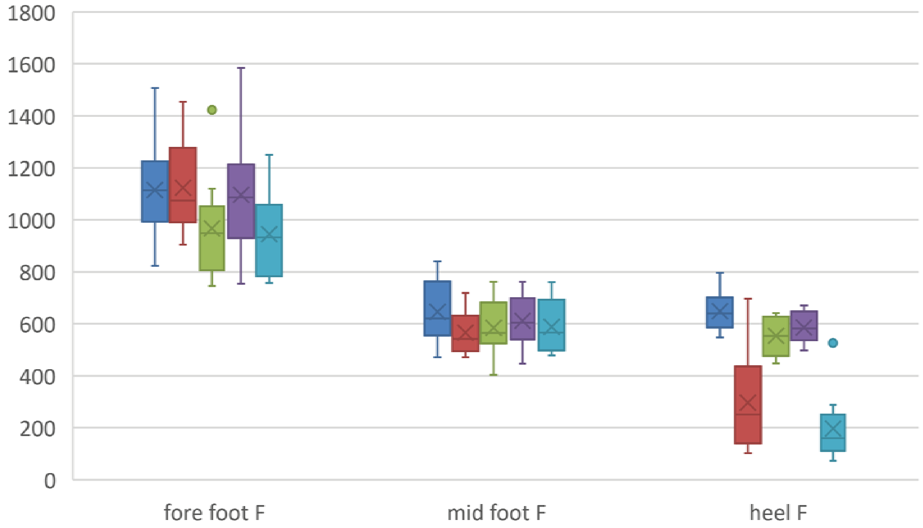
1 = cue 1: change to ball-of-foot strike (only); 2 = cue 2: increase cadence to 180 steps per minute (only); 3 = cue 3: stand up taller, don't bend over at the waist (only); 95% CI = 95 % confidence interval; *based on 11 values, one missing value.

Table 4.
The relative importance of three gait retraining cues: resulting vertical ground reaction forces, expressed as a percentage of Run 1 (personal running style) and in order of importance.
Note: all cues, in isolation and combined, resulted in a reduction of most vertical ground reaction forces. The combination cue 1+2+3 ranked first in reducing forces for four of the six force variables (final column).

	Run 1	Cue 1 only %	order	Cue 2* only %	order	Cue 3 only %	order	Cues 1+2+3 %	order
fore-foot max Force (N)	100	100.8	4	86.7	2	98.3	3	84.7	1
mid-foot max Force (N)	100	87.7	1	90.6	3	94.8	4	91.2	2
heel max Force (N)	100	45.8	2	85.4	3	90.4	4	30.4	1
fore-foot max Pressure (N/cm^2)	100	107.2	4	88.4	1	94.5	2	102.9	3
mid-foot max Pressure (N/cm^2)	100	82.5	2	96.1	3	97.3	4	80.9	1
heel max Pressure (N/cm^2)	100	67.2	2	91.8	3	94.1	4	60.7	1

1 = cue 1: change to ball-of-foot strike (only); 2 = cue 2: increase cadence to 180 steps per minute (only); 3 = cue 3: stand up taller, don't bend over at the waist (only); order 1 = cue with the greatest reduction of vertical ground reaction forces; order 2 = cue with the second largest reduction etc.; *based on 11 values, one missing value.

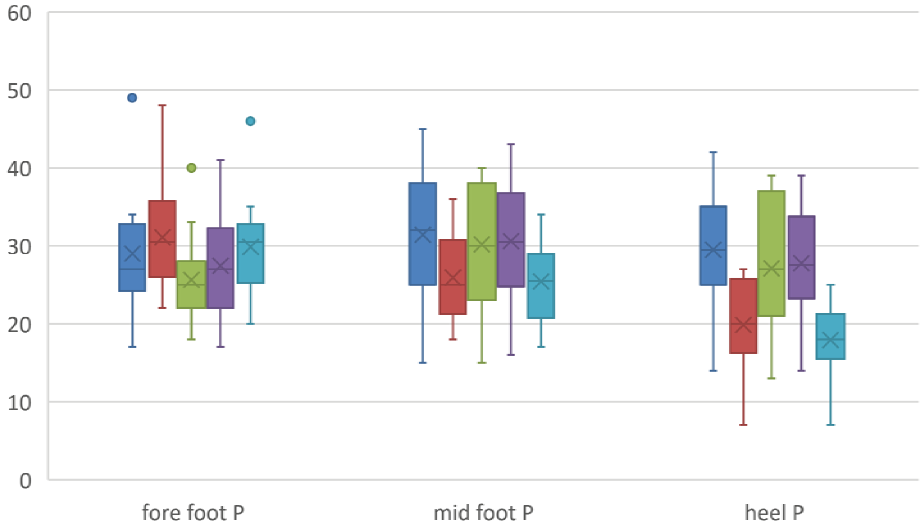
Figure 1A.
The relative importance of three gait retraining cues on maximal forces (N), per section of the foot; graphical summary of Tables 2, 3 and 4.



Dark blue = Run 1 = personal running style; Red = cue 1 = change to a ball-of-foot strike; Green = cue 2 = increase cadence to 180 steps/min; Purple = cue 3 = stand up taller; Light blue = three cues combined.

Note: Cue 1 (red) and three cues combined (light blue) cause the largest reduction of maximal forces on the heel.

Figure 1B.
The relative importance of three gait retraining cues on maximal pressures (N/cm²), per section of the foot; graphical summary of Tables 2, 3 and 4.



Dark blue = Run 1 = personal running style; Red = cue 1 = change to a ball-of-foot strike; Green = cue 2 = increase cadence to 180 steps/min; Purple = cue 3 = stand up taller; Light blue = three cues combined.

Note: Cue 1 (red) and three cues combined (light blue) cause the largest reduction of maximal pressures on the heel.

DISCUSSION

This study set out to determine the relative importance of three gait retraining cues in reducing vGRF in a group of military ERLP patients. The principal finding of this study is that the combination of all three gait retraining cues is advantageous.

Measurements in this study of running gait before and after gait retraining are similar to findings in earlier studies in our department with service members with ERLP. [9,10,12] With more than one hundred cases reported in these papers combined, we feel comfortable the measurements of running parameters presented here accurately describe this specific patient population. The findings of this study reconfirm that changing from a heel strike tot a ball-of-the-foot strike reduces vGRF on the lower extremity and that increasing cadence does the same. [5,7,8] In addition, in this study it was found that adjusting running posture, achieved with the cue "stand up taller" (do not bend over at the waist) also reduced vGRF. This is possibly the first time the contribution of this cue to reducing vGRF has been quantified.

The increase of cadence from 160 to 180 steps per minute represents an average increase of 12.3 percent. This is slightly less than 15%, the optimal cadence increase for vGRF reduction. [7] Also, none of the participants had any trouble increasing cadence to 180 steps per minute, where in some studies it is suggested that increasing cadence by more than ten percent can be challenging to adopt. [13]

Gait retraining is assumed to be an important component of a comprehensive, conservative treatment program for this particular group of patients. [9,14] For a clinician, to provide gait retraining, no expensive equipment is necessary and a simple cue, such as "run softer", may already reduce tibial acceleration. [15] The three cues used in this study provide the trainer and the trainee concrete options for "how to" reduce vGRF. It is important to note that the combination of the three cues is advantageous. When a patient uses one technique already (e.g., fore foot strike), further reduction of vGRF can be achieved by introducing the other cues. A smartphone, which is nowadays owned by every service member, can be helpful as a metronome, indicating the number of steps per minute, and as a camera, filming old and new running techniques. The smartphone thereby is a learning tool capable of providing auditory and visual feedback to learn a new motor skill, inside in the laboratory setting and outside in the real world.

A limitation of this study is that bone load, and reduction of bone load, were not measured directly (e.g., with an accelerometer). Instead, vGRF were measured on an instrumented treadmill. The focus was on finding clinically relevant gait retraining cues, working with a small number of participants. Therefore, statistical analyses were not undertaken.

Measurements were presented with means and 95% confidence intervals, so that statistical significance can be calculated if so desired. This study did not include female participants, but our earlier work indicated that the effects of gait retraining are not different for men and women. [12] In addition, this study cannot speculate on the long term retention of gait retraining sessions. Earlier findings with this group of patients showed that ten months post gait retraining, stride length and cadence were slightly less than immediately after gait retraining, but, overall, still evidenced positive changes. In other words, a reduction of vGRF remained, as compared to the moment of intake. [9] Finally, this study reports the results of gait retraining in a controlled indoor setting on an instrumented treadmill and under supervision. Running on a treadmill is biomechanically dissimilar to running outdoor and the kinetics/kinematics of observed running may be quite different from habitual, unobserved running. However, for the sake of research, the laboratory setting is considered acceptable and widely used, as long as results are interpreted with caution. [16,17] Accepting the aforementioned limitations, the strength of this study is that it presents new and practical information on gait retraining in running shoes for a group of patients for whom gait retraining would be particularly recommended. Future research is warranted to determine if these findings apply to healthy athletes and whether the same cues have the same relative importance for gait retraining while running in military boots, since this is an occupational requirement in the military.

CONCLUSIONS

Each gait retraining cue, i.e. change in running technique, produced a different pattern of changes in vGRF, mostly reductions. The combination of cues 1+2+3 ranked first in reducing forces for four of the six force variables. When a patient uses one technique already (e.g., fore-foot strike), further reduction of vGRF can be achieved by introducing the other cues.

LITERATURE

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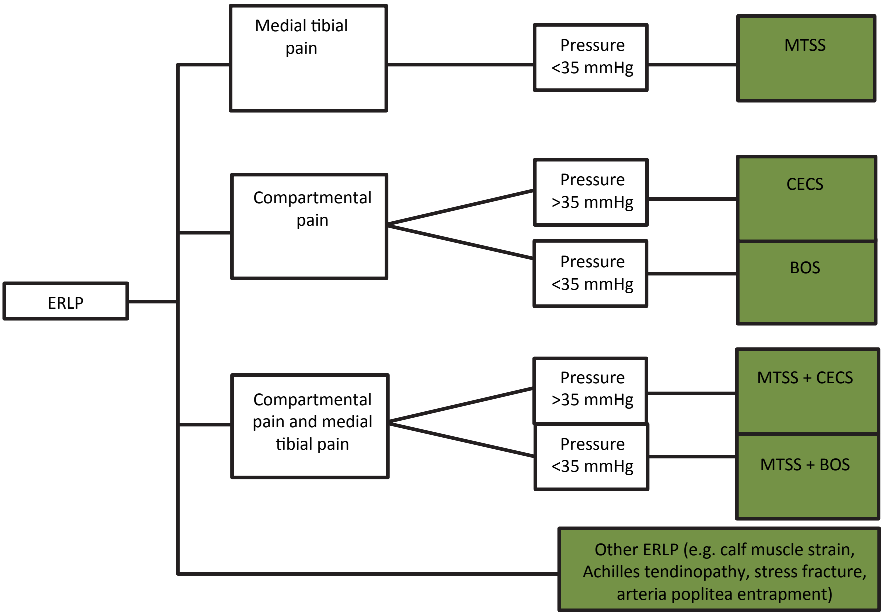
Appendix 1

Diagnostic flowchart for ERLP in the Royal Netherlands Armed Forces.



