Chronic Exertional Compartment Syndrome of the Leg in the Military

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KEYWORDS

- Chronic exertional compartment syndrome • Intracompartmental pressure
- Paresthesia

KEY POINTS

- Chronic exertional compartment syndrome affects young athletic individuals, especially those in active duty military service.
- Nonoperative treatment may benefit low-demand patients; however, in an athletic cohort surgical decompression must be considered in a patient that fails conservative management.
- Although good surgical outcomes have been reported by tertiary referral centers, return to duty rates in the military are poor, with only 55% of patients experiencing complete resolution of symptoms.
- Patient education, activity modification, and gait retraining may be beneficial to optimize symptomatic relief.

INTRODUCTION

Activity-related lower extremity pain is common among athletes and other active patient populations. Along with other overuse conditions, chronic exertional compartment syndrome (CECS) may contribute significantly to the development of effort-dependent leg symptoms. One of the earliest descriptions of CECS occurred during the British expedition to the South Pole in 1912, in which Edward Wilson described anterior leg swelling and pain during long treks in the Arctic.[1] Subsequent historical records have also emphasized the prevalence of CECS in military cohorts,[2,3] earning the appellation "march gangrene."[4]

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Acute compartment syndrome typically develops after trauma, and secondary tissue ischemia and muscle breakdown warrant emergent fasciotomy to preserve limb viability. By contrast, CECS, otherwise known as exercise-induced compartment syndrome, develops after prolonged exertion in the absence of injury and it is often evaluated in the ambulatory setting. During intensive exercise, intramuscular volume can expand by up to 20% in response to increased metabolic demands, tissue perfusion, and muscle fiber hypertrophy.[5–7] When sustained, compartment syndrome may develop as the interstitial pressure becomes critically elevated above the diastolic pressure of a closed fascial compartment. Consequently, compromised vascular perfusion leads to tissue ischemia, metabolite accumulation, and extremity pain. Alternatively, other investigators have proposed that fluid extravasation and increased intracompartmental pressures (ICPs) contribute to neural compression and potentially irreversible damage with chronic untreated compartment syndrome. Other investigators have also implicated decreased capillary density or hindered venous outflow in the development of CECS.[8,9]

Although the pathophysiology is not fully understood, CECS remains a frequent source of lower extremity disability in contemporary military service members. With heightened occupational demands, daily exercise, and mandated physical fitness performance standards, the military represents a unique, high-demand population at elevated risk for the development of CECS. This article explores the epidemiology, risk factors, diagnosis, and management of CECS within this cohort.

EPIDEMIOLOGY AND RISK FACTORS

The exact prevalence of CECS is currently unclear because of the frequency of self-directed treatment or activity modification, errors in clinical diagnosis, and/or failure to seek medical attention. According to smaller series, CECS may account for 14% to 34% of activity-related leg pain referred for orthopedic treatment.[10–12] Further estimates have indicated that approximately one in every 2000 US military service members is diagnosed with CECS each year,[13] with 4100 individuals identified over a 6-year period.

CECS is most commonly described in the leg, accounting for more than 95% of all cases.[14] However, other investigators have variably reported involvement of the hand,[15,16] forearm,[17–19] thigh,[20,21] and foot[22] in narrow high-risk cohorts. When evaluating the distribution of CECS in the compartments of the leg, the anterior compartment is most frequently affected (42%–60%) followed by the lateral (35%–36%), deep posterior (19%–32%), and the superficial posterior (3%–21%).[10,23] Davis and colleagues[23] found that single compartment involvement was less common (37%). In their series, 40% of cases were symptomatic in two compartments, 18% involved three compartments, and only 5% affected all four compartments. Similarly, bilateral involvement is more common, accounting for up to 95%[23,24] and no differences by laterality have previously been identified.[25]

This condition has usually been described among younger, athletic populations. Patients typically present in the second and early fourth decade of life, often with a long duration of preexisting symptoms.[23,26,27] Earlier studies have described a greater preponderance of affected men,[8,12,28] whereas other investigations have suggested the potential for increased incidence among women.[9,13,23] Meanwhile, selected investigations from the civilian literature have reported that the incidence of CECS between men and women is roughly equal.[10,11,26]

