Der Unfallchirurg

Leitthema

Unfallchirurg 2020 · 123 (Suppl 1):S8–S14
https://doi.org/10.1007/s00113-019-0641-9
Published online: 12 April 2019

Johan de Bruijn · Michiel Winkes · Percy van Eerten · Marc Scheltinga
Máxima Medical Center, Veldhoven, The Netherlands

Chronic exertional compartment syndrome as a cause of anterolateral leg pain

Anatomy of the lower leg

The lower leg consists of four muscle compartments that are restricted by the fascia cruris, tibial bone, fibular bone, and an interosseous membrane (**Fig. 1**). The muscles in the anterior compartment (blue area in Fig. 1) induce dorsiflexion of the foot and contribute to inversion and eversion. The lateral compartment muscles (green) lead to plantarflexion and eversion, while contraction of the superficial posterior compartment (red) leads to plantarflexion and contributes to flexion of the knee joint. The deep posterior compartment (purple) contains the deep flexor muscles that plantarflex the foot and help with inversion. Recent magnetic resonance imaging (MRI) and perioperative findings confirm the existence of a fifth compartment containing the tibialis posterior muscle having a separate fascia [45, 46].

Definition and types of leg CECS

Recurrent exercise-induced pain and tightness in a portion of the leg due to elevated tissue pressure in a muscle compartment is termed "chronic exertional compartment syndrome" (CECS). There are three different locations of leg CECS [35]. In most individuals the syndrome affects the anterior tibialis muscle compartment (ant-CECS). This type is mostly isolated and bilateral. When individuals have a deep posterior (flexor) compartment syndrome (dp-CECS), symptoms are more often unilateral [44]. Lastly, CECS can occur in the lateral (peroneal) compartment (lat-CECS), which is frequently in concert with an ant-CECS [12]. In daily practice, a substantial portion of patients with CECS present with a combination of the three types (e. g., ant-CECS and lat-CECS), or they develop different types over time (e. g., dp-CECS followed by ant-CECS) [4].

Anterolateral-CECS, ant-CECS, or lat-CECS?

Confusion exists on the correct terminology for the different type(s) of CECS that can cause pain in the anterolateral leg. Some have considered an elevated intracompartmental pressure (ICP) in the anterior tibialis muscle sufficient evidence of a CECS and classify these cases simply as CECS [32]. However, it is now generally accepted that ant-CECS is a more appropriate term for the type of CECS associated with anterolateral leg pain [4]. Information on possibly elevated ICP in lateral compartments contributing to pain in these patients is seldomly provided. Therefore, a portion of these so-called ant-CECS patients may theoretically also harbor a concomitant lat-CECS. It is unclear whether, and to what extent, ant-CECS and lat-CECS are together present in patients with anterolateral pain. Some think that a lat-CECS is always combined with an ant-CECS [12, 32]. Others consider lat-CECS and ant-CECS as two separate entities [3, 22, 40]. These issues were circumvented by a proposal to use the somewhat awkward and not generally accepted term "anterolateral CECS" [32].

Several observations underlie this semantic confusion. Firstly, it was thought in earlier days that just one type of leg CECS existed, i.e., ant-CECS. Only later was it realized that leg CECS could also develop in other leg compartments. Secondly, most patients have great difficulty in pinpointing the exact area of pain. Only a minority is able to distinguish between the anterior compartment or the lateral compartment. Even a concise physical examination including palpation often does not identify the compartment(s) causing the pain. Moreover, patients are usually examined in resting conditions and not immediately after a provocative test. Thirdly, sports physicians preferentially limit invasive ICP measurements to the most accessible compartment of the leg, i.e., the anterior compartment. For reasons of safety, an ICP of the lateral compartment containing the profundal peroneal nerve may be avoided.

A recent study aimed to clarify this issue [39]. From a large general population, 73 individuals with anterolateral leg pain were selected who had undergone simultaneous ICP measurements in both the anterior and lateral compartments and had an elevated pressure in at least one compartment. Of these 73 patients, more than half ($n = 42$, 58%) had anterolateral pain due to elevated pressures in both compartments. A smaller portion had isolated ant-CECS (26%), whereas only 7% of the patients had isolated lat-CECS. The clinical relevance of this study is yet to be determined. One may argue that a simultaneous ICP of both compartments is justified in patients reporting a diffuse

The German version of this article can be found under https://doi.org/10.1007/s00113-019-0642-8.