ERLP = exercise-related leg pain; MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; BOS = biomechanical overload syndrome.

Chapter 9

Conservative treatment of anterior chronic exertional compartment syndrome in the military, with a mid-term follow-up

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ABSTRACT

Objectives: To assess the outcome of conservative treatment for chronic exertional compartment syndrome as it relates to the reduction in surgical fasciotomy and return to active duty in a military population.

Methods: Historic cohort. From 2015-2018, 75 surgically eligible patients with pressure positive anterior chronic exertional compartment syndrome (CECS) (Group 1), or with positive pressures and associated medial tibial stress syndrome (Group 2), underwent a conservative treatment program emphasizing gait retraining of running and marching. Treatment success was defined as return to duty, without surgery. Fifty patients from 2015-2017 were surveyed to assess mid-term outcomes.

Results: The average duration of conservative treatment was 144.9 (± 59.6) days. Initially, 65% (49/75) were able to return to duty; 28% (21/75) were referred for surgery; and 7% (5/75) left the armed forces. There was no difference in outcomes between Group 1 and Group 2. Survey response rate, on average after 742 days (SD 267, range 381-1256), was 84% (42/50); 57% (24/42) had continued duty, without surgery; of them 43% at the same military specialty, 57% in a physically less demanding job.

Conclusion: A conservative treatment program for anterior CECS was able to return 65% of patients to active duty, without surgery. At two years, the success rate decreased slightly, but remained positive at 57%. In this high-risk group, initiating a conservative treatment protocol with an emphasis on gait retraining can significantly reduce the need for surgical fasciotomy. For those that fail conservative treatment, surgical release may still be indicated.

KEYWORDS

- exercise-related leg pain
- gait retraining
- fasciotomy
- occupational
- prognosis.

INTRODUCTION

Chronic exertional compartment syndrome (CECS) is one of the causes of exercise-related leg pain in athletes and service members. A clinical description of CECS is repetitive pain and pathologically elevated pressure in a muscular compartment during physical exercise, which returns to normal with cessation of exercise. [1] CECS can present in any muscular compartment of the human body, but is most prevalent in the anterior compartment of the lower leg (anterior CECS). [2] The incidence of CECS in the USA armed forces is estimated at 0.49 cases per 1000 person years (4100 cases diagnosed in 5 years). [3]

Several authors have claimed that non-operative treatment of CECS rarely leads to complete resolution of symptoms or return to previous levels of athletic or military activity; thus, surgery (fasciotomy) has been strongly recommended as first line treatment and been termed the gold standard of treatment. [4,5] Unfortunately, it has also been recognized in a number of studies that the results of fasciotomy and return to former activity level are less favorable in the military population. [1,3,5,6] In the Central Military Hospital (Utrecht, The Netherlands), every patient with anterior CECS and a positive pressure test received fasciotomy without delay for many years. [7] Unfortunately, the occupational prognosis after surgery proved to be poor: A two-year follow-up of 44 anterior CECS patients after surgery showed that only 15 patients (34%) had returned to their original military jobs, 28 patients (64%) had left the military, and 25 patients (57%) still had symptoms of exercise-related leg pain. [8] Therefore, the Central Military Hospital changed its policy regarding the protocol of surgical indication. From 2011 onward, patients with clinically proven anterior CECS and a positive pressure test, i.e. eligible for surgery, were send first to a comprehensive conservative treatment program, either in the Military Rehabilitation Center (Doorn, The Netherlands) or the department of Military Sports Medicine (Utrecht, The Netherlands). Referral was not truly random, more complicated cases were sent to the Military Rehabilitation Center. This center offered an inpatient conservative treatment program containing physical therapy, physical fitness, mental coaching and podiatry. The results were described in two studies: 56% of patients were able to return to base in order to resume military duties without surgery, the others returned to the surgeon. [9,10] The results of the conservative treatment program of the department of Military Sports Medicine were unknown till now. An evaluation is important to determine whether delaying surgery is justified.

The purpose of this study was to determine the initial and mid-term follow-up results of the comprehensive conservative treatment program in service members with clinically proven anterior CECS and a positive pressure test offered at the department of Military Sports Medicine.

MATERIAL AND METHODS

This study is a historic cohort, involving patients seen by the first author (WZ) in the Central Military Hospital and in the department for Military Sports Medicine, with a follow-up survey, minimally one year after completion of a special conservative treatment program. National law does not require approval of an ethical board for this type of study. All patients provided written consent for anonymous use of clinical data.

Organization of care

The Royal Netherlands Armed Forces have a diagnostic and treatment protocol for exercise-related leg pain coordinating physicians and physical therapists working in outlying primary care clinics with specialists in the Central Military Hospital. This protocol describes that service members with exercise-related leg pain be referred to the Central Military Hospital if conservative therapy in primary care has not been successful within six months. [8] Since 2013 this hospital has offered a specialty clinic for service members with exercise-related leg pain. A multidisciplinary team of surgery, sports medicine, and physiatry evaluates patients in a one-stop shop setting. Diagnostic imaging is ordered if stress fractures, malign or vascular disorders have to be excluded. The latter is in less than five percent of cases. After medical clearance, a sports medicine physician supervises the patient in a standardized running test on a treadmill to pain tolerance and performs an intracompartmental pressure measurement of compartments suspected for CECS. The standardized running test, the minute-by-minute pain scoring system, the exact execution of the pressure measurement with a Stryker needle manometer, and the diagnostic flowchart for exercise-related leg pain were described previously in detail and are available here as Appendices 1, 2 and 3. [11] All patient information is stored in an electronic patient record. Based on the evaluations, patients may be referred to conservative treatment in the Military Rehabilitation Center (inpatient) or the Department of Military Sports (outpatient) or to fasciotomy in house. The criteria for surgery for anterior CECS are pain with exertion in the anterior compartment of the leg and pressure ≥ 35 mm Hg in the first minute post exercise and were established locally. [7]

Inclusion

Medical records at the department of Military Sports Medicine were searched for all patients diagnosed with anterior CECS (Group 1) and anterior CECS + Medial Tibial Stress Syndrome (MTSS) (Group 2) send from the Central Military Hospital in the years 2015-2018. The following baseline information was obtained: age (years), sex (male/female), height (m), weight (kg), body mass index, diagnosis (anterior CECS or anterior CECS+MTSS), intracompartmental pressure measurement values, duration of symptoms (months), repeat episode (yes/no), symptoms in first year of service (yes/no), the Single Assessment Numerical Evaluation (SANE) score at intake. This SANE score is a single question instrument evaluating patients' subjective injury status with the following question:

"how would you rate your lower leg today as a percentage of normal, on a 0-100 scale, with 100 being normal". The SANE score was developed and validated in a military health care setting. [12]

Comprehensive conservative outpatient treatment program

At the department of Military Sports Medicine, each patient received a comprehensive conservative outpatient treatment program with a selection of interventions described in the literature: [13,14] stretching and/or strengthening of lower extremity musculature, massage of hypertonic musculature, dry needling of trigger points, extracorporeal shockwave therapy to the medial tibial border, supplementation of vitamin D, evaluation of running shoes, evaluation of shoe inlays, maintaining fitness with a low impact training program, gait retraining of running and marching, and a progressive running schedule. For each of the aforementioned interventions local protocol describes criteria for application (Table 1). If patients received extracorporeal shockwave therapy for MTSS (once per week, four sessions), gait retraining was postponed for the duration of this treatment. Once free of pain in rest, every service member received a 6-week progressive running program building up to a 15-minute uninterrupted run. Some service members with a physically demanding specialty, received an additional 6-week progressive running schedule to build to a 30-minute uninterrupted run, before return to base. Overall, special emphasis was placed on gait retraining of running and marching, in shoes and boots, and retention of these newly learned movement skills. Each anterior CECS patient received four - six individual gait retraining sessions also described previously in detail. [15]

Evaluation of clinical progress was done every time the patient visited the department. If resumption of running and marching with low pain scores was not possible and it was unlikely that treatment success was to be expected, the patient was sent back to the department of surgery in the Central Military Hospital. Patients were allowed to return to base, when they could run at least 12 minutes pain free and when patient and physician both thought return to base could lead to resumption of military duties. During final evaluation, the SANE score was recorded again (SANE-evaluation).

Follow-up survey

Minimal follow-up was set at one year. Therefore, in December 2018 and January 2019 all 2015-2017 patients were contacted by telephone by an instructed medical student. A brief survey with closed questions on military status (active duty, yes/no), less demanding military specialty (yes/no), fasciotomy (yes/no), symptoms (yes/no) and SANE score (0-100) was conducted.

Table 1.
Standard care for exercise-related leg pain: criteria for application (version 2018).

Intervention	Criterion
Stretching	Gastrocnemius tightness = minimal angle compared to a vertical line: 70 degrees or more (Appendix 4, Fig. A); Soleus tightness = maximal distance 5 cm from the wall or less (Appendix 4, Fig. B).
Strengthening	Calf strength insufficient: not able to perform 30 consecutive calf raises on one leg.
Massage hypertonic m. plantaris	m. plantaris palpation painful (patient in prone position).
Dryneedling of triggerpoints	Medial and lateral gastrocnemius: if the patient identifies the calf as a pain location.
Compression stockings	Not given to patients with proven anterior CECS (ICPM ≥ 35 mm Hg).
Shockwave (ESWT)	For MTSS only: once a week, 4-5 sessions; each session 2000 radial shocks, frequency 8 per second and intensity 2.5 bar, on the posteromedial tibial border.
Vitamin D supplementation	If MTSS is present. Criterion: < 50 nmol/l = insufficient, supplementation required; optimal 75 nmol/l.
New running shoes	Every year or after 500 miles (800 km); If the patient describes a relation between symptoms and shoes; Minimalist shoes are discouraged, low drop shoes are encouraged (± 6-8 mm drop).
Customized anti-pronation inlays	If navicular drop is positive (> 1.0 cm) and if over-pronation is established with slow motion video analysis of barefoot running
Maintaining fitness with low impact training	Resume three sessions of low impact exercise per week. Keep leg pain scores ≤ 3 (on a Numeric Pain Rating Scale 0-10).
Gait retraining while running in sports shoes	Four cues for running: 1. Change to a ball-of-the-foot strike (when applicable); 2. Increase cadence to 180 steps/min; 3. Stand up tall (don't bend over at the waist); 4. Increase knee lift 1-2 cm.
Gait retraining while matching in boots	Two cues for marching: 1. 5% increase in cadence from preferred; 2. Try not to stomp on the heels.
Progressive running schedule	Week 1-6: run twice a week, end goal = a 15-minute uninterrupted run, pain free with new running technique; Week 7-12: run twice or three times per week, end goal is a 30-minute uninterrupted run, pain free with new running technique.

CECS = chronic exertional compartment syndrome; MTSS = medial tibial stress syndrome; ICPM = intracompartmental pressure measurement; mm Hg = millimeter Mercury.