More than 90% of patients presenting with CECS are involved in athletics[23] and there is no reported difference between those involved in elite and recreational levels of competition.[5] Although many forms of athletics have been linked with the development of CECS of the leg, including lacrosse, soccer, basketball, skiing, and field hockey,[23] it is most characteristically described in endurance runners,[5,12,23] which accounts for up to 68% of cases.[26] However, CECS may also present in less-active, atypical patient populations. Edmundsson and colleagues[9] reported on a series of 36 nonathletic, more sedentary subjects with CECS. In this cohort, nearly two-thirds of subjects developed pain after routine walking and low-demand activity.

Excessive exercise, especially running, has been linked to increased incidence of CECS.[23] Significant physical activity precipitates physiologic and metabolic changes that affect muscle volume and compartment pressures.[5–7] Eccentric muscle strengthening in adults has been implicated as a cause for decreased fascial compliance and the development of CECS.[29] Similarly, patients with CECS have been found to have a thickened fascia[30] and may have a higher prevalence of fascial defects compared with asymptomatic patients.[31] These factors can also be exacerbated by dietary supplements. The use of muscle enhancing supplements, such as creatine and androgenic steroids, may potentiate abnormal elevations in ICPs, and these have been offered as possible risk factors for CECS.[5]

As with other active cohorts, CECS is commonly reported among military populations[1–4,13,25,32] and should be separately considered due to its unique occupational demands. Recently published, large-scale reviews of this military subset have underscored the burden of lower extremity CECS among this high-risk cohort.[13,25] In this study, although greater than 90% of subjects with CECS were men, women had a slightly higher incidence rate while controlling for other variables. Similarly, junior enlisted military rank and Army service carried the highest incidence rate of developing CECS, which is likely attributable to the increased physical rigors of ground forces in the current military conflicts. Interestingly, increasing age category corresponded with increasing incidence rates of CECS in the military. This may reflect a previously undetected association between age and the development of CECS and certainly merits further investigation.

CLINICAL PRESENTATION AND DIAGNOSIS

In terms of frequency, CECS is the second-leading cause of exertional leg pain after medial tibial stress syndrome (MTSS), with a prevalence of up to one-third of athletes.[10] The differential diagnosis should also include evaluations for nerve entrapment, stress fracture, deep vein thrombosis, and other clinical entities (**Table 1**). The natural history of CECS is mostly atraumatic, although a remote history of low-energy injury may be disclosed in certain individuals.[33] Patients often complain of tightness, pain, or aching in the anterior and lateral portion of the leg after periods of prolonged exercise, and these symptoms often resolve with rest or diminished activity. As previously mentioned, symptoms are bilateral in up to 95% of patients.[24] In addition to neuritic symptoms overlying the superficial peroneal nerve distribution, affected patients may also show decreased vibratory sensation and altered motor amplitude that contribute to poor foot and ankle control.[34]

History and physical examination are the cornerstones for a diagnosis of CECS. It is important to document the frequency, duration, and intensity of training sessions, as well as corresponding trends in onset and resolution of patient-reported symptoms. At rest, the patient may not have any symptoms; however, on exertion the patient may develop significant activity-limiting symptoms. Patients with CECS typically complain of five cardinal symptoms: pain, tightness, cramps, weakness, and diminished sensibility in the dorsum of the foot.[35] On physical examination, pain on passive stretch of a

