# Chronic Exertional Compartment Syndrome of the Deep Posterior Lower Leg and Forearm

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# Chronic Exertional Compartment Syndrome of the Deep Posterior Lower Leg and Forearm

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*Aan mijn ouders*

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# CHAPTER 1

# INTRODUCTION AND OUTLINE

# INTRODUCTION

A compartment syndrome is defined as "a condition in which increased pressure within a limited space compromises the circulation and function of tissues within that space".[26] Compartment syndromes can present as acute, chronic (exertional), or in transition from chronic to acute. The acute compartment syndrome (ACS), most commonly occurring after serious injury such as fractures, crush injury or revascularization, is a true surgical emergency.[10,21] Unless the pressure in the affected compartment is relieved within hours, ACS will result in irreversible tissue damage and permanent disability.[44] Further discussion of ACS is beyond the scope of this thesis.

A chronic variant of compartment syndrome (chronic exertional compartment syndrome, CECS) is a relatively benign condition. Extremity pain becomes progressively apparent during repetitive muscle action whereas symptoms disappear during rest.[15] CECS may develop in every muscle group covered by a fascia including forearm,[4,7,19] upper thigh,[30] or hand.[24,38] However, CECS is most frequently demonstrated in the lower leg. A lower leg CECS most commonly occurs in the anterior muscle compartment (ant-CECS, 40-60%) although the deep posterior (dp-CECS, 32-60%) or lateral (lat-CECS, 12-35%) compartments may also be affected.[9,25]

The lower leg deep posterior variant (dp-CECS) is considered the most challenging type, both from a diagnostic as well as from a treatment point of view. Because of an extensive differential diagnosis, dp-CECS may not be the first diagnosis doctors consider once a patient presents with exercise-related pain in medial and deep aspects of the calf. Moreover, once dp-CECS is correctly diagnosed, optimal type and extent of treatment modalities including surgical decompression are largely unknown.

## Historical aspects of lower leg CECS

The first case of a lower leg CECS was possibly reported by dr. Edward Wilson in 1912. Being an English junior military surgeon and zoologist, he suffered from severe leg pain during an Antarctic expedition. In his diaries, he reported on extreme pain and swelling over anterior portions of his lower legs while skiing. Symptoms intensified with each trip but disappeared after rest. In the end, rest pain occurred, possibly after transition from CECS to an ACS. However, all five Antarctic expedition members including himself perished on their home journey.

In 1953, Freedman was the first to publish an article on CECS and illustrated his contribution with Wilson's story.[12] Three years later, Mavor evaluated a healthy young professional football player with bilateral lower leg pain and dubbed this syndrome 'the anterior tibial syndrome'.[27] In 1974, a deep posterior variant of lower leg CECS was described that was termed 'the medial tibial syndrome'.[32] A series of 11 athletes reported pain at an area medial to the tibial bone towards the end of a run. It was found that the syndrome was due to increasing tissue pressures in the deep flexor muscle compartment of the lower leg.

During the following four decades, consensus on terminology was not attained. Terms such as 'shin splints', 'fresher's leg', 'medial tibial syndrome', ‘anterior tibial syndrome’, 'chronic compartment syndrome' and 'exertional compartment syndrome' were proposed. Nowadays, the most appropriate term to describe the condition is 'chronic exertional compartment syndrome' (CECS). Additionally, subtypes may be labeled such as ant-CECS (anterior tibialis muscle), dp-CECS (deep posterior muscles) or lat-CECS (peroneus muscle).[47]

## General anatomy of extremity muscle compartments

CECS cannot develop without the existence of a fascia enveloping muscular tissues. Fascia (*Latin*: band, bandage, bundle, strap) can be considered part of the connective tissue that permeate the human body.[22] All muscle groups are enveloped by fascia.

Consensus is lacking on the exact definition of a fascia.[11,36,39] For example, terms such as dense connective tissue, deep fascia, superficial fascia, interosseus membranes, intermuscular septae, epi-, peri-, and endomysium, periosteum, neurovascular tract as well as intra- and extramuscular aponeuroses have all been proposed.[23] It is thought that a fascia plays several functional roles such as myofascial force transmission and transformation of mechanical forces (‘mechanotransduction’). A fascial layer may contribute to propriocepsis and nocicepsis and may serve as an interface allowing other structures to nearly frictionless slide upon one another.[22,40]

In the lower leg, fascial structures such as the anterior intermuscular septum, the posterior intermuscular septum, the transverse intermuscular septum and the interosseus membrane (connecting the tibia and fibula) separate the lower leg into four compartments (Figure 1.1). Each compartment harbors muscles, nerves and blood vessels. A lower leg contains an anterior, a lateral (peroneal), a superficial posterior and a deep posterior (flexor) compartment. The anterior compartment contains the tibialis anterior muscle, extensor hallucis longus muscle, extensor digitorum longus muscle, and fibularis tertius muscle. Together these 4 muscles exert foot dorsiflexion and participate in inversion and eversion. Vascularization of this compartment is maintained by the anterior tibial artery, whereas muscles are innervated by the deep peroneal nerve. The lateral compartment consists of the fibularis longus and brevis muscles, which evert the foot and weakly plantar flex the ankle. They are innervated by the superficial peroneal nerve whereas blood supply is assured via branches of the posterior tibial and fibular artery. The superficial posterior compartment harbours the gastrocnemius, soleus and plantaris muscles. The gastrocnemius and soleus muscles form the lower leg calf and are involved in running, jumping and other fast leg movements. Together they plantar flex the foot at the ankle joint and flex the leg at the knee joint.

The deep posterior compartment contains the flexor hallucis longus (FHL) muscle, the flexor digitorum longus (FDL) muscle, the tibialis posterior (TP) muscle and the popliteus muscle. The FHL and FDL flex the big toe and four digits, respectively. They support the arch of the foot and, together with the TP, they plantar flex the ankle. The

TP also inverts the foot. The popliteus mainly unlocks the knee. All four deep posterior compartment muscles are innervated by the tibial nerve.

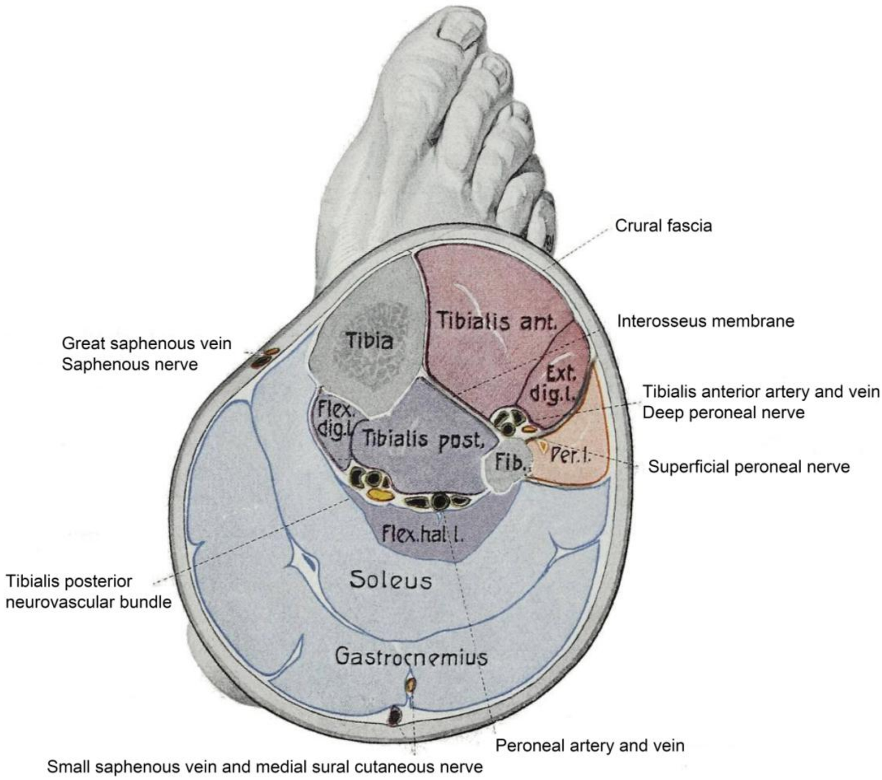


**FIGURE 1.1** Cross sectional anatomy of the lower leg.

The forearm consists of two compartments, a volar (flexor) and a dorsal (extensor) one. Both compartments are separated by the interosseus membrane connecting the radial and ulnar bone. The flexor compartment contains two subcompartments (Figure 1.2). The superficial flexor compartment contains the pronator teres muscle, the flexor carpi radialis muscle, the palmaris longus muscle, the flexor carpi ulnaris muscle, and the flexor digitorum superficialis muscle. They are innervated by the median and ulnar nerve and blood supply is warranted from the ulnar and radial artery. These muscles are largely involved in flexion of the wrist and fingers and in pronation of the forearm. The deep flexor compartment contains the flexor pollicis longus muscle, the flexor digitorum profundus muscle, and the pronator quadratus muscle. The extensor compartment contains 12 muscles which are mainly responsible for extension of the wrist and digits as well as supination of the forearm. These muscles can be divided

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further into a superficial layer (brachioradialis, extensor carpi radialis longus, brevis, carpi ulnaris, and anconeus muscles), an intermediate layer (extensor digitorum and extensor digiti minimi) and a deep layer (abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, extensor indicis, and supinator muscles). All 12 muscles are innervated by the radial nerve and blood supply comes from the radial artery and its branches.

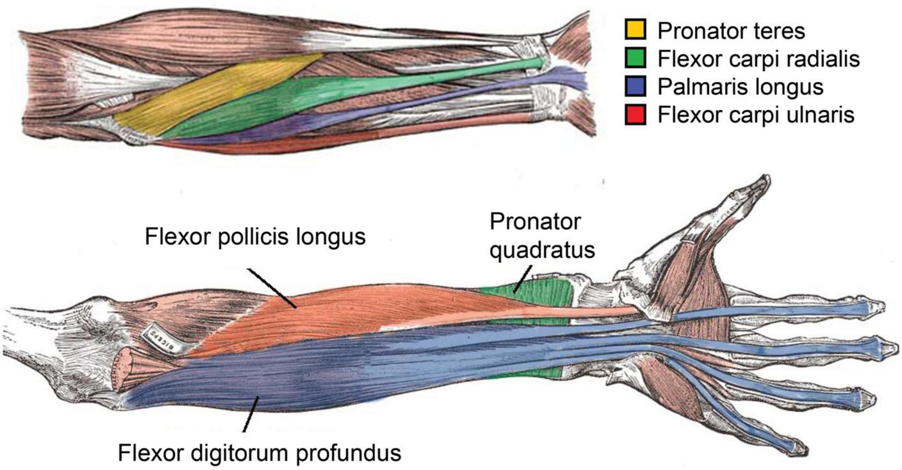


**FIGURE 1.2** Anatomy of the superficial (upper image) and deep (lower image) flexor compartments of the forearm. Edited image, original obtained from www.teachmeanatomy.com.

## Pathophysiology of CECS

Research regarding the pathophysiology of compartment syndromes started with studying the acute type. Many of the findings in ACS were consequently extrapolated to CECS in an attempt to describe the etiology of CECS.[6] However, the exact pathophysiology and origin of pain in CECS are unknown. Some studies in CECS focused on altered changes in vascular flow.[49] Several findings such as increased lactate in muscle biopsy specimens immediately after exercise,[33] pathologically increased muscle relaxation pressures,[41,42] reductions in arteriovenous pressure gradients,[5,6,18] and compromised muscle oxygen saturation[29] all support this theory.[3] However, other studies questioned the role of ischemia or altered vascular flow conditions.[1,2] The role of the fascia in explaining the pathophysiology of CECS is also unclear. Some studies suggested that a repetitive fascial loading contributes to inflammation and fibrosis, which renders the fascia less compliant and in turn may result in higher compartment pressures.[9,43] However, a recent study found no differences in fascia thickness and stiffness in CECS and controls.[8]

Other hypotheses regarding the source of pain are stimulation of intramuscular pressure receptors, stimulation of stretch receptors or release of metabolic by-products leading to stimulation of pain nerve endings, however these are not clarified.[17] It must be mentioned that, if pain originates from sources other than increased intramuscular pressures, then symptoms will persist despite correct compartment decompression.

## Diagnosis of lower leg dp-CECS and forearm CECS

A typical patient with lower leg dp-CECS is a young athlete reporting progressive pain in areas dorsomedial to the medial border of the tibial bone. Moreover, he may also feel pain deep into the calf muscles during exercise. Pain is so severe that sports are often terminated prematurely. Pain may be accompanied by cramps and feelings of tightness. Occasionally, altered sensation in the lower leg and foot may be reported suggesting tibial nerve compression. Complaints usually disappear completely in rest. Typical provoking activities are soccer and running. Physical examination is often normal. However, pain may be felt during deep palpation of the medial calf muscles.

The gold standard for the diagnosis of dp-CECS is provided by a dynamic intracompartmental pressure (ICP) measurement. During this procedure, a small flexible slit catheter is inserted via a hollow splittable needle into the deep posterior compartment and fixed onto the skin. Pressures are obtained during rest and after a standard provocative treadmill test using a pressure monitor device. Generally accepted pressure cut off criteria are proposed by Pedowitz.[31] A pre-exercise pressure ≥15 mm Hg, or a 1-minute postexercise pressure ≥30 mm Hg or a 5-minute postexercise pressure ≥20 mm Hg are associated with CECS.[31] Some doubt the absolute value of these cut-off points as they were originally obtained from a retrospective, heterogeneous series of patients with just a lower leg ant-CECS.[35] Other modalities such as MRI or near-infrared spectroscopy were promising in patients with ant-CECS. However, diagnosing dp-CECS is a different story.

In the forearm, the complex of CECS symptoms is highly similar as observed in lower leg CECS. Progressive pain accompanied by tight feelings, cramps, arm "fullness" and muscle weakness of forearm and hand may be reported. Almost all patients are engaged in motocross racing. The syndrome is usually bilateral as the steering bar needs constant control and stabilization without an opportunity to relax the lower arms. If a forearm CECS is suspected, muscle compartment pressure measurements are also considered gold standard. Again, the Pedowitz criteria are frequently used. Others proposed resting pressures >10 mm Hg and a pressure normalization time exceeding 15 minutes as abnormal.[13,14] Deep flexor compartment pressures between 15-30 mm Hg during recovery after maximal stress testing are also highly suggestive of forearm CECS as well as an ICP above 30 mmHg.[7,37]

A number of aspects of the diagnosis CECS are unclear. For example, the accuracy of catheter placement into the deep posterior compartment is not known. Moreover, it is unknown whether ICP predicts outcome after treatment.

### Treatment of lower leg dp-CECS

Potential other contributing factors and overlapping disease such as medial tibial stress syndrome (MTSS) must be identified.[20] Once excluded, most patients with lower leg dp-CECS report attempts of conservative treatment regimens including reduced exercise and deep massage therapy.[28,46,48] Dry needling or prolotherapy may occasionally be helpful.[20] However, conservative strategies may fail, especially when reducing sports activities is no option in professional athletes. Therefore, a fasciotomy entailing incision of fascias covering the superficial and deep flexor compartment is widely considered gold standard of invasive treatment.[47] Unlike anterior CECS, results after fasciotomy for dp-CECS are reportedly modest, with success rates ranging from 33% to 65%.[16,34,45] However, short- and long-term results after surgery for dp-CECS have only been reported retrospectively in small, heterogeneous patient populations. To date, prospective studies on efficacy of surgery for dp-CECS are not available.

### Treatment of forearm CECS

If conservative modalities for forearm-CECS are unsuccessful, treatment is classically surgical. Results are excellent although long-term results are scarce. Moreover, it is unknown whether a small-incision fasciotomy is superior compared to a wide-open fasciotomy or an endoscopic fasciotomy.

## GENERAL AIM OF THESIS

General aim of this thesis was to study several aspects of diagnosis and treatment of deep posterior lower leg chronic exertional compartment syndrome (dp-CECS) and to study results after surgical treatment of forearm flexor muscles CECS.

## SPECIFIC AIMS

1. To provide a critical analysis of the existing literature on the surgical management of lower leg dp-CECS.
2. To study whether preoperative intracompartmental pressure measurements predict surgical outcome in lower leg dp-CECS.
3. To study accuracy of catheter placement for intracompartmental pressure measurements in patients suspected of having a dp-CECS.
4. To prospectively assess long term results of fasciotomy in a homogeneous population with dp-CECS.
5. To assess long term results of fasciotomy in patients with forearm flexor CECS.

# OUTLINE



Compared to lower leg ant-CECS, outcomes after fasciotomy for lower leg dp-CECS are generally poor. Currently reported surgical approaches for dp-CECS are highly diverse whereas factors influencing suboptimal outcomes are unknown. A systematic review providing a critical analysis of existing literature on surgical management for dp-CECS is reported in **chapter 2**.

A dynamic intracompartmental pressure (ICP) measurement before and after a standard provocative treadmill test is considered gold standard for the diagnosis of dp-CECS. Whether characteristics of ICP are related to outcome is unknown. Patient selection may be optimized once an ICP has predictive properties. In **chapter 3**, the prognostic value of an ICP curve in patients operated for lower leg dp-CECS is analyzed.

Insertion of an ICP catheter in the deep posterior compartment of the lower leg is usually guided by anatomical landmarks (‘free hand technique’). However, accuracy of a free hand insertion was not previously studied. Inaccurate placement may lead to faulty patient selection. **Chapter 4** describes a study aimed at determining accuracy of deep posterior compartment catheter placement using MRI analysis.

Prospectively acquired long-term results after surgery for dp-CECS were never reported. **Chapter 5** describes the first prospective trial in a homogeneous group of patients after surgery for lower leg dp-CECS.

Studies describing long-term results after fasciotomy for forearm CECS are scarce. It is unknown whether a fascio-tomy or a fasciec-tomy is superior in forearm CECS. In **chapter 6**, long-term effects of two surgical techniques for forearm flexor CECS are studied in a group of motocross racers.

**Chapter 7** reports on a unique case of a motorcyclist racer undergoing surgery for a combined forearm flexor and extensor CECS. A literature review and a surgical 'how-to' for correct release of the forearm extensor and deep flexor compartments are provided.

A summarizing discussion and future perspectives are provided in **chapter 8**. A valorization addendum is described in **chapter 9**. In **chapter 10**, a Dutch summary is provided. Acknowledgements, publications and a curriculum vitae of the author are listed at the end of this thesis.