Statistics

Baseline age, biometrics (height in meters, weight in kilograms, body mass index), and disease characteristics i.e., duration of symptoms (months), repeat episode of exercise-related leg pain (count), diagnosis and the SANE score at intake (0-100) were described with appropriate measures of central tendency and dispersion for three outcome groups: return to base (treatment success), return to surgeon and exit from the military. Initial treatment success was defined as return to duty, without surgery. The results of the conservative treatment program were presented with absolute and relative frequencies for the same three outcome groups. For the follow-up survey (minimal follow-up time one year), we defined treatment success as continued military service, without surgery. Subsequently, the results of the items of the follow-up survey i.e.: military status, less demanding military specialty, fasciotomy, symptoms and SANE score were described appropriately.

Table 2.
Baseline characteristics and initial treatment results for all patients and three outcome subgroups. Note: 1. Return to base 49/75 (65%, treatment success); 2. Return to surgeon 21/75 (28%); 3. Exit from service 5/75 (7%).

	all	return to base (success)	return to surgeon (failure)	exit from service (failure)
number of patients (%)	75 (100%)	49	21	5
male (n; %)	59 (79%)	41	16	2
female (n; %)	16 (21%)	8	5	3
age (years; median, interquartile range)	21 (4)	21 (4)	22 (5)	22 (2)
diagnosis anterior CECS (n; %)	37 (49%)	25	11	1
diagnosis anterior CECS, ICPM R ant, mm Hg	65.6 (24.5)	67.8 (25.1)	61.6 (24.6)	54 (-)
diagnosis anterior CECS, ICPM L ant, mm Hg	63.1 (19.1)	63.7 (19.8)	62.9 (19.0)	52 (-)
diagnosis anterior CECS+MTSS (n; %)	38 (51%)	24	10	4
diagnosis anterior CECS+MTSS, ICPM R ant, mm Hg	65.3 (22,4)	64.6 (19.4)	70.6 (28.0)	56.5 (27.5)
diagnosis anterior CECS+MTSS, ICPM L ant, mm Hg	61.4 (22.1)	62.6 (21.4)	61.2 (22.2)	54.5 (30.5)
symptoms (months)	10.5 (7.0)	10.9 (7.7)	10.4 (5.9)	7.2 (3.3)
repeat episode (yes/no)	32 (43%)	22/49 (45%)	10/21 (48%)	0/5 (0%)
symptoms in first year of service (yes/no)	51 (68%)	35/49 (71%)	13/21 (62%)	3/5 (60%)
SANE score at intake (0-100)	45.0 (16.0)	47.7 (15.1)	39.5 (15.5)	41.0 (22.2)
duration of treatment (days)	144.9 (59.6)	153.6 (61.8)	125.6 (49.1)	140.8 (70.0)
SANE score at evaluation (0-100)	74.2 (21.2)	85.7 (8.7)	45.7 (17.1)	81.0 (6.5)

CECS = chronic exertional compartment syndrome; MTSS = medial tibial stress syndrome; ICPM = intracompartmental pressure measurement; mm Hg = millimeter Mercury; SANE = single assessment numerical evaluation; n = number.

Table 3A and 3B.
Results of the follow-up survey, group 1 = CECS (table 3A) and group 2 = CECS+MTSS (table 3B).
Note: in total 42/50 patients were reached (84%). At follow-up: 24/42 patients (57%) were still active duty and without fasciotomy; 18/42 returned to their original military specialty (43%); 15/42 left the military (36%); 20/42 still had symptoms (48%); 5/42 patients received fasciotomy (12%).

Table 3A.

M/F	Age (years)	Follow up (days)	Active duty yes / no	Less demanding specialty yes / no	Faciotomy yes / no	Symptoms now yes / no	SANE now	Treatment success yes / no
M	30	1102	1	0	1	1	70	0
M	21	1093	0	n.a.	0	1	70	0
M	29	701	1	0	1	1	70	0
M	23	511	0	n.a.	0	0	70	0
F	25	889	0	n.a.	0	1	80	0
M	23	731	0	n.a.	0	1	80	0
M	22	625	0	n.a.	1	0	90	0
M	22	1137	1	1	1	0	100	0
M	25	1098	0	n.a.	0	0	100	0
M	19	408	1	0	0	1	50	1
M	22	653	1	0	0	1	75	1
F	23	827	1	0	0	0	80	1
M	19	801	1	1	0	1	80	1
M	24	556	1	0	0	1	80	1
F	23	434	1	0	0	1	80	1
M	21	907	1	0	0	0	85	1
M	25	961	1	0	0	0	100	1
M	21	731	1	1	0	0	100	1
M	23	445	1	0	0	0	100	1
M	21	497	1	0	0	0	100	1
n = 20	23 *	755.4	14	3	4	10	83.0	11
	(3.75)	(241.2)	(70%)	3/14 = 21%	(20%)	(50%)	(13.9)	(55%)

* median and Interquartile Range; M = male; F = female; SANE = single assessment numerical evaluation; CECS = chronic exertional compartment syndrome;MTSS = medial tibial stress syndrome; n.a. = not applicable; 0 = no; 1 = yes.

Table 3B.

M/F	Age (years)	Follow up (days)	Active duty yes / no	Less demanding specialty yes / no	Faciotomy yes / no	Symptoms now yes / no	SANE now	Treatment success yes / no
M	21	1026	0	n.a.	0	1	20	0
M	23	1030	0	n.a.	1	1	40	0
F	19	516	0	n.a.	0	1	40	0
M	22	1088	0	n.a.	0	1	60	0
M	22	878	0	n.a.	0	1	60	0
M	19	996	0	n.a.	0	1	70	0
F	22	1256	0	n.a.	0	0	70	0
F	21	839	0	n.a.	0	1	70	0
F	22	381	0	n.a.	0	1	80	0
F	20	477	1	0	0	1	30	1
F	24	433	1	0	0	1	75	1
M	31	1056	1	0	0	0	80	1
M	24	408	1	0	0	0	80	1
M	21	530	1	1	0	0	85	1
M	19	471	1	1	0	0	90	1
M	25	1173	1	1	0	0	90	1
M	21	381	1	0	0	0	95	1
M	21	520	1	1	0	0	95	1
M	27	526	1	1	0	0	100	1
M	21	462	1	1	0	0	100	1
M	21	764	1	0	0	0	100	1
M	18	839	1	0	0	0	100	1
n = 22	21 *	729.5	13	6	1	10	74,1	13
	(2.5)	(293.8)	(59%)	6/12 = 50%	(5%)	(48%)	(23.8)	(59%)

* median and Interquartile Range; M = male; F = female; SANE = single assessment numerical evaluation; CECS = chronic exertional compartment syndrome;MTSS = medial tibial stress syndrome; n.a. = not applicable; 0 = no; 1 = yes.

RESULTS

Initial results

In total 75 patients from the years 2015-2018 with anterior CECS or anterior CECS+MTSS, eligible for surgery, completed the comprehensive conservative treatment program as described. Table 2 shows baseline characteristics and initial treatment results for all patients, and also divided in three outcome groups: return to base (treatment success), return to surgeon and exit from the military. For males, average height was 1.79 m (SD 0.06), average weight 84.0 kg (SD 11.0), average BMI 26.1 (SD 3.0). For females, average height was 1.70 m (SD 0.07), average weight 72.1 kg (SD 7.3), average BMI 25.1 (SD 2.9). Group 1 (n = 37) and Group 2 (n = 38) were different in duration of treatment 128.4 (± 59.8) versus 161.0 (± 55.6) days, not in treatment outcome.

Follow-up results

Tables 3A and 3B show the results of the follow-up survey presented per diagnostic group. Fifty patients from 2015-2017 were surveyed by telephone. The response rate was 84% (42/50). The average follow-up time was slightly greater than two years; 742 (± 267) days. At follow-up: 24/42 patients (57%) were still active duty and without fasciotomy; 18/42 returned to their original military specialty (43%); 15/42 left the military (36%); 20/42 still had symptoms (48%); 5/42 patients received fasciotomy (12%).

DISCUSSION

This study evaluated a comprehensive conservative treatment program for service members with proven anterior CECS, with and without associated MTSS, eligible for surgery. Almost two third of patients were able to return to duty without surgery and it was hoped and expected that under supervision of primary care these patients would recover and maintain their status on active duty (initial treatment success). Before 2011 all of these patients would have received fasciotomy in the Central Military Hospital without delay. Twenty-one patients were referred back to the department of surgery and five left the armed forces voluntarily (35% initial treatment failure). From the follow-up survey it was learned that 24/42 patients were still active duty and did not have surgery (57% follow-up treatment success).

The initial results at the department of Military Sports Medicine with conservative treatment for anterior CECS are comparable to those presented by the Military Rehabilitation Center, return to base 65% versus 56%. [10] Comparison of the programs must be done with caution; the inpatient treatment program at the Military Rehabilitation Center was shorter, six weeks versus twenty one weeks, and our outpatient program emphasized gait retraining of running and marching to a greater extent. Gait retraining for service members with exercise-related leg pain has been a topic of special interest in our department over the last years. Moreover, several studies showing the importance of training sessions in boots and the effectiveness of combining gait retraining cues have been published. [15,16,17] A possible confounder is that the patients send to the Military Rehabilitation Center had more severe exercise-related leg pain symptoms.

Our two year follow-up results compare favorably with the results of fasciotomy in the Central Military Hospital: return to the original military specialty 43% vs 34%, leaving the military 36% vs 64%, still exercise-related leg pain symptoms 48% vs 57%. A randomized study directly comparing the results of a conservative approach versus fasciotomy would be valuable to determine which pathway is most beneficial for the individual patient.

Including the current study, there are now at least five case series on the conservative treatment of anterior CECS available. [10,18,19,20] In addition, one case study also presents promising results. [21] While admittedly the quality of level of evidence remains low (poor control groups, primarily retrospective studies with small number case series and potential observer bias), this growing body of evidence on the effectiveness of comprehensive conservative treatment for anterior CECS can no longer be ignored, certainly not for military patients. It is reasonable and perhaps safer and more cost-effective to follow a protocol in which surgery for exercise-related leg pain is offered only after "optimal" conservative treatment has been attempted. It appears that comprehensive conservative treatment for anterior CECS should be at least a 6-week program and should include gait retraining of running and, in a military setting, retraining of marching and running while in boots. Fortunately, the same gait retraining cues are beneficial to treat the other overuse injuries in the exercise-related leg pain group including MTSS and overuse stress injuries. [15,16]

In this study, the average duration of treatment for all patients was 144,9 days. Group 2 patients needed 32 days longer than Group 1. This is not surprising, but reflects the treatment protocol. Group 2 patients received four weeks of extracorporeal shockwave, before gait retraining was started. Average duration of treatment for those patients referred back to a surgeon was 125.6 days. This reflects that if patients were not experiencing sufficient relief with the comprehensive conservative treatment program, unnecessary surgical treatment delay was prevented.

One subgroup that requires additional focus and analysis is the group of five patients who chose not to have surgery and left the services. They were all first episode anterior CECS patients, the duration of symptoms was relatively short and they left the program with high SANE scores. It could be argued that these patients represented treatment success, but their goals were different, they had no intention of returning to active duty and were granted dismissal by request.