Table 1
Sources of leg pain in physically-active patients

Category	Condition	Diagnosis
Vascular	Popliteal artery entrapment syndrome	Ankle or brachial index, Doppler
	Popliteal artery aneurysm	Angiogram
	Deep vein thrombosis	Doppler
Bone	Tibial stress fracture	MRI
	Medial tibial stress syndrome	Bone scintigraphy
	Periostalgia	Infection work-up
Soft Tissue	Muscle strain	Physical examination
	Tendinopathy	—
	Tenosynovitis	—
	CECS	ICP, MRI, near-infrared spectroscopy
Neurologic	Peripheral nerve entrapment (superficial peroneal nerve, tibial nerve)	Electromyogram, nerve conduction studies
	Neurogenic claudication	—
Miscellaneous	Metabolic bone disease	Dual energy x-ray absorptiometry
	Muscle or bone neoplasm	MRI
	Bone or soft tissue infection	—

compartment may be present if the patient has recently exercised, although this would be rare at rest. Fascial defects may also be detected on palpation and are present in 39% to 46% of affected patients.[6–10]

Although currently debated, the historical standard for diagnosis of CECS has been ICP measurement.[36] ICP monitoring may be completed with many commercial devices.[36] At the authors' institution, the Stryker Intra-Compartmental Monitor (Stryker Corporation, Kalamazoo, MI, USA) is commonly used as a component of the standard preoperative evaluation, with comparison of affected and unaffected compartments in bilateral lower extremities (Fig. 1). On presentation, patients complete an exercise stress test. A series of manometry measurements are taken both before and after exercise to analyze ICP trends of symptomatic compartments. Typical resting ICPs of the leg measures less than 10 mm Hg, although measurements are operator-dependent and may vary considerably between patients.[36]

Fig. 1. ICPs measurements of the leg for evaluation of CECS after exercise stress testing. (*Courtesy of* Justin Orr, MD, El Paso, TX.)

Davis and colleagues[23] carefully monitored a cohort of CECS subjects during exercise stress testing. In this analysis, subjects reported having leg pain after an average of 11 minutes of exertion. The exertional leg pain was rated as an eight out of ten on the visual analog scale, and symptoms subsided after an average of 45 minutes of rest. In this study, 36% of the subjects developed numbness or tingling in addition to pain after exertion. CECS was also objectively quantified after exercise testing. The anterior compartment increased from a preexercise average of 25.3 mm Hg to an average of 48 mm Hg after exercise stress testing, with similarly increased readings in the lateral (baseline 21.5 to 51.5 mm Hg postexercise), deep posterior (22.1 to 47.1 mm Hg), and superficial posterior compartments (24.9 to 34.3 mm Hg).

As an adjunct to clinical examination, Pedowitz and colleagues[10] established several diagnostic criteria to confirm the presence of CECS. If one of these three criteria is met, a diagnosis of CECS may be made: (1) a preexercise pressure of greater than 15 mm Hg, (2) a 1-minute postexercise pressure of greater than 30 mm Hg, or (3) a 5-minute post-exercise pressure of greater than 20 mm Hg. Although these thresholds are the most widely used in current clinical practice, pressure measurements are not always reliable and may be confounded by poor patient tolerance, inconsistent operator technique, and/or the use of different measurement devices. To this end, Aweid and colleagues[36] reviewed 32 studies that evaluated the usefulness of ICP measurements in the diagnosis of CECS. Reported preexercise ICPs ranged from 7.4 to 50.8 mm Hg in CECS subjects and 5.7 to 12 mm Hg in controls, whereas postexercise measurements ranged from 42 to 150 mm Hg and 28 to 141 mm Hg, respectively. At 1-minute postexercise, there was less overlap between subjects with CECS and controls (CECS, 34–55.4 mm Hg; controls, 9–19 mm Hg). The investigators concluded that there is limited evidence to validate four commonly used criteria using ICPs for the evaluation of patients with lower extremity pain. Furthermore, they suggested that a diagnosis of CECS should rely more heavily on classic clinical presentation.

