

# Chronic exertional compartment syndrome: current management strategies

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**Abstract:** Chronic exertional compartment syndrome (CECS) is an underdiagnosed condition that causes lower and upper extremity pain in certain at-risk populations. Lower-extremity CECS is most often observed in running athletes and marching military members. Upper-extremity CECS is most commonly seen in rowers and professional motorcyclists. Although early outcome research on CECS has been based mostly on adult male patients, there has been an increase in the number of studies in pediatric and adolescent patient populations, particularly in females. Evaluation of CECS must include a thorough history and physical exam to rule out other causes of exertional leg pain, but differential diagnosis must remain high on the list. Needle manometry can be used to confirm diagnosis of CECS by measuring intracompartmental pressure. Operative treatment of CECS with fasciotomy has been shown to be effective in resolution of CECS, and new surgical techniques are being developed. In the pediatric population, endoscopy-assisted compartment release has provided high success rates with low complication rates. Nonoperative management of CECS is more commonly described in the literature, and consists of cessation of activities, altering foot-strike pattern, physical therapy, taping, and injections of botulinum toxin A. Nonetheless, larger samples and a more diverse population are needed to better understand the outcomes of non-operative management. There have been fewer studies on upper-extremity CECS, given its rarity. Success has been found in the treatment of upper-extremity CECS with open fasciotomy, but more studies are needed to understand the efficacy of minimally invasive techniques in the upper extremity. Further research also needs to be done to understand why a large portion (approximately 20%) of the patient population does not experience full resolution of symptoms after fasciotomy.

**Keywords:** chronic exertional compartment syndrome, CECS lower extremity, CECS upper extremity, pediatric CECS

## Introduction

Chronic exertional compartment syndrome (CECS), first described in 1912, is a rare clinical diagnosis that occurs more frequently in the lower extremity than the upper extremity.<sup>1-6</sup> Lower-extremity CECS is most often observed in running athletes<sup>7</sup> and marching military members.<sup>8-10</sup> Upper-extremity CECS is most commonly seen in rowers<sup>11</sup> and professional motorcyclists.<sup>5,12,13</sup> Although early outcome research on CECS was based mostly on adult male patients, there has been an increase in the number of studies in pediatric and adolescent patient populations, particularly in females.<sup>5,14-16</sup>

CECS is characterized by a reversible increase in pressure within an inelastic fascial compartment leading to compromised tissue perfusion and subsequent pain and neurologic symptoms.<sup>4</sup> Symptoms rapidly improve with rest, typically without permanent sequelae in the affected tissue. This contrasts starkly with

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acute compartment syndrome, which can be limb-threatening if not emergently addressed.<sup>17</sup> The purpose of this review is to provide a brief overview of the etiology and diagnosis of CECS and up-to-date understanding of the current management strategies for CECS in the adult and pediatric populations.

## Pathological and anatomical features

The symptoms of CECS are secondary to decreased blood flow due to increased compartment pressures.<sup>2,4,6</sup> While the exact pathophysiology leading to increased compartment pressure is not well understood, it is accepted that the cause is likely multifactorial, with muscle hypertrophy, decreased venous return, micro-trauma, myopathies and noncompliant fascia playing a role.<sup>18,19</sup> Studies have shown the total intramuscular pressure of patients with CECS remains overall higher than unaffected individuals, even in patients who are postfasciotomy.<sup>20</sup> In addition, patients with CECS tend to have increased total intramuscular pressure at rest compared to controls.<sup>21</sup> Other factors that have been implicated in playing a role in CECS include improper training, limb malalignment, leg-length discrepancy, running technique, and uncoordinated muscle control.<sup>4</sup> Despite a lack of consensus on the exact pathophysiology, repetitive exertion of the muscles within a compartment leading to decreased perfusion is accepted as the primary pathway to the onset of symptoms in CECS.