From the follow-up survey it was learned that not all patients referred back to the Central Military Hospital received fasciotomy. At retesting some no longer qualified for surgery, intracompartmental pressure measurement values were now below 35 mm Hg. For these patients conservative treatment failed and surgery was not offered. Currently reduction of activity is the only treatment option offered for these patients, which is unsatisfactory. Future research must explore other treatment options for this group of patients, such as intramuscular injection with botulinum toxin.

This study illustrates the impact of anterior CECS on service members and the military organization. It also demonstrates the diversity of possible treatment outcomes, active duty, with or without transfer to a less physically demanding specialty, and continuing work with different levels of exercise-related leg pain symptoms, as reflected by the follow-up SANE scores. In a time where recruiting and retaining young men and women in the military is very difficult, efforts in primary prevention of exercise-related leg pain are paramount, with continuing emphasis on developing efficient and durable early-stage treatment strategies to prevent chronic and recurrent symptoms. [8]

The authors must acknowledge limitations in the research approach and design. This historic cohort design in the absence of a defined control group introduces the potential of observer bias, the outcome pathways of reduced surgical risk and exposure using this protocol are based on defined numbers of surgeries performed in the primary military hospital for a single country. Those numbers and the reduction in surgical procedures in this cohort are not subject to such bias. A separate area of concern might target the specifics of diagnosis and definitions of success of outcomes as defined as return to active duty. Patients received individualized treatments plans and had two different diagnostic categories (anterior CECS with and without associated MTSS). The follow-up survey was not a validated questionnaire. Be that as it may, the study is enormously valuable in demonstrating that a comprehensive conservative first protocol can not only be effective in returning military patients to duty, but it can significantly decrease the number of surgical procedures and associated risks and costs for this population.

CONCLUSION

In conclusion, for patients with anterior CECS in the military population, initiating care with a comprehensive conservative treatment protocol can have a two third return to duty rate while avoiding surgery and reduce the total number of fasciotomies required. At follow-up, on average more than two years later, 57% of patients surveyed were active duty, without surgery (follow-up treatment success). Surgical fasciotomy may still be effective and reasonable in patients who fail the comprehensive conservative first protocol.

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Appendix 1

Running Leg Pain Profile

The Running Leg Pain Profile (RLPP) is the pain scoring system used to diagnose military patients with ERLP. Patients are asked every minute, to give a pain score of 0-10 for four (or six, when including the calves) regions of the legs. The RLPP assists in pinpointing an accurate diagnosis and also provides information on the severity of symptoms: MTSS is suspected when pain is reported in regions 2 and 3, and anterior-CECS is suspected with pain in regions 1 and 4. Combined symptoms may indicate concurrence of the two diagnoses. The RLPP is performed with a standardized treadmill protocol (see Appendix 2). This 14-minute protocol comprises running and marching and is designed to reproduce symptoms to the limit of tolerable pain in the military patient group. The test is performed in running shoes, shorts and a t-shirt.

Appendix 2

Treadmill protocol and template to record the Running Leg Pain Profile (RLPP) scores (0-10) in this study.

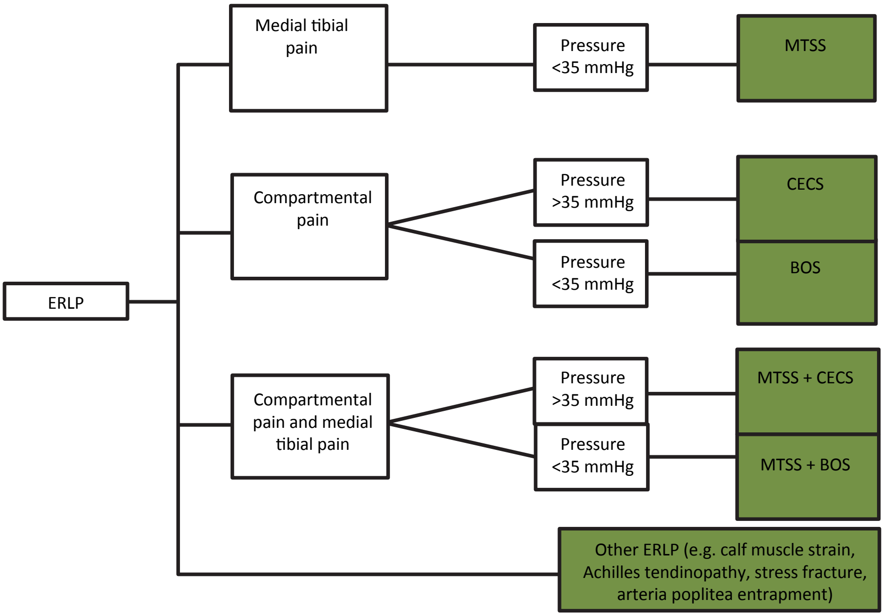
velocity km/h	slope %	time	anterior compartm. right	medial tibial border right	medial tibial border left	anterior compartm. left	calve right (optional)	calve left (optional)
5	1	0’55”						
6	1	1’55”						
7	1	2’55”						
8	1	3’55”						
9	1	4’55”						
10	1	5’55”						
11	1	6’55”						
12	1	7’55”						
12	5	8’55”						
12	5	9’55”						
7,5	5	10’55”						
7,5	5	11’55”						
12	1	12’55”						
12	1	13’55”						
finish	time:							

Appendix 3

Diagnostic categories

The combination of the RLPP and ICPM allows for differentiation of service members with exercise related leg pain into the following five potential diagnoses: 1. MTSS; 2. CECS (ICPM ≥ 35 mm Hg); 3. Biomechanical overload syndrome (BOS) (ICPM < 35 mm Hg); 4. MTSS + BOS; 5. MTSS + CECS.

Diagnostic flowchart for ERLP in the Royal Netherlands Armed Forces.



ERLP = exercise-related leg pain; MTSS = medial tibial stress syndrome; CECS = chronic exertional compartment syndrome; BOS = biomechanical overload syndrome.

Appendix 4

Figure A.
Gastrocnemius / Achilles stretch (right leg, barefoot); criterion for normal value = maximal angle compared to a vertical line: 70 degrees or less.

Figure B.
Soleus stretch (left leg, barefoot); criterion for normal value = minimal distance 5 cm from the wall or more.

Chapter 10

General discussion

1. Lessons learned

This thesis aimed to explore the utility of new and promising treatment forms for Exercise-related Leg Pain (ERLP) in the Royal Netherlands Armed Forces: Extracorporeal Shockwave Therapy (ESWT) for Medial Tibial Stress Syndrome (MTSS) and gait retraining for Chronic Exertional Compartment Syndrome (CECS). Eight studies were undertaken and the following lessons were learned:

Chapter 2: The body of knowledge on ERLP in the military is growing and the number of publications is increasing. Despite these recent developments, the occupational problem of ERLP in the military is far from solved. MTSS and CECS continue to have a high incidence, long recovery time and large impact on training.

Chapter 3: In four years' time, 573 Dutch service members were referred to the Central Military Hospital (CMH) for evaluation of chronic ERLP and treatment suggestions. They underwent a new diagnostic protocol. Intracompartmental Pressure Measurement (ICPM), a standardized pain assessment tool (i.e., the Running Leg Pain Profile - RLPP) and a standardized running protocol were useful in subcategorizing patients with exertional leg pain. Subsets of patients may have high compartment pressures and low compartment pain scores, or vice versa. The clinical treatment ramifications of these categories is still evolving and further research into optimal treatment strategies for all subgroups of patients is warranted. Current advice to avoid or minimize ICPM due to needle pain concerns does not appear warranted.

Chapter 4: Radial ESWT did not reduce the length of tenderness along the posterior medial tibial border during the weeks of application in patients with chronic MTSS. It is a painful treatment, but tolerable by self-application. The majority of patients did not experience post treatment pain. In this group of patients, 81% would recommend ESWT. More studies are necessary to establish if ESWT for MTSS is clinically effective.

Chapter 5: In 19 patients diagnosed with CECS, a 6-week forefoot running intervention performed in both a center-based and home-based training setting led to decreased post running lower leg ICPM values, improved running performances, and self-assessed leg condition. The influence of training group, center-based or home-based, was not statistically significant. Overall, this finding is promising, taking into consideration the significantly reduced investments in time and resources needed for the home-based program.

Chapter 6: Service members with ERLP, among them patients with chronic MTSS, responded well to a treatment program that included on average 2.4 gait retraining sessions. Ten months post gait retraining, repeated measures on a treadmill, still showed positive changes from intake. It is suggested that four gait retraining sessions, delivered over a period of two-three months, with homework exercises, can be sufficient to produce lasting positive clinical results.

Chapter 7: Gait retraining in military boots achieved similar changes in stride length (reduction), cadence (increase), force and pressure in the heel (reduction) and in the fore foot (force reduction, pressure increase) compared to running shoes. However, in boots, mid foot maximal force and pressure increased. The same gait retraining cues can be used to optimize ground reaction forces in running shoes and in military boots.

Chapter 8: Three commonly used gait retraining cues are: Cue 1. Change to a ball-of-foot strike; Cue 2. Increase cadence to 180 steps/minute; Cue 3. Stand up taller. When applied in isolation, all three cues achieved reduction of vertical ground reaction forces. The combination of the three cues achieved the largest reduction of vertical ground reaction forces.

Chapter 9: A conservative treatment program for anterior CECS was able to return 65% of patients to active duty, without surgery. At two-year follow-up, the success rate decreased slightly, but remained positive at 57%. In this group of service members with pressure positive anterior CECS, initiating a conservative treatment protocol with an emphasis on gait retraining can significantly reduce the need for surgical fasciotomy. For those who fail conservative treatment, surgical release may still be indicated.

2. Levels of evidence

In medicine the quality of research is often graded. There are several grading systems. These grading systems all have in common that randomization of patients is considered the most important component of research methodology. [1] An example of a 5-level scoring system for research is presented in Box 1.

Chapters 4, 5, 6 and 9 presented evaluations of the effect of interventions in a specific group of patients, cohorts were followed prospectively. According to the levels of evidence presented in Box 1 these studies can be classified at level 3, 4 or 5 depending on criteria applied. This does not mean the contents of these studies are of low importance. Lower level studies play a very important role in hypothesis generation and are a necessary precursor to higher level analytic studies. [2] In addition, some experts propose that the grading system of research itself is not based on sound scientific principles and agree that non-randomized studies can be very valuable for the physician practitioner, provided they are executed in a reliable manner (i.e., avoiding methodological errors). [1]

In chapter 2 we presented an extensive, narrative review of the literature. Insufficient literature was available for a meaningful systematic review of ERLP in the armed forces. Chapter 3 included a descriptive analysis of patient records. Chapter 7 and 8 concentrated on biomechanical measurements, the subjects were patients and the 5-level grading system is not applicable.

Box 1.
A 5-level grading system for levels of evidence for research in medicine. [1]

Level 1:	Randomized controlled trial (RCT) or meta-analysis (Lower limit of confidence interval for treatment effect exceeds minimal important benefit);
Level 2:	RCT or meta-analysis (Lower limit of confidence interval for treatment effect overlaps with minimal important benefit);
Level 3:	Nonrandomized concurrent cohort study;
Level 4:	Nonrandomized historic cohort study;
Level 5:	Case series without control subjects.