In addition to ICP monitoring, other modalities may hold promise for diagnosis of CECS. Although not commonly used in current practice, the use of MRI has been reported and may useful in excluding other disease, such as MTSS.[37] Postexercise MRI has demonstrated increased diffuse intracompartmental signal on T2 sequences when compared with baseline and this may be pronounced in symptomatic patients.[37,38] Although these studies examined the increase in intracompartmental edema, MRI can also be scrutinized for fascial defects or other structural lesions. With that said, the use of MRI is not well studied in the setting of CECS and would likely prove logistically difficult after exercise stress testing. The use of near-infrared spectroscopy (NIRS) has recently been studied in Europe as a measure of oxygen saturation of hemoglobin in deep tissues. Although less well studied than direct intracompartmental measurement, NIRS offers a noninvasive technique with improved patient tolerance. van den Brand and colleagues[39] evaluated subjects after an exercise test with NIRS and demonstrated a significant decrease in oxygen saturation in patients with CECS compared with controls. When compared with other diagnostic modalities,[40] NIRS was at least as efficacious as MRI or ICP monitoring for patients with known CECS. The sensitivity of ICP monitoring was 77%, 85% for NIRS, and 86% for MRI. Although MRI and NIRS have potential as noninvasive tools in the diagnosis of CECS, ICP monitoring remains the most prevalent.

NONSURGICAL TREATMENT

The reported results of nonoperative management are modest and conservative interventions have generally been unsuccessful in restoring active patients to pain-free physical activity. In a retrospective cohort study comparing nonoperative and surgical management of CECS, Packer and colleagues[41] reported that only 41% of subjects experienced significant symptomatic relief with activity modification, ice, medication, and/or physical therapy. These and other specific modalities to alleviate symptoms, including massage, orthotics, and stretching, have been associated inconsistent outcomes and incomplete relief.[29,42] Blackman and colleagues[42] demonstrated significant delays in the onset of pain during athletic activity after a 5-week stretching and massage regimen. However, ICP measurements remained unchanged, and most subjects had persisting complaints of exertional leg pain. Activity limitation remains the single most effective measure to reduce symptomatic episodes.[32] Running may be substituted with cycling or other forms of aerobic exercises to maintain cardiorespiratory fitness because these alternatives have been associated with a lower risk of CECS.[43] However, complete avoidance of exercise is not an option for many patients involved in competitive athletics or endurance running. Similarly, although daily physical fitness routines can be customized to mitigate symptoms, certain at-risk activities (eg, ruck marching, training exercises) associated with military service cannot be curtailed.

Recent research has suggested that alterations in running biomechanics and tailored physical therapy protocols may be beneficial in selected individuals with CECS. In a cadet cohort at the US Military Academy, a forefoot running program was initiated for 10 symptomatic subjects with a hindfoot strike gait pattern and indications for surgical intervention (**Fig. 2**).[44] The underlying premise is that a forefoot running technique diminishes the increased ICP and eccentric activity of the anterior compartment while reducing ground-reaction forces. After intervention, all subjects demonstrated significant improvements in running performance and exercise-induced pain, with sustained benefits indicated on subject-reported outcome measures at up to 1 year. More importantly, the average postexercise ICP decreased from 78 mm Hg to 32 mm Hg after 6 weeks of forefoot running training and all patients avoided surgical treatment. A large-scale, prospective, randomized trial is warranted to determine the comparative efficacy of gait retraining vis-à-vis elective surgical intervention.

SURGICAL TREATMENT

When nonsurgical measures are ineffective or patients are unwilling to accept permanent activity or duty restrictions, operative management may be considered, with decompression of all symptomatic compartments. Although, historically, most investigators have described fasciotomy for elective treatment of CECS, selective use of partial fasciectomy for primary[45] or revision cases[46] may also be considered.

For isolated anterior, lateral, or combined anterolateral involvement, a single lateral incision may be used. The single incision technique involves a longitudinal incision from just anterior and proximal to the lateral malleolus and extends to the fibular neck. The lateral and anterior compartments are identified in relation to the intermuscular septum. These are then released by making an "H" in the fascia with Metzenbaum scissors. After identifying the superficial peroneal nerve, the fascial release is taken distally and proximally in each anterior and lateral compartment. Owing to the presence of anomalous neural anatomy and the risk of iatrogenic neural injury during fasciotomy, the authors prefer a more limited, distally-based incision overlying the exit of the superficial peroneal nerve at the intermuscular fascia (**Fig. 3**). When neuritic symptoms predominate, we also recommend careful neurolysis of the superficial peroneal nerve and scrutiny for any potential sites for scar tissue entrapment.