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# REFERENCES


1. Amendola A, Rorabeck CH, Vellett D, Vezina W, Rutt B, Nott L. The use of magnetic resonance imaging in exertional compartment syndromes. *Am J Sports Med.* 1990;18(1):29-34.
2. Balduini FC, Shenton DW, O'Connor KH, Heppenstall RB. Chronic exertional compartment syndrome: correlation of compartment pressure and muscle ischemia utilizing 31P-NMR spectroscopy. *Clin Sports Med.* 1993;12(1):151-165.
3. Barbour TD, Briggs CA, Bell SN, Bradshaw CJ, Venter DJ, Brukner PD. Histology of the fascial-periosteal interface in lower limb chronic deep posterior compartment syndrome. *Br J Sports Med.* 2004;38(6):709-717.
4. Barrera-Ochoa S, Haddad S, Correa-Vazquez E, et al. Surgical Decompression of Exertional Compartment Syndrome of the Forearm in Professional Motorcycling Racers: Comparative Long-term Results of Wide-Open Versus Mini-Open Fasciotomy. *Clin J Sport Med.* 2016;26(2):108-14.
5. Black KP, Taylor DE. Current concepts in the treatment of common compartment syndromes in athletes. *Sports Med.* 1993; 15(6):408-418.
6. Blackman PG. A review of chronic exertional compartment syndrome in the lower leg. *Med Sci Sports Exerc.* 2000;32(3 Suppl):S4-10.
7. Brown JS, Wheeler PC, Boyd KT, Barnes MR, Allen MJ. Chronic exertional compartment syndrome of the forearm: a case series of 12 patients treated with fasciotomy. *J Hand Surg Eur Vol.* 2011;36(5):413-419.
8. Dahl M, Hansen P, Stal P, Edmundsson D, Magnusson SP. Stiffness and thickness of fascia do not explain chronic exertional compartment syndrome. *Clin Orthop Relat Res.* 2011;469(12):3495-3500.
9. Detmer DE, Sharpe K, Sufit RL, Girdley FM. Chronic compartment syndrome: diagnosis, management, and outcomes. *Am J Sports Med.* 1985;13(3):162-170.
10. Duckworth AD, Mitchell SE, Molyneux SG, White TO, Court-Brown CM, McQueen MM. Acute compartment syndrome of the forearm. *J Bone Joint Surg Am.* 2012; 94(10):e63.
11. Findley TW. Second international fascia research congress. *Int J Ther Massage Bodywork.* 2009;2(2):1-6.
12. Freedman BJ. Dr. Edward Wilson of the Antarctic; a biographical sketch, followed by an inquiry into the nature of his last illness. *Proc R Soc Med.* 1954;47(3):183-189.
13. Garcia-Mata S. Chronic exertional compartment syndrome of the forearm in adolescents. *J Pediatr Orthop.* 2013;33(8): 832-837.
14. Garcia Mata S, Hidalgo Ovejero A, Martinez Grande M. Bilateral, chronic exertional compartment syndrome of the forearm in two brothers. *Clin J Sport Med.* 1999;9(2):91-99.
15. George CA, Hutchinson MR. Chronic exertional compartment syndrome. *Clin Sports Med.* 2012;31(2):307-319.
16. Howard JL, Mohtadi NG, Wiley JP. Evaluation of outcomes in patients following surgical treatment of chronic exertional compartment syndrome in the leg. *Clin J Sport Med.* 2000;10(3):176-184.
17. Humphries D. Exertional compartment syndromes. *Medscape general medicine* 1999;1(2). http://www.medscape.com/viewarticle/717391_4.
18. Hutchinson MR, Ireland ML. Common compartment syndromes in athletes. Treatment and rehabilitation. *Sports Med.* 1994;17(3):200-208.
19. Jans C, Peersman G, Peersman B, Van Den Langenbergh T, Valk J, Richart T. Endoscopic decompression for chronic compartment syndrome of the forearm in motocross racers. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(9):2522-7.
20. Khan K, Brukner P. *Brukner & Khan's Clinical Sports Medicine*. 4th ed: McGraw-Hill Education; 2011.
21. Kostler W, Strohm PC, Sudkamp NP. Acute compartment syndrome of the limb. *Injury.* 2005;36(8):992-998.
22. Kwong EH, Findley TW. Fascia: Current knowledge and future directions in physiatry: narrative review. *J Rehabil Res Dev.* 2014; 51(6):875-884.
23. Langevin HM, Huijing PA. Communicating about fascia: history, pitfalls, and recommendations. *Int J Ther Massage Bodywork.* 2009;2(4):3-8.
24. Lee CH, Lee KH, Lee SH, Kim YS, Chung US. Chronic exertional compartment syndrome in adductor pollicis muscle: case report. *J Hand Surg Am.* 2012;37(11):2310-2312.

25. Martens MA, Backaert M, Vermaut G, Mulier JC. Chronic leg pain in athletes due to a recurrent compartment syndrome. *Am J Sports Med.* 1984;12(2):148-151.
26. Matsen FA, 3rd, Winquist RA, Krugmire RB, Jr. Diagnosis and management of compartmental syndromes. *J Bone Joint Surg Am.* 1980;62(2):286-291.
27. Mavor GE. The anterior tibial syndrome. *J Bone Joint Surg Br.* 1956;38-b(2):513-517.
28. Micheli LJ, Solomon R, Solomon J, Plasschaert VF, Mitchell R. Surgical treatment for chronic lower-leg compartment syndrome in young female athletes. *Am J Sports Med.* 1999; 27(2):197-201.
29. Mohler LR, Styf JR, Pedowitz RA, Hargens AR, Gershuni DH. Intramuscular deoxygenation during exercise in patients who have chronic anterior compartment syndrome of the leg. *J Bone Joint Surg Am.* 1997;79(6):844-849.
30. Orava S, Rantanen J, Kujala UM. Fasciotomy of the posterior femoral muscle compartment in athletes. *Int J Sports Med.* 1998;19(1):71-75.
31. Pedowitz R, Hargens A, Mubarak S, Gershuni D. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med.* 1990;18(1):35-40.
32. Puranen J. The medial tibial syndrome: exercise ischaemia in the medial fascial compartment of the leg. *J Bone Joint Surg Br.* 1974;56-b(4):712-715.
33. Qvarfordt P, Christenson JT, Eklof B, Ohlin P, Saltin B. Intramuscular pressure, muscle blood flow, and skeletal muscle metabolism in chronic anterior tibial compartment syndrome. *Clin Orthop Relat Res.* 1983(179): 284-290.
34. Rorabeck C, Fowler P, Nott L. The results of fasciotomy in the management of chronic exertional compartment syndrome. *Am J Sports Med.* 1988;16(3):224-227.
35. Roscoe D, Roberts AJ, Hulse D. Intramuscular compartment pressure measurement in chronic exertional compartment syndrome: new and improved diagnostic criteria. *Am J Sports Med.* 2015;43(2):392-398.
36. Schleip R, Jager H, Klingler W. What is 'fascia'? A review of different nomenclatures. *J Bodyw Mov Ther.* 2012;16(4):496-502.
37. Schoeffl V, Klee S, Strecker W. Evaluation of physiological standard pressures of the forearm flexor muscles during sport specific ergometry in sport climbers. *Br J Sports Med.* 2004;38(4):422-425.
38. Soderberg TA. Bilateral chronic compartment syndrome in the forearm and the hand. *J Bone Joint Surg Br.* 1996;78(5):780-782.
39. Standring S, Borley NR. *Gray's Anatomy: The Anatomical Basis of Clinical Practice*: Churchill Livingstone/Elsevier; 2008.
40. Stecco C, Macchi V, Porzionato A, et al. The ankle retinacula: morphological evidence of the proprioceptive role of the fascial system. *Cells Tissues Organs.* 2010;192(3):200-210.
41. Styf J. Chronic exercise-induced pain in the anterior aspect of the lower leg. An overview of diagnosis. *Sports Med.* 1989;7(5):331-339.
42. Styf J, Korner L, Suurkula M. Intramuscular pressure and muscle blood flow during exercise in chronic compartment syndrome. *J Bone Joint Surg.* 1987;69(2):301-305.
43. Turnipseed WD, Hurschler C, Vanderby R, Jr. The effects of elevated compartment pressure on tibial arteriovenous flow and relationship of mechanical and biochemical characteristics of fascia to genesis of chronic anterior compartment syndrome. *J Vasc Surg.* 1995;21(5):810-816; discussion 816-817.
44. Vaillancourt C, Shrier I, Vandal A, et al. Acute compartment syndrome: how long before muscle necrosis occurs? *CJEM.* 2004;6(3): 147-154.
45. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR. Chronic deep posterior compartment syndrome of the leg in athletes: postoperative results of fasciotomy. *Int J Sports Med.* 2008;29(5):419-423.
46. Winkes MB, Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Compartment pressure curves predict surgical outcome in chronic deep posterior compartment syndrome. *Am J Sports Med.* 2012;40(8):1899-1905.
47. Winkes MB, Hoogeveen AR, Scheltinga MR. Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. *Br J Sports Med.* 2014;48(22):1592-1598.
48. Winkes MB, van Zantvoort AP, de Bruijn JA, et al. Fasciotomy for Deep Posterior Compartment Syndrome in the Lower Leg: A Prospective Study. *Am J Sports Med.* 2016 May;44(5):1309-1316.

49. Zhang Q, Styf J. Abnormally elevated intramuscular pressure impairs muscle blood flow at rest after exercise. *Scand J Med Sci Sports.* 2004;14(4):215-220.

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# CHAPTER 2

# IS SURGERY EFFECTIVE FOR DEEP POSTERIOR COMPARTMENT SYNDROME OF THE LEG? A SYSTEMATIC REVIEW

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# ABSTRACT

**Background**
Results of surgery for lower leg deep posterior chronic exertional compartment syndrome (dp-CECS) are inferior compared to other types of CECS. Factors influencing suboptimal surgical results are unknown. The purpose of this systematic review was to provide a critical analysis of the existing literature on the surgical management of dp-CECS aimed at identifying parameters determining surgical results.

**Methods**
A literature search was performed using Pubmed, EMBASE, MEDLINE and CINAHL (EBSCO). Studies including surgical results for dp-CECS were systematically reviewed.

**Results**
Seven studies of level III evidence reporting on a total of 131 patients met inclusion criteria (>5 patients, reporting intracompartmental pressures [ICP], clearly stating postoperative outcome). Only four studies strictly adhered to predefined ICP criteria. Cutoff ICP levels varied widely among the 7 studies. Surgical procedures ranged from a superficial crural fasciotomy to multiple fasciotomies of various deep posterior compartments. No single surgical procedure proved superior. Prolonged high ICP levels following provocation were associated with postoperative success. Success rates after fasciotomy were modest ranging from 33% to 65%. Risk factors for failure of surgery were not identified.

**Conclusions**
The quality of studies reporting on surgery for dp-CECS is poor. Prospective, controlled or randomized studies are lacking. Diagnostic criteria and surgical techniques are diverse. As functional results of current management regimes are disappointing, future studies of dp-CECS should focus on optimising diagnostic criteria and standardisation of treatment modalities.

# INTRODUCTION

Deep posterior chronic exertional compartment syndrome (dp-CECS) of the lower leg is a common cause of exercise-related pain in young endurance athletes, especially runners.[29] CECS most commonly occurs in the anterior compartment (40-60%). However, the deep posterior (32-60%) or the lateral compartment (12-35%) of lower legs may also be affected.[10,20,23]

A dp-CECS is defined as "a condition where abnormally elevated intramuscular pressure induced by exercise impedes local blood flow impairing neuromuscular tissue function within the deep posterior compartment".[4,39,57] Patients with a dp-CECS typically experience progressive pain deep into the calf muscles leading to premature termination of the exertion. Pain is often accompanied by tightness, cramps and altered sensibility.[51] There is controversy on the most appropriate terminology describing the condition. Various terms were proposed including 'shin splints',[26,31] 'fresher's leg',[2] 'medial tibial syndrome',[26] 'medial compartment syndrome',[24] 'chronic compartment syndrome'[10,23,43] and 'exertional compartment syndrome'.[14,15] The present review uses the term 'deep posterior CECS' (dp-CECS).

Exertional compartment syndromes were first described more than half a century ago. A deep posterior variant was described in 1974, which was termed 'the medial tibial syndrome'.[26] A series of 11 athletes reported pain at an area medial to the lower leg tibial bone towards the end of a run. It was found that the syndrome was due to increasing tissue pressures in the deep flexor muscles compartment. A variant of the chronic dp-CECS was identified in 1986. This type was not caused by increasing tissue pressures but symptoms were exclusively characterized by tenderness of the medial tibial bone itself, and is currently known as a medial tibial stress syndrome (MTSS).[2,22]

The prevalence of dp-CECS in a general population is not known. A substantial portion of athletes probably decrease their activity to a level that they can manage and never seek medical attention. Moreover, the syndrome is likely underdiagnosed as awareness among trainers and physicians is poor. Some have estimated that up to one of every seven young athletes with exercise-related lower leg pain suffers from CECS.[27] Of this group, 30% is found to harbour a dp-CECS.[29]

A dynamic intracompartmental pressure measurement (ICP) is considered mandatory for establishing the diagnosis. According to generally accepted criteria, a ≥15 mm Hg resting pressure or a ≥30 mm Hg 1-minute postexercise pressure or a ≥20 mm Hg 5-minute postexercise pressure serve as cutoff points.[23,38,40]

Many conservative treatment options were proposed including physical therapy, icing, dynamic cupping therapy, compressing stockings or orthotics, but these strategies are often unsuccessful.[51] Only prolonged rest offers some relief in most cases, but this approach is rejected by most athletes as an unacceptable alternative to their lifestyle.[21]

A fasciotomy entailing incision of both fascias covering the superficial and the deep flexor compartment is widely considered as the gold standard for invasive treatment. Some authors advocate an additional partial fasciectomy by removing a strip of fascial tissue, particularly in case of recurrent dp-CECS.[12,16,38,42-43] Others proposed an extended fasciotomy with additional release of the tibialis posterior muscle as this muscle sometimes contains its own fascia, thereby acting as a subcompartment within the deep flexor compartment.[9,31,32,35,53] However, short-term and long-term success rates after surgery are still modest ranging from 33% to 65%.[16,31,47,51]

The objective of this review is to provide a critical analysis of the existing literature on the surgical management of dp-CECS aimed at identifying parameters determining surgical results.



# MATERIALS AND METHODS

## Literature search

PubMed, EMBASE, MEDLINE and CINAHL (EBSCO) were searched from their earliest entry points to June 26, 2012 using step 1 to 7 as listed in Table 2.1.

**TABLE 2.1**
Seven initial steps of literature search on lower leg deep posterior chronic exertional compartment syndrome.

| Step | Keywords/Mesh terms | PubMed | MEDLINE | EMBASE | CINAHL |
|---|---|---|---|---|---|
| 1 | "compartment syndrome" OR "chronic compartment syndrome" OR "exertional compartment syndrome" OR "chronic exertional compartment syndrome" OR "lower-leg compartment syndrome" OR "compartment syndromes" OR "tibialis posterior" OR "deep posterior" | 5972 | 5796 | 8398 | 1396 |
| 2 | "Fasciotomy" OR "Fasciectomy" | 1792 | 1716 | 3571 | 240 |
| 3 | #1 AND #2 | 887 | 847 | 1730 | 147 |
| 4 | Limit to English and humans | 661 | 677 | 1359 | Limit to humans impossible |
| | Limit to Full text (EMBASE only) | | | 358 | |
| 5 | Combined results, removal of duplicates | | 883 | | |
| 6 | Exclusion of abdominal compartment syndrome (n = 30) | | 853 | | |
| 7 | Exclusion of acute compartment syndrome (based on title) (n = 592) | | 261 | | |

About 261 potential articles were identified on completion of steps 1-7. Based on this large collection of articles, reports were eligible for inclusion if the following criteria were met:

1. Undergoing surgery for lower leg dp-CECS;
2. Reporting absolute numbers of elevated compartmental pressures;
3. Clearly stating postoperative outcome;
4. Including > 5 patients;
5. Full paper.



Twenty-seven articles were deemed possibly eligible on the basis of the abstract.[1-3, 10,12,14,16-17,18-20,22-24,28,31,34,36,38,41-43,47,49-51,54] Reference lists of these articles yielded 5 additional articles.[9,26,21,25,32] Five reviews were excluded as novel patient data were absent.[1,4,31,41,55] A detailed study of the remaining 27 articles indicated that 20 did not meet all criteria (Table 2.2).[2,9,10,14,16-18,20,21,24-26,28,31,38,41-43,49, 50] Therefore, the present review is based on data provided by seven articles.[3,23,32,34,36,47,51]

## Data collection

During line-by-line reading of included articles, all relevant data were inserted by the first author into a Excel spreadsheet (Microsoft, Redmond, Washington, 2008) using different tabs. These tabs contained information on demographics, patient history, physical examination, ICP, operative details, postoperative outcomes and prognostic factors. Questions regarding data interpretation were solved on the basis of consensus with the senior author. Studies were scored for level of evidence.[55] Postoperative outcomes included severity of symptoms were reported using a visual analogue scale (VAS) or verbal rating scale (VRS). Outcome was termed excellent, good, fair or poor as followed in three studies (Table 2.3).[36,47,51]

**TABLE 2.2**

Details of 27 full papers reporting on surgery for lower leg deep posterior chronic exertional compartment syndrome.

| Study | Description of (elevated) deep flexor compartmental pressures | Postoperative outcome clearly stated | >5 patients | Full paper | Inclusion in present review |
|---|---|---|---|---|---|
| Puranen et al.[26] | Yes | No | Yes | Yes | No |
| Puranen et al.[24] | Yes | No | Yes | Yes | No |
| Wallensten et al.[50] | No | Yes | Yes | Yes | No |
| Rorabeck et al.[32] | Yes | Yes | Yes | Yes | Yes |
| Davey et al.[9] | Yes | Yes | No | Yes | No |
| Martens et al.[20] | Yes | No | Yes | Yes | No |
| Wallensten et al.[49] | Yes | No | Yes | Yes | No |
| Detmer et al.[10] | No (only means of all CECS reported) | Yes | Yes | Yes | No |
| Allen et al.[2] | Yes | No | Yes | Yes | No |
| Rorabeck et al.[34] | Yes | Yes | Yes | Yes | Yes |
| Rorabeck et al.[31] | No (only means of all CECS reported) | Yes | Yes | Yes | No |
| Jarvinnen et al.[17] | No | Yes | Yes | Yes | No |
| Turnipseed et al.[41] | No | No | Yes | Yes | No |
| Pedowitz et al.[23] | Yes | Yes | Yes | Yes | Yes |
| Puranen et al.[25] | No | No | Yes | Yes | No |
| Schepsis et al.[36] | Yes | Yes | Yes | Yes | Yes |
| Biedert et al.[3] | Yes | Yes | Yes | Yes | Yes |
| Micheli et al.[21] | No | Yes | Yes | Yes | No |
| Howard et al.[16] | No | Yes | No | Yes | No |
| Slimmon et al.[38] | No | Yes | Yes | Yes | No |
| Turnipseed et al.[43] | No | No | Yes | Yes | No |
| Turnipseed et al.[42] | No | No | Yes | Yes | No |
| Raikin et al.[28] | Yes | No | Yes | Yes | No |
| Edmundsson et al.[14] | No | No | Yes | Yes | No |
| Lohrer et al.[18] | No | Yes | Yes | Yes | No |
| van Zoest et al.[47] | Yes | Yes | Yes | Yes | Yes |
| Winkes et al.[51] | Yes | Yes | Yes | Yes | Yes |

2

2

**TABLE 2.3**
Grading of treatment results following surgery for lower leg deep posterior chronic exertional compartment syndrome.[36]

| Outcome | Criteria |
|---|---|
| Excellent | No pain during or after exercise |
| | No limitation of duration and extent of exercise |
| | Patient considers him/herself "cured" |
| Good | Minimal discomfort or soreness during/after exercise |
| | No limitation of duration and extent of exercise |
| | Significantly improved |
| | Glad to have had surgery |
| Fair | Pain with running/exercise or afterward |
| | Still has limitations |
| | Recurrence of symptoms |
| | Only slight improvement |
| Poor | Unchanged or worse |
| | Complications |

# RESULTS

## Literature search

Seven studies met all 5 inclusion criteria. All studies were of Level III evidence. The earliest study was performed in 1983, whereas the most recent was published in 2012. Data collection periods ranged from 1978 to 2010.