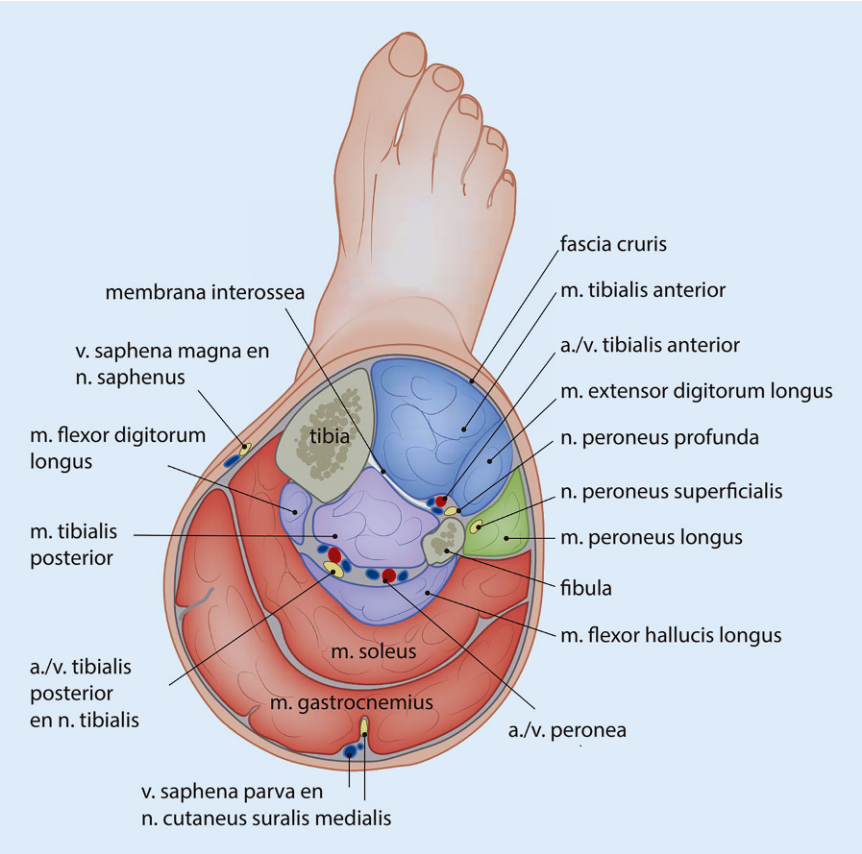

Fig. 1 ▲ Cross section of the lower leg

anterolateral pain and tightness suggesting CECS.

Milestones in ant-CECS

The first possible case of ant-CECS was documented in 1912. The English military surgeon Wilson wrote in his diary that he had severe pain in anterior portions of both legs while skiing during an Antarctic expedition. Symptoms intensified with each consecutive trip but always disappeared after rest. Over time, rest pain also emerged suggesting a gradual transition from a chronic to a subacute compartment syndrome. Unfortunately, all expedition members perished on their journey home and the presence of a CECS could not be confirmed [11].

In 1945, Horn described a 26-year-old previously healthy soldier with an acute painful state of the right leg that started immediately after an evening's walk. In the months preceding this emergency he had noted pains in both legs during marching. On examination, the anterior portion of the right leg was stone hard. A surgical exploration via a fasciotomy revealed severe tibial muscle ischemia necessitating an extensive necrotectomy. In retrospect, he was likely suffering from ant-CECS that had turned into an acute compartment syndrome [15].

» The first possible case of ant-CECS was documented in 1912

Eleven years later, Mavor diagnosed bilateral ant-CECS in a soccer player who was bothered with pain for over 2 years. He had several small muscle hernias in the anterior tibialis fascia that were considered spontaneous ruptures due to an elevated muscle compartment pressure. Mavor incised the muscle's fascia including the hernias and closed the defect with a piece of fascia lata leading to a full recovery [20].

In 1975, Reneman presented the first case series of 61 (mostly military) patients with CECS. He demonstrated that the elevated ICP was normalized after diathermically cutting the anterior tibialis fascia with a thin metal wire. Symptoms persisted in patients who refrained from surgery [30].

Until 1976, a variety of invasive and occasionally irreproducible techniques were used for determination of muscle pressures. In that year, Mubarak introduced a wick-catheter technique that allowed for accurate and reproducible ICP measurements in a dog and a human model [24]. In 1987, Due and Nordstrand introduced an instrument termed a "fasciotome" that allowed for a quick and safe surgical opening of the fascia (fasciotomy) leading to pressure relief [9]. Pedowitz used the wick-catheter technique 3 years later to compare ICP values in ant-CECS patients with values of healthy individuals. He defined timed cut-off values before and after a provocative test suggesting CECS if pressures were beyond these thresholds. To this day, the Pedowitz criteria are still considered the gold standard [27].

Ant-CECS: who is at risk?