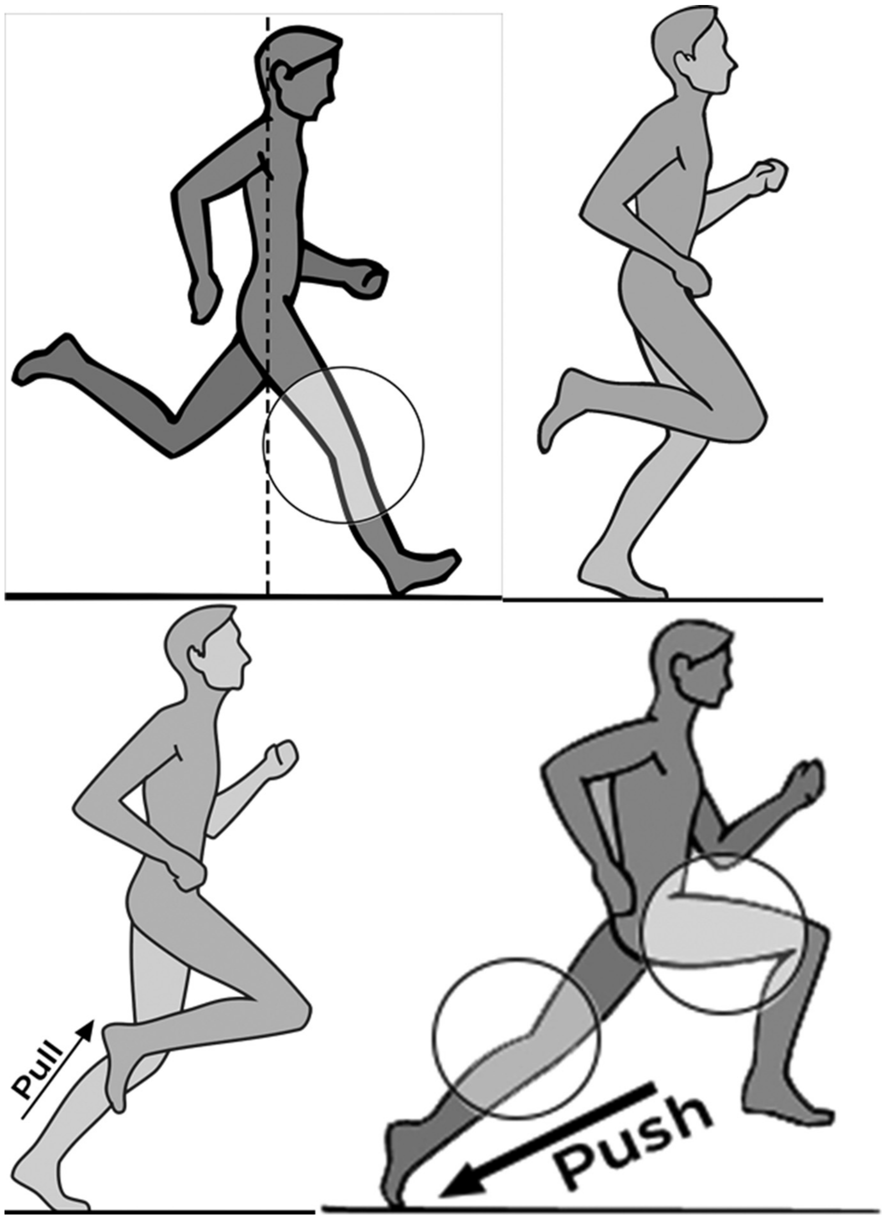

Fig. 2. Physical therapy and gait retraining emphasizing a transition from a hindfoot to a forefoot strike method for the treatment of anterior CECS. (*Courtesy of* Pose Tech, Inc, Miami, FL; with permission.)