## Demographic data

Demographic data are summarized in Table 2.4. Approximately 131 patients with dp-CECS were identified. Gender was specified in four articles including 45 men and 39 women. The remaining three studies did not specify gender in their dp-CECS population but a male-to-female ratio was provided for their total CECS cohort. (male:female; 9:3,[32] 29:17,[47] and male: 55.6%[23]). Overall, slightly more men were operated compared to women. Mean ages ranged from 22 to 35 years, the youngest being 18 years.

Sports frequently associated with dp-CECS were running/athletics (62/116, 53%).[3,32,34,36,47,51] Soccer, swimming, ice-skating, field hockey, lacrosse, basketball, diving, turning, fitness, horseback-riding and dancing were also reported.

Duration of symptoms prior to diagnosis was 16 months (range, 6-28), 22 months (range, 0.8-98) and 53 months (range, 12-180), respectively.[3,23,36] Time from onset of symptoms to surgery was reported in just one study and was >24 months in 46%, 12 to 24 months in 25% and <12 months in 29% of the patients.[51] Minimum of follow-up was 3 months with mean ranging from 8 months to 4 years.

**TABLE 2.4**

Demographical data of seven studies on deep posterior chronic exertional compartment syndrome fulfilling inclusion criteria.[a]

| Author | Collection period | Design | Level of Evidence | Type Compartment (n patients) | dp-CECS patients (and compartments) | Sex (M:F) | Length of Follow-up |
|---|---|---|---|---|---|---|---|
| Rorabeck[32] 1983 | 1981 - 1983 | Retrospective case series | III | MTA/Pe (7)<br>MTA/DP (2)<br>DP (3) | 5 (10) | NP | 1 year (6-24 months) |
| Rorabeck[34] 1986 | NP | Retrospective case series | III | DP (5) | 5 | 3:2 | 6-24 months |
| Pedowitz[23] | 1978 - 1987 | Retrospective cohort | III | 80 (45, CECS+) vs. 210 (75, CECS-) | (15) in CECS+ group | NP | 8 months (6 months - 9 years) |
| Schepsis[36] | 1982 - 1990 | Retrospective cohort | III | MTA (16)<br>DP (12) | 12 (20) | 5:7 | 4 years (1-7.4) |
| Biedert[3] | 1988 - 1994 | Retrospective cohort | III | DP (15) vs. control (9) | 15 | 14:1 | 27 ± 9 months (8-72) |
| van Zoest[47] | 2000 - 2003 | Retrospective cohort | III | DP (27) vs. control (19) | 27 | NP | 36 ± 4 months (19-44) |
| Winkes[51] | 1996 - 2010 | Retrospective cohort | III | DP (52) | 52 | 23:29 | 39 ± 24 months (3-89) |
| **Total** | **1978 - 2010** | | | **287** | **116+15** | **45:39** | |

[a] MTA, anterior tibial muscle compartment; Pe, peroneal compartment; DP, deep posterior compartment; NP, not provide.

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## Symptomatology

During rest, all patients were free of symptoms. When performing provocative activities, principal symptoms were pain[3,23,32,34,47,51] (severe, 49%; moderate, 41%; mild, 6%; no pain, 4%) and tightness[51] (severe, 62%; moderate, 32%; mild, 6%; no tightness, 10%). Pain usually started within 30 minutes of exercise and was located along the posteromedial tibial border, often radiating towards the back of the ankle joint or deep into the calf muscles. One study described pain as aching (31%), dull (24%), sharp (20%), pressure (20%), cramping (8%) or unknown (18%).[23]



Moderate or severe cramps were reported in 31% and 29% of cases, respectively. Diminished sensibility was present in 27% (severe) and 23% (moderate), whereas muscle weakness was severe in 12% and moderate in 31%.[51] Other symptoms such as fullness or loss of coordination were also reported.[32,47] Severity of symptoms consistently interfered with athletic performance forcing patients to often stop their activity (52%).[51] Maximum duration of symptomatology was not provided.

## Physical examination

Physical examination was reported in just 2 studies.[23,32] Patients did not report tenderness but rather a vague discomfort during palpation along the posteromedial border of tibia.[32] Neurological signs were absent. A second study reporting on a heterogeneous group of CECS (n=45) found that compartments were tender to palpation in 73% of the cases.[23]

## Diagnostic intracompartmental pressure techniques

Three studies routinely used imaging techniques (X-ray, bone scans) to exclude stress fractures or a medial tibial stress syndrome (MTSS) in some[3,36] or all[32] of the patients.

Four studies adhered to ICP cutoff points for diagnosing CECS (Table 2.5).[23,36,47,51] The three remaining studies did not use cutoff points but relied on the clinical picture supported by pressure characteristics.[3,32,34] Six[3,23,32,34,51] studies used a Slit catheter system, a technique currently accepted as the most accurate.[5,33] The seventh study used a microsyringe with transducer connected to a Witscher-Wegmüller portable monitor.[3]

Bilateral pressure measurements were routinely performed in three studies, whereas the most symptomatic leg was measured exclusively in the remaining four studies. Patients were supine with calves free from the table preventing false-positive pressures. One study inserted one needle into the tibialis posterior muscle while a second needle was present in the deep posterior compartment allowing simultaneous pressure readings.[34] Three additional studies used a similar medial approach.[3,36,47] Needle placement was at the junction of middle and distal thirds of the leg at the point where the soleus bridge is assumed to end and where the belly of the flexor digitorum longus muscle was thickest. To avoid harming the posterior tibial artery and nerve, the needle was placed directly dorsally to the medial tibial rim. One study stated that if the medial aspect of the fibular bone was touched, the needle was withdrawn some 5 mm ensuring proper positioning.[51] After the catheter placement sleeve (e.g., the splitting needle itself) was withdrawn, the catheter was taped to the skin. Two studies did not provide the exact technique of needle insertion.[23,32] Measurements were usually performed during rest and 1 and 5 minutes after exercise as depicted in Figure 2.1.

**TABLE 2.5**
Pressure criteria used for diagnosing lower leg deep posterior chronic exertional compartment syndrome (mm Hg).

| | Rest | Immediately after exercise | 1 minute after | 5 minutes after |
|---|---|---|---|---|
| Rorabeck et al.[32] | | | | |
| Rorabeck et al.[34] | | | | |
| Pedowitz et al.[23] | ≥15 | | | ≥25 |
| Schepsis et al.[36] | ≥15 | ≥30 | | ≥20 |
| Biedert et al.[3] | | | | |
| van Zoest et al.[47] | >20 | >25 | >25 | >25 |
| Winkes et al.[51] | ≥15 | ≥30 | | ≥20 |

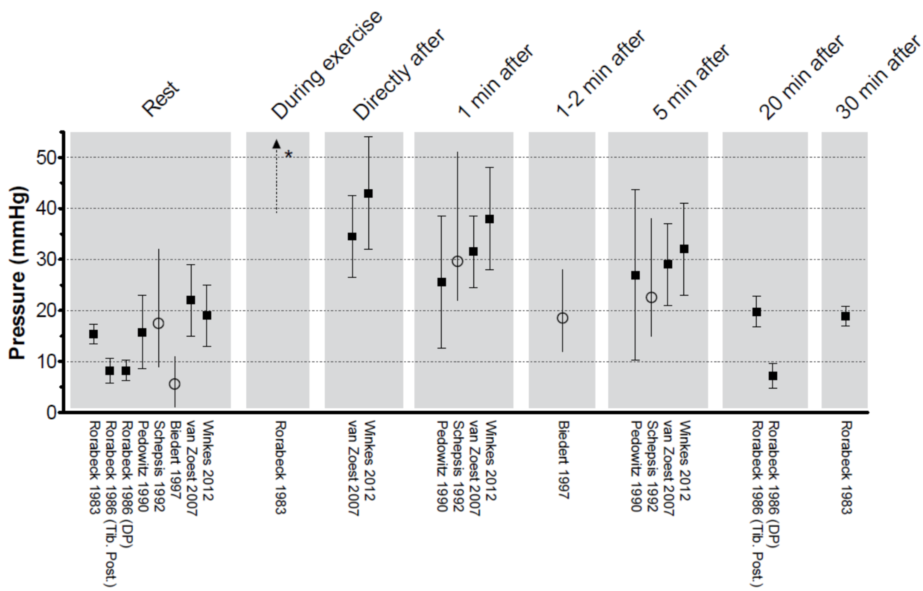


**FIGURE 2.1** Reported intracompartmental pressure in lower leg deep posterior chronic exertional compartment syndrome before and after a standard challenge (squares, mean ± SD; circles, median with min–max). DP, deep posterior compartment; Tib. Post, tibialis posterior muscle. *100 ± 13.2 mm Hg.

## Conservative management

One study found that icing, physical therapy, orthotics or shockwaves had little effect.[51] A second study also reported limited efficacy of a 4-week period of rest, anti-inflammatory drugs or local Xylocaine injections.[32]

Another study described 46 patients who were clinically diagnosed with dp-CECS.[47] Twenty-seven of the 46 patients (the 'high pressure group') underwent surgery, whereas the remaining 19 patients who did not meet the pressure criteria ('low pressure group') received conservative treatment including corrective inlays and physical therapy for at least 6 months. At a 3-year follow-up, six conservatively treated patients (32%) were improved. Interestingly, other diagnoses (herniated disk, n=4; intermittent claudication, n=3; venous disease, n=2; popliteal entrapment syndrome, n=1) were established and successfully treated during this follow-up period in 10 additional patients. The authors advised a conservative approach if ICP values were below cut-off points as other diseases may mimic CECS. The three remaining studies did not report on conservative management strategies.[3,34,36]

## Surgical technique

Six studies used a single 5- to 10-cm posteromedial incision at the transition zone between the middle and distal thirds of the lower leg gaining access to the crural fascia.[3,23,34,36,47,51] In the seventh study, two vertical incisions in the proximal and distal thirds of the lower leg were performed allowing a larger exposure of the superficial and posterior compartments.[32] The crural fascia covering the soleus muscle is bluntly freed of overlying tissue and longitudinally opened using a knife and/or scissors proximally and distally beyond the area of preoperatively marked painfulness. Five studies reported partial release of the soleus muscle from the tibial bone if required.[32,34,36,47,51] This manoeuvre optimalises exposure of proximal portions of the deep posterior compartment. Small transversing vessels require ligation. The fascia covering the flexor digitorum longus muscle is then incised using scissors[32] or a fasciotome described by Due and Nordstrand[13] or a Smillie Knife.[8] An additional fasciotomy is occasionally performed in the presence of a posterior tibial subcompartment.[34,36] The skin is closed in 1-2 layers.

Surgery was performed by one dedicated surgeon,[34,36,47] by several,[51] or was unspecified.[3,23,32] Type of anaesthesia was spinal in two studies[3,47] and mixed general or spinal in a third study.[51] Application of a tourniquet was suggested in an early study,[32] whereas more recent studies either did not state its use or advised not to.[51]

## Rehabilitation protocol

Rehabilitation protocols were specified in 5 studies.[3,32,36,47,51] In general, patients were allowed full range of motion of the ankle joint from the first postoperative day onwards. They were encouraged to walk but jumping or running was prohibited in the 2-week postoperative period. If needed, patients were allowed to use crutches, usually for the first 3 days postoperatively. Jogging was advised in week 4-6, whereas full activity was usually resumed in week 8-12.[36] In one study, patients received compressive stockings day and night for 14 days.[51]

## Outcomes and return to sports

Results after surgery are shown in Table 6. Only two studies provided information on residual symptomatology after surgery.[23,51] The first study reported that pain measured using a VAS decreased by 36 points from 69 ± 27 to 33 ± 27. The postoperative VAS for tight feeling was 36 ± 32 (a 36-point decrease), cramps 26 ± 31 (a 20-point decrease), loss of force 19 ± 23 (a 13-point decrease) and diminished sensibility 23 ± 25 (a 17-point decrease).[51] The second study reported that follow-up was available in 21 of 45 patients. Seven of these 21 patients reported persistent moderate-to-severe pain on the long term. However, 28% of patients described minimal pain, whereas 39% were totally free of pain during exercise. Sixty per cent of these 21 patients returned to their highest level of sports activity. Persistent weakness or numbness was still present in 22%.[23] Interestingly, the two studies in which all patients returned to running were different concerning their surgical technique.[3,34] In one of these studies, the author reported that he retracted the flexor digitorum longus muscle to expose the tibialis posterior muscle followed by a fasciotomy thereof.[34]

## Risk factors and prognostic indicators

One study in 52 patients reported that ICP characteristics were predictive of success.[51] Area-under-a-pressure curve appeared related to immediate postoperative success rates (OR 1.04; 95% CI 1.01 to 1.08). Moreover, differences in ICP between the success and non-success groups were significant in rest, directly and 1 minute after exercise. ICP directly after exercise and a decline in ICP towards 5 minutes after exercise were also prognostic for success (OR 1.06; 95% CI 1.00 to 1.13; and OR 1.11; 95% CI 1.01 to 1.21, respectively). There was no difference in success rates between men (13/23) and women (14/29, $P$=.59). However, long delay prior to surgery predicted an unsuccessful response. Complications (infection, bleeding, antibiotics use, saphenous nerve damage) were not reported in any study.

**TABLE 2.6**
Results after surgery for lower leg dp-CECS.

| | Rorabeck 1983 | Rorabeck 1986 | Pedowitz | Schepsis* | Biedert | Van Zoest | Winkes | |
|---|---|---|---|---|---|---|---|---|
| Postoperative result | | | | | | | *3 months follow-up* | *Long term follow-up* |
| Excellent | | | | 5 (25%) | | 9 (33%) | 7 (14%) | 9 (17%) |
| Good | 2 of 5 patients had recurrence | All symptom free when running (n=5) | Return to highest activity level in 60%, one third (7/21) reported persistent, moderate to severe pain | 8 (40%) | All symptom free when running (n=15) | | 20 (38%) | 16 (31%) |
| Fair | | | | 4 (20%) | | 5 (19%) | 18 (35%) | 27 (52%) |
| Poor | | | | 3 (15%) | | 13 (48%) | 7 (13%) | |

* Numbers represent compartments.

## DISCUSSION

The objective of this review was to provide a critical analysis of the existing literature on surgery for a CECS of the deep flexor compartment of the lower leg (dp-CECS). Surgery for most types of CECS, including tibialis anterior muscle and lower arm, is successful.[48,52] In contrast, outcome for dp-CECS is traditionally considered unpredictable. Erratic functional results following surgery were indeed confirmed by the present analysis. Although inclusion criteria were realistically chosen, only 7 of 32 articles on dp-CECS qualified for analysis. This low inclusion rate illustrates the heterogeneity of study populations. Overall quality of these included studies appeared suboptimal. Prospective, randomised controlled data were not found. Quality and quantity of symptoms/signs that are present in dp-CECS patients remained largely unknown. Reporting of postoperative results is exceedingly diverse, whereas complications associated with the fasciotomy are ignored.



Why are the results for dp-CECS suboptimal? The first reason for disappointing treatment results is the extensive differential diagnosis of exercise-related pain in the medial and deep aspect of the calf. It may be related to muscular/tendon structures (strains, tendinopathy, dp-CECS), vascular (popliteal artery entrapment syndrome [PAES], endofibrotic disease, intermittent claudication, cystic adventitial disease, deep vein thrombosis), bone/periosteum (stress fracture, MTSS, metabolic bone disease), nerve entrapment (peripheral neuropathies, dorsal root disease, herniated disk), or infectious origin (osteomyelitis).[6]

A commonly observed affliction in exercise-related pain in the lower leg is MTSS. A MTSS is characterized by pain on the posteromedial tibial border during exercise, with pain on palpation of the tibia over a length of at least 5 cm. This entity is not caused by increased intramuscular pressure but by overload adaptation of the tibia where bony resorption outpaces bone formation of the tibial cortex.[22] It can be diagnosed clinically and with additional imaging such as MRI, high-resolution CT scan and dual energy X-ray absorptiometry.[22] MTSS is the greatest mimicker of dp-CECS. Moreover, a substantial portion of patients with dp-CECS do demonstrate signs associated with MTSS such as distal tibial bone tenderness.

Also high up in the differential diagnosis of dp-CECS is the PAES. In this condition, compression of the popliteal artery by musculoskeletal structures in the popliteal fossa occurs during exercise. Its incidence is unknown, but PAES is believed to be responsible for a significant proportion of intermittent claudication in young patients and it can even coexist with dp-CECS.[37,42] Due to various anatomical abnormalities that may cause the syndrome, many variants have been described, impingement of the popliteal artery by the medial head of the gastrocnemius muscle being the most common form. Treatment is surgical entailing division of the obstructing structure.

Similar to other types of CECS, symptoms associated with a dp-CECS are gradually progressive lacking an acute start. Most patients appear free of symptoms during rest. The two principal symptoms are pain and loss of proper lower leg function during provocative activities, usually running. The pain frequently starts within 30 minutes of exercise and is experienced along the posteromedial border of the tibia, frequently radiating deep into the calf muscles. Patients may describe tightness, cramps and muscle weakness. However, some patients have trouble in describing the exact location of the discomfort. Symptoms are usually severe forcing most patients to stop their provoking activities. Duration of symptomatology after the challenge may range from minutes to several days and is often related to the time the 'pain is ignored'. Findings at physical examination are uncharacteristic although some perceive a vague discomfort during palpation of soft tissue just dorsal to the posteromedial tibial border. Sensations of pain are less outspoken compared to the typical bony tenderness as observed in a medial tibial stress syndrome. However, dp-CECS and MTSS probably overlap in a substantial number of patients. Neurological signs are almost always absent although skin overlying the medial border of the foot may occasionally be irritated suggesting involvement of medial plantar and medial calcaneal branches of the tibialis posterior nerve. It is advised that potential dp-CECS patients undergo consultation of an orthopedic surgeon, a neurologist and a vascular surgeon as other syndromes as described above may be present. A standardised preoperative evaluation probably aids in optimising patient selection benefitting from surgery.[47]

The role of imaging techniques in diagnosing lower leg dp-CECS is limited to exclusion of other syndromes although findings using near infrared spectroscopy or MRI may suggest anterior CECS.[30,46] Dynamic ICP measurements are universally considered gold standard for dp-CECS. The present review identified a large diversity in ICP criteria. Some rely on cutoff levels including a resting ICP (≥15 mm Hg), a 1 minute measurement after exercise (≥30 mm Hg), or a 5 minute value (≥20 mm Hg).[23] Cutoff criteria for ICP values obtained immediately after termination of the provocation are not used. However, a recent study suggested that this latter ICP value was most predictive of all.[51] A possible explanation of suboptimal surgical results may also be related to these generally accepted ICP criteria. Interestingly, cutoff points were initially derived from a retrospective and heterogeneous group of various types of CECS patients possibly lacking sensitivity and specificity in lower leg dp-CECS. Future studies should focus on unveiling the relationship between characteristics identified by ICP signal analysis and postoperative results per type of CECS.