## Clinical presentation

Upon initial presentation, patients with CECS usually complain of pain that can be severe in a specific location, usually a localized compartment, during exercise. Occasionally, patients experience paresthesia, numbness, and even transient nerve palsy, such as foot drop.<sup>22</sup> This pain predictably becomes worse with increased exercise intensity and duration. Symptoms are usually relieved within minutes to hours of stopping the aggravating activity.<sup>22</sup> In general, patients usually deny a history of trauma or direct injury.<sup>4,11</sup> Patients typically report recurrence of symptoms soon after resuming the activity.<sup>23</sup> When obtaining a thorough history and physical, it is important to consider differential diagnoses for patients presenting with these symptoms in the upper or lower extremities (Table 1).

**Table 1** Differential diagnoses to consider in chronic exertional compartment syndrome evaluation

Differential diagnoses	
Lower extremity	Upper extremity
Medial tibial stress syndrome ("shin splints")	Stress fracture
Stress fracture	DVT
DVT	Radiculopathy
Claudication (PAD)	Tendonitis/myositis
Radiculopathy	Peripheral nerve entrapment (ie, CTS, CuTS)
Tendonitis/myositis	Fibromyalgia
Popliteal artery-entrapment syndrome	
Oncological etiology	
Fibromyalgia	

**Abbreviations:** DVT, deep venous thrombosis; PAD, peripheral artery disease; CTS, carpal tunnel syndrome; CuTS, cubital tunnel syndrome.

## Evaluation and workup

In the clinical setting, physical exam of patients with CECS is often unremarkable. However, patients with long-standing severe CECS may exhibit point tenderness and atrophy of the affected compartment. Additionally, muscle fascial herniation may be evident on inspection of the limb, especially with contraction of the affected muscle groups within a compartment. Interestingly, patients with CECS of the lower leg have fascial defects over the anterolateral lower leg at four to five times the rate of asymptomatic individuals.<sup>21</sup> Diagnostic testing can aid in narrowing differential diagnosis. Common tests include radiography, bone scintigraphy, magnetic resonance imaging, and electromyography.

Although CECS was initially thought to be a diagnosis of exclusion, needle manometry can be used to confirm diagnosis. Patients with CECS have increased intracompartmental pressure in the affected extremity at rest and during and after exercise. Resting and postexercise measurements have shown to have confirmatory value in the diagnosis.<sup>24,25</sup> Pedowitz et al<sup>22</sup> proposed the following diagnostic criteria, which are still commonly used today: 1) preexercise pressure  $\geq 15$  mmHg, 2) 1-minute postexercise pressure  $\geq 30$  mmHg, or 3) 5-minute postexercise pressure  $\geq 20$  mmHg. Of note, if at-rest measurements or 1-minute postexercise measurements are confirmatory, further sequential testing is not required.

In the upper extremity, diagnosis is mostly based on history and exam. After physical exam and ruling out other

causes of exercise-induced forearm pain, intracompartmental pressure measurements can be obtained. However, there is currently no consensus on diagnosing forearm CECS based only on compartment pressure, given the rarity of the condition. In general, pressure  $\geq 30$  mmHg in any of the forearm compartments supports a diagnosis of CECS.<sup>3</sup>

## Operative management in the lower extremity

There are both operative and nonoperative management strategies described for the treatment of CECS. After confirming the diagnosis of CECS, it is recommended to exhaust nonoperative management prior to consideration of surgical options. Rajasekaran and Hall recently performed a more specific and detailed systematic review of nonoperative management in adult populations.<sup>26,42</sup> Operative management strategies for CECS recalcitrant to nonoperative management will thus be discussed in more detail. Surgical techniques for lower-extremity CECS include traditional open fasciotomy, endoscopy-assisted compartment release, single minimal-incision fasciotomy, percutaneous fasciotomy under local anesthesia, and ultrasound-guided fasciotomy. Each of these techniques is described together with reported outcomes, in order to provide an integrated view of operative management as a whole.

### Traditional open fasciotomy

The mainstay of surgical treatment of CECS is fasciotomy, given its increased success rate compared to nonoperative management.<sup>21</sup> In a traditional open technique, a 10 cm incision is made over the anterolateral aspect of the leg in its midportion between the tibial crest and the fibula to release the anterior and lateral compartments. Distal dissection is careful to avoid transection of superficial peroneal nerve branches. Through extended dissection, the superficial posterior and deep posterior compartments can be released as well from a single incision. Alternatively, a 10 cm incision can be made medially just posterior to the tibia bone to release the superficial posterior and deep posterior compartments.<sup>21</sup> Careful dissection is completed to avoid injury to the saphenous nerve and vein.