Exact CECS incidence rates in the general population are unknown. One study found that one in seven individuals who were evaluated for exercise-induced leg pain (ELP) had an ant-CECS [28]. Early reports suggested that CECS is predominantly found in young and healthy individuals, mainly in military personnel and athletes [19, 30]. However, more recent reports show that CECS can also be found in older and less active individuals [6, 10]. Gender distribution is more or less equal. Typical activities that may provoke ant-CECS are running, soccer, and skating [4]. Recently, a predictive model based on a large retrospective cohort of patients with ELP was proposed. Male gender, young age, bilateral symptoms, absent history of lower leg pathology, skating, and a tensed muscle compartment were identified as independent predictors for CECS [4].

Patient history in ant-CECS

A characteristic ant-CECS patient is a young individual who experiences

exercise-induced pain and tightness. Cramps, muscle weakness, and altered foot skin sensation may also be reported. Additionally, some patients describe a sensation of "filling up" during sports leading to a rock hard and tense muscle. Over time, symptoms tend to start earlier during the provocative exercise necessitating premature termination of the sportive activities. The presence of pain and tightness is conditional for the diagnosis. A recent study of ant-CECS focusing on a variety of aspects in the patient history found that the incidence rate of pain and tightness during exercise was 100 and 96%, respectively. Contrary to popular beliefs, however, pain and tightness were also often experienced during resting conditions (85 and 81%, respectively), albeit at a lower intensity [39].

Physical examination in ant-CECS

Physical examination entails observation of the patient standing, walking, and running. A muscle herniation through a fascial defect may occasionally be visible during active extension. Firm palpation of the anterior tibialis or peroneal muscles may cause tenderness, possibly different from the contralateral side in a one-sided CECS. Palpation as well as active and passive range of motion and resistance tests should be performed before and after a provocative exercise such as a treadmill run. Since these symptoms are mostly nonspecific, physical examination is often normal in patients with ant-CECS. Therefore, the role of a physical examination in the management of CECS is not to confirm the diagnosis but to exclude concomitant entities other than CECS. A painful palpation of the distal posteromedial tibial rim in an ant-CECS patient may indicate a simultaneous medial tibial stress syndrome (MTSS, formerly "shin splints"; [23]). Tenderness of the distal flexor muscles just proximal to the medial malleolus suggests dp-CECS [46]. Hypoesthesia (occasionally hyperesthesia) of portions of the foot and/or distal portions of the leg indicate entrapment of branches of the common peroneal or tibial nerve [41]. Blanching of the foot sole or reduced arterial pulsations in prone position may indicate popliteal artery entrapment syndrome (PAES; [36]).

Dynamic ICP measurement

In patient with ELP with a suggestive history and physical examination, ant-CECS is confirmed using a dynamic ICP measurement. The ICP is measured at rest and after a provocative exercise (usually a treadmill run). Static ICP measurements are considered obsolete. A slit-catheter technique connected to an arterial line transducer system is currently regarded as most accurate for timed pressure measurements [2, 13]. In cases of bilateral complaints, values are obtained from the most symptomatic leg.

The most commonly used cut-off points are suggested by Pedowitz (rest pressure ≥20 mm Hg, ≥30 mm Hg 1 min

Unfallchirurg 2020 · 123 (Suppl 1):S8–S14 https://doi.org/10.1007/s00113-019-0641-9

J. de Bruijn · M. Winkes · P. van Eerten · M. Scheltinga

Chronic exertional compartment syndrome as a cause of anterolateral leg pain

Abstract

Exercise-induced leg pain (ELP) and tightness may be caused by a chronic exertional compartment syndrome (CECS). Although CECS can develop in any muscle compartment, most individuals suffer from an anterior tibial muscle CECS (ant-CECS). Typically, a patient with ant-CECS experiences discomfort toward the end of sports activity or in the hours thereafter. Physical examination may reveal tenderness upon palpation of the anterior tibial muscle belly. The gold standard diagnostic tool is a dynamic intracompartmental pressure (ICP) measurement demonstrating elevated muscle tissue pressures. Duplex analysis and imaging may be indicated for exclusion of concomitant entities such as entrapment of the popliteal artery or nerves. Conservative treatments including modification of the patient's running technique can be successful. A fasciotomy must be considered in recalcitrant cases. Residual or recurrent disease may necessitate partial removal of the fascia. The aim of this overview is to discuss the management of CECS in the anterolateral portion of the leg.