An important additional reason for suboptimal surgical results is related to type and extent of surgery. The optimal surgical procedure for a dp-CECS is currently unknown. The present review demonstrates that current surgical practice is highly 'expert-dependent'. Length and number of incisions, detachment of the soleus muscle (yes/no), release of the deep posterior compartment (yes/no), additional release of the tibialis posterior muscle (yes/no) or treatment of overlying fascia (fasciotomy/ fasciectomy) is currently left to the surgeon. Optimal sequence of operations in case of a bilateral dp-CECS or a combined anterior CECS/dp-CECS is unknown. Randomised controlled trials comparing different surgical techniques are obviously needed but have not been performed. In this review, we added a step-by-step surgical 'how-to' for correct release of the deep posterior compartment as performed in our practice (Figure 2.2).

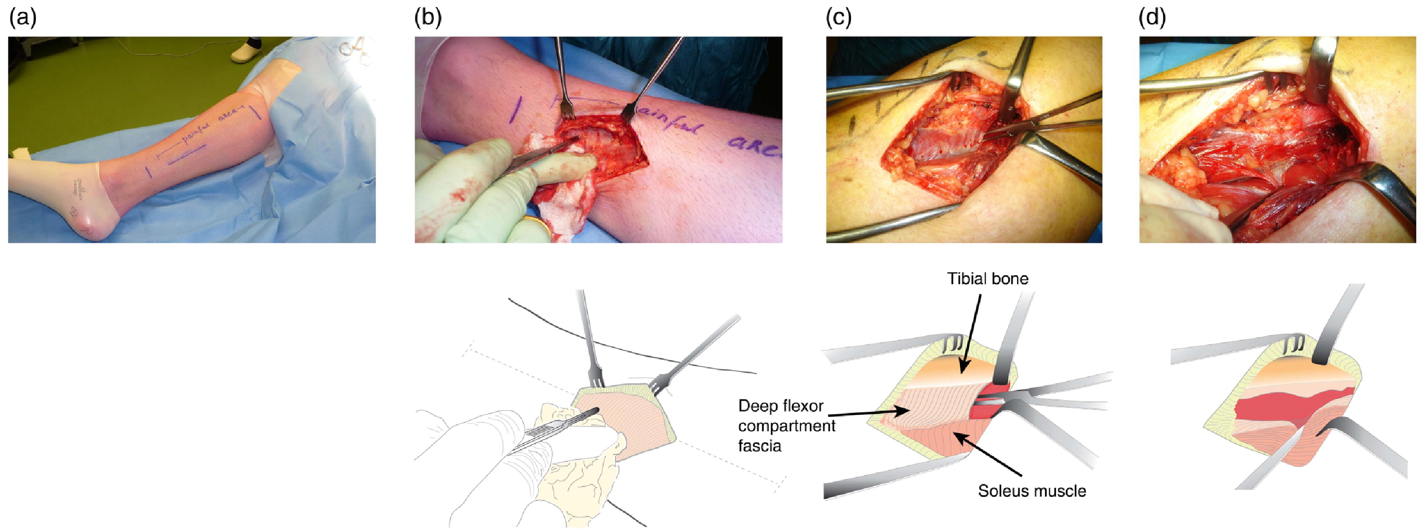


**FIGURE 2.2** Step-by-step surgical ‘how-to’ for correct release of the deep flexor compartment. (A) Prior to surgery, the painful area as indicated by the patient using deep digital palpation is marked onto the skin. A 6- to 8-cm incision just dorsal to the tibial bone is used for access. (B) The crural fascia is freed bluntly from its surrounding tissue using finger fraction. Once free, the fascia is incised and opened proximally and distally using scissors beyond the oblique skin markers indicating the painful area. (C) The soleus muscle is freed from the tibial bone using diathermia. Occasional small oblique vessels are ligated. Following soleal detachment, a direct view of the deep flexor compartment allows inspection. A tight deep compartment fascia overlying the flexor digitorum longus muscle is shown. (D) Flexor digitorum longus muscle protruding from the deep once overlying fascia is incised. Caveat: The anatomy of the deep flexor lower leg compartment may be diverse. Additional inspection and palpation dorsomedial to the flexor digitorum longus muscle may identify separate fascias covering the tibialis posterior muscle and/or the flexor hallucis longus muscle. If present and if deemed too tight, these fascias probably also require incision.

A series of causes possibly explaining disappointing treatment results in lower leg dp-CECS were identified in the current review. An incorrect diagnosis (PAES or MTSS!), possibly unreliable ICP cut-off criteria and a subjective surgical approach based on personal preference may all contribute to surgical failure. Interestingly, this review was based on just seven studies reporting on a mere 131 patients indicating publication bias. All studies were retrospective indicating recall bias. Not one study seriously reported on complications which are much more common and severe compared to surgery for anterior or lateral CECS. Complications are possibly related to increased vascularity of the (released) muscle insertion medial of the tibia compared to the pure fascial release that is performed for anterior CECS. A more extensive type of surgery may in turn increase the risk of postoperative bleeding and cellulitis due to retained and resorbing haematoma.

In conclusion, the quality of studies reporting on surgery for lower leg dp-CECS is limited as prospective data are lacking. Diagnostic criteria and surgical techniques are highly subjective. As results of current invasive management are disappointing, future studies should focus on standardisation of all aspects involved in the diagnostic and therapeutic pathway of dp-CECS.

# REFERENCES


1. Abramowitz AJ, Schepsis AA. Chronic exertional compartment syndrome of the lower leg. *Orthop Rev*. 1994;23:219-25.
2. Allen MJ, Barnes MR. Exercise pain in the lower leg. Chronic compartment syndrome and medial tibial syndrome. *J Bone Joint Surg*. 1986;68-B(5):818-23.
3. Biedert RM, Marti B. Intracompartmental pressure before and after fasciotomy in runners with chronic deep posterior compartment syndrome. *Int J Sports Med*. 1997;18:381-6.
4. Blackman PG. A review of chronic exertional compartment syndrome in the lower leg. *Med Sci Sports Exerc*. 2000;32(3 suppl):S4-10.
5. Boody A, Wongworawat M. Accuracy in the Measurement of Compartment Pressures: a comparison of three commonly used devices. *J Bone Joint Surg*. 2005;87:2415-22.
6. Brewer RB, Gregory AJ. Chronic lower leg pain in athletes: a guide for the differential diagnosis, evaluation, and treatment. *Sports Health*. 2012;4:121-7.
7. Brown JS, Wheeler PC, Boyd KT, Barnes MR, Allen MJ. Chronic exertional compartment syndrome of the forearm: a case series of 12 patients treated with fasciotomy. *J Hand Surg Eur Vol*. 2011;36:413-9.
8. Chin ES, Byron T. Old instrumentation with a new application: Smillie knife. *J Foot Surg*. 1991;30:122-4.
9. Davey JR, Rorabeck CH, Fowler PJ. The tibialis posterior muscle compartment. An unrecognized cause of exertional compartment syndrome. *Am J Sports Med*. 1984;12:391-7.
10. Detmer DE, Sharpe K, Sufit RL, Girdley FM. Chronic compartment syndrome: diagnosis, management, and outcomes. *Am J Sports Med*. 1985;13:162-70.
11. de Fijter WM, Scheltinga MR, Luiting MG. Minimally invasive fasciotomy in chronic exertional compartment syndrome and fascial hernias of the anterior lower leg: short- and long-term results. *Mil Med*. 2006; 171:399-403.
12. Detmer DE. Chronic shin splints. Classification and management of medial tibial stress syndrome. *Sports Med*. 1986;3:436-46.
13. Due J Jr., Nordstrand K. A simple technique for subcutaneous fasciotomy. *Acta Chir Scand*. 1987;153:521-2.
14. Edmundsson D, Toolanen G, Sojka P. Chronic compartment syndrome also affects nonathletic subjects: a prospective study of 63 cases with exercise-induced lower leg pain. *Acta Orthop*. 2007;78:136-42.
15. Edwards P, Myerson MS. Exertional compartment syndrome of the leg: steps for expedient return to activity. *Phys Sportsmed*. 1996;24:31-46.
16. Howard JL, Mohtadi NG, Wiley JP. Evaluation of outcomes in patients following surgical treatment of chronic exertional compartment syndrome in the leg. *Clin J Sport Med*. 2000;10:176-84.
17. Jarvinnen M, Aho H, Niittymaki S. Results of the surgical treatment of the medial tibial syndrome in athletes. *Int J Sports Med*. 1989;10:55-7.
18. Lohrer H, Nauck T. Endoscopically assisted release for exertional compartment syndromes of the lower leg. *Arch Orthop Trauma Surg*. 2007;127:827-34.
19. Lutz LJ, Goodenough GK, Detmer DE. Chronic compartment syndrome. *Am Fam Physician*. 1989;39:191-6.
20. Martens MA, Backaert M, Vermaut G,Mulier JC. Chronic leg pain in athletes due to a recurrent compartment syndrome. *Am J Sports Med*. 1984;12(2):148-51.
21. Micheli LJ, Solomon R, Solomon J, Plasschaert VF, Mitchell R. Surgical treatment for chronic lower-leg compartment syndrome in young female athletes. *Am J Sports Med*. 1999;27:197-201.
22. Moen MH, Tol JL, Weir A, Steunebrink M, De Winter TC. Medial tibial stress syndrome: a critical review. *Sports Med*. 2009;39:523-46.
23. Pedowitz RA, Hargens AR, Mubarak SJ, Gershuni DH. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med*. 1990;18(1):35-40.
24. Puranen J, Alavaikko A. Intracompartmental pressure increase on exertion in patients with chronic compartment syndrome in the leg. *J Bone Joint Surg Am*. 1981;63:1304-9.
25. Puranen J. The medial tibial syndrome. *Ann Chir Gynaecol*. 1991;80:215-8.
26. Puranen J. The medial tibial syndrome: exercise ischaemia in the medial fascial compartment of the leg. *J Bone Joint Surg Br*. 1974;56-B(4):712-5.

27. Qvarfordt P, Christenson JT, Eklof B, Ohlin P, Saltin B. Intramuscular pressure, muscle blood flow, and skeletal muscle metabolism in chronic anterior tibial compartment syndrome. *Clin Orthop Relat Res*. 1983;(179): 284-90.
28. Raikin SM, Rapuri VR, Vitanzo P. Bilateral simultaneous fasciotomy for chronic exertional compartment syndrome. *Foot Ankle Int*. 2005;26:1007-11.
29. Reinking MF. Exercise related leg pain (ERLP): a review of the literature. *North Am J Sports Phys Ther*. 2007;2:170-80.
30. Ringler MD, Litwiller DV, Felmlee JP,Shahid KR, Finnoff JT, Carter RE, Amrami KK. MRI accurately detects chronic exertional compartment syndrome: a validation study. *Skeletal Radiol*. 2013;42:385-92.
31. Rorabeck CH, Fowler PJ, Nott L. The results of fasciotomy in the management of chronic exertional compartment syndrome. *Am J Sports Med*. 1988;16(3):224-7.
32. Rorabeck CH, Bourne RB, Fowler PJ. The surgical treatment of exertional compartment syndrome in athletes. *J Bone Joint Surg Am*. 1983;65:1245-51.
33. Rorabeck CH, Castle GS, Hardie R*, et al.* Compartmental pressure measurements: an experimental investigation using the slit catheter. *J Trauma*. 1981;21:446-9.
34. Rorabeck CH. Exertional tibialis posterior compartment syndrome. *Clin Orthop Relat Res*. 1986;208:61-4.
35. Ruland RT, April EW, Meinhard BP. Tibialis posterior muscle: the fifth compartment? *J Orthop Trauma*. 1992;6:347-51.
36. Schepsis AA, Martini D, Corbett M. Surgical management of exertional compartment syndrome of the lower leg. Long-term followup. *Am J Sports Med*. 1993;21:811-7; discussion 7.
37. Sinha S, Houghton J, Holt PJ*,Thompson MM, Loftus IM, Hinchliffe RJ.*Popliteal entrapment syndrome. *J Vasc Surg*. 2012;55:252-62 e30.
38. Slimmon D, Bennell K, Brukner P, Crossley K, Bell SN. Long-term outcome of fasciotomy with partial fasciectomy for chronic exertional compartment syndrome of the lower leg. *Am J Sports Med*. 2002;30:581-8.
39. Styf J, Korner L, Suurkula M. Intramuscular pressure and muscle blood flow during exercise in chronic compartment syndrome. *J Bone Joint Surg*. 1987;69(2):301-5.
40. Tucker AK. Chronic exertional compartment syndrome of the leg. *Curr Rev Musculoskelet Med*. 2010;3:32-7.
41. Turnipseed W, Detmer DE, Girdley F. Chronic compartment syndrome. An unusual cause for claudication. *Ann Surg*. 1989;210:557-62.
42. Turnipseed WD. Clinical review of patients treated for atypical claudication: a 28-year experience. *J Vasc Surg*. 2004;40:79-85.
43. Turnipseed WD. Diagnosis and management of chronic compartment syndrome. *Surgery*. 2002;132:613-7; discussion 7-9.
44. Turnipseed WD. Functional popliteal artery entrapment syndrome: a poorly understood and often missed diagnosis that is frequently mistreated. *J Vasc Surg*. 2009;49:1189-95.
45. van den Brand JG, Nelson T, Verleisdonk EJ, van der Werken C. 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*. 2005;33: 699-704.
46. van den Brand JG, Verleisdonk EJ, van der Werken C. Near infrared spectroscopy in the diagnosis of chronic exertional compartment syndrome. *Am J Sports Med*. 2004;32:452-6.
47. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR.Chronic deep posterior compartment syndrome of the leg in athletes: postoperative results of fasciotomy. *Int J Sports Med*. 2008;29:419-23.
48. Verleisdonk EJ, Schmitz RF, van der Werken C. Long-term results of fasciotomy of the anterior compartment in patients with exercise-induced pain in the lower leg. *Int J Sports Med*. 2004;25:224-9.
49. Wallensten R, Eriksson E. Intramuscular pressures in exercise-induced lower leg pain. *Int J Sports Med*. 1984;5:31-5.
50. Wallensten R. Results of fasciotomy in patients with medial tibial syndrome or chronic anterior-compartment syndrome. *J Bone Joint Surg Am*. 1983;65:1252-5.
51. Winkes MB, Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Compartment pressure curves predict surgical outcome in chronic deep posterior compartment syndrome. *Am J Sports Med*. 2012;40(8):1899-905.
52. Winkes MB, Luiten EJ, van Zoest WJ,Sala HA, Hoogeveen AR, Scheltinga MR. Long-term results of surgical decompression of chronic

exertional compartment syndrome of the forearm in motocross racers. *Am J Sports Med*. 2012;40:452-8.
53. Wittstein JR, Levin LS, Moorman CT, III. Chronic exertional compartment syndrome. In: Wiesel SW, Miller MD. eds. *Operative Techniques in Orthopaedic Surgery.* 1st ed. Philadelphia: Lippincott Williams & Wilkins, 2010:437-51.
54. Wood ML, Almekinders LC. Minimally invasive subcutaneous fasciotomy for chronic exertional compartment syndrome of the lower extremity. *Am J Orthop.* 2004; 33:42-4.
55. Wright JG, Swiontkowski MF, Heckman JD. Introducing levels of evidence to the journal. *J Bone Joint Surg Am*. 2003;85-A:1-3.
56. Zandi H, Bell S. Results of compartment decompression in chronic forearm compartment syndrome: six case presentations. *British journal of sports medicine*. 2005;39:e35.
57. Zhang Q, Jonasson C, Styf J. Simultaneous intramuscular pressure and surface electromyography measurement in diagnosing the chronic compartment syndrome. *Scand J Med Sci Sports*. 2011; 21(2):190-5.

2

# ‘BEWARE OF THE DEEP’: THE DEEP POSTERIOR COMPARTMENT IN COMPLEX/CHRONIC LEG PAIN

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Br J Sports Med. 2014 Dec;48(22):1584.



Michiel Winkes and his colleagues[1] do an admirable job of performing a systematic review on a controversial topic for those of us who care for athletes with leg pain. Like these authors, most of us have come to the frustrating realisation that patients with deep posterior exertional compartment syndromes do less well than those with the more classic anterior or lateral exertional compartment syndrome. The authors validate the clinical experience of many through a comprehensive, systematic review. Through this review, the authors also expose several key issues that limit our ability to definitively conclude why the deep posterior compartment is more commonly associated with poor outcomes. While some of the literature available for this systematic review was graded at evidence level III, most was level IV, meaning that the ultimate conclusions of this systematic review can be no greater than level IV evidence. In addition, techniques in diagnosis and surgical technique vary between authors, making it impossible to draw universal conclusions.

Nonetheless, these authors underscore the conclusion that the surgical success for release of the deep posterior compartment to treat exertional compartment syndrome is more variable and generally less successful than anterior or lateral compartment releases. I would agree.

## Why is surgery less successful in ‘the deep’?

My clinical impression is that overlapping diagnoses such as popliteal artery entrapment and medial tibial stress syndrome can lead to suboptimal outcomes. Clearly, if these conditions are also present and left untreated, they may lead to residual postoperative pain despite surgical release in the deep posterior compartment. In addition, there are technical challenges for the surgeon operating on the deep posterior compartment. Generally speaking, it requires a release (cutting!) of 80% of the entire length of the fascia in order to adequately decompress a fascial compartment. When releasing the posterior compartment, it is not uncommon that the surgeon is tentative in favour or safety and does not go far enough proximally, misses associated bands or releases only the superficial compartment and not the deep compartment.

## Clinical implications

Ultimately, I would emphatically agree with these authors that to assure better outcomes for our patients we need to ensure that our diagnosis is accurate and our releases are adequate and reproducible among surgeons. Kudos to these authors for keeping our attention focused on a weak link in patient care; patients with leg pain presumed to be coming from the deep posterior compartment need very meticulous clinical work-up, consideration of alternative 'contributing diagnoses' and, if appropriate, referral to surgeons who are experienced in that specific operation.



# REFERENCE

1 Winkes MB, Hoogeveen AR, Scheltinga MR. Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. Br J Sports Med Dec 2014;48(22):1592-8.

## SUPPLEMENT TO THIS ARTICLE

### BMJ Learning: take the test

**Questions**

1. In a dp-CECS of the lower leg, the most commonly reported symptom during activity is:
   A. Pain
   B. Cramps
   C. Diminished sensibility
   D. Muscle weakness

2. In a suspected lower leg dp-CECS, intracompartmental pressure readings before and after a standard treadmill test:
   A. Are only used to identify patients who benefit from surgical intervention
   B. Can be helpful in difficult cases but these tests are not considered "gold standard"
   C. Are not recommended because of high risk of damaging the tibial nerve or artery
   D. Are required for the diagnosis and demonstrate predictive properties in relation to successful surgery

3. A commonly used safe approach for pressure needle placement in the deep posterior compartment is using the following route:
   A. Anterior, through the anterior tibial muscle and the interosseus membrane directly into the belly of the tibialis posterior muscle
   B. Medial, just dorsal to the medial tibial rim
   C. Lateral, one fingertip anteriorly of the ventral rim of the fibula
   D. Posterior, through the soleus muscle in a prone patient

4. The optimal way to rehabilitate after surgery for a lower leg dp-CECS is:
   A. To start running as soon as possible
   B. To rest during the first two weeks
   C. To normally walk and to regain full range of ankle motion from the first operative day on and avoid jumping or running in the first two postoperative weeks
   D. It does not matter how you behave after surgery. Rehabilitation can be left at the discretion of the patient

5. In contrast to other types of compartment syndromes (e.g. anterior lower leg or forearm), surgical outcome for a lower leg dp-CECS:
   A. Is predictably successful
   B. Is unpredictable
   C. Is not related to doctor's and patient's delay
   D. Is associated with a high complication rate



**Answers**

1. The correct answer is **A**. Exercise induced pain located posteromedially to the tibia and radiating deep into the calf muscles is the most common reported symptom. Moderate tightness is also present in more than 90% of patients. Cramps, diminished sensibility and muscle weakness also occur but are less common. A combination of all above reported symptoms force more than half of the athletes to stop their activities.