When compared to nonoperative management, operative management appears to have better patient satisfaction and favorable functional outcomes in the general population,<sup>26</sup> as well as elite athletes.<sup>27</sup> Pasic et al<sup>26</sup> reported a 78%

satisfaction rate and 11% reoperation rate at a mean of 54.9 months in a retrospective case series of 42 patients. In a retrospective cohort study by Packer et al,<sup>28</sup> 81% of operative patients had successful reduction in pain and functional outcomes in comparison to 41% of patients treated nonoperatively. However, these outcomes have multifactorial influences. Age, location of compartment(s) released, number of compartments released, fascial thickness, duration of symptoms, and compartment-pressure measurements appear to be related to postsurgical outcomes.<sup>14,28</sup> In the Packer et al<sup>28</sup> study, patients aged  $<23$  years had improved outcomes after fasciotomy. It is believed that younger patients have a thicker/stiffer fascia, and thus decompression tends to provide favorable results in this patient population.<sup>15,28</sup> Lower success rates after fasciotomy have been reported in older patients (mean age 39 years), likely secondary to chronic changes to muscle, nerves, fascia, and vasculature with age.<sup>28,29</sup>

More research is needed to investigate outcomes after surgical release of specific compartments or combinations thereof. Packer et al<sup>28</sup> reported that patients who had combined anterior-lateral compartment release had an increased failure rate (31%) in comparison to those who underwent an isolated anterior release (0). On the other hand, Beck et al<sup>14</sup> reported that legs with only anterior-and/or lateral-compartment releases had 3.4 times the odds of reoperation compared with legs that underwent four-compartment fasciotomies.

Regarding resting pressures, both Packer et al<sup>28</sup> and Beck et al<sup>14</sup> found worse results and a higher rate of reoperation in patients with lower compartment pressure. It is unclear why this was the case, but Beck et al<sup>14</sup> speculated that this group of patients could have been misdiagnosed.

Duration of symptoms may be related to clinical outcomes after fasciotomy in CECS, particularly in adults. Slimmon et al<sup>30</sup> found that patients who had compartment releases within 12 months of symptoms had improved outcomes. Those with statistically longer duration of symptoms had lower satisfaction scores. The authors hypothesized that this may have been due to irreversible damage from the chronicity of the condition. In contrast, in the pediatric population, Beck et al<sup>14</sup> showed no correlation between duration of symptoms and reoperation rates. Based on their treatment algorithm, surgical treatment was delayed for pediatric patients until nonoperative modalities had been exhausted.

Although outcomes after compartment release for the treatment of CECS are generally favorable in civilians, studies in the military population have shown lower success rates.<sup>31,32</sup> In a large retrospective study on 611 military personnel who underwent surgical management for CECS, Waterman et al<sup>31</sup> found that 44.7% had recurrence of symptoms and 27.7% were unable to return to full duty. In this patient population, 17.3% were referred for medical discharge due to failure of surgery. In their multivariate analysis, surgical failure was associated with perioperative complications, bilateral involvement, and activity limitations. The prospect of obtaining a disability-associated military discharge and constant physical demands of the job were possible confounders mentioned by the authors of this study in a military population. Roberts et al<sup>32</sup> found similar results in the UK military. In their study, 36% of their cohort showed no improvement and 15% had a poor outcome.

### Endoscopy-assisted compartment release

The authors prefer a less invasive, endoscopy-assisted technique, particularly in pediatric patients.<sup>14</sup> Under tourniquet and general anesthesia, a 3 cm incision is made over the anterolateral midcalf. Dissection is then carried through skin and subcutaneous tissue to the fascia. Subcutaneous elevation is performed with a Cobb elevator proximally and distally. Retractors are placed anteriorly to identify the anterior-compartment fascia. Under direct visualization with a 4 mm arthroscope, an incision is then made in the anterior-compartment fascia and carried proximally and distally under the skin using meniscal knives. Retractors are then placed posteriorly to identify the lateral-compartment fascia. A skin mark is made 8 cm proximally to the distal fibula, estimating the location of the superficial peroneal nerve. This reference mark is used as the distal extent of the fasciotomy. Similarly to the anterior compartment, an incision is made in the mid-portion of the lateral-compartment fascia and carried proximally and distally under the skin using meniscal knives. Completion of the fasciotomy is confirmed with direct endoscopic visualization. To release the deep posterior and superficial posterior compartments, a 3 cm incision is made on the medial midcalf at the posterior border of the tibia. Dissection is carried through skin and subcutaneous tissue. Importantly, the saphenous vein and nerve must be identified and protected. Under direct endoscopic visualization, the superficial posterior-