Keywords

Anterior tibial muscle · Sports medicine · Fasciotomy · Exercise · Differential diagnosis

Chronisches belastungsbedingtes Kompartmentsyndrom als Ursache anterolateraler Beinschmerzen

Zusammenfassung

Belastungsinduzierte Beinschmerzen und Anspannung können durch ein chronisches belastungsbedingtes Kompartmentsyndrom („chronic exertional compartment syndrome", CECS) verursacht werden. Ein CECS kann zwar in jedem Muskelkompartiment entstehen, aber die meisten Patienten leiden an einem CECS des M. tibialis anterior (ant-CECS). Typisch dabei ist, dass ein Patient mit ant-CECS bis zum Ende der sportlichen Aktivitäten oder in den Stunden danach Beschwerden hat. Bei der körperlichen Untersuchung kann sich Schmerzempfindlichkeit bei Palpation des Muskelbauchs des M. tibialis anterior zeigen. Goldstandard in der Diagnostik ist die dynamische intrakompartmentale Druckmessung („intracompartmental pressure", ICP), die dann erhöhte Drücke im Muskelgewebe ergibt. Duplexuntersuchung und Bildgebungsverfahren können zum Ausschluss begleitender Erkrankungen wie einer Einklemmung der A. poplitea oder von Nerven indiziert sein. Die konservative Behandlung unter Einschluss einer Veränderung der Lauftechnik des Patienten kann erfolgreich sein. In hartnäckigen Fällen muss eine Fasziotomie erwogen werden. Bei einem Verlauf mit Residualbeschwerden oder Rezidiven wird möglicherweise eine Teilentfernung der Faszie erforderlich. Ziel der vorliegenden Arbeit ist es, die Behandlung eines CECS im anterolateralen Bereich des Beins darzustellen.

Schlüsselwörter

M. tibialis anterior · Sportmedizin · Fasziotomie · Sport · Differenzialdiagnose

Table 1 Differential diagnosis of chronic exertional compartment syndrome (CECS)

Diagnosis	Patient history	Physical examination	Imaging or tests
Stress fracture	Localized pain, does not disappear at rest	Localized painful palpation at tibia. Worsens when jumping	X-ray, bone scan or MRI
MTSS	Worsens with activities, disappears partially at rest. Pain along inner border of tibia	Tenderness upon palpation along posteromedial border of distal tibia. Often local edema	Ultrasound
CECS	Exertional pain, usually disappears within 30 min of sport cessation	Tense muscle belly, particularly after exercise	Dynamic ICP
Fascial hernia	Often asymptomatic, sometimes localized pain	Defect may be visible and painful on palpation	Ultrasound
PAES	Exertional pain, mostly proximal portion of the calf, occasionally entire lower leg	Positive "pedal pulse" sign (disappearance of pedal pulses in prone position when plantarflexing foot)	Duplex ultrasound or MR angiography
Muscle/tendon injuries (strain, tendinopathy)	Localized pain, aggravated when stretching	Localized trigger points. Mostly tendon insertions or muscle bellies. Passive stretching painful	Ultrasound
Nerve entrapment	Awkward sensations in foot, occasionally less control. Sleep is disturbed	Altered skin sensation using cotton swab, painful skin pinching	Electromyography or nerve conducting velocity
Peripheral artery disease	Patients often >50 years. Pain or tightness disappears <5 min of standing	Diminished pulsations, slow capillary refill, trophic disturbances	Ankle–brachial index before and after treadmill test
Venous pathology	Discomfort during rest but no pain. Walking provides relief	Visible varicose veins	Duplex ultrasound

ICP intracompartmental pressure, *MRI* magnetic resonance imaging, *MTSS* medial tibial stress syndrome, *PAES* popliteal arterial entrapment syndrome

after, or ≥20 mm Hg 5 min after a provocative exercise; [27]). However, threshold values as well as the validity of the technique itself are criticized [1]. Several reports indicate that an elevated pressure alone is not sufficient for the diagnosis [31]. Another group presented a potentially improved method and cut-off values, requiring confirmation in future studies [33].

Imaging and other techniques

The role of imaging for possible ant-CECS is limited. Near-infrared spectroscopy (NIRS) or MRI has a potential to confirm the diagnosis, but they are not used on a large-scale basis [37, 38]. Recently, MRI detected diffuse compartment edema in a patient with isolated lat-CECS who recovered following surgery [26]. Similar to the role of physical examination, imaging is predominantly indicated for exclusion of MTSS (bone scintigraphy, ultrasound), intermittent claudication (ankle–brachial index), PAES (Duplex), nerve entrapments (MRI), or stress fractures (plain X-ray).