2. The correct answer is **D.** A diagnosis of lower leg dp-CECS is established once pathological high pressure patterns elicited by exercise are demonstrated using sequential pressure readings. For instance, these tests may identify patients with a MTSS (medial tibial stress syndrome) compared to those having a dp-CECS. Therefore, timed ICP readings are considered gold standard. Inserting a pressure needle just dorsal to the medial tibial rim is a safe way to avoid harming the tibial nerve and artery.

3. The correct answer is **B**, a medial approach. The patient is lying supine with the affected lower leg in neutral position. While the calve is hanging free from the examination table, the needle is inserted horizontally at the level of the transition of the middle and distal thirds of the lower leg. The needle is placed directly dorsal to the medial tibial rim in order to prevent harming of the posterior tibial artery and nerve. The anterior approach is not recommended because of possible damaging the anterior tibial artery and the deep peroneal nerve located onto the interosseus membrane. If an anteriorly oriented needle is placed too deep, the peroneal artery can be damaged. The same may happen when using a lateral needle placement as the anterior rim of the fibula is difficult to palpate. Posterior needle placement is discouraged because both the sural nerve and the neurovascular tibial bundle can be harmed using this approach.

4. The correct answer is **C**. Absolute rest is not encouraged whereas full range of motion is advised to prevent possible scarring and fascial adhesions. Running in the immediate postoperative period may be harmful because of the onset of hematomas.

5. The correct answer is **B**. Surgery for anterior lower leg CECS is usually successful with reported success rates varying from 83% to 100%. Moreover, surgery for forearm CECS is also very successful as most studies report >90% success percentages after decompression. However, outcomes after surgical treatment for lower leg dp-CECS still are highly diverse ranging from 48% (large and recent cohort) to 100% success (small cohort studies). Factors such as variability in pressure criteria, unknown anatomy, unknown optimal surgical approach may all contribute to lower clinical success rates. A large study recently suggested that a prolonged delay was associated with poor surgical outcome. Complications following surgery are not reported in most studies.

2

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# CHAPTER

# 3

## COMPARTMENT PRESSURE CURVES PREDICT SURGICAL OUTCOME IN CHRONIC DEEP POSTERIOR COMPARTMENT SYNDROME

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AM J SPORTS MED. 2012 AUG:40(8):1899-905. 2015 IF: 4.5

# ABSTRACT

**Background**

Results of surgery for chronic exertional compartment syndrome (CECS) of the lower leg deep posterior compartment are inferior compared with other types of CECS. Factors predicting success after surgery are unknown.

**Purpose**

To study the prognostic value of preoperative compartmental pressure curves in patients receiving surgery for deep posterior compartment CECS.

**Study Design**

Case series; Level of evidence: 4.

**Methods**

Intracompartmental pressures (ICPs) of patients with deep posterior lower leg CECS were obtained at 4 time points (i.e., before, immediately after, and 1 and 5 minutes after a standard exercise challenge test). Area under the 4-point pressure curve was calculated. Patients received a questionnaire investigating residual symptoms after surgery.

**Results**

A complete data set was available for 52 patients (men, n=23; age, 33 ± 14 years). They rated their 3-month postoperative clinical outcome as excellent (14%), good (38%), fair (35%) or poor (13%). Outcome at 3 months was related to the area under the preoperative 4-point pressure curve (excellent, 127 ± 28; good, 113 ± 25; fair, 100 ± 22 and poor, 88 ± 15; *P*=.005; odds ratio [OR], 1.04; 95% confidence interval [CI], 1.01-1.08). At the long term follow up (39 ± 24 months), all 5 cardinal symptoms (pain, tight feeling, cramps, weakness and diminished sensibility) were greatly attenuated (*P*<.001) in the successfully operated group. Long-term success was 48%. Delay in diagnosis was related to poor outcome (*P*=.04). Correlations between pressures/area under the 4 point pressure curve and long-term outcome were not significant, however.

**Conclusion**

Preoperative measured intracompartmental pressures obtained in rest and after a standard exercise test may predict success of surgery for deep posterior compartment CECS of the lower limb. Further standardizing of preoperative pressure protocols may confirm that compartmental pressure analysis has diagnostic as well as predictive properties.

# INTRODUCTION

The differential diagnosis of exercise-related lower leg pain in young athletes includes chronic exertional compartment syndrome (CECS), medial tibial stress syndrome, stress fractures, tendinopathy, nerve entrapment, deep vein thrombosis, and vascular entrapments such as a popliteal entrapment syndrome.[15] Up to 13% of these young people are found to suffer from a CECS.[14] Lower leg CECS is usually associated with high pressures in the anterior (60%) or deep posterior (30%) compartment.[15] Short- and long-term results of surgery for anterior CECS are usually excellent, with success rates ranging from 83% to 100%.[6,17,24] In contrast, success rates of just 33% to 65% have been reported after fasciotomy for deep posterior CECS.[9,17,23] Risk factors for clinical failure after surgery are unknown although it is suggested that suboptimal treatment results are obtained in female patients.[11] However, factors associated with a beneficial outcome after fasciotomy for deep posterior CECS have not been identified.[1,5,7,9]

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A dynamic intracompartmental pressure (ICP) measurement is the gold standard for diagnosing CECS. According to generally accepted criteria, a ≥15 mm Hg resting pressure or a ≥30 mm Hg 1-minute postexercise pressure or a ≥20 mm Hg 5-minute postexercise pressure serves as cutoff points for the diagnosis.[12,20,21] Whereas the discriminative value of elevated ICP in diagnosing CECS appears undisputed, it may be that derivatives of ICP have a potential to predict surgical outcome. However, to date, such a correlation has not been identified. One study showed an insignificant -0.07 correlation coefficient between immediate postexercise ICP and postoperative pain relief in 31 patients.[8] A second study also reported no significant correlations between resting ICP and functional outcome in 100 patients with various types of CECS.[7] A study on the predictive value of ICP obtained by a rigorous protocol in a large homogeneous group of CECS patients has never been performed.

The present study aims to answer whether preoperative ICP characteristics in patients with deep posterior compartment CECS are related to functional outcome after fasciotomy. It was hypothesized that a prolonged elevation of ICP would be associated with improved outcome.

# MATERIALS AND METHODS

## Subjects

Demographic and clinical data of patients referred to the Department of Sports Medicine of the Máxima Medical Center, Veldhoven, the Netherlands, have been prospectively entered into a database since January 1996. This department serves as a referral center for sports-related injuries in the Netherlands. More than 800 patients suspected of having CECS were analyzed between 1996 and December 2010. A total of 458 patients with diagnosed CECS met published cutoff points (≥15 mm Hg at rest, or

≥30 mm Hg after 1 minute or ≥20 mm Hg after 5 minutes of provocative exercise).[12] As 342 of them did not qualify for the present study (CECS of anterior/lateral lower leg (n=306) or forearm (n=36), 116 patients with deep posterior CECS were eligible for analysis. If a complete set of 4 pressure measurements (ICP in rest, immediately after exercise, and 1 min and 5 min thereafter) was not available, patients were also not eligible for the present study. Most of these excluded patients had already developed such high pressures (and associated symptoms) when crossing the parking lot or climbing the stairs toward our outpatient department that a single elevated resting pressure measurement was deemed sufficient for the diagnosis CECS.

## Dynamic intracompartmental pressure measurements



One of the investigators (A.R.H.) performed the measurements. A Slit catheter (Indwelling Slit Catheter Set; Stryker Instruments, Kalamazoo, Michigan) technique currently assumed the most accurate was used.[4] An arterial line manometer was connected and pressures were projected on an attached display (Pressure Monitor Device 783547; Hewlett Packard, Palo Alto, California).[4] Before each measurement, the system was calibrated and saline flushed to prevent accumulation of air bubbles. In case of bilateral complaints, measurements were obtained from the most symptomatic leg.

The patients were lying supine with the ankle joint in 20° plantar flexion and the knee in 10-30° flexion[12]. The affected calf was hanging free from the examination table avoiding false positive pressures. The leg was positioned horizontally with the anterior tibial margin in neutral position.[23] Before needle introduction, a 1-$cm^2$ portion of overlying skin was infiltrated using 2 mL of 1% lidocaine. The needle containing the catheter was inserted horizontally in a “blind” manner.[2] Placement was at the junction of middle and distal thirds of the leg at the point where the soleus bridge is assumed to end where the belly of the flexor digitorum longus muscle is thickest.[19] To avoid harming of the posterior tibial artery and nerve, the needle was placed directly dorsally to the medial tibial rim.[3] A perceptible ‘pop’ is usually experienced upon piercing the fascia of the deep posterior compartment. If the medial aspect of the fibular bone is touched, the needle is withdrawn some 5 mm ensuring proper positioning.

After needle insertion, patients were instructed to pronate and plantar flex the foot against resistance as a test for correct catheter placement. Resting pressures were measured and administrated. The arterial line manometer was subsequently disconnected and the catheter end was taped to the skin. The exercise protocol depended on the patients’ physical ability and on the activity provoking the symptoms. In the majority of patients, symptoms were elicited during treadmill running starting with an 8-km/h speed and an 8% inclination during 5 minutes. If symptoms were absent after this challenge, tip-toe walking was used as a provocative maneuver. Patients were encouraged to continue until symptoms were maximal. Pressures were recorded immediately after cessation and after 1 and 5 minutes.

## Surgical procedure

Patients were informed about the characteristics of surgery, including complications and historical success rates. They consented orally and in writing. On the day of operation, the painful area along the medial tibial rim was marked on the skin. They received 2500 IU of a low molecular weight heparin subcutaneously just before surgery. Patients were operated under general anesthesia or a regional technique in a day care facility. After sterile exposure, a 6- to 8-cm longitudinal incision some 2 cm dorsal to the tibial margin allowed access to the crural fascia. Side branches of the greater saphenous vein were occasionally ligated if necessary, whereas the accompanying nerve was spared. The crural fascia was bluntly freed of overlying tissue and longitudinally opened using a knife and scissors proximally and distally beyond the area of marked painfulness. The soleus muscle was subsequently detached from the tibia. The fascia of the underlying posterior muscle group was opened using similar standard techniques. The skin was closed in 1 layer. Patients received compressive stockings for 14 days. They were instructed to mobilise but were not allowed to participate in sports or jumping during this time period. Wound inspection occurred thereafter followed by gradual reactivation. The majority of patients were operated in the Máxima Medical Center (70%), whereas the remaining group received surgery by their referring orthopaedic surgeon.

## Questionnaire

All patients who had undergone surgery for CECS of the deep posterior compartment were evaluated using a questionnaire that was sent by mail in April 2011 (see Appendix 3.1). The questionnaire investigated additional characteristics regarding the patients' preoperative history. They were asked to judge the 3-month postoperative clinical outcome as excellent, good, fair or poor. Successful surgery was defined as an excellent or good outcome, whereas ‘not successful’ represented fair and poor outcomes. The questionnaire was modified on the basis of a previous study on lower leg CECS.[23] Patients were also asked about their present situation and residual symptoms. Five different symptom levels (pain, muscle cramps, tightness, diminished sensibility and muscle weakness) were investigated using a visual analog scale (VAS) consisting of a horizontal 100-mm line with symptom severity quantified on the left as "absent" (0 mm) and on the right as "excruciating" (100 mm). The patients were instructed to put a mark on the line at the position representing their perception of that symptom prior to operation as well as the current situation. Two typical examples were provided together with the questionnaire as a means of reducing the chance of scale failure. The VAS levels were categorized as severe (>70 mm), moderate (31-70 mm), mild (10-30) and no symptoms (<10 mm), as suggested and validated by others.[10] Patients who received a 2-stage procedure because of a bilateral syndrome were instructed to report outcome after both procedures were completed. Nonresponders received 1 reminder by mail and 1 by telephone.

3

## Calculations

Area under each 4-point pressure curve was calculated using the following formula: 0.5 x resting pressure + pressure immediately after exercise + pressure 1 minute post exercise + 0.5 x pressure 5 minutes after exercise. The formula is illustrated in Figure 3.1.

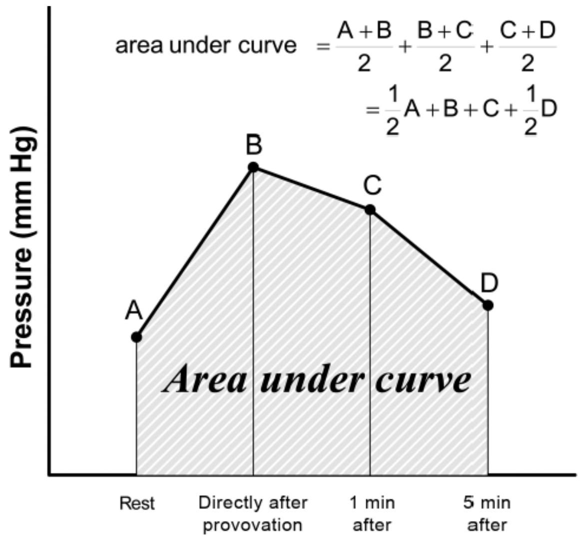


**FIGURE 3.1** Calculation of the surface under the 4-point pressure curve.

## Statistical analysis

The relation between area under the 4-point pressure curve and 4 categories of clinical outcome (excellent, good, fair, poor) were compared using a Kruskal-Wallis test, whereas a Mann-Whitney *U* test was used to compare 2 categories (success and no success). Depending on normal distribution, pre- and postoperative VAS scores were compared using a Wilcoxon signed-rank or a paired-samples *t* test. In addition, a univariate logistic regression analysis was used to relate variables of ICP to clinical outcomes. Data were expressed as mean ± standard deviation (SD) when normally distributed or as median and range if not normal. For all tests, $P \leq .05$ was considered significant. Statistical analysis was performed using SPSS Statistics, Windows version 17.0.1 (SPSS Inc., Chicago, Illinois).

# RESULTS

## Subject characteristics

The questionnaire response rate was 90% (105/116). Of the 105 respondents, 53 were excluded from analysis based on an incomplete pressure registration (<4 points). Thus, a complete data set consisting of a 4-pressure registration and a questionnaire was available in 52 patients. This study population was representative of the complete operated cohort (n=105) because the study group (n=52) and the excluded group (n=53) were not significantly different (Table 3.1). Demographic and clinical data of both populations are listed in Table 3.1.



**TABLE 3.1**
Characteristics of patients with deep posterior chronic exertional compartment syndrome (n=52) and a control group (n=53).

| | Study group | Excluded group | *P* value |
|---|---|---|---|
| Number | 52 | 53 | |
| Male/female, No. | 23/29 | 26/27 | .70 |
| Age, y, mean ± SD | 33 ± 14 | 29 ± 12 | .15 |
| Height, cm, mean ± SD | 173 ± 8 | 175 ± 10 | .40 |
| Weight, kg, mean ± SD | 76 ± 14 | 75 ± 14 | 1.00 |
| Body mass index, kg/m$^2$, mean ± SD | 25 ± 4 | 25 ± 4 | 1.00 |
| Resting pressure, mmHg, mean ± SD (n) | 19 ± 6 (52) | 23 ± 9 (47) | .09 |
| | 43 ± 11 (52) | 43 ± 13 (42) | .60 |
| | 38 ± 10 (52) | 37 ±11 (35) | .76 |
| | 32 ± 9 (52) | 32 ± 10 (4) | .85 |
| Level of sports, No. (%) | | | |
| International | 2 (4) | 3 (6) | |
| National | 14 (27) | 12 (23) | |
| Local competitive | 20 (38) | 25 (47) | |
| Social | 12 (23) | 6 (11) | |
| No sports | 4 (8) | 7 (13) | |

Provocative sports were mostly soccer (n=13) and running (n=9). Other activities were swimming, ice-skating, athletics, hockey, turning, fitness, horseback-riding and dancing. Prior to operation, patients had received conservative treatment including icing (67%), physical therapy (88%) or orthotics (75%). However, these measures only provided temporary relief. Some patients (15%) reported additional shockwave therapy, dynamic cupping therapy or the use of compressing stockings but also to no avail.

45 patients (87%, 45/52) were operated for an isolated deep posterior compartment syndrome. Seven additional patients underwent a combined one stage anterior and posterior fasciotomy because of CECS of both compartments. Nine patients (9/52, 17%) reported a history of an earlier successfully operated anterior compartment syndrome.

## Symptoms before operation

The 2 principal symptoms were pain when performing provocating activities (severe pain in 49%, moderate in 41%, mild in 6%, and no pain in 4%) and tightness (severe in 62%, moderate in 23%, mild in 6%, and no tightness in 10%)(Figure 3.2). Moderate and severe cramps were reported in 31% and 29%, respectively. Diminished sensibility was present in 27% (severe) and 23% (moderate) whereas muscle weakness was severe in 12% and moderate in 31%. A combination of these symptoms forced more than half of the patients (54%) to stop their sport activities.

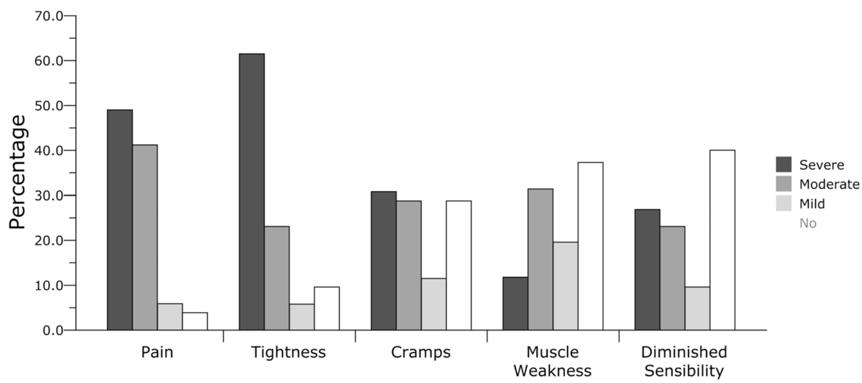


**FIGURE 3.2** Preoperative symptoms of deep posterior chronic exertional compartment syndrome (n=52).

## Compartmental pressures and short-term clinical success

Mean ± SD compartmental pressures during rest in the 52 patients were 19 ± 6 mm Hg (range, 8-34 mm Hg). Provocation resulted in a more than 2-fold rise to 43 ± 11 mm Hg (range, 25-72 mm Hg) measured immediately after exercise. Values remained well above the 30-mm Hg threshold at the 1-minute measuring point (38 ± 10 mm Hg; range, 21-65 mm Hg) and well above the 20 mm Hg at the 5-min time point (32 ± 9 mm Hg; range, 10-64). Differences in pressure between the success and the nonsuccess group were significant in rest (21 ± 6 versus 18 ± 6 mm Hg, *P*=.04), directly after exercise (46 ± 11 versus 40 ± 10 mm Hg, *P*=.02) and 1 minute after exercise (40 ± 10 vs 35 ± 10 mm Hg, *P*=.05, Figure 3.3).