compartment fascia can be identified and released first with an incision and then using meniscal knives proximally and distally. To release the deep posterior compartment, an incision into the periosteum of the posterior border of the tibia is made. The periosteum is elevated at the posterior tibia. An incision is then made in the periosteum into the deep posterior compartment and carried proximally and distally under the skin using meniscal knives. Endoscopic visualization confirms completion of the fasciotomy. Lui<sup>33</sup> recently described a similar endoscopic approach to the superficial and deep posterior compartments of the leg to minimize the risk of hemorrhage. In this approach, the operative field is away from the saphenous vein and nerve.

The endoscopic, minimally invasive technique has resulted in an overall 79.5% return-to-sports rate in the pediatric population. However, 18.8% of legs treated had recurrent CECS requiring reoperation at a median of 1.3 years after initial compartment release.<sup>14</sup> Additionally, legs that had only the anterior and/or lateral compartment(s) released had 3.4 times the odds of reoperation compared to legs that had all four compartments released. Multivariate analysis revealed that time between presentation and surgery was also an independent predictor of revision of compartment release. For each additional month between presentation and release, the odds of recurrence decreased by 12%. The researchers also reported an 11.2% wound-complication rate; however, all the wound issues resolved with nonoperative management.

Endoscopy-assisted compartment release has been described in the adult population.<sup>11,34,35</sup> Lohrer and Nauck<sup>34</sup> released 19 deep posterior, 16 anterior, and three lateral compartments in 17 athletes. In their study, outcomes were good or excellent in ten of 17 patients. Patients experienced no complications after release of the anterior and lateral compartments, but two patients underwent open revision surgery after release of the deep posterior compartment, due to hemorrhage. The authors concluded that endoscopic release can provide good results for anterior- and lateral-compartment releases but recommended against endoscopic deep posterior compartment release, due to the risk of hemorrhage. Similarly, Wittstein et al<sup>35</sup> reported good results after endoscopic release; however, the most common complication was postoperative hematoma.

Lohrer et al<sup>36</sup> recently published a systematic review on the results of endoscopy-assisted compartment releases

for CECS versus minimally invasive techniques. No statistically significant differences were found between endoscopy-assisted vs minimally invasive techniques, but the authors recognized that their patient samples were not large enough to draw final conclusions.

### Single minimal-incision technique

Maffulli et al<sup>37</sup> reported excellent outcomes after the use of a single minimal-incision fasciotomy for CECS. In their case series of 18 athletes, 94% returned to preinjury or higher level of sport between 8–13 weeks after surgery. The technique involves a 2.5 cm vertical incision in the middle third of the leg, 1 cm laterally to the tibial crest. After subcutaneous dissection, the fascia is incised proximally and distally with scissors under direct vision. Through the same incision, the lateral-compartment fascia can be released in similar fashion. Drexler et al<sup>38</sup> performed a large retrospective case-series study on outcomes after use of the single minimal-incision technique in young athletes. In their study, satisfaction rates were high in 75.5% of patients, but there were four nerve injuries and eight patients with recurrence. Although the single minimal-incision technique appears to have favorable results, more studies with larger samples and a more diverse patient population are needed to understand the true incidence of complications, as well as success rates.