Diagnosis and differential diagnosis of ant-CECS

The diagnosis of ant-CECS is primarily based on a suggestive patient history. Physical examination and imaging are used to exclude concomitant or other entities causing ELP. The absolute role of the ICP analysis is controversial. Therefore, a patient suspected of having ant-CECS with a strongly suggestive history (pain and tightness during or shortly after exercise) but without any suggestive signs during physical examination or elevated ICP raises a diagnostic dilemma. As such, this patient may still undergo surgical treatment for CECS if conservative treatments fail.

The differential diagnosis of ant-CECS is extensive (**Table 1**). An elaborate patient history and a structured physical examination are pivotal to diagnose alternative pathologies or for guiding additional measurements/imaging. Some diagnoses are solely based on physical examination (fascial herniation, muscle/tendon injuries), while other entities may require additional imaging (PAES, stress fracture, peripheral artery disease).

Conservative treatment for ant-CECS

Evidence supporting the efficacy of conservative treatments for ant-CECS is scarce [29]. The most frequently used nonoperative treatments are rest, massage, stretching exercises, ice, or extracorporeal shockwave therapy. A long-term reduction of symptoms in the general population might not be attained. However, adverse effects are absent and thus a conservative regimen is often advised 3–6 months prior to considering surgery. Correction of foot overpronation and optimization of walking gait and shoes may help. Adopting a midfoot or forefoot strike resulted in fewer symptoms, a longer pain-free walking interval, and lowered ICP [7]. A 6-week forefoot running intervention in both a center-based and home-based setting led to similar improvements [14]. In an experimental setting, botulinum toxin A (Botox) injections were useful as pain disappeared in 15 of 16 patients, whereas ICP dropped by two thirds [16]. However, the long-term efficacy is unknown.

Surgery for ant-CECS

Surgery is offered to patients with ant-CECS who do not respond to conser-

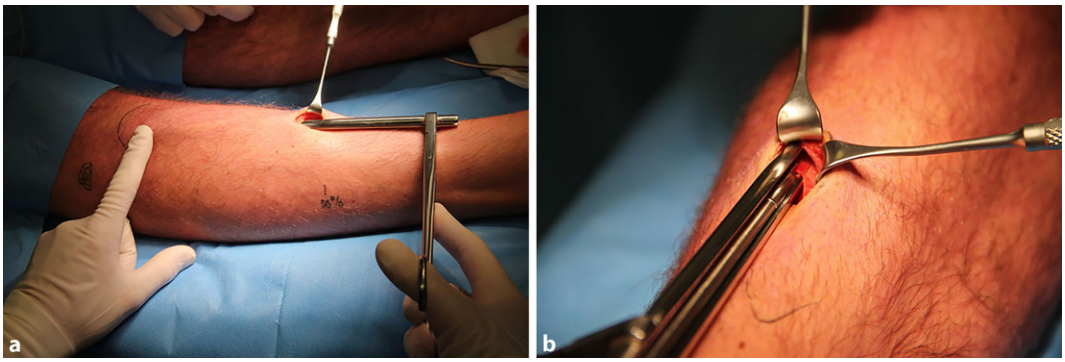

Fig. 2 ◀ Fasciotomy for anterior chronic exertional compartment syndrome using the FascioMax. **a** Positioning of the speculum; **b** introduction of the fasciotome

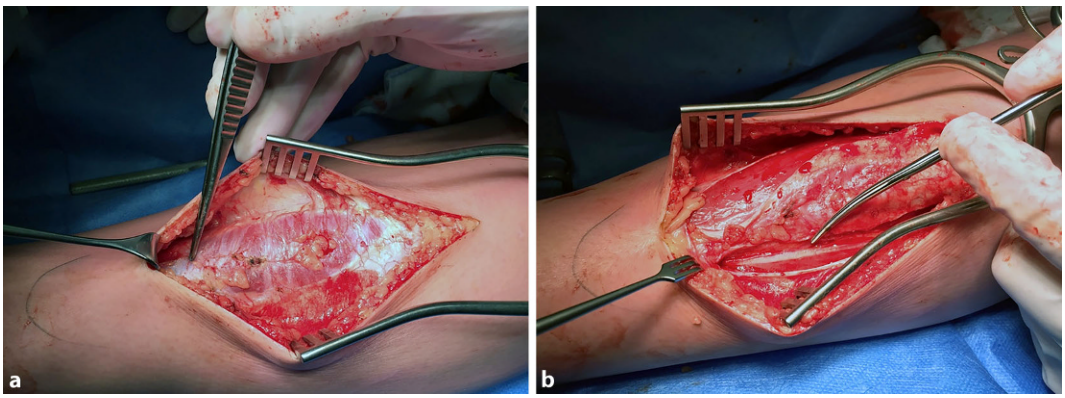

Fig. 3 ◀ Recurrent pain following fasciotomy for anterior chronic exertional compartment syndrome. **a** De novo fascial layer; **b** excision of strip of new and old fascia. Note superficial peroneal nerve at tip of scissors

vative therapy. The fascia is either split (fasciotomy) or a strip thereof is removed (fasciectomy).