3. Organization of care in the armed forces, 2013 and onward

In the Royal Netherlands Armed Forces, the base physician is responsible for starting the treatment of ERLP. In 2014 (revision 2017 and 2019), a treatment protocol for exercise-related leg pain was published by the author of this thesis and distributed among on-base primary care providers nationwide (Table 1). [3] The physician on base may refer the military patient to secondary care if clinical progress is insufficient after 3-6 months.

Only one secondary care center is point of contact for ERLP, which is the CMH. The CMH offers a specialty clinic for service members. A multidisciplinary team of surgery, sports medicine, and physiatry evaluates patients in a one-stop shop setting. In a small percentage of cases, diagnostic imaging is ordered if stress fractures, malign or (neuro-)vascular disorders are suspected. After medical clearance, a sports medicine physician supervises the patient in a standardized running test on a treadmill to maximal pain tolerance and performs an ICPM of compartments suspected for CECS. All patient information is stored in an electronic patient record specifically designed for ERLP, which allows for clinical data analysis. Based on the evaluations, patients may be referred to any of four treatment arms: surgery in the CMH, outpatient conservative treatment in the Military Sports Medicine department, inpatient conservative treatment in the Military Rehabilitation Center (MRC), or referral back to their original military base to re-engage with primary care.

Table 1.
Treatment guideline for ERLP in primary care in the Royal Netherlands Armed Forces, version 2019 (first version 2014).[3]

Week	Treatment action	Caregiver	Treatment phase	Comp	Ref
0	significant reduction of running, marching, etc.	MD	visit 1	1	4,5
0	examine ROM of ankle, knee, hip	MD	visit 1	2	6,7
0	reduce BMI if too much	MD	visit 1	3	8-10
0	stop creatin supplements	MD	visit 1	3	11,12
0	stop smoking	MD	visit 1	3	13
0	vitamin D in blood (goal > 78 nmol/L)	MD	visit 1	3	14-19
0-2	NSAID (avoidance of)	MD	visit 1	2	20,21
0-2	ice	MD	visit 1	2	20,22
2	send patient to physical therapist on base	MD	visit 2	1	
2	place in on base part-time rehab program	MD	visit 2	1	23,24
2	place in off base full-time rehab program	MD	visit 2	1	25,26
3	assess running shoes and boots	PT	physio phase 1	3	27-31
3	assess walking biomechanics	PT	physio phase 1	3	32,33
3	assess running biomechanics	PT	physio phase 1	3	33-35
3	assess (need for) orthopedic inlays	PT	physio phase 1	3	36-39
3	compression stockings (not for CECS)	PT	physio phase 1	4	40,41
3-8	massage	PT	physio phase 1	2	42-45
3-8	taping (kinesio-)	PT	physio phase 1	2	46,47
3-8	dry needling, (neuro-) prolotherapy	PT, MD	physio phase 1	2	48
3-8	improve range of motion (stretching)	PT	physio phase 1	3	
3-12	improve relevant strength	PT	physio phase 1+2	3	49-54
3-12	maintain / improve cardiovascular fitness	PT	physio phase 1+2	3	4,5
6-12	gradual transfer from low impact to impact	PT	physio phase 1+2	4	55,56
6-12	gait retraining marching (boots)	PT	physio phase 1+2	3	57,58
6-12	gait retraining running (running shoes)	PT	physio phase 1+2	3	59-67
6-12	gait retraining running (military boots)	PT	physio phase 1+2	3	68
8-12	extracorporeal shockwave therapy (ESWT)	sportsmed	physio phase 1	2	20,69-72
12-20	gradual increase marching (km)	mil instr.	sports + specific	4	73
12-20	gradual increase running (km)	mil instr.	sports + specific	4	4
12-20	goal evaluation	MD	evaluation	5	24
12-24	send to regional military hospital	MD	stagnation	5	74,75

BMI = body mass index; ROM = range of motion; CECS = chronic exertional compartment syndrome; PT = physical therapist; MD = medical doctor; Comp = component of treatment (see Box 2); Ref = reference; sportsmed = Department of Sports Medicine; mil instr = military instructor.

4. Chronic exercise-related leg pain, current diagnostic and treatment protocol in the Netherlands Armed Forces

As no single intervention is proven to be superior in the treatment of MTSS and conservative treatment for CECS logically precedes surgery, a complete or comprehensive treatment program for ERLP has been developed, based on evidence in the literature. [4,5] Table 1 shows the 2019 version. The column 'references' (ref) shows supporting literature. Box 2 shows a subdivision of the treatment program into five components. Addressing modifiable risk factors during the treatment (component 3 in Box 2), is paramount to achieve successful outcomes and minimize recurrence. [20,76] Component 5 in Box 2, goal evaluation (*is it realistic for this service member to return to the intended military training or specialty?*) is important for secondary prevention. For each of the interventions presented in the protocol, criteria for application have been set (Appendix 1). The protocol has been developed in a secondary care setting with chronic ERLP patients, using sophisticated instruments, such as an instrumented treadmill and high speed cameras for gait retraining. The proposed interventions, however, can all be executed by primary care professionals on base using the available regular treadmill and private mobile phones as supportive tool for auditory (metronome) and visual (camera) motor learning.

Box 2.
Five components of a comprehensive treatment program for exercise-related leg pain.

1. Significant reduction of symptoms producing activities (running, marching, jumping, etc.);
2. Treatment of local pain in soft tissues and reduction of limitations in joint range of motion of ankle, knee and hip;
3. Improvement of modifiable risk factors for ERLP in a military setting;
4. Gradual return to leg loading activities;
5. Goal evaluation: is it realistic for this service member to return to the intended military training or specialty?

5. MTSS and CECS, highlights from the international literature 2013-2019

A valid, reliable and responsive patient reported outcome measure for MTSS was developed: the MTSS score. [77] It can be used to evaluate injury severity in patients with MTSS and is recommended for studies on MTSS treatment. Two studies reported positive effects of ESWT for MTSS, [20,71] but a randomized double blind study (n = 24) found that standard dose ESWT was not more effective than a sham dose at improving pain or running distance in MTSS. [72] Clearly, further investigation including a no intervention control group is warranted to evaluate the effect of ESWT in the management of MTSS.

In the British Armed Forces, patients suspected of CECS have been offered a gait retraining program before intracompartmental pressure measurement (ICPM). [78] Only patients who fail the conservative program are put forward for pressure testing. More information was presented to show that the occupational outcome of fasciotomy for CECS in the military is unfavorable. [79] In a study of 16 patients, botulinum toxin type A reduced intramuscular pressure and eliminated exertional pain in the anterior or anterolateral lower leg for up to nine months after the intervention. [80]

Also in the British armed forces, it was shown that pressure plate assessment of gait can help categorize patients into low, medium or high risk for overuse lower limb injury. [34] In a follow up study, individuals identified as at-risk for developing MTSS based on pressure plate assessment, received supervised gait retraining, including exercises to increase neuromuscular control and flexibility (three sessions per week) and biofeedback (one session per week). The intervention was associated with a substantially reduced relative risk of MTSS versus control. [61] In summary, assessment of gait can predict ERLP in the military and gait retraining can prevent MTSS. The evidence for an association between ground reaction forces and musculoskeletal injuries in runners from both retrospective and prospective data is now considered “compelling”. [81]

6. Future perspectives concerning research

The studies in this thesis on ERLP in the armed forces have all suggested possible future study topics. From this thesis the following research questions are most pressing:

- Is ESWT an effective treatment for MTSS? A randomized controlled trial is required (Chapter 4).
- Can gait retraining in shoes and boots be maintained over a long time (retention) and what is the effect on military employability? (Chapters 5, 6 and 7).
- Which treatment is best for CECS in the military: a comprehensive conservative program including gait retraining, or fasciotomy? A randomized controlled trial is required (Chapter 9).
- What is the best treatment for patients with exercise-related anterior compartment pain and low intracompartmental pressures? (Chapters 3 and 9).

From the international literature, the following research questions for ERLP in the military are most relevant for the Royal Netherlands Armed Forces:

- Can CECS be diagnosed accurately with a non-invasive procedure? [45]
- Can the results of fasciotomy for CECS in the military be improved? [79]
- Can gait retraining in basic military training prevent ERLP? [61]
- Is botulinum toxin type A an effective conservative treatment for CECS? [80]

A broader perspective

It seems logical that the findings in this thesis, based on studies on service members, also apply for civilian recreational runners. Keeping in mind the many differences between basic military training and civilian recreational running, learning to run appropriately (gait retraining) may be the single most important primary and secondary preventive measure to positively change the course of running injuries. [81]

In The Netherlands in 2018 a national workgroup “exercise-related leg pain” has been formed with representatives from all medical and paramedical professions involved in the care of athletes, supported by the Netherlands Association for Sports Medicine (VSG). Goal of the workgroup is to improve care for all athletes, civilian and military, by exchanging knowledge between experts, initiating joint (multi-center) research efforts and updating national treatment guidelines for ERLP.

The cooperation between the Royal Netherlands Armed Forces and the Uniformed Services University of the Health Sciences (USUHS) will not end with the completion of this thesis. Both institutions feel a responsibility to continue the quest for better care for military athletes with exercise-related leg pain. Studies to test the use of botulinum toxin type A for CECS are planned on both sides of the Atlantic Ocean.

7. Conclusions of this thesis

Diagnosis:

- Using a new diagnostic protocol was useful in subcategorizing patients with exertional leg pain. In particular, the patient group with high anterior compartment pain, but low anterior compartment pressures one minute after exercise, has not been described before (Chapter 3). [82]

- Service members rated needle pain of the ICPM procedure as moderate: median pain rating 5 (range 0-10) (Chapter 3). Current advice to avoid or minimize ICPM due to needle pain concerns does not appear to be warranted.

Extracorporeal shockwave therapy:

- Radial extracorporeal shockwave therapy did not reduce the length of tenderness along the posterior medial tibial border during the weeks of application in patients with chronic MTSS (Chapter 4).

- 81% of military patients with recalcitrant MTSS symptoms would recommend ESWT (Chapter 4).

Gait retraining:

- Gait retraining reduced intracompartmental pressure and symptoms in service members with CECS (Chapter 5).

- Service members with chronic MTSS respond well to a conservative treatment program including gait retraining (Chapter 6).

- The same gait retraining cues can be used to reduce vertical ground reaction forces in running shoes and in military boots (Chapter 7)

- Three commonly used gait retraining cues, when applied in isolation, all achieve reduction of vertical ground reaction forces. The combination of all three cues produces the best result (Chapter 8).

- A conservative treatment program for anterior CECS, with an emphasis on gait retraining, was able to return 65% of service members to active duty, without surgery. At two year follow-up the success rate was 57% (Chapter 9).

8. How might the findings impact clinical practice in the future? Paradigm shifts.

- To diagnose (recalcitrant) ERLP, it is crucial to make the patient run on a treadmill. A standardized running protocol, a standardized pain assessment tool (i.e., the Running Leg Pain Profile) and ICPM are useful in subcategorizing patients.