### Percutaneous fasciotomy under local anesthesia

Percutaneous fasciotomy of the anterior compartment under local anesthesia (10 mL 1% lidocaine without epinephrine + 10 mL 0.5% bupivacaine) has been described in the treatment of CECS.<sup>39</sup> This technique involves a 4 cm incision over the middle of the anterior compartment, 1.5 cm laterally to the tibial crest. A slight slit is made in the fascia, and long gynecological scissors are used to dissect the fascia blindly proximally and distally. The authors showed a clinically significant decrease in pain after intervention; however, three of 16 (18.8%) patients sustained a superficial peroneal nerve injury. Their protocol differed from most reported ones, as they described the use of the forefoot-rise test to increase pressure and provoke pain in the anterior compartment to aid in the diagnosis. Although similar to the technique described by Beck et al,<sup>14</sup> reliance on local anesthetic in this technique does not allow for the release of other compartments, and is thus limited in its use.

### Ultrasound-guided fasciotomy

Ultrasound-guided fasciotomy for percutaneous compartment release has been described.<sup>40,41</sup> The ultrasound allows for visualization of the superficial peroneal nerve, vessels, and fascia. Over a 3-year period, seven patients underwent ultrasound-guided anterior-compartment release.<sup>41</sup> In that study, all patients had decrease in pain and six of seven returned to presymptomatic exercise levels in about 35 days. There were no hemorrhage or peroneal nerve complications. As with endoscopic techniques, more research is needed to understand the outcomes and generalizability of ultrasound-guided fasciotomy.

### Nonoperative management in the lower extremity

As previously discussed, treatment of CECS should begin with nonoperative management. Initial nonoperative management consists of cessation of all activities that bring the onset of symptoms. However, this conservative approach is usually unsuccessful, as most patients who experience CECS are unwilling to give up the sport or activity that is causing the symptoms.<sup>4,21</sup> Rajasekaran and Hall performed a systematic review of nonoperative management of CECS, including massage, gait changes, chemodenervation, and ultrasound-guided fascial fenestration.<sup>42</sup> Although their study reported that all the nonoperative management strategies had few to no adverse effects, the authors concluded that there was a lack of robust data regarding their effectiveness. This is because the data available comes primarily from case series and case reports. Other nonoperative modalities that have been attempted include the use of arch supports to change the biomechanical load on lower extremities,<sup>43,44</sup> traditional physical therapy, and NSAID regimens.<sup>44</sup>

Gait and foot-strike modifications may play a role in the nonoperative management of CECS.<sup>8–10,45</sup> Three foot-strike patterns have been described: forefoot, midfoot, and hindfoot. Hind-foot striking involves initial contact with the ground occurring at the heel or posterior part of the foot, whereas forefoot striking is a pattern in which the anterior region of the foot strikes the ground first. Midfoot striking is where the posterior and anterior portions of the foot contact the ground simultaneously.<sup>46</sup> Other factors, such as hindfoot eversion, stride length, ground-contact time, vertical oscillation, and lower-extremity angle, as well as type of shoes worn all contribute to running economy.<sup>47</sup> These factors, in combination with ground-

reaction forces and vertical loading, may be related to the development of increased stress to the lower extremities.<sup>48</sup>

Given that the development of CECS appears to be multifactorial, recent case series have evaluated running and marching techniques and their effect on CECS symptoms on military members.<sup>8–10</sup> Two studies reported a 6-week training program that focused on implementing forefoot running led to decreased postexercise lower-leg intracompartmental pressure, pain, and disability for up to 1 year.<sup>9,10</sup> Another study demonstrated that a 5-week training program focusing on decreasing the workload of the anterior-compartment muscles led to improvement in self-assessed leg condition, marching performance, and pain.<sup>8</sup> Breen et al<sup>49</sup> presented a case series in which runners demonstrated improvement in running distance and subjective lower-limb function scores and pain after 6 weeks of gait retraining to increase hip flexion, alter cadence, maintain upright torso, and achieve a midfoot-strike pattern.

Although these studies are encouraging, foot-strike pattern does not fully explain why some individuals are more susceptible to CECS than others. It has been reported that up to 89% of runners are hindfoot strikers, yet CECS is overall a rare diagnosis. These studies were also limited in that they were case series of military personnel with small samples. These studies thus may not be generalizable to the athletic and pediatric populations that experience CECS. Furthermore, while adaptation of forefoot/midfoot striking has been shown to be beneficial in some, it is important to consider the biomechanical consequences of such changes as well. Higher eccentric activity of the calf musculature is required to control the speed of ankle dorsiflexion following foot contact with the ground, which may increase susceptibility to Achilles tendinopathy/gastrosoleus strains.<sup>50</sup> Therefore, changes in gait pattern could lead to other pathologies. More gait/running-analysis studies are needed to determine clinical implications of gait modification as a conservative method of treatment in CECS.