Fasciotomy in the early days was performed via a 10- to 15-cm longitudinal incision [25]. The introduction of a fasciotome reduced the size of the skin incision to 2 cm [9]. The technique that is proposed by Due is termed "semi-blind" as the subcutaneous advancement of the tip of the fasciotome does not occur under direct visualization. Potential disadvantages of this semi-blind approach are collateral muscle or nerve damage as the tip of the fasciotome may lose contact with the fascia during the pushing movement. A recent alternative to Due's fasciotome is termed "FascioMax" [5]. This is a speculum-type instrument with two blades that are advanced in planes ventral and dorsal to the fascia (◘ **Fig. 2**). By closing the blade, a hollow tube is formed allowing for a protected introduction of a thin fasciotome.

In the case of bilateral ant-CECS, both legs are operated in a one-stage procedure in day-care requiring approximately 20 min of operation time. A compressing bandage is applied for the first 24 h after which patients wear compressive stockings for 14 days. They refrain from sports but normal ambulation is recommended. Jogging is allowed from day 14 on.

For lat-CECS, two separate skin incisions are used that are located more dorsal compared with the fasciotomy for ant-CECS. The distal incision is placed over the location where the superficial peroneal nerve (SPN) may possibly exit the fascia avoiding any potential iatrogenic nerve damage. Recently, the assistance of an endoscope was proposed [17]. Although in theory this technique may improve outcome and reduce nerve injury rates, clinical results are not superior to those achieved with other techniques [18, 47].

Surgical complications and outcome

Complication rates of a fasciotomy are as high as 19% and include bleeding, SPN injury, and wound infection [8, 34, 42]. Long-term outcome largely depends on the definition of success and the expectations of the patient. Favorable outcomes vary between 50 and 100% in athletes and civilian populations. Success rates in military personnel are lower. For instance, nearly half of a military population who underwent fasciotomy reported recurrent symptoms, and one in four patients were not able to return to full activity [43]. In another study this number was even lower, as only 41% of military personnel who underwent elective fasciotomy were able to return to full military duty [21].

Persistent pain after CECS surgery: recurrence or concomitant disease?

A portion of ant-CECS patients might report residual symptoms within 3 months of surgery, or may have recurrent pain following an earlier successful fasciotomy. Persistent pain can be caused by either a concomitant disease such as MTSS or CECS in another compartment, or by insufficient surgical decompression. A recent study found that approximately one in four patients with persistent or recurrent pain after surgical treatment for CECS had residual or recurrent disease as demonstrated by pathologically elevated pressure in one or more compartments [40]. We therefore recommend a repeat ICP if history and physical examination

are similar to the clinical picture prior to the fasciotomy. If history and physical examination differ from the preoperative situation, other entities such as dp-CECS, MTSS, intermittent claudication, PAES, nerve entrapments, or stress fractures must be excluded using the appropriate testing or imaging. When recurrent CECS is demonstrated, a fasciectomy is recommended. During this 30-min operation, a 5–7-cm-wide and 20–25-cm-long strip of fascia is excised (**Fig. 3**). The outcome is beneficial but a 15-cm incision is required.

Conclusion

- **Pain and tightness in anterolateral portions of the leg are crucial for the diagnosis of ant-CECS.**
- **Physical examination should be performed before and after a provocative treadmill test and may reveal a tender anterior tibialis muscle belly upon palpation.**
- **An ICP measurement may support the diagnosis of ant-CECS.**
- **Additional imaging is reserved for exclusion of concomitant entities such as artery or nerve entrapments.**
- **Modification of the patient's running technique may be successful.**
- **A fasciotomy is considered in patients for whom conservative treatment has failed.**
- **Recurrent disease may necessitate removal of a strip of the fascia.**

Corresponding address

Marc Scheltinga
Máxima Medical Center
P.O. Box 7777, De Run 4600, 5500
MB Veldhoven, The Netherlands
m.scheltinga@mmc.nl

Compliance with ethical guidelines

Conflict of interest J. de Bruijn, M. Winkes, P. van Eerten, and M. Scheltinga declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

The supplement containing this article is not sponsored by industry.