Seven patients (14%) judged their 3-month clinical outcome as excellent, 20 patients (38%) as good, 18 subjects (35%) fair and 7 (13%) as poor. Therefore, the short-term success rate (excellent and good) was 52% (27/52). The area under the 4-point pressure curve was associated with outcome (excellent, 127 ± 28 mm Hg; good, 113 ± 25 mm Hg; fair, 100 ± 22 mm Hg; poor, 88 ± 15 mm Hg; *P*=.005) and appeared indicative of success (odds ratio [OR], 1.04; 95% confidence interval [CI], 1.01-1.08). Pressure immediately after exercise and a decline in pressure toward 5 minutes after exercise were also prognostic for success (OR, 1.06; 95%CI: 1.00-1.13 and OR, 1.11; 95%CI, 1.01-1.21, respectively). There was no difference between men (13/23) and women (14/29; *P*=.59)(Table 3.2).

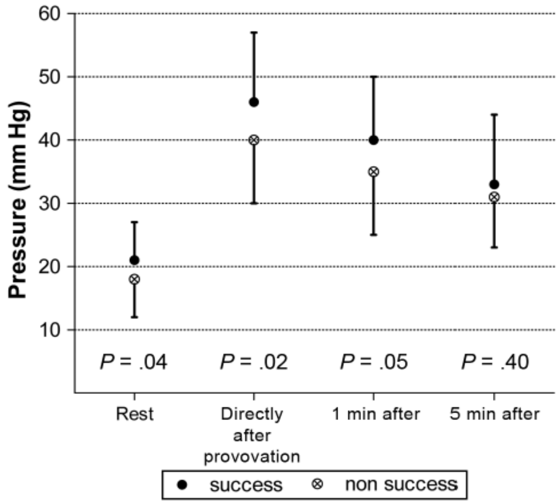


**Figure 3.3** Compartment pressure and outcome (success vs no success) in patients with deep posterior chronic exertional compartment syndrome (n=52; mean ± SD).

**TABLE 3.2**
Predictors of success 3 months after surgery in patients with deep posterior chronic exertional compartment syndrome (n=52).[α]

| Variable | OR (95% C.I.) | *P* |
|---|---|---|
| Area under 4-point pressure curve | 1.04 (1.01 - 1.08) | .01 |
| P5 min after – Pimmediately after | 1.11 (1.01 – 1.21) | .04 |
| Pressure immediately after exercise | 1.06 (1.00 - 1.13) | .04 |
| Resting pressure | 1.10 (0.99 - 1.21) | .07 |
| Pressure 1 min after exercise | 1.05 (0.99 - 1.12) | .10 |
| Pimmediately after – Prest | 1.03 (0.98 – 1.09) | .26 |
| Pressure 5 min after exercise | 1.03 (0.97 – 1.09) | .38 |
| P1 min after – Prest | 1.02 (0.96 – 1.08) | .54 |
| Male sex | 1.39 (0.46 – 4.19) | .56 |

[α] OR, odds ratio; C.I., confidence interval; P, pressure.

## Long-term follow-up

Mean ± SD follow-up was 39 ± 24 months (range, 3-89 months). Overall, 48% of the patients (25/52) reported their long-term outcome as excellent (17%) or good (31%). A significant relationship was present between duration of symptoms before surgery and an unsuccessful response after surgery (>24 months, success in 8/24; 12-24 months, success in 5/13; 6-12 months, success in 7/10; 0-6 months, success in 5/5; *P*=.04).

VAS reductions in both groups are shown in Figure 3.4. In the long-term success group (n=25), VAS score for tight feelings decreased from 71 ± 33 to 16 ± 19. Pain dropped from 69 ± 17 to 16 ± 13 and cramps from 50 ± 33 to 13 ± 17. Scores for loss of force and diminished sensibility were reduced from 36 ± 31 to 12 ± 16 and from 45 ± 34 to 12 ± 15, respectively (all *P*<.001). The VAS scores in the unsuccessful group (n=27) are depicted in the lower panel of Figure 3.4. Although the overall result was judged unsuccessful by these patients, reductions in feelings of tightness (*P*<.02), pain (*P*<.001) and cramps (*P*=.07) were still significant. Correlations between pressures/area under 4-point pressure curve and long term outcome were not significant. Long-term results were also not correlated with short-term success rates.

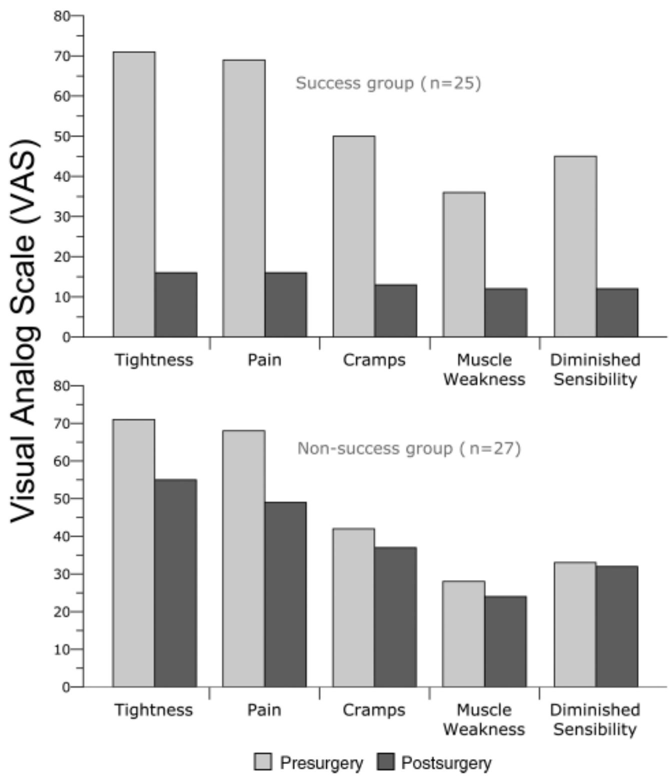


**FIGURE 3.4** Symptoms at long-term follow-up in patients with operated deep posterior chronic exertional compartment syndrome (successful, n=25; unsuccessful, n=27).

## DISCUSSION

Success rates of fasciotomy for chronic exertional compartment syndrome of the deep posterior muscle compartment of the lower leg are inferior compared to other types of CECS.[9,17,23] Factors predicting successful outcome for this subtype of CECS are largely unknown. It has been suggested that sex is related to failure as (young) men showed a tendency to be more satisfied.[11] However, most studies must be interpreted with caution as populations were small and heterogeneous with reference to CECS type. The present study includes a relatively large homogenous group of 52 patients with deep posterior CECS, possibly allowing for more robust conclusions. A priori it, was hypothesized that beneficial outcome was related to pressure characteristics derived from the affected compartment. The present study found an association between character of compartmental pressures and surgical outcome, whereas sex characteristics were not significant. Delay in diagnosis was related to poor outcome.



Studies on various types of CECS failed to show a relationship between ICP characteristics and outcome of surgery. One study in 100 patients involving 233 different lower leg compartments demonstrated the absence of a significant correlation between resting compartment pressures and functional outcome after surgery.[7] Another study in 39 patients with mixed involvement of muscle compartments also showed no association between immediate post exercise compartment pressures and pain relief after surgery.[9] These 2 studies involving heterogeneous patient populations suggested that pressure measurements had no prognostic value. The present study demonstrated that a large area under the 4-point pressure curve predicted success. Interestingly, pressures directly after exercise appeared the most important of all 4 static pressures. One may conclude that the nature of compartment pressures may possibly help the physician in clinical decision making.

The present study attracts attention to the importance of several timed pressure measurements. A number of factors may contribute to unreliable compartmental pressures in CECS. Apart from the operator’s experience, technical considerations are numerous. Dynamic measurements are indicated, whereas static ones are obsolete. Data obtained from a system including a Slit catheter combined with an arterial line manometer and a display appear more precise compared with data generated by the use side-port or straight needles and a Whitesides manometer apparatus. Arterial line calibration is mandatory before each measurement as the effects of atmospheric and hydrostatic pressure are eliminated. Zeroing (calibrating) must be done while the connector is leveled with the tip of the Slit catheter after it is inserted in the deep posterior compartment. Leg position is important as calves must be freely dependent with the knee joint bent at 10° to 30°.[8] Pressure curves must respond to foot movements in a characteristic and predictive manner reflecting proper catheter position.

Apart from measuring resting pressures in a protocolized manner, a standard environment is also required for the exercise that is used to provoke symptoms (usually running) as well as the ensuing pressure measurements. Patients are advised to run with their own shoes. Some consider it crucial that symptoms are maximal (and normal running has become impossible) before postexercise measurements can reliably be performed.[13,18] If these conditions are not met, maximally elevated intramuscular pressures may not be attained, possibly leading to false negative readings. The onset of symptoms is accelerated using progressive treadmill inclination. As for the postexercise pressure measurements, it appears quite difficult to measure immediately after test discontinuation as this time interval may differ anywhere from 10 to 20 seconds. Commonly used 1- and 5- minute postexercise time intervals are utilized as a means of standardisation. Corresponding pressure criteria are 30 mm Hg and 20 mm Hg, respectively.[12,20,21] However, these cutoff levels are accepted by just 35% of physicians involved in compartmental pressure measurements.[22] A meta-analysis including 21 studies showed that pressure levels varied up to 500% regarding the recommended parameters for diagnosing CECS. It is clear that uniformity in the diagnostic pathway of CECS is absent. Conversely, one may expect that results of any treatment, including surgery, may improve once all steps in the diagnostic regimen are strictly protocolized.

Results of fasciotomy for deep flexor lower leg CECS are fair, and our short-term (52%) and long-term (48%) success rates are in line with previous literature.[9,16,23] Comparing our long-term with the short-term results suggests that residual pain was not just due to insufficient recovery from surgery. One study[20] reported a somewhat better success rate of 75% (15/20) in the long term. However, analyzing these results demonstrated that data on 26 patients were reported. As 6 in this population required repeat surgery, the true success rate may have been 58%. It is unknown why unsuccessful patients do not respond favorably to fasciotomy as follow-up studies in these populations were not performed. For instance, it remains unknown if they suffered from residual or recurrent disease. Moreover, it remains unclear if CECS developed in other compartments, possibly explaining (part of) the remaining symptoms. The authors are currently involved in standardized follow-up studies of patients who reported a poor surgical outcome according to the questionnaire.

The present study suffers from methodological flaws inherently associated with its retrospective nature. Recall bias may have influenced the analysis as the questionnaire investigating preoperative symptomatology was performed after the operation. Attrition bias was thought negligible as the response rate was 90%. Surface under the pressure curve was calculated using the summation of 3 columns under the curve. A flaw may have been that the middle column is of more influence than the other two. To circumvent these limitations, a continuous pressure registration would allow for an integral calculation of the pressure curve. This approach would reduce bias in timing, whereas each pressure point is of equal importance. Limitations of the present study have encouraged us to start a prospective standardized monitoring using timed analyses of all patients treated for posterior CECS.

In conclusion, success rates after surgery for chronic compartment syndrome of the posterior flexor compartment of the lower leg are related to preoperative 4-point pressure curves. Further standardizing of preoperative pressure protocols may confirm that compartmental pressure analysis has diagnostic as well as predictive properties.

# REFERENCES


**1.** Biedert RM, Marti B. Intracompartmental pressure before and after fasciotomy in runners with chronic deep posterior compartment syndrome. *Int J Sports Med.* 1997;18(5):381-386.

2. Blackman PG. A review of chronic exertional compartment syndrome in the lower leg. *Med Sci Sports Exerc.* 2000;32(3 Suppl):S4-10.

3. Bong MR, Polatsch DB, Jazrawi LM, Rokito AS. Chronic exertional compartment syndrome: diagnosis and management. *Bull Hosp Jt Dis.* 2005;62(3-4):77-84.

4. Boody AR, Wongworawat MD. Accuracy in the measurement of compartment pressures: a comparison of three commonly used devices. *J Bone Joint Surg Am.* 2005;87(11): 2415-2422.

5. Brennan FH Jr., Kane SF. Diagnosis, treatment options, and rehabilitation of chronic lower leg exertional compartment syndrome. *Curr Sports Med Rep.* 2003;2(5):247-250.

6. de Fijter WM, Scheltinga MR, Luiting MG. Minimally invasive fasciotomy in chronic exertional compartment syndrome and fascial hernias of the anterior lower leg: short- and long-term results. *Mil Med.* 2006;171(5):399-403.

7. Detmer DE, Sharpe K, Sufit RL, Girdley FM. Chronic compartment syndrome: diagnosis, management, and outcomes. *Am J Sports Med.* 1985;13(3):162-170.

8. Gershuni DH, Yaru NC, Hargens AR, Lieber RL, O'Hara RC, Akeson WH. Ankle and knee position as a factor modifying intracompartmental pressure in the human leg. *J Bone Joint Surg Am.* 1984;66(9):1415-1420.

9. Howard JL, Mohtadi NG, Wiley JP. Evaluation of outcomes in patients following surgical treatment of chronic exertional compartment syndrome in the leg. *Clin J Sport Med.* 2000;10(3):176-184.

10. Loos MJ, Houterman S, Scheltinga MR, Roumen RM. Evaluating postherniorrhaphy groin pain: visual analogue or verbal rating scale? *Hernia.* 2008;12(2):147-151.

11. Micheli LJ, Solomon R, Solomon J, Plasschaert VF, Mitchell R. Surgical treatment for chronic lower-leg compartment syndrome in young female athletes. *Am J Sports Med.* 1999;27(2):197-201.

12. Pedowitz RA, Hargens AR, Mubarak SJ, Gershuni DH. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med.* 1990;18(1):35-40.

13. Pedowitz RA, Weichel DW. Chronic Compartment Syndrome. In: Pedowitz RA, Johnson DH, eds. *Practical Orthopaedic Sports Medicine and Arthroscopy*: Lippincott Williams & Wilkins; 2006:849-850.

14. Qvarfordt P, Christenson JT, Eklof B, Ohlin P, Saltin B. Intramuscular pressure, muscle blood flow, and skeletal muscle metabolism in chronic anterior tibial compartment syndrome. *Clin Orthop Relat Res.* 1983;179: 284-290.

15. Reinking MF. Exercise Related Leg Pain (ERLP): a review of the literature. *North Am J Sports Phys Ther.* 2007;2(3):170-180.

16. Rorabeck CH, Bourne RB, Fowler PJ. The surgical treatment of exertional compartment syndrome in athletes. *J Bone Joint Surg Am.* 1983;65(9):1245-1251. Rorabeck CH,

17. Fowler PJ, Nott L. The results of fasciotomy in the management of chronic exertional compartment syndrome. *Am J Sports Med.* 1988;16(3):224-227.

18. Schepsis AA, Martini D, Corbett M. Surgical management of exertional compartment syndrome of the lower leg: long-term followup. *Am J Sports Med.* 1993;21(6):811-817; discussion 817.

19. Schepsis AA, Watson FJ, Creevy WR. Surgical treatment of overuse injuries of the lower extremity. In: Elattrache NS, ed. *Surgical Techniques in Sports Medicine*: Philadelphia, PA: Lippincott Williams & Wilkins; 2007:624-625.

20. Slimmon D, Bennell K, Brukner P, Crossley K, Bell SN. Long-term outcome of fasciotomy with partial fasciectomy for chronic exertional compartment syndrome of the lower leg. *Am J Sports Med.* 2002;30(4):581-588.

21. Tucker AK. Chronic exertional compartment syndrome of the leg. *Curr Rev Musculoskelet Med.* 2010;3(1-4):32-37.

22. Tzortziou V, Maffulli N, Padhiar N. Diagnosis and management of chronic exertional compartment syndrome (CECS) in the United Kingdom. *Clin J Sport Med.* 2006;16(3):209-213.

23. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR. Chronic

deep posterior compartment syndrome of the leg in athletes: postoperative results of fasciotomy. *Int J Sports Med.* 2008;29(5):419-423.

24. Verleisdonk EJ, Schmitz RF, van der Werken C. Long-term results of fasciotomy of the anterior compartment in patients with exercise-induced pain in the lower leg. *Int J Sports Med.* 2004;25(3):224-229.

3

# APPENDIX 3.1

## Questionnaire for the evaluation of patients operated for deep posterior chronic exertional compartment syndrome

1. How did your legs symptoms influence your behaviour?
   a. It was impossible to continue my activities
   b. I was able to exercise but not for a full 100%
   c. I was able to exercise for a full 100% but with pain

2. At what level did you compete prior to surgery?
   a. International
   b. National
   c. Local competitive
   d. Social
   e. No sports

3. After how many minutes of sports (or other activities) did the symptoms start?
   a. In rest
   b. < 5 minutes after sports
   c. 5-15 minutes
   d. 15-30 minutes
   e. >30 minutes

4. Did you experience the following symptoms at night?

| | |
|---|---|
| a. Pain: | always / sometimes / never |
| b. Tinglings: | always / sometimes / never |
| c. Tight feelings: | always / sometimes / never |

5. Which treatment did you undergo prior to surgery?

| | |
|---|---|
| a. Rest: | yes / no |
| b. Cooling: | yes / no |
| c. Physiotherapy: | yes / no |
| d. Orthotics: | yes / no |
| e. Other, ___________________ | |

6. What additional investigations did you undergo prior to surgery?

| | |
|---|---|
| a. No investigation | |
| b. X-ray | yes / no |
| c. MRI scan | yes / no |
| d. Bone scan | yes / no |
| e. Near infrared spectroscopy (NIRS) | yes / no |
| f. Electromyography (EMG) | yes / no |
| g. Ultrasound-duplex | yes / no |
| h. Ankle-Brachial pressure index (ABI) | yes / no |
| i. Intracompartmental pressure measurements | yes / no |

7. How much time expired between the first symptoms and operation?
   a. < 3 months
   b. 3-6 months
   c. 6-12 months
   d. 1-2 years
   e. >2 years

8. How did you judge the postoperative result 3 months after surgery?
   a. Excellent
   b. Good
   c. Fair
   d. Poor

9. How do you judge the postoperative result at this very moment?
   a. Excellent
   b. Good
   c. Fair
   d. Poor

10. How did you rate your pain level when performing activities, <u>before</u> surgery?
    Horizontal visual analog scale (VAS): 0 -100 mm

11. How do you judge pain when performing activities, <u>at this very</u> moment?
    VAS: 0-100mm

12. How did you rate the tightness when performing activities, before surgery?
    VAS: 0-100mm

13. How do you rate the tightness when performing activities, at this moment?
    VAS: 0-100mm

14. How did you judge cramps when performing activities, before surgery?
    VAS: 0-100mm

15. How do you judge the cramps when performing activities, at this moment?
    VAS: 0-100mm

16. How did you judge the muscle weakness when performing activities, before surgery?
    VAS: 0-100mm

20. How do you judge the muscle weakness when performing activities, at this moment?
    VAS: 0-100mm

21. How did you judge diminished sensibility when performing activities, before surgery?
    VAS: 0-100mm

22. How do you judge diminished sensibility when performing activities, at this moment?
    VAS: 0-100mm

23. Did you receive any other surgical interventions of your leg?
    a. Yes, ________________________
    b. No

24. What is your weight?

25. What is you height?

26. What is your age?

3

# CHAPTER 4

# 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

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# ABSTRACT

**Background**
A diagnosis of lower leg deep posterior chronic exertional compartment syndrome (dp-CECS) is made by a dynamic pressure measurement. The insertion of a pressure catheter is guided by anatomic landmarks (freehand) or by ultrasound. The catheter tip is ideally positioned in the tibialis posterior muscle (TP). The accuracy of in vivo catheter placement using lower leg magnetic resonance imaging (MRI) in healthy patients suspected of having dp-CECS has never been studied.