Taping has increased in popularity in the nonoperative management of lower disorders. Recent data have shown that there may be a role for kinesiotaping in the management of medial tibial stress syndrome (“shin splints”), for the reduction of pain and functional activity<sup>51</sup> and in decreasing the rate of medial foot loading;<sup>52</sup> however, no studies have evaluated the role of kinesiotaping in the management of CECS. Functional manual therapy addressing motor-control deficits, myofascial restrictions, and

neuromuscular function showed resolution of symptoms at 3 year follow-up in a case report of a competitive triathlete with bilateral CECS;<sup>44</sup> however, more research is needed to evaluate the efficacy of this intervention.

The use of botulinum toxin A injections (Botox) has been proposed as a novel treatment for CECS. Isner-Horobeti et al<sup>53</sup> injected Botox in a total of 16 patients and showed a significant decrease in intracompartmental pressures for up to 9 months; however, 69% of patients experienced some loss of muscle strength. Despite their reported success, there have seldom been other studies testing the efficacy of Botox injections for the treatment of CECS. Most recently, Hutto et al<sup>54</sup> published a case report in which a military service member was treated with Botox injections for bilateral lower-leg CECS and remained pain-free for 11 months following treatment. Baria et al<sup>55</sup> also documented resolution of CECS symptoms in a patient after injection of Botox at 14-month follow-up. Although Botox injections may have potential in the treatment of CECS, the data available are once again limited to case series. A large randomized control trial is needed to better understand the role of Botox in the treatment of CECS.

## Treatment and outcomes for upper-extremity CECS

Given the rarity of CECS in the forearm, there have been few studies on the outcomes of fasciotomy of the upper extremity. As previously stated, forearm CECS has been described in rowers<sup>11</sup> and motorcyclists.<sup>5,12,13</sup> For patients that fail nonoperative therapy (eg, massage, stretching, splinting, activity modification), fasciotomy is recommended, as it generally offers excellent results.<sup>3,5</sup> As with lower-leg CECS, new minimally invasive approaches and techniques are being put into practice. Croutzet et al<sup>13</sup> describe a minimally invasive technique in competitive motorcyclists using endoscopy with good results in 16 cases. All patients were able to return to competition by 6 weeks, and there were no complications. The authors highlighted that recovery time and smaller scars were advantages of this approach. Barrerra-Ochoa et al<sup>12</sup> did a comparative study on the long-term results of wide-open versus mini-open fasciotomy after 45.35±12 months of follow-up. They found no significant difference between the surgical groups.

## Conclusion

CECS is an underdiagnosed condition that may be easily missed, given the large differential diagnosis for chronic exertional pain. Running athletes, particularly adolescent females, and marching military members are at increased risk of lower-extremity CECS. Upper-extremity CECS, though rare, is common in rowers and motorcyclists.

Nonoperative management has a limited role in the treatment of CECS, but hindfoot runners may benefit from forefoot running training. The use of Botox injections may have potential in the treatment of CECS, but more studies are needed to confirm their efficacy.

Fasciotomy is the preferred operative treatment for both lower-extremity and upper-extremity CECS. Good results have been reported after open, single-incision, minimally invasive, percutaneous, endoscopic, and ultrasound-guided techniques. Nerve damage, hematoma, and wound issues are the most common complications.

Improved surgical outcomes are seen in younger patients and those who undergo fasciotomies of all compartments. Worse outcomes are seen in those with lower-compartment pressure, military members, older individuals, and adults with a longer duration of symptoms. There is limited literature on postsurgical rehabilitation protocols after fasciotomies for CECS in the upper and lower extremities and in the adult versus pediatric population.

Studies of higher quality and power are needed to better understand the efficacy and outcomes of the newer surgical techniques. Further research also needs to be done to understand why a large portion (~20%) of the patient population does not experience full resolution of symptoms after fasciotomy.

## Disclosure

The authors report no conflicts of interest in this work.

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