- It is not necessary to avoid or minimize ICPM due to needle pain.

- It is not necessary to perform an ICPM before the start of a conservative treatment program for ERLP. Only patients who fail the conservative treatment program should be put forward for pressure testing.

- Gait retraining as a treatment for ERLP, including CECS, can reduce the need for surgical fasciotomy substantially.

- Significant and lasting changes can be achieved in running biomechanics, in particular reduction of force and pressure on the heels, with four-five gait retraining sessions and homework exercises.

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Appendix 1

Standard care for exercise-related leg pain (ERLP): criteria for application (version 2019).

Intervention	Criterion
Stretching	Gastrocnemius tightness = minimal angle compared to a vertical line: 70 degrees or more; Soleus tightness = maximal distance 5 cm from the wall or less.
Strengthening	Calf strength insufficient: not able to perform 30 consecutive calf raises on one leg.
Massage hypertonic m. plantaris	m. plantaris palpation painful (patient in prone position).
Dryneedling of triggerpoints	Medial and lateral gastrocnemius: if the patient identifies the calf as a pain location.
Compression stockings	Not given to patients with proven anterior CECS (ICPM ≥ 35 mm Hg).
Shockwave (ESWT)	For MTSS only: once a week, 4-5 sessions; each session 2000 radial shocks, frequency 8 per second and intensity 2.5 bar, on the posteromedial tibial border. [69]
Vitamin D supplementation	If MTSS is present. Criterion: < 50 nmol/l = insufficient, supplementation required; optimal 75 nmol/l. [19]
New running shoes	Every year or after 500 miles (800 km); If the patient describes a relation between symptoms and shoes; Minimalist shoes are discouraged, low drop shoes are encouraged (± 6-8 mm drop).
Customized anti-pronation inlays	If navicular drop is positive (> 1.0 cm) and if over-pronation is established with slow motion video analysis of barefoot running
Maintaining fitness with low impact training	Resume three sessions of low impact exercise per week. Keep leg pain scores ≤ 3 (on a Numeric Pain Rating Scale 0-10).
Gait retraining while running in sports shoes	Four cues for running: 1. Change to a ball-of-the-foot strike (when applicable); 2. Increase cadence to 180 steps/min; 3. Stand up tall (don't bend over at the waist); 4. Increase knee lift 1-2 cm.
Gait retraining while matching in boots	Two cues for marching: 1. 5% increase in cadence from preferred; 2. Try not to stomp on the heels.
Progressive running schedule	Week 1-6: run twice a week, end goal = a 15-minute uninterrupted run, pain free with new running technique; Week 7-12: run twice or three times per week, end goal is a 30-minute uninterrupted run, pain free with new running technique.

CECS = chronic exertional compartment syndrome; MTSS = medial tibial stress syndrome; ICPM = intracompartmental pressure measurement; mm Hg = millimeter Mercury.

Chapter 11

Summary in English

This thesis aimed to explore the utility of new and promising treatment forms for Exercise-related Leg Pain (ERLP) in the Royal Netherlands Armed Forces: Extracorporeal Shockwave Therapy (ESWT) for Medial Tibial Stress Syndrome (MTSS) and gait retraining for Chronic Exertional Compartment Syndrome (CECS). Eight studies were undertaken and the following lessons were learned:

Chapter 2: The body of knowledge on ERLP in the military is growing and the number of publications is increasing. Despite these recent developments, the occupational problem of ERLP in the military is far from solved. These overuse injuries continue to have a high incidence, long recovery time and large impact on training.

Chapter 3: In four years' time, 573 Dutch service members were referred to the Central Military Hospital (CMH) for evaluation of chronic ERLP and treatment suggestions. They underwent a new diagnostic protocol. Intracompartmental Pressure Measurement (ICPM), a standardized pain assessment tool (i.e., the Running Leg Pain Profile - RLPP) and a standardized running protocol were useful in subcategorizing patients with exertional leg pain. Subsets of patients may have high compartment pressures and low compartment pain scores, or vice versa. The clinical treatment ramifications of these categories is still evolving and further research into optimal treatment strategies for all subgroups of patients is warranted. Current advice to avoid or minimize ICPM due to needle pain concerns does not appear warranted.

Chapter 4: Radial ESWT did not reduce the length of tenderness along the posterior medial tibial border during the weeks of application in patients with chronic MTSS. It is a painful treatment, but tolerable by self-application. The majority of patients did not experience post treatment pain. In this group of patients, 81% would recommend ESWT. More studies are necessary to establish if ESWT for MTSS is clinically effective.

Chapter 5: In 19 patients diagnosed with CECS, a 6-week forefoot running intervention performed in both a center-based and home-based training setting led to decreased post running lower leg ICPM values, improved running performances, and self-assessed leg condition. The influence of training group, center-based or home-based, was not statistically significant. Overall, this finding is promising, taking into consideration the significantly reduced investments in time and resources needed for the home-based program.

Chapter 6: Service members with ERLP, among them patients with chronic MTSS, responded well to a treatment program that included on average 2.4 gait retraining sessions. Ten months post gait retraining, repeated measures on a treadmill, still showed positive changes from intake. It is suggested that four gait retraining sessions, delivered over a period of two-three months, with homework exercises, can be sufficient to produce lasting positive clinical results.

Chapter 7: Gait retraining in military boots achieved similar changes in stride length (reduction), cadence (increase), force and pressure in the heel (reduction) and in the fore foot (force reduction, pressure increase) compared to running shoes. However, in boots, mid foot maximal force and pressure increased. The same gait retraining cues can be used to optimize ground reaction forces in running shoes and in military boots.

Chapter 8: Three commonly used gait retraining cues are: Cue 1. Change to a ball-of-foot strike; Cue 2. Increase cadence to 180 steps/minute; Cue 3. Stand up taller. When applied in isolation, all three cues achieved reduction of vertical ground reaction forces. The combination of the three cues achieved the largest reduction of vertical ground reaction forces.

Chapter 9: A conservative treatment program for anterior CECS was able to return 65% of patients to active duty, without surgery. At two-year follow-up, the success rate decreased slightly, but remained positive at 57%. In this group, initiating a conservative treatment protocol with an emphasis on gait retraining can significantly reduce the need for surgical fasciotomy. For those who fail conservative treatment, surgical release may still be indicated.

How might the findings impact clinical practice in the future? Paradigm shifts.

- To diagnose (recalcitrant) ERLP, it is crucial to make the patient run on a treadmill. A standardized running protocol, a standardized pain assessment tool (i.e., the Running Leg Pain Profile) and ICPM are useful in subcategorizing patients.

- It is not necessary to avoid or minimize ICPM due to needle pain.

- It is not necessary to perform an ICPM before the start of a conservative treatment program for ERLP. Only patients who fail the conservative treatment program should be put forward for pressure testing.

- Gait retraining as a treatment for ERLP, including CECS, can reduce the need for surgical fasciotomy substantially.

- Significant and lasting changes can be achieved in running biomechanics, in particular reduction of force and pressure on the heels, with four-five gait retraining sessions and homework exercises.

Chapter 12

Summary in Dutch

Samenvatting in het Nederlands

Samenvatting in het Nederlands

De doelstelling van dit proefschrift was de bruikbaarheid te onderzoeken van nieuwe en veelbelovende behandelvormen voor inspanningsgebonden onderbeenklachten (Engels = exercise-related leg pain, ERLP) in de Koninklijke Nederlandse strijdkrachten; met name shockwave therapie (Engels = extracorporal shockwave therapy, ESWT) voor het mediale tibiale stresssyndroom (MTSS) en loopscholing voor chronisch inspanningsgebonden compartiment syndroom (Engels = chronic exertional compartment syndrom, CECS). Acht studies werden uitgevoerd en de volgende lessen werden geleerd:

Hoofdstuk 2: De hoeveelheid kennis over inspanningsgebonden onderbeenklachten in het leger groeit en het aantal publicaties neemt toe. Ondanks deze recente ontwikkelingen is het probleem van deze groep beroepsgerelateerde aandoeningen in het leger nog lang niet opgelost, er is sprake van een hoge incidentie, lange hersteltijd en een grote, beperkende invloed op de training.

Hoofdstuk 3: In vier jaar tijd werden 573 Nederlandse militairen doorverwezen naar het Centraal Militair Hospitaal (CMH) voor evaluatie van chronische onderbeenklachten en behandelsuggesties. Ze ondergingen een nieuw diagnostisch protocol. Intracompartimentale drukmeting (kort: drukmeting), een gestandaardiseerd pijnscore systeem, het zogenoemde Running Leg Pain Profile (RLPP) en een gestandaardiseerd hardloopprotocol, waren nuttig bij het indelen van patiënten met onderbeenklachten in subgroepen. Een deel van de patiënten kunnen hoge compartimentdrukken en lage pijnscores hebben, of omgekeerd. De gevolgen voor de behandeling zijn nog in ontwikkeling en verder onderzoek naar optimale behandelstrategieën voor alle subgroepen van patiënten is gerechtvaardigd. Het advies om de drukmeting niet uit te voeren of zo veel mogelijk te beperken vanwege de pijnlijkheid van het onderzoek lijkt niet gerechtvaardigd.

Hoofdstuk 4: Shockwave therapie verminderde de lengte van het pijnlijke gebied langs de posterieure mediale rand van de tibia tijdens de weken van toepassing bij patiënten met chronische MTSS niet. Het is een pijnlijke behandeling, maar aanvaardbaar middels zelftoepassing. De meerderheid van de patiënten ondervond geen pijn vlak na de behandeling. In deze groep patiënten zou 81% ESWT aanbevelen. Meer studies zijn nodig om vast te stellen of ESWT voor MTSS klinisch daadwerkelijk effectief is.

Hoofdstuk 5: Bij 19 patiënten met de diagnose CECS leidde een voorvoet-loopscholingsprogramma van zes weken tot verlaagde drukwaarden na het lopen, een grotere loopafstand en minder onderbeenklachten, zowel in een groep die volledig op ons instituut trainde als in een groep met 50% huiswerkopdrachten. De invloed van trainingsgroep, op het instituut of gedeeltelijk vanuit huis, was niet statistisch significant. Dit is een veelbelovende bevinding, een thuisprogramma voor technische loopscholing vraagt minder investering in tijd en middelen.

Hoofdstuk 6: Militairen met inspanningsgebonden onderbeenklachten, waaronder patiënten met chronische MTSS, reageerden goed op een behandelprogramma met technische loopscholing. Tien maanden na het behandelprogramma vertoonden herhaalde metingen op een loopband nog steeds positieve veranderingen ten opzichte van het moment van inname.

Hoofdstuk 7: Loopscholing op militaire laarzen leidde tot vergelijkbare veranderingen in paslengte (reductie), pasfrequentie (toename), kracht en druk op de hiel (reductie) en in de voorvoet (krachtreductie, druktoename) als loopscholing op sportschoenen. Bij laarzen namen de maximale kracht en druk op het middelste deel van de voet echter toe. Bij technische loopscholing op laarzen kunnen dezelfde aanwijzingen worden gebruikt om de verticale grondreactiekrachten te optimaliseren als bij loopscholing op sportschoenen.