**Purpose**
To analyze whether a freehand catheter insertion results in accurate positioning in the TP as confirmed by MRI in patients with suspected dp-CECS.

**Study design**
Case series; Level of evidence, 4.

**Methods**
Catheters were inserted into central portions of the TP using a standard puncturing technique guided by lower leg anatomic landmarks. After timed muscle pressure measurements during a standard provocative treadmill running test, lower leg MRI scans were obtained and evaluated by 2 skilled radiologists. Catheter tip placement was termed accurate (in the TP), suboptimal (in the deep posterior compartment but outside the TP), or inaccurate (outside the deep posterior compartment).

**Results**
Between March 2013 and September 2014, a total of 24 patients (8 male, 16 female; age, 30 years [range, 18-54 years]) underwent an intracompartmental pressure (ICP) measurement, followed by MRI. Cardinal symptoms were pain during exertion (20% very severe, 53% severe, and 20% moderate) and tightness (29% very severe, 43% severe). Symptoms were bilateral in 74% of patients. Nine of the 24 patients were diagnosed with dp-CECS based on elevated ICPs. Of the 24 patients, catheter tip placement was accurate in 10 (42%), whereas suboptimal placement was achieved in 9 (38%). Five procedures were inaccurate (transition zone between the deep and superficial compartments, n=3; in the superficial lower leg compartment, n=2). Signs of a hematoma were found in 38% of the patients, although there were no associated clinical symptoms.

**Conclusion**
Palpation-guided placement of catheters for TP pressure measurements is suboptimal in more than half of the patients with suspected lower leg dp-CECS. Optimizing the pressure catheter tip positioning technique may improve diagnostic accuracy in dp-CECS.

# INTRODUCTION

Exercise-induced lower extremity pain is occasionally caused by the presence of chronic exertional compartment syndrome (CECS). CECS may develop in any muscle, but the anterior (ant-CECS) and deep posterior (dp-CECS) portions of the lower leg are frequently affected.[5,6,25,26] Elevated intracompartmental pressures (ICPs) obtained during a dynamic measurement are widely accepted as the most objective diagnostic criterion.[19] If CECS is likely and nonoperative treatments fail, surgical fasciotomy may offer relief.

In general, surgical success rates are determined by various parameters, including patient selection, definition of success, and type of CECS. The treatment success rates of dp-CECS are generally considered lowest of all for a number of reasons. Large crossing veins may preclude the exploration of fascias of the deep posterior compartment. As a consequence, high pressure in the tibialis posterior muscle (TP) compartment may persist after incomplete fasciotomy. Moreover, it is unknown if all 3 flexor muscles require exploration and fasciotomy.[27] Others have suggested that an aponeurotic fibular origin of the flexor digitorum longus muscle (FDL) could enclose portions of the TP (''fifth'' subcompartment), leading to suboptimally treated CECS.[8,9,17,20] These anatomic factors may contribute to limited success rates after surgery for dp-CECS.

However, other factors may also play a role in suboptimal treatment success rates in dp-CECS. For instance, inconsistencies in the diagnostic pathway may possibly lead to an inaccurate patient selection. Dynamic instead of static measurements of the ICP are conditional.[19] ICP is ideally obtained at timed intervals (''dynamic'') after a standard provocative test. Different recording devices are advocated, but a slit catheter technique coupled to an arterial line transducer system is currently regarded as accurate and best suited for multiple monitoring.[3,7] The catheter is ''blindly'' inserted into the deep posterior compartment by a palpating investigator. Correct catheter placement is checked by instructing patients to pronate and plantar flex the foot against resistance, leading to predictable ICP fluctuations. Others advocate the use of ultrasound (US) guidance for optimal catheter placement.[16,17] However, evidence for higher diagnostic accuracy after US is currently not available. Magnetic resonance imaging (MRI) is an accurate noninvasive modality for muscle compartment anatomy. The present study aimed to answer whether a blindly inserted ICP catheter is accurately positioned in the deep posterior muscle compartment (more precisely, the TP). If not, individual patient selection may be suboptimal, possibly explaining inferior treatment results after surgery for dp-CECS.

# METHODS

Our Department of Sports Medicine serves as a national referral center for exercise-related injuries. Considerable expertise has been gained in treating lower leg injuries such as CECS or medial tibial stress syndromes. Yearly, approximately 250 ICP readings are performed, 40% of which concern the deep posterior compartment. Between January 2013 and July 2015, patients older than 18 years who were suspected of having dp- CECS and who were scheduled for an ICP measurement of the deep posterior compartment of the lower leg were asked to participate in the present study by a telephone consultation. If a patient was interested, study information was provided by mail. Some weeks later when presenting to the Department of Sports Medicine, patients provided verbal and written consent for the study. After a history and physical examination were performed by the sports physician, patients were asked to first undergo an ICP measurement, followed by MRI. Patients were not eligible for the study if they had undergone previous lower leg surgery, they had a history of lower leg fractures, or contraindications for MRI were identified (pacemaker, foreign metal bodies such as nails or plates, claustrophobia, dyspnea when lying flat). Our Medical Ethics Committee approved study design, protocol, and informed consent procedures (study No. NL41251.015.12).



## Dynamic ICP

Pressure measurements were performed by 2 sports physicians having a large experience with the technique (>1000 ICP measurements). A slit catheter (Indwelling Slit Catheter Set; Stryker Instruments) and an arterial line manometer (pressure monitor device 783547; Hewlett-Packard) were used. Pressures were projected on an attached display. Before each measurement, the system was calibrated and saline flushed to prevent the accumulation of air bubbles. In case of bilateral complaints, measurements were obtained from the most symptomatic leg. The goal of the sports physician was to ideally insert the tip of the catheter into the most voluminous portion of the TP, as this muscle is generally considered the most important of the 3 flexor muscles that constitute the deep posterior compartment.

Patients were lying supine with the ankle joint in 20° of plantar flexion and the knee in 10° to 30° of flexion, with the popliteal fossa resting on a little pillow. The affected calf was hanging free from the examination table, avoiding false-positive pressures. The leg was positioned horizontally with the anterior tibial margin in neutral position. Before needle introduction, a 1-cm$^2$ portion of overlying skin was infiltrated using 2 mL of 1% lidocaine. A 5- to 10-mL lidocaine depot was additionally injected along the projected catheter route. The hollow needle containing the catheter was inserted perpendicularly through the skin in a ‘‘blind’’ manner. Ultrasonography was therefore not used. Placement occurred at the junction of the proximal and middle thirds via a medial approach at the point where the belly of the TP is thickest (Figure 4.1). To avoid harming the posterior tibial artery and nerve, the needle was placed directly dorsally to the medial tibial rim. During puncturing, digital compression of the needle insertion site was carried out to flatten the soleus muscle and reduce the distance for the needle to reach the TP. This maneuver may increase the ''safety window'' by separating the neurovascular bundle from the tibial cortex.[29] A perceptible ''pop'' is usually experienced upon piercing the fascia of the deep posterior compartment. If the medial aspect of the fibular bone was touched, the needle was withdrawn some 5 mm, ensuring proper positioning in the TP as the central muscle of the deep posterior compartment.



**FIGURE 4.1** Catheter placement for dynamic pressure measurements of the lower leg deep posterior compartment.

While leaving the plastic catheter in situ, the splittable needle was withdrawn and removed. Patients were instructed to pronate and plantar flex the foot against resistance as a test for correct catheter placement. Theoretically, an ICP response after selective toe flexion with a straight ankle suggests catheter localization in the FDL.

Conversely, a proper ICP response after ankle flexion in the absence of an ICP response after selective toe flexion suggests positioning in the TP. However, the sensitivity and specificity of this maneuver are unknown. Proper catheter patency was confirmed after expected ICP reactions were observed on the display directly after these movements. In case a catheter was occluded or in the presence of an air bubble, dampening of the pressure signal was visible as a straight horizontal line or as a continuously increased signal of >100 mm Hg. If present, a catheter flush was initiated. Resting pressures were measured and administrated. The arterial line manometer was subsequently disconnected, and the catheter end was taped to the skin.

The exercise protocol depended on the patients' physical ability and on the activity provoking the symptoms. In the majority of patients, symptoms were elicited during treadmill running starting with an 8-km/h speed and an 8% inclination during 5 minutes. If symptoms were absent after this challenge, tiptoe walking was used as a provocative maneuver. Patients were encouraged to continue until symptoms were maximal. Pressures were again recorded immediately after cessation and after 1 and 5 minutes. A resting pressure of ≥15 mm Hg, 1-minute postexercise pressure of ≥30 mm Hg, or 5-minute postexercise pressure of ≥20 mm Hg served as cutoff points for the diagnosis of CECS.[14]



## MRI protocol

Directly after completing the ICP protocol, patients were transferred in a wheelchair to the Department of Radiology. Imaging was performed on a 3-T clinical scanner (Achieva 3T TX; Philips Healthcare) with an 8-element phased array knee coil. Patients were positioned supine with their legs in neutral position. Scans of the middle part of the lower leg were obtained after a survey scan. The imaging protocol based on recognition of anatomy and the catheter tip consisted of the acquisition of T1-weighted turbo spin echo transverse images (repetition time/echo time [TR/TE], 912/15 ms; echo train length, 7; 2-mm slices; slice gap, 0.2 mm; 14-cm field of view [FOV]; acquisition matrix, 348 3 164; number of signal averages [NSA], 3; 90° flip angle; imaging time, 4:30 minutes), followed by T2-weighted images with a spectral attenuated inversion recovery fat suppression technique in the coronal plane (TR/TE, 4276/65 ms; echo train length, 15; 2-mm slices; slice gap, 0.2 mm; 20-cm FOV; acquisition matrix, 324 3 225; NSA, 2; 90° flip angle; imaging time, 4:25 minutes) and 3-dimensional proton density–weighted volumetric isotropic turbo spin echo fat-suppressed images (TR/TE, 1300/32 ms; echo train length, 65; over contiguous 0.5-mm slices; 16-cm FOV; acquisition matrix, 280 3 266; NSA, 2; 90° flip angle; imaging time, 7:25 minutes). Of the latter multiplanar reformation, images with a 0.5-mm slice thickness without an interslice gap were obtained. No contrast agents were used.

## Lower leg MRI

The evaluation was performed by 2 blinded musculoskeletal radiologists with >10 years of experience on 6-megapixel medical screens (Barco) using a picture archiving and communication system (Impax version 6.5.3.1005; Agfa HealthCare). In each patient, catheter tip positioning, relation to the tibia and posterior and peroneal neurovascular bundles, length between skin, crural fascia and catheter tip, presence of a separate TP fascia, and a ‘‘fibular slip’’ of the FDL were tabulated into a custom-made Excel sheet (Microsoft Corp).

## Definitions

Positioning was termed ‘‘accurate’’ if the catheter tip was clearly visible in the TP. Positioning was labeled ‘‘suboptimal’’ in case the catheter tip was visible in the deep posterior compartment but in 1 of 2 other flexor muscles (FDL, flexor hallucis longus muscle). A measurement was scored as ‘‘inaccurate’’ if the tip was not located in the deep posterior compartment but in the superficial compartment (SC) (Figures 4.2-6). If the tip was visible at the transition zone of the FDL/TP, accuracy was labeled suboptimal, and for the transition zone of the SC/FDL, a score of inaccurate was given. If a disagreement occurred, the 2 radiologists were asked to reach a consensus during a separate meeting.

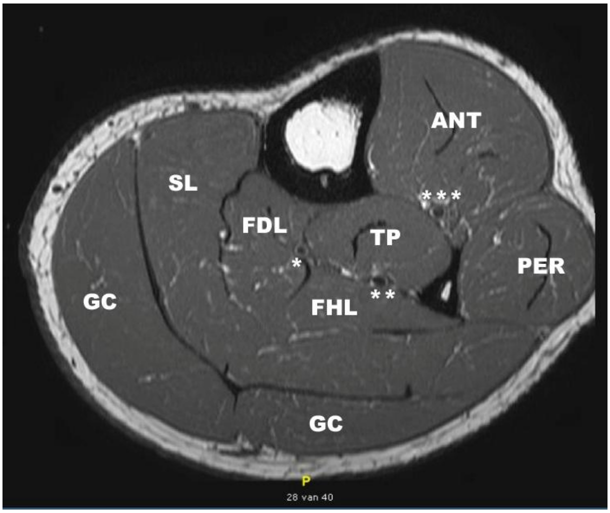


**FIGURE 4.2** Lower leg magnetic resonance imaging anatomy. ANT, anterior compartment; FDL, flexor digitorum longus muscle; FHL, flexor hallucis longus muscle; GC, gastrocnemius muscle; PER, peroneal compartment; SL, soleus muscle; TP, tibialis posterior muscle. *Tibialis posterior neurovascular bundle, **peroneal artery and vein, and ***tibialis anterior artery and vein and deep peroneal nerve.

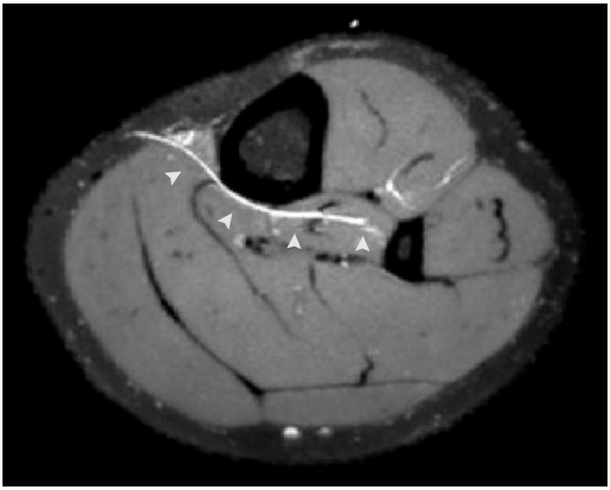

**FIGURE 4.3** Accurate position of the pressure catheter with the tip located in the tibialis posterior muscle. The arrowheads indicate the course of the catheter.



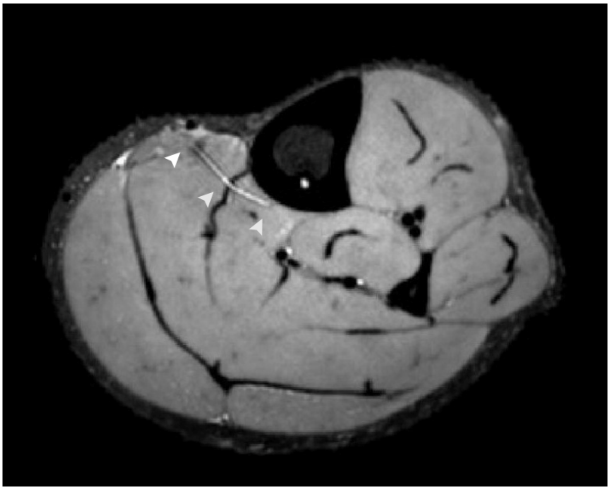

**FIGURE 4.4** Suboptimal position of the catheter. The tip is located in the flexor digitorum longus muscle and not reaching into the tibialis posterior muscle. The arrowheads indicate the course of the catheter.

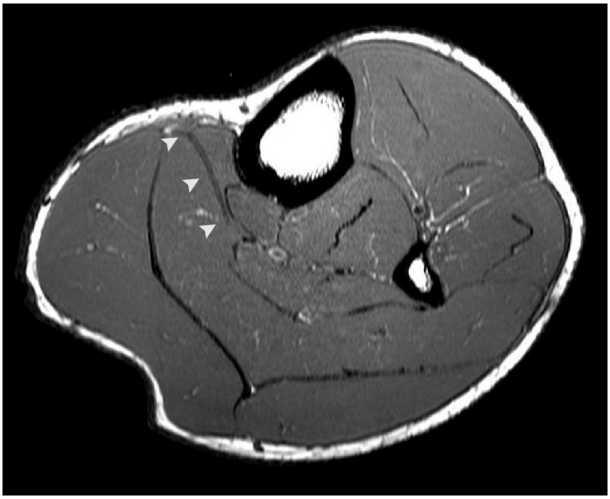



**FIGURE 4.5** Inaccurate position of the catheter. The tip does not reach the deep posterior compartment; however, it is positioned in the superficial compartment (soleus muscle). The arrowheads indicate the course of the catheter.

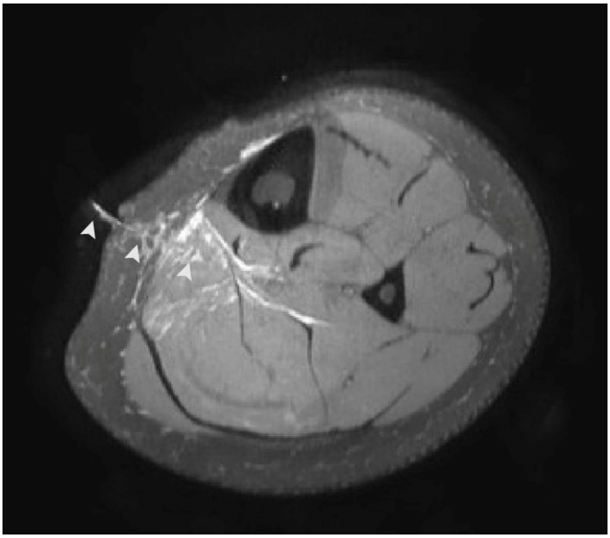

**FIGURE 4.6** Inaccurate superficial catheter position with a hematoma in the soleus muscle and subcutaneous tissue. The arrowheads indicate the course of the catheter.

### Statistical analysis

We intended to study 25 patients. As this was a pilot study in which a comparison with data from other studies was not available, a robust sample size calculation was not possible. Statistical analysis was performed using SPSS Statistics version 17.0.0 for Windows (SPSS Inc). For continuous data, mean values were calculated.

## RESULTS

### Patient characteristics

Between March 2013 and September 2014, a total of 25 patients scheduled for an ICP measurement for suspected dp-CECS agreed to undergo MRI. One patient with intramedullary osteosynthesis was excluded, leaving 24 patients available for analysis (8 male, 16 female; age, 30 years [range 18-54 years]; 17 left sided). ICP measurements in these 24 patients were performed with no visible or subjective complications. Nineteen patients also underwent simultaneous ICP measurements of the anterior (n=18) or lateral (n=4) compartment.



### History and previous treatments

Provocative activities included running (n=7), soccer (n=3), fitness (n=3), hockey (n=2), handball (n=1), tennis (n=1), basketball (n=1), crossfit (n=1), cardio training (n=1), ice skating (n=1), and no sports/normal daily activities (n=3). Patients had received rest (87%), physical therapy (80%), orthotics (64%), or icing (47%), but with no effect. Four patients reported previously undergoing dry needling, extracorporeal shock wave therapy, or prolotherapy.