References

1. Aweid O, Del Buono A, Malliaras P et al (2012) Systematic review and recommendations for intracompartmental pressure monitoring in diagnosing chronic exertional compartment syndrome of the leg. Clin J Sport Med 22:356–370
2. Boody AR, Wongworawat MD (2005) Accuracy in the measurement of compartment pressures: A comparison of three commonly used devices. J Bone Joint Surg Am 87:2415–2422
3. Davis DE, Raikin S, Garras DN et al (2013) Characteristics of patients with chronic exertional compartment syndrome. Foot Ankle Int 34:1349–1354
4. de Bruijn JA, van Zantvoort APM, van Klaveren D et al (2018) Factors predicting lower leg chronic exertional compartment syndrome in a large population. Int J Sports Med 39:58–66
5. de Bruijn JA, van Zantvoort APM, Winkes MB et al (2015) Feasibility and safety of an operative tool for anterior chronic exertional compartment syndrome treatment. Foot Ankle Int 36:1475–1482
6. de Bruijn JA, van Zantvoort APM, Winkes MB et al (2018) Lower leg chronic exertional compartment syndrome in patients 50 years of age and older. Orthop J Sports Med. https://doi.org/10.1177/2325967118757179
7. Diebal AR, Gregory R, Alitz C, Gerber JP (2012) Forefoot running improves pain and disability associated with chronic exertional compartment syndrome. Am J Sports Med 40:1060–1067
8. Drexler M, Rutenberg TF, Rozen N et al (2017) Single minimal incision fasciotomy for the treatment of chronic exertional compartment syndrome: Outcomes and complications. Arch Orthop Trauma Surg 137:73–79
9. Due J, Nordstrand K (1987) A simple technique for subcutaneous fasciotomy. Acta Chir Scand 153:521–522
10. Edmundsson D, Toolanen G, Sojka P (2007) Chronic compartment syndrome also affects nonathletic subjects: a prospective study of 63 cases with exercise-induced lower leg pain. Acta Orthop 78:136–142
11. Freedman BJ (1954) Dr. Edward Wilson of the Antarctic; a biographical sketch, followed by an inquiry into the nature of his last illness. Proc R Soc Med 47:183–189
12. Gatenby G, Haysom S, Twaddle B, Walsh S (2017) Functional outcomes after the surgical management of isolated anterolateral leg chronic exertional compartment syndrome. Orthop J Sports Med. https://doi.org/10.1177/2325967117737020
13. Hammerberg EM, Whitesides TE, Seiler JG (2012) The reliability of measurement of tissue pressure in compartment syndrome. J Orthop Trauma 26:e166 (author reply e166)
14. Helmhout PH, Diebal AR, van der Kaaden L et al (2015) The effectiveness of a 6-week intervention program aimed at modifying running style in patients with chronic exertional compartment syndrome: Results from a series of case studies. Orthop J Sports Med. https://doi.org/10.1177/2325967115575691
15. Horn CE (1945) Acute ischaemia of the anterior tibial muscle and the long extensor muscles of the toes. J Bone Joint Surg Am 27:615–622
16. Isner-Horobeti M-E, Dufour SP, Blaes C, Lecocq J (2013) Intramuscular pressure before and after botulinum toxin in chronic exertional compartment syndrome of the leg: A preliminary study. Am J Sports Med 41:2558–2566
17. Leversedge FJ, Casey PJ, Seiler JG, Xerogeanes JW (2002) Endoscopically assisted fasciotomy: Description of technique and in vitro assessment of lower-leg compartment decompression. Am J Sports Med 30:272–278
18. Lohrer H, Nauck T, Lohrer L (2016) Endoscopic-assisted release of lower leg chronic exertional compartment syndromes: Results of a systematic literature review. Sports Med Arthrosc 24:19–23
19. Martens MA, Backaert M, Vermaut G, Mulier JC (1984) Chronic leg pain in athletes due to a recurrent compartment syndrome. Am J Sports Med 12:148–151
20. Mavor GE (1956) The anterior tibial syndrome. J Bone Joint Surg Br 38:513–517
21. McCallum JR, Cook JB, Hines AC et al (2014) Return to duty after elective fasciotomy for chronic exertional compartment syndrome. Foot Ankle Int 35:871–875
22. Micheli LJ, Solomon R, Solomon J et al (1999) Surgical treatment for chronic lower-leg compartment syndrome in young female athletes. Am J Sports Med 27:197–201
23. Mubarak SJ, Gould RN, Lee YF et al (1982) The medial tibial stress syndrome. A cause of shin splints. Am J Sports Med 10:201–205
24. Mubarak SJ, Hargens AR, Owen CA et al (1976) The wick catheter technique for measurement of intramuscular pressure. A new research and clinical tool. J Bone Joint Surg Am 58:1016–1020
25. Mubarak SJ, Owen CA (1977) Double-incision fasciotomy of the leg for decompression in compartment syndromes. J Bone Joint Surg Am 59:184–187
26. Park S, Lee HS, Seo SG (2017) Selective fasciotomy for chronic exertional compartment syndrome detected with exercise magnetic resonance imaging. Orthopedics 40:e1099–e1102
27. Pedowitz RA, Hargens AR, Mubarak SJ, Gershuni DH (1990) Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. Am J Sports Med 18:35–40
28. Qvarfordt P, Christenson JT, Eklöf B et al (1983) Intramuscular pressure, muscle blood flow, and skeletal muscle metabolism in chronic anterior tibial compartment syndrome. Clin Orthop Relat Res 179(1):284–290
29. Rajasekaran S, Hall MM (2016) Nonoperative management of chronic exertional compartment syndrome: A systematic review. Curr Sports Med Rep 15:191–198
30. Reneman RS (1975) The anterior and the lateral compartmental syndrome of the leg due to intensive use of muscles. Clin Orthop Relat Res 113:69–80
31. Roberts A, Franklyn-Miller A (2012) The validity of the diagnostic criteria used in chronic exertional compartment syndrome: A systematic review. Scand J Med Sci Sports 22:585–595
32. Rorabeck CH, Bourne RB, Fowler PJ (1983) The surgical treatment of exertional compartment syndrome in athletes. J Bone Joint Surg Am 65:1245–1251
33. Roscoe D, Roberts AJ, Hulse D (2014) Intramuscular compartment pressure measurement in chronic exertional compartment syndrome: New and improved diagnostic criteria. Am J Sports Med 43:392–398