Decompression of a single anterior compartment without adjacent lateral compartment release has previously been a topic of debate. In a prospective comparative investigation, Schepsis and colleagues[47] performed fasciotomies on subjects with bilateral leg CECS in which one leg received anterior and lateral compartment decompression and the contralateral leg underwent isolated anterior release. Regardless of

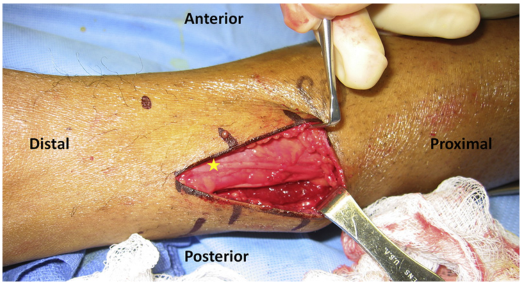

Fig. 3. Distally-based surgical exposure for anterior and lateral involvement with identification of the superficial peroneal nerve (*asterisk*). (*Courtesy of* Brett Owens, MD, West Point, NY.)

technique, approximately 90% of subjects experienced symptomatic relief without statistically significant differences. The investigators concluded that fasciotomy of the anterior compartment is sufficient treatment of CECS in the absence of lateral compartment involvement. However, decompression of a single compartment is rare in the military population, with approximately 1% of patients receiving either an anterior or lateral fascial release.

Historically, some investigators have described four-compartment fasciotomy through a single-incision or perifibular technique, both for CECS[31] and in the traumatic setting.[48–50] Although this technique obviates an additional posteromedial incision, some investigators express concern about the ability to completely decompress all four compartments, especially the deep posterior compartment.[51] Similarly, single-incision techniques also may prolong operative times and may provide poorer visualization of neurovascular structures at risk.

As popularized by Mubarak and Owen,[52] four-compartment fasciotomy can also be performed through a dual-incision technique.[53] This preferred technique involves two slightly shorter, 10-cm incisions, where the medial incision lies 2 cm medial to the tibia and the lateral incision is midway between the tibial crest and fibula. A separate posteromedial approach may offer better access to the deep compartments and elevation of the soleus off of the posterior tibia permits decompression of the so-called fifth compartment of the leg.[54,55] The tibialis posterior muscle is often contained entirely within its own osseofascial compartment and may contribute to the persistent symptoms of CECS.[54] Hislop and colleagues[56] implicated the importance of the fibular origin of the flexor digitorum longus (FDL) in patients with deep posterior involvement. In individuals with a more extensive FDL attachment at the fibula, greater ICPs were detected in the deep posterior compartment in a cadaveric CECS model. As such, the investigators propose that this anatomic variant may factor more prominently in the development of deep posterior CECS.

In recent years, several techniques for endoscopic fasciotomy have also been described, with encouraging results in multiple, small case series.[57–61] This offers a minimally-invasive approach with improved cosmesis and the potential for less postoperative scar formation. Advocates have also noted excellent visualization of the intermuscular septum, superficial peroneal nerve, and perforating vessels without use of a traditional incision. However, these investigations are of limited enrollment and are best suited for isolated anterolateral involvement.

After meticulous hemostasis and wound closure with a two-compartment or four-compartment fasciotomy, a standardized physical therapy protocol is undertaken. At our military institution, knee and ankle range of motion exercises and gentle scar mobilization are initiated early to prevent fascial adhesions. Staged fasciotomy (greater than 6 weeks) for patients with bilateral involvement is recommended, although concurrent intervention may be considered for selected, motivated patients. Patients are instructed for touch-down weight-bearing with crutches for 4 weeks, with progression to full weight-bearing as tolerated by week six. Thereafter, patients begin a progressive strengthening program and may begin walking on a treadmill. By the twelfth week, patients may begin a transition to running program. At 4-months post-operatively, the goal is to pass the Army Physical Fitness Test. This protocol has been successfully used in war zones[62] and is also similar to that described for the civilian populations.[63]

In reported civilian cohorts, the results of surgical treatment of CECS are generally encouraging, with up to 90% to 96% of patients reporting good to excellent outcomes.[12,26,64] However, the treatment of patients with posterior involvement is much less reliable than that for isolated anterior CECS. In one study, release of the anterior compartments resulted in 96% excellent results, whereas the release of the posterior compartments yielded only 25% excellent results.[64] Other published data have reported an 80% success rate for anterior and lateral releases, whereas only 50% of subjects with fasciotomy of the posterior compartments experience significant relief.[27] The cause of this is not well elucidated, although thickened posterior fascia and scar formation have been proposed.[26] Additionally, inadequate decompression of all deep posterior compartments may also compromise surgical outcomes, particularly with limited release of the soleus and deep posterior compartments. To this end, Rorabeck and colleagues[53] have suggested that formally releasing the tibialis posterior may improve outcomes of the posterior fasciotomy. More aggressive decompression using partial fasciectomy has not demonstrated any increased usefulness versus traditional fasciotomy in index procedures for CECS, with only 60% successful outcomes after release.[45]

Although the civilian literature has reported beneficial results, the clinical outcomes after surgical release in the military population have been less optimal for CECS of the leg. In a review of 611 US military service members with 754 surgical releases, 78% of patients were free from medical discharge or revision after index surgery at short-term to mid-term follow-up.[25] These results parallel the 73% success rate reported by Almdahl and Samdal[65] in the Norwegian military. However, 28% of service members were unable to return to full duty in the US military cohort and 45% experienced incomplete relief of symptoms.[25] In similar study of UK military personnel with CECS, only 47% of subjects' symptoms improved after surgery.[66] Presumably, these poor outcomes are partially attributable to the rigorous daily physical fitness demands common to the military.

PERIOPERATIVE COMPLICATIONS AND REVISION SURGERY

Perioperative complications often manifest early after surgical intervention, most commonly with local surgical site infections, wound healing difficulties, hematoma or seroma development, and/or iatrogenic neurovascular injury. By contrast, recurrences typically occur after an initial symptom-free interval, and may result from inadequate release, failure to decompress a symptomatic compartment, postsurgical fibrosis, or nerve compression. Entrapment of the superficial peroneal nerve has been found in 44% of subjects presenting with recurrent CECS after initial surgical treatment and remains an important consideration during primary and revision procedures.[46] In subjects with localized neuritic symptoms, Schepsis and colleagues[46] demonstrated 100% satisfactory outcomes with partial fasciectomy, decompression of the superficial peroneal nerve, and excision of all fibrotic tissue during revision surgery. Conversely, all subjects without nerve entrapment had a 50% success rate after revision surgery.

Whereas prior civilian series have documented complications in up to 11%[26] and recurrence in 2% to 17%,[12,27,53,64] military cohorts have demonstrated a higher risk of adverse surgical outcomes.[25,66] In a Norwegian military cohort with 10-year follow-up on 56 fascial releases for anterior compartment CECS, 2% of subjects required repeat fasciotomy.[65] Another contemporary analysis involving the US military revealed a complication rate of 15.7% after elective fasciotomies for CECS.[25] In this case series, nearly three-quarter of these were identified as infections or other wound-healing problems, whereas approximately 25% were related to neurologic injury. Furthermore, the rate of surgical revision was 5.9%, with 14% of service members experiencing complete resolution of symptoms and 67% returning to full activity. Finally, an evaluation of the UK military population revealed that infection was also the most common complication (9%), followed by seroma and hematoma formation.[66]

SUMMARY

CECS is a common source of lower extremity disability among young athletic cohorts and military personnel. The five cardinal symptoms are pain, tightness, cramps, weakness, and diminished sensation. History and clinical examination remain the hallmarks for identifying CECS, although ICP measurements during exercise stress testing may be used to confirm diagnosis. Nonsurgical management is generally unsuccessful, although gait retraining may have benefits in selected individuals. When conservative measures have failed, operative management may be considered with fascial release of all affected compartments. Although clinical success has been documented in civilian cohorts, the results of surgical treatment in military service members have been far less reliable. Only approximately half of the military service members experience complete resolution of symptoms and at least 25% are unable to return to full duty.

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