### Symptoms

The median time to diagnosis was 18 months (range, 3 months to 11 years). Symptoms were bilateral in 74% of patients; 81% of patients reported that symptoms had started after completing an intense sports workout. Symptoms were experienced in 40% of patients within 5 minutes of engaging in sports and in almost all (93%) patients within 30 minutes. More than half (56%) of the patients were forced to terminate sports, 13% changed to a different type of sports, and 19% were able to continue, albeit at a less intense level. Only 13% of patients performed at their desired level. The level of sports was social (56%), local competitive (25%), or national competitive (19%). Symptoms during exertion were pain (20% very severe, 53% severe, and 20% moderate) and tightness (29% very severe, 43% severe). Other reported complaints were cramps, muscle weakness, and diminished sensations in the lower leg.

## Pressure measurements and diagnosis

The mean (± SD) compartment pressure at rest was 15 ± 5 mm Hg (range, 7-31 mm Hg). Provocation resulted in a rise to 26 ± 14 mm Hg (range, 9-63 mm Hg) directly after exercise, 27 ± 13 mm Hg (range, 15-59 mm Hg) 1 minute after exercise, and 24 ± 11 mm Hg (range, 12-52 mm Hg) 5 minutes after exercise. Nine of the 24 patients were diagnosed with dp-CECS (isolated dp-CECS, n=2; combined ant-CECS/dp-CECS, n=5; combined ant-CECS/per-CECS/dp-CECS, n=2). In this positive CECS subgroup, mean pressures were 18 ± 6 mm Hg (range, 11-31 mm Hg) at rest, 41 ± 14 mm Hg (range, 27-63 mm Hg) directly after exercise, 37 ± 12 mm Hg (range, 28-59 mm Hg) 1 minute after exercise, and 29 ± 12 mm Hg (range, 14-51 mm Hg) 5 minutes after exercise.

The 15 patients with low deep posterior compartment pressures were diagnosed with soleus syndrome (n=3), medial tibial stress syndrome (n=2), chronic soleus/gastrocnemius strain (n=2), isolated ant-CECS (n=2), ant-CECS with medial tibial stress syndrome (n=1), isolated per-CECS (n=1), common peroneal tunnel syndrome (n=1), pseudoradicular syndrome (n=1), chronic complaints after a soleus tear (n=1), and unclear deep compartment pain (n=1).



## MRI scans

MRI scans were obtained within 30 minutes after ICP measurements. The catheter tip was positioned in the deep posterior compartment in 79% of patients (19/24). Accuracy for TP placement was 42% (10/24). Suboptimal placement of the catheter tip, within the deep posterior compartment but outside the TP, was found in 38% (9/24) of patients. Of these 9 suboptimally placed catheters, 3 were present in the transition zone of the FDL/TP, and 6 were in the FDL. There were 5 inaccurately placed catheters: 2 were clearly positioned in the SC (soleus muscle), and 3 ended up in the transition zone of the SC/FDL (Table 4.1). All catheters were straight or slightly curved; kinking was not observed. The mean catheter length from skin to the tip was 44 ± 10 mm (range, 28-62 mm), and the mean distance from the crural fascia to the tip was 30 ± 12 mm (range, 7-51 mm). The mean distance between the catheter and the tibial cortex was 4 ± 2 mm (range, 1-9 mm). Nine of the 24 patients (38%) showed signs of a hematoma (around the fascia of the deep posterior compartment, n=2; FDL, n=2; posterior neurovascular bundle, n=1; soleus, n=1; subcutis, n=3). A separate fascia around the TP was visible in all (100%; 24/24) patients. However, this fascia was not recognized as a fibular slip of the FDL in any of the 24 patients. In the subgroup of 9 patients diagnosed with dp-CECS, the catheter tip was positioned in the deep posterior compartment in only 56% (5/9). Accuracy for TP placement was a mere 33% (3/9).

**TABLE 4.1**

Localization and accuracy of catheter tip placement for intracompartmental pressure measurements in the deep posterior compartment of the lower leg.[a]

| Patient | Accuracy | Catheter tip in DP | Place of catheter tip | Shortest distance from tibial cortex to catheter, mm | Catheter position | | Distance, mm | |
|---|---|---|---|---|---|---|---|---|
| | | | | | In relation to posterior neurovascular bundle | In relation to peroneal neurovascular bundle | Cutis to tip | Crural fascia to tip |
| 1 | Accurate | Yes | TP | 3 | Ventral | Not reaching | 33 | 27 |
| 2 | Accurate | Yes | TP | 1 | Ventral | Not reaching | 46 | 37 |
| 3 | Accurate | Yes | TP | 4 | Ventral | Not reaching | 48 | 33 |
| 4 | Accurate | Yes | TP | 3 | Ventral | Not reaching | 56 | 39 |
| 5 | Accurate | Yes | TP | 1 | Ventral | Not reaching | 62 | 51 |
| 6 | Accurate | Yes | TP | 1 | Ventral | Not reaching | 47 | 34 |
| 7 | Accurate | Yes | TP | 5 | Ventral | Not reaching | 43 | 33 |
| 8 | Accurate | Yes | TP | 2 | Ventral | Not reaching | 61 | 51 |
| 9 | Accurate | Yes | TP | 2 | Ventral | Ventral | 57 | 47 |
| 10 | Accurate | Yes | TP | 2 | Ventral | Ventral | 46 | 33 |
| 11 | Suboptimal | Yes | transition FDL/TP | 5 | Ventral | Not reaching | 51 | 29 |
| 12 | Suboptimal | Yes | transition FDL/TP | 5 | Ventral | Not reaching | 39 | 25 |
| 13 | Suboptimal | Yes | transition FDL/TP | 4 | Not reaching | Not reaching | 34 | 19 |
| 14 | Suboptimal | Yes | FDL | 1 | Ventral | Not reaching | 47 | 34 |
| 15 | Suboptimal | Yes | FDL | 2 | Ventral | Not reaching | 51 | 43 |
| 16 | Suboptimal | Yes | FDL | 5 | Not reaching | Not reaching | 33 | 18 |
| 17 | Suboptimal | Yes | FDL | 1 | Not reaching | Not reaching | 39 | 32 |
| 18 | Suboptimal | Yes | FDL | 6 | Not reaching | Not reaching | 34 | 15 |
| 19 | Suboptimal | Yes | FDL | 1 | Ventral | Not reaching | 50 | 33 |
| 20 | Inaccurate | Borderline | transition SC/FDL | 9 | Not reaching | Not reaching | 32 | 19 |
| 21 | Inaccurate | Borderline | transition SC/FDL | 8 | Not reaching | Not reaching | 28 | 18 |
| 22 | Inaccurate | Borderline | transition SC/FDL | 6 | Not reaching | Not reaching | 31 | 14 |
| 23 | Inaccurate | No | SC | 6 | Not reaching | Not reaching | 37 | 28 |
| 24 | Inaccurate | No | SC | 3 | Not reaching | Not reaching | 29 | 7 |

[a] DP; deep posterior compartment, FDL; flexor digitorum longus muscle, SC; superficial compartment, TP; tibialis posterior muscle.

# DISCUSSION

Success after fasciotomy for CECS is known to depend on the type of affected compartment. In contrast to superior success rates after surgery for ant-CECS, outcomes after dp-CECS surgery are only successful in approximately half of the patients.[25,27] Several factors including suboptimal patient diagnostics and selection may contribute to these limited operative success rates. The aim of the present study was to verify whether a routinely used catheter insertion technique using digital palpation (freehand) was accurately measuring TP pressures, assuming that the TP is the most important muscle of the deep posterior compartment in patients suspected of having dp-CECS. Catheter tip visualization was based on an MRI analysis. The results indicate that the freehand technique was accurate in only 42% of patients. Conversely, a completely inaccurate tip position (eg, not even in the deep posterior compartment) was found in 21% (5/24) of patients. As a consequence, optimizing the positioning technique may improve diagnostic accuracy and may lead to a superior selection of patients possibly benefiting from surgery.



A limited number of reports studied the accuracy of needle placement in the lower leg compartments, predominantly for nerve conduction studies or electromyography (EMG) diagnosing neuromuscular disease.[16,29,31] Literature on verification of the proper placement of a diagnostic compartment pressure catheter in CECS is scarce.[13,23] One article on cadaveric limbs found that palpation-guided accuracy of the placement of an EMG needle in the TP was 50% (8/16). In half of the patients, the needle was incorrectly positioned in the soleus muscle. In contrast, US-guided TP needle placement was 100% accurate (16/16). It was concluded that US guidance resulted in superior accuracy of catheter needle placement. However, a different approach was used in the 2 groups. In the palpation-guided needle placement group, a posteromedial approach was used. Conversely, an anterior approach via the tibialis anterior muscle and interosseous membrane was practiced in the US-guided group.[31]

A second study comparing palpation- versus US-guided compartment pressure catheter placement in the deep posterior compartment found similar success rates (90% vs 88%, respectively) in 20 cadaveric specimens, regardless of the investigators' experience.[13] Moreover, US-guided accuracy of punctures appeared superior to landmark-guided punctures in other body parts such as the shoulder girdle,[1] hip joint,[10] knee,[11] ankle,[28] and peroneal tendon.[12] This is the first in vivo MRI study on accuracy rates of palpation-guided catheter placement in the TP and deep posterior compartment. A 79% (19/24) rate of tip placement in the deep posterior compartment was found. Accurate catheter positioning in the TP was modest (42%; 10/24). However, 3 catheter tips were positioned at the SC/FDL transition zone and therefore judged as inaccurate, possibly leading to slightly underrated accuracy. If the aim of a dp-CECS measurement is to determine elevated pressures in the TP, a palpation-guided insertion technique clearly performs suboptimally.

Two methods are currently used for measuring muscle pressures in the lower leg deep posterior compartment. If the anterior approach is preferred, the hollow needle penetrates the TP after passing the tibialis anterior muscle and the interosseous membrane. On the other hand, a posteromedial approach includes needle passage through the soleus and FDL.[16] The anterior route possibly results in a more accurate puncture as the TP lies directly below a thick interosseous membrane that is definitely felt upon piercing. This approach also avoids erroneous positioning in the FDL as this muscle is hidden behind the tibial bone. We did not use this approach because of the risk of potential injuries of the anterior tibial artery and deep peroneal nerve, which are both positioned on top of the interosseous membrane. Moreover, the anterior approach should not be used if the FDL is possibly affected. Different strategies for optimizing catheter placement were advocated for either approach. Some authors advised puncturing one handbreadth distal to the tibial tuberosity and one fingerbreadth dorsal from the medial tibial margin.[13,15,31] Others prefer to place the needle at the junction of the middle and distal thirds of the lower leg at the place where the soleus bridge ends; with the catheter angled proximally, the fleshy portion of the FDL is reached.[21] Others prefer a more distal portion of the lower leg below the soleus bridge, at the point where the deep posterior compartment becomes superficial.[20] Our preference is to insert the catheter at the junction of the proximal and middle thirds. This posteromedial approach is preferred as the TP is most voluminous and the ‘‘safety window’’ is large.[30] Moreover, this method theoretically allows for obtaining FDL pressures. However, the claimed safety of this posteromedial approach may be questioned as the present MRI study demonstrated a 38% hematoma rate, although these were clinically asymptomatic. The safety issue, together with previously reported high accuracy rates of the anterior approach,[31] raises questions as to whether the posteromedial approach should be used rather than the anterior approach.

Fasciotomy is more challenging to perform for dp-CECS compared with ant-CECS or lateral CECS. During this procedure, deeply hidden flexor muscles surrounded by crucial neurovascular structures may be encountered. Currently, a consensus on the extent of fasciotomy for dp-CECS is absent. To date, the literature on dp-CECS favors a medial approach using a longitudinal incision. After opening of the crural fascia, most authors subsequently perform fasciotomy of the FDL.[2,14,18,22,24] However, some favor an additional deep posterior compartment exploration and standard fasciotomy of the TP.[17,20,27] Surgical success rates are comparable, suggesting that the optimal technique is still unknown. However, randomized trials were not performed. We have experienced a number of patients with dp-CECS reporting persisting symptoms after fasciotomy that were limited to the crural and FDL fascias. After a second operation opening the ultrathin but very tight TP fascia, patients became free of symptoms. As a consequence, we standardly include fasciotomy of this TP, although it is appreciated that this may not be required in all patients. Moreover, some patients may suffer from isolated TP CECS in the presence of normal deep posterior compartment pressures.[4,17] Interestingly, the present MRI study found a 100% TP fascia rate, indicating that all patients do have a separate fascia covering the TP. One may question whether it is more informative to synchronously measure both the deep posterior compartment and its separate flexor muscles with multiple catheters. Alternatively, one may withdraw the catheter from the TP to obtain FDL and SC pressures using a posteromedial approach. However, if high TP pressures are measured, one may perform crural fasciotomy as well as opening the FDL on the way to the TP. Nevertheless, it is recommended to standardly examine the deep posterior compartment for additional fascias while performing standard deep flexor fasciotomy.

Several limitations of the current study may be discussed. The accuracy of catheter placement was analyzed after the patients finished a standard exercise protocol. It is unknown whether inaccurately placed catheters (as determined by MRI) were initially positioned correctly but were dislodged during running, despite firmly taping the catheter to the skin. A perpendicularly inserted catheter may bend somewhat proximally during exercise as flexor muscle fibers will slide proximally with respect to the fascial entry point of the catheter during repetitive contractions. Moreover, some MRI scans demonstrated that the catheter was slightly curved around the medial tibial margin as a result of gastrocnemius muscle flattening because the calf was not held free from the MRI table. This may possibly have resulted in shortening of the original catheter course. Second, radiologists considered it difficult to score the exact position of the catheter tip in some cases. If in doubt, the position was scored as suboptimal, possibly leading to lower accuracy rates. For instance, of 5 inaccurately labeled catheters, 3 ended up in the transition zone of the SC/FDL. The role of US was not compared with palpation-guided catheter placement. A future randomized study should focus on the accuracy of a freehand technique versus US-guided catheter placement as confirmed by MRI.

In conclusion, the current palpation-guided catheter placement for pressure measurements of the TP in dp-CECS performs suboptimally. The accuracy of palpation-guided catheter placement in the deep posterior compartment is acceptable. Future research should focus on the possible benefits of alternative tools of guidance such as US as a control tool for correct compartment pressure measurements as elevated compartmental pressures remain the cornerstone for the diagnosis of dp-CECS.

# REFERENCES


1. Aly AR, Rajasekaran S, Ashworth N. Ultrasound-guided shoulder girdle injections are more accurate and more effective than landmarkguided injections: a systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1042-1049.
2. Biedert RM, Marti B. Intracompartmental pressure before and after fasciotomy in runners with chronic deep posterior compartment syndrome. Int J Sports Med. 1997;18(5):381-386.
3. Boody A, Wongworawat M. Accuracy in the measurement of compartment pressures: a comparison of three commonly used devices. J Bone Joint Surg Am. 2005;87(11):2415-2422.
4. Davey JR, Rorabeck CH, Fowler PJ. The tibialis posterior muscle compartment: an unrecognized cause of exertional compartment syndrome. Am J Sports Med. 1984;12(5):391-397.
5. David V, Thambiah J, Kagda F, Kumar VP. Bilateral gluteal compartment syndrome: a case report. J Bone Joint Surg Am. 2005; 87(11):2541-2545.
6. Frink M, Hildebrand F, Krettek C, Brand J, Hankemeier S. Compartment syndrome of the lower leg and foot. Clin Orthop Relat Res. 2010;468(4):940-950.
7. Hammerberg EM, Whitesides TE Jr, Seiler JG 3rd. The reliability of measurement of tissue pressure in compartment syndrome. J Orthop Trauma. 2012;26(1):24-31, discussion 32.
8. Hislop M, Tierney P. Anatomical variations within the deep posterior compartment of the leg and important clinical consequences. J Sci Med Sport. 2004;7(3):392-399.
9. Hislop M, Tierney P, Murray P, O'Brien M, Mahoney N. Chronic exertional compartment syndrome: the controversial ''fifth'' compartment of the leg. Am J Sports Med. 2003;31(5):770-776.
10. Hoeber S, Aly AR, Ashworth N, Rajasekaran S. Ultrasound-guided hip joint injections are more accurate than landmark-guided injections: a systematic review and meta-analysis Br J Sports Med. 2016 Apr;50(7):392-6.
11. Maricar N, Parkes MJ, Callaghan MJ, Felson DT, O'Neill TW. Where and how to inject the knee: a systematic review. Semin Arthritis Rheum. 2013;43(2):195-203.
12. Muir JJ, Curtiss HM, Hollman J, Smith J, Finnoff JT. The accuracy of ultrasound-guided and palpation-guided peroneal tendon sheath injections. Am J Phys Med Rehabil. 2011;90(7):564-571.
13. Peck E, Finnoff JT, Smith J, Curtiss H, Muir J, Hollman JH. Accuracy of palpation-guided and ultrasound-guided needle tip placement into the deep and superficial posterior leg compartments. Am J Sports Med. 2011; 39(9):1968-1974.
14. Pedowitz R, Hargens A, Mubarak S, Gershuni D. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. Am J Sports Med. 1990;18(1):35-40.
15. Perotto A, Delagi EF, Lazetti J, Morrison D. Tibialis posterior. In: Perotto A, ed. Anatomical Guide for the Electromyographer: Limbs and Trunk. Springfield, Illinois: Charles C. Thomas Publisher; 2005:195.
16. Rha DW, Park ES, Jung S, Lee SC, Suh M, Choi HS. Comparison of ultrasound-guided anterior and posterior approaches for needle insertion into the tibialis posterior in hemiplegic children with spastic cerebral palsy. Am J Phys Med Rehabil. 2014;93(10): 841-848.
17. Rorabeck CH. Exertional tibialis posterior compartment syndrome. Clin Orthop Relat Res. 1986;208:61-64.
18. Rorabeck CH, Bourne RB, Fowler PJ. The surgical treatment of exertional compartment syndrome in athletes. J Bone Joint Surg Am. 1983;65(9):1245-1251.
19. Roscoe D, Roberts AJ, Hulse D. Intramuscular compartment pressure measurement in chronic exertional compartment syndrome: new and improved diagnostic criteria. Am J Sports Med. 2015;43(2): 392-398.
20. Schepsis AA, Martini D, Corbett M. Surgical management of exertional compartment syndrome of the lower leg: long-term followup. Am J Sports Med. 1993;21(6):811-817.
21. Schepsis AA, Watson FJ, Creevy WR. Surgical treatment of overuse injuries of the lower extremity: exertional compartment syndrome. In: Elattrache NS, ed. Surgical Techniques in Sports Medicine. Philadelphia: Lippincott Williams & Wilkins; 2007:624-625.
22. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR. Chronic

deep posterior compartment syndrome of the leg in athletes: postoperative results of fasciotomy. Int J Sports Med. 2008;29(5):419-423.
23. Wiley JP, Short WB, Wiseman DA, Miller SD. Ultrasound catheter placement for deep posterior compartment pressure measurements in chronic compartment syndrome. Am J Sports Med. 1990;18(1): 74-79.
24. Winkes MB, Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Compartment pressure curves predict surgical outcome in chronic deep posterior compartment syndrome. Am J Sports Med. 2012;40(8):1899-1905.
25. Winkes MB, Hoogeveen AR, Scheltinga MR. Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. Br J Sports Med. 2014;48(22):1592-1598.
26. Winkes MB, Luiten EJ, van