34. Schepsis AA, Gill SS, Foster TA (1999) Fasciotomy for exertional anterior compartment syndrome: Is lateral compartment release necessary? Am J Sports Med 27:430–435
35. Tucker AK (2010) Chronic exertional compartment syndrome of the leg. Curr Rev Musculoskelet Med 3:32–37
36. Turnipseed WD (2009) Functional popliteal artery entrapment syndrome: A poorly understood and often missed diagnosis that is frequently mistreated. J Vasc Surg 49:1189–1195
37. Van den Brand JGH, Nelson T, Verleisdonk EJMM (2005) The diagnostic value of Intracompartmental pressure measurement, magnetic resonance imaging, and near-infrared spectroscopy in chronic exertional compartment syndrome: A prospective study in 50 patients. Am J Sports Med 33(5):699–704. https://doi.org/10.1177/0363546504270565
38. van den Brand JGH, Verleisdonk EJMM, van der Werken C (2004) Near infrared spectroscopy in the diagnosis of chronic exertional compartment syndrome. Am J Sports Med 32:452–456
39. van Zantvoort APM, de Bruijn JA, Hundscheid HPH, Scheltinga MR (2019) Isolated lateral chronic exertional compartment syndrome of the leg: A new entity? Submitted
40. van Zantvoort APM, de Bruijn JA, Winkes MB et al (2017) Role of repeat muscle compartment pressure measurements in chronic exertional compartment syndrome of the lower leg. Orthop J Sports Med. https://doi.org/10.1177/2325967117711121
41. van Zantvoort APM, Setz MJM, Hoogeveen AR, Scheltinga MRM (2018) Common peroneal nerve entrapment in the differential diagnosis of chronic exertional compartment syndrome of the lateral lower leg: A report of 5 cases. Orthop J Sports Med. https://doi.org/10.1177/2325967118787761
42. Verleisdonk EJMM, Schmitz RF, van der Werken C (2004) Long-term results of fasciotomy of the anterior compartment in patients with exercise-induced pain in the lower leg. Int J Sports Med 25:224–229
43. Waterman BR, Laughlin M, Kilcoyne K et al (2013) Surgical treatment of chronic exertional compartment syndrome of the leg: Failure rates and postoperative disability in an active patient population. J Bone Joint Surg Am 95:592–596
44. Winkes MB, Hoogeveen AR, Scheltinga MR (2014) Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. Br J Sports Med 48:1592–1598
45. Winkes MB, Tseng CM, Pasmans HL et al (2016) Accuracy of palpation-guided catheter placement for muscle pressure measurements in suspected deep posterior chronic exertional compartment syndrome of the lower leg: A magnetic resonance imaging study. Am J Sports Med 44(10):2659–2666
46. Winkes MB, van Zantvoort APM, de Bruijn JA et al (2016) Fasciotomy for deep posterior compartment syndrome in the lower leg: A prospective study. Am J Sports Med 44:1309–1316
47. Wittstein J, Moorman CT, Levin LS (2010) Endoscopic compartment release for chronic exertional compartment syndrome: Surgical technique and results. Am J Sports Med 38:1661–1666