Hoofdstuk 8: Drie veel gebruikte aanwijzingen bij technische loopscholing zijn: Aanwijzing 1: Verander de voetplaatsing naar een bal-van-de-voet landing; Aanwijzing 2: Verhoog de stapfrequentie naar 180 stappen / minuut; Aanwijzing 3: Houd het lichaam rechtop. Wanneer afzonderlijk toegepast, resulteerden alle drie deze aanwijzingen in een vermindering van verticale grondreactiekrachten. De combinatie van de drie aanwijzingen resulteerde in de grootste vermindering van verticale grondreactiekrachten.

Hoofdstuk 9: Een conservatief behandelprogramma voor militaire patiënten met CECS van het voorste compartiment van de onderbenen was in staat om 65% van hen terug te brengen naar actieve militaire dienst, zonder chirurgische ingreep. Na twee jaar follow-up daalde dit percentage licht, maar bleef positief met 57%. In deze groep kan het starten met een conservatief behandelprotocol waarin de nadruk wordt gelegd op technische loopscholing de behoefte aan chirurgische behandeling, met name de zogenaamde fasciotomie, aanzienlijk verminderen. Voor degenen waarbij de conservatieve behandeling faalt, is chirurgische behandeling mogelijk toch geïndiceerd.

Welke invloed kunnen de bevindingen in dit proefschrift in de toekomst hebben op de klinische praktijk? Paradigmaverschuivingen.

- Om chronische inspanningsgebonden onderbeenklachten te diagnosticeren, is het van groot belang om de patiënt op een loopband te laten lopen. Een gestandaardiseerd hardloopprotocol, een gestandaardiseerd pijnscore systeem en een intracompartimentale drukmeting zijn nuttig bij het subcategoriseren van patiënten.

- Het is niet nodig om de drukmeting achterwege te laten of te beperken tot enkele compartimenten vanwege de pijnlijkheid van de procedure.

- Het is niet nodig om een drukmeting uit te voeren vóór de start van een conservatief behandelprogramma voor chronische inspanningsgebonden onderbeenklachten. Alleen patiënten bij wie het conservatieve behandelprogramma niet slaagt, moeten worden voorgedragen voor een drukmeting.

- Technische loopscholing als behandeling voor inspanningsgebonden onderbeenklachten, inclusief patiënten met CECS, kan het aantal chirurgische behandelingen (fasciotomiën) aanzienlijk doen verminderen.

- Een significante en blijvende verandering in de biomechanica van het hardlopen, met name een vermindering van kracht en druk op de hielen, kan worden bereikt met vier tot vijf lessen technische loopscholing en thuisoefeningen.

Appendix 1

Acknowledge-ments

From experience I can now say that a PhD thesis is a lot of work for the principal author. For seven years the studies presented in this thesis have dominated my thoughts. It is impossible to complete a work of this nature without the help of many learned people, friends and family. In this appendix I would like to acknowledge those people to whom I am most indebted. I want to apologize if I have forgotten someone.

First and foremost my gratitude goes out to all military and civilian patients who have visited my office over the last 20 years seeking treatment for exercise-related leg pain. You have trusted me with your personal histories and trusted me to design a treatment strategy for you. You have cooperated in studies for the benefit of other patients with exercise-related leg pain. If only I could have been a wiser physician earlier, I might have helped more of you satisfactorily.
A special mention is required to thank The Royal Netherlands Armed Forces. Due to consecutive budget cuts during the first 15 years of my employment, the armed forces have not always received positive critiques as an employer. I must say, I have always worked in a privileged position. All of my requests to develop my skills as a physician and scientist over the years have been approved. I have served under several commanders who all have supported my ambition to improve care for military patients, in chronological order: Col Julius de Graaf, Ltcol Jos Pelzers, Ltcol Ronald Wemering, Ltcol Leon Jans, Ltcol Rob Krekelberg, General Marius van Zeijts, General Frits van Dooren, General Cees de Rijke, Surgeon General Remco Blom MD. Thank you all.

Professor Pete Seidenberg MD, Penn State University: thank you for inviting me to speak at ACSM the first time. You trusted in me and started the ball rolling. The chapter on exercise-related leg pain we wrote for a textbook on the radiology of sports injuries was the starting point for the review in Chapter 2.

Professor Brian Reamy MD, Uniformed Services University of the Health Sciences, Bethesda, Maryland: thank you for inviting me to join the academic advancement program of the university. You multiplied my enthusiasm for research and brought me in contact with eminent scholars in the field of military sports medicine, who have all been very supportive: Professor Francis O'Connor MD, COL (ret) US Army, Professor Jeffrey Quinlan MD, CAPT US Navy and Professor Mark Stephens MD, CAPT (ret) US Navy. Thank you all.

Professor Anthony Beutler MD, Uniformed Services University of the Health Sciences, Bethesda, Maryland: you are a co-author on six of the eight published studies presented in this thesis. Thank you for guiding me on my academic path and helping me formulate research questions most relevant to the military population with chronic exercise-related leg pain. You are both a learned scholar and a pragmatic physician. Thank you for allowing me to contribute to the Sports Medicine

Fellowship and for furbishing my American English and most of all thank you for being a friend.

To all co-authors: thank you for your important input to the chapters in this thesis. You all have made contributions in brainstorm sessions, in data processing, data presentation, writing and final lay-out. Thank you for helping me in those areas where my talents are limited and yours are impressive. In chronological order: Pieter Helmhout PhD, Emilia Ligthert, Christian Linschoten MD, Ltcol Angela Diebal, Lianne van der Kaaden, Chris Harts, Naomi van Valderen, Ruud van den Berg.

Professor Frank Backx MD, PhD, University of Utrecht, department of Rehabilitation, Physical Therapy Science and Sports, Utrecht, The Netherlands: thank you for inviting me to compile a PhD thesis at your prestigious department. You recognized the value of the data we collected in military sports medicine over the years and encouraged me to raise the level of reporting from national journals (in Dutch), to international journals. Thank you for incorporating me into your extensive network of sports medicine experts in The Netherlands and thank you for giving me the opportunity to participate in national partnerships on exercise-related leg pain. Your mentoring is well appreciated.

Dr. Eric Bakker, University of Amsterdam: you are one of the brightest minds in sports medicine in The Netherlands. Thank you for your guidance in scientific reasoning and writing, thank you for your tireless and speedy correction of concept texts.

Commander Rigo Hoencamp MD, PhD: thank you for your no-nonsense and pragmatic approach in guiding me through the last stages of this project. Your commitment to improve care for wounded service members is unsurpassed. I will be proud to work side by side with you in the coming years to promote military sports medicine.

Professor Mark Hutchinson MD, University of Illinois at Chicago, Chicago, Illinois: thank you for inviting me to “battle” with you at ACSM 2019. It was an honor to represent conservative treatment of chronic exertional compartment syndrome versus your expertise in surgical treatment. Thank you for helping with the correct wording on Chapter 9 in the thesis. I hope it will stimulate more physicians to explore conservative treatments for CECS.

Professor Rob Reneman MD, professor emeritus of cardiovascular research, Department of Physiology, Cardiovascular Research Institute, Maastricht University. Maastricht, The Netherlands: in 1968 you completed your PhD thesis on chronic exertional compartment syndrome at the military hospital in Utrecht, The Netherlands. In fact, you were one of the first physicians worldwide to describe military patients with this disorder. It is absolutely amazing that 50 years later you are still active as a scientist and willing to help in my efforts to serve the same patients in the same military hospital. Thank you for the inspiring brainstorm sessions on the possible etiology of chronic exertional compartment syndrome.

To the colleagues at the department of Training Medicine and Training Physiology, Utrecht, The Netherlands: thank you for creating a professional atmosphere where high quality sports medicine care and research can coexist.

To the colleagues at the Central Military Hospital, thank you for the stimulating brainstorm sessions and for accepting the new approach and insights sports medicine has to offer: Puck Hulstaert MD, Col Sjors de Jong MD, Col Fred van der Meer MD, Capt Eelco Huizinga MD.

Professor Jeff Huber PhD, Indiana University, Bloomington, Indiana: thank you for your critical appraisal of several chapters in this thesis. Your expertise in the science and application of learning complex motor skills is unique. You have been a coach and academic mentor to me for over 35 years. It cannot be a surprise to you that in this thesis I have pursued the value of motor learning (gait retraining!) as a therapeutic strategy. Thank you for being a lifelong friend.

To my children Romy, Misha and Jana and my brother Niek: thank you for letting me pursue this work, let's make up soon for the quality time lost.

To my beloved fiancé Nicole, our time has yet to come!

Appendix 2

Lists of relevant publications and presentations

List of relevant publications by Wes O. Zimmermann

1. Zimmermann WO. Evaluation of the rehabilitation of soldiers in basic military training. *Nederl Mil Geneesk T* 2005;March:47-56. Dutch.
2. Zimmermann WO. The remedial platoon of basic infantry training. *Nederl Mil Geneesk T* 2008;January:21-24. Dutch.
3. Zimmermann WO, Paantjens MA. Compression stockings, part 1: experiences of 50 military users. *Nederl Mil Geneesk T* 2009;November:209-213. Dutch.
4. Moen MH, Bongers T, Bakker EW, Weir A, Zimmermann WO, van der Werve M, et al. The additional value of a pneumatic leg brace in the treatment of recruits with medial tibial stress syndrome; a randomized study. *J R Army Med Corps* 2010;156(4):236-240.
5. Moen MH, Bongers T, Bakker EW, Zimmermann WO, Weir A, Tol JL, Backx FJG. Risk factors and prognostic indicators for medial tibial stress syndrome. *Scand J Med Sci Sports* 2010;22(1): 34-39.
6. Godefrooij DA, Zimmermann WO. Developments in the treatment of chronic exertional compartment syndrome. *Nederl Mil Geneesk T* 2012;September:160-162. Dutch.
7. Zimmermann WO. Compression stockings, part 2: the effect on running performance in 100 soldiers with Exercise-related Leg Pain. *Nederl Mil Geneesk T* 2013;January:11-17. Dutch.
8. Zimmermann WO, Willeboordse E. Chronic Exercise-related Leg Pain in soldiers: new findings in the soft tissues? *Nederl Mil Geneesk T* 2013;July:92-99. Dutch.
9. Zimmermann WO, Harts CC, Helmhout PH. The treatment of soldiers with MTSS and CECS. *Nederl Mil Geneesk T* 2014;May:72-82. Dutch.
10. Zimmermann WO, Harts CC, Helmhout PH. The treatment of soldiers with *MTSS and CECS. Sport & Geneesk* 2015;1:6-19. Dutch.
11. Helmhout PH, Diebal AR, van der Kaaden L, Harts CC, Beutler A, Zimmermann WO. The effectiveness of a 6-week intervention program aimed at modifying running style in patients with chronic exertional compartment syndrome. *The Orthop J Sports Med* 2015;3(3).
12. Zimmermann WO, Helmhout PH, Noest R. The ankle-brachial index before and after exercise in normals and soldiers with exercise-related leg pain. *Nederl Mil Geneesk T* 2015;May:44-49. Dutch.
13. Zimmermann WO, Seidenberg PH, Kolwadkar YV. Lower Leg Injuries. In: Radiologic imaging in sports injuries. Glaudemans *WJM*, ed. 2015;689-709.
14. Winters M, Moen MH, Zimmermann WO, Lindeboom R, Weir A, Backx FJG, Bakker EWP. The medial tibial stress syndrome score: a new patient reported outcome measure. *BJSM* 2016;50(19): 1192-1199.
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16. Helmhout PJ, Diebal A, Poelsma L, Harts CC, Zimmermann WO. Modifying marching technique in military service members with chronic exertional compartment syndrome: a case series. *Int J Sports Phys Ther* 2016;11(7):1106-1124.

17. Zimmermann WO, Helmhout PH, Beutler A. Prevention and treatment of exercise-related leg pain in young soldiers; a review of the literature and current practice in the Dutch armed forces. *J R Army Med Corps* 2017;163:94-103.

18. Zimmermann WO. Vitamin D in service members with medial tibial stress syndrome. *Nederl Mil Geneesk T* 2017;March:32-36. Dutch.

19. Ligthert E, Helmhout PH, Wurff van der P, Zimmermann WO. A specialty clinic for exercise-related leg pain in the central military hospital, part 1. *Nederl Mil Geneesk T* 2017;July:90-98. Dutch.

20. Zimmermann WO, Linschoten CW, Beutler AI. Gait retraining as part of the treatment program for soldiers with exercise-related leg pain: preliminary clinical experiences and retention. *S Afr J Sports Med* 2017;29(1).

21. Ligthert E, Helmhout PH, Wurff van der P, Onnouw EGJ, Zimmermann WO. A specialty clinic for exercise-related leg pain in the central military hospital, part 2. *Nederl Mil Geneesk T* 2017;November:138-142. Dutch.

22. Ligthert E, Onnouw EGJ, Helmhout PH, Zimmermann WO. The application of PROMs and PREMs in military health care: an essay. *Nederl Mil Geneesk T* 2017, November:143-145. Dutch.

23. Zimmermann WO, Sahetapij CJ. Prevention of exercise-related leg pain: the preemployment medical exam. *Nederl Mil Geneesk T* 2017;November:146-148. Dutch.

24. Zimmermann WO, van Valderen N, Beutler AI. Gait retraining for young soldiers with resistant exercise-related leg pain: a short communication on recent findings. *J of Yoga & Phys Ther* 2017; 7(4).

25. Zimmermann WO, Ligthert E, Helmhout PH, Beutler AI, Hoencamp R, Backx FJG, Bakker EWP. Intracompartmental pressure measurements in 501 service members with exercise-related leg pain. *Transl J of ACSM* 2018;3(14):107-112.

26. Zimmermann WO, van Valderen NRI, Linschoten CW, Beutler AI, Hoencamp R, Bakker EWP. Gait retraining reduces vertical ground reaction forces in running shoes and military boots. *Transl Sports Med* 2019;2:90-97.

27. Dijksma I, Zimmermann WO, Lucas C, Stuiver MM. A pre-training conditioning program to increase physical fitness and reduce attrition in Dutch Airmobile recruits: study protocol for a randomised controlled trial. *Contemp Clin Trials Comm* 2019;14:100342.

28. Zimmermann W, Hutchinson MR, Van den Berg RH, Hoencamp R, Backx FJG, Bakker EWP. Conservative treatment of anterior chronic exertional compartment syndrome in the military, with a mid-term follow-up. *BMJ Open Sport Exerc Med* 2019,5,e000532.

29. Zimmermann WO, Bakker EWP. Reducing vertical ground reaction forces: the relative importance of three gait retraining cues. *Clin Biom* 2019;69:16-20.

30. Zimmermann WO, Linschoten CW, Beutler AI, Bakker EWP. The immediate effect of Extracorporeal shockwave therapy for chronic medial tibial stress syndrome. *Arch Phys Health Sports Med* 2019;2(1):20-28.

31. Zimmermann WO, Duijvesteijn NM. The effects of increasing cadence on vertical ground reaction forces when walking in military boots. *Nederl Mil Geneesk T* 2019;May:57-63.

32. Dijksma I, Perry S, Zimmermann WO, Lucas C, Stuiver MM. Effects of agility training on body control, change of direction speed and injury attrition rates in Dutch recruits: a pilot study. *J Mil Vet Health* 2019;27(2):28-40.

List of relevant presentations by Wes O. Zimmermann

1. International presentations

Uniformed Services University of the Health Sciences, Bethesda, Maryland, USA

2012 Bethesda, Prevention and Treatment of Exercise-related Leg Pain (ERLP) in the Royal Netherlands Army; 2013, 2015, 2016, 2017, 2018, 2019.

American College of Sports Medicine

2011 Denver, Evidence based diagnosis of CECS.

2013 Indianapolis, Overuse injuries of the legs in the Royal Netherlands Armed Forces.

2019 Orlando, Conservative treatment of CECS.

NATO

2016 Paris, exploratory task group HFM-ET-150: Overuse injuries in the Royal Netherlands Armed Forces.

2017 Paris, research task group, HFM-RTG-283: Reducing musculoskeletal injuries in the Royal Netherlands Armed Forces.

International Institute for Race Medicine

2017 Washington DC, Developments in the treatment of Exercise-related Leg Pain.

George Town University, Washington DC

2018 Developments in the conservative treatment of Exercise-related Leg Pain.

Lithuanian Armed Forces

2019 Druskininkai, Lithuania, Gait Retraining for Exercise-related Leg Pain.

2. National presentations

2008 Yearly, continuous: Principles of sports medicine for Dutch military physicians.
2007 Dutch college of sports medicine: the position of the sports medicine physician in a professional sports team.
2009 Royal Netherlands Navy: Preventing drop out in basic military training.
2010 Royal Netherlands Army: Exercise testing for occupational medicine physicians.
2010 Dutch college of sports medicine: the use of compression stockings for ERLP.
2012 City council of Amersfoort: the importance of medical care for junior college students in physical education and pre-military training.
2013 Royal Netherlands Army: Screening for ERLP, improving the entrance medical exam.
2013 National Dutch congress for anatomy: ERLP in the Royal Netherlands Armed Forces.
2014 Central Military Hospital: developments in the conservative treatment of ERLP.
2015 Family physicians: Prevention and treatment of ERLP for the family physician.
2016 Special Forces Command, Royal Netherlands Army: how much running is necessary?
2016 University of Utrecht department of sports medicine: developments in the conservative treatment of ERLP.
2016 University of Utrecht department of orthopedic surgery: developments in the conservative treatment of CECS.
2016 Dutch college of sports medicine: the use of compression stockings for ERLP.
2017 Dutch society of physicians in dance: ERLP in soldiers and dancers, a comparison.
2017 Physiotherapists: North of the Netherlands: developments in the treatment of ERLP.
2017 Physiotherapists: East of the Netherlands: developments in the treatment of ERLP.
2018 Post Olympics sports medicine congress (surgeons): developments in the conservative treatment of ERLP.
2018 Doctor's assistants of family physicians: interaction between family physician and sports medicine physician.
2018 Regional symposium of family physicians: treating overuse injuries, the sports medicine approach.
2018 Royal Dutch Korfbal association: ERLP, role of the therapist.
2019 National symposium of physicians for non-operative orthopedics: developments in the treatment of ERLP.
2019 Dutch College of Sports Medicine: conservative treatment of ERLP.

Appendix 3

Biography and curriculum vitae

Biography

Wes O. Zimmermann (1964) is a primary care sports medicine physician working for the Royal Netherlands Army since 2000. He is a native of The Hague, The Netherlands. He earned an undergraduate degree in general arts and sciences from the University of Nebraska, USA. His medical degree is from the University of Leiden, The Netherlands. His sports medicine degree is from the University of Utrecht, The Netherlands.

He has a particular interest in the treatment of overuse injuries of the lower extremity. He is a fellow of the European College of Sports Medicine and holds an appointment as Adjunct Associate Professor with the Uniformed Services University of the Health Sciences in Bethesda, Maryland, USA. Dr. Zimmermann is an experienced presenter (ACSM 3x) and publisher. He is a former international springboard diver and member of the World Swimming Federation (FINA - Federation International de Natation) Doping Control Review Board.

Curriculum Vitae

name: Wesselius Oncke Zimmermann (Wessel, Wes)

born: 4-oct-1964, The Hague, The Netherlands

nationality: Dutch

children: 1 daughter, Romy, 1997.
1 son, Misha Wes, 2000.
1 daughter, Jana, 2001.

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Education:

High school: Gymnasium B, The Hague, the Netherlands, 1976-1983.

College: B.A. in General Arts and Sciences, University of Nebraska, Lincoln, Nebraska, USA, with distinction, 1983-1987.

Medical school: University of Leiden, The Netherlands, 1987-1995.

Specialization: 1. Sports medicine, University of Utrecht, The Netherlands, 1996-2000.
2. Occupational medicine, University of Nijmegen, The Netherlands, 2001-2005.

Work experience:

2000-2010	Clinical physician (civilian) for sports injuries and occupational medicine, Royal Netherlands Army.
2010-present	Clinical physician (lt col) for sports injuries and occupational medicine, Royal Netherlands Army.
2010-2019	Private practice: sports medicine clinic Amersfoort, Netherlands.
2012-2015	Adjunct assistant professor of family medicine, USUHS, Bethesda, Maryland, USA.
2015	Fellow European College of Sports Medicine (FECSM)
2015-2018	Adjunct associate professor of family and military medicine, USUHS, Bethesda, Maryland, USA.
2017	FINA (World Swimming Federation, Lausanne): member Doping Control Review Board.
2019	Private practice: sports medicine, Zeewolde, Netherlands.

Other:

1972-1991	Competitive springboard and platform diver, international level.
1988-2009	Part-time diving coach, international level.
2004-2018	Eurosport televison diving commentator, a.o. Olympic Games 2004, 2008, 2012 (in Dutch).

Professional philosophy:

I am a sports medicine physician specializing in the treatment of overuse injuries in service members, athletes and workers. I want to bring the best ideas from sports to medicine and the best ideas from medicine to sports.

Appendix 4

List of abbreviations

ACS	acute compartment syndrome
BMI	body mass index
BMT	basic military training
BOS	biomechanical overload syndrome
CECS	chronic exertional compartment syndrome
CI	confidence interval
CMH	central military hospital
ERLP	exercise-related leg pain
ESWT	extra corporeal shockwave therapy
GPE	global perceived effect
GROC	global rating of change
ICPM	intra compartmental pressure measurement
IQR	inter quartile range
LLOS	lower leg outcome survey
mm Hg	milimeters Mercury
MTSS	medial tibial stress syndrome
MRI	magnetic resonance imaging
OLLI	overuse lower leg injury
OR	odds ratio
PSC	patient specific complaints
PT	physical therapy
RLPP	running leg pain profile
RNAF	Royal Netherlands Armed Forces
ROM	range of motion
RR	relative risk
SANE	single assessment numerical evaluation
SD	standard deviation
VAS	visual analog scale
vGRF	vertical ground reaction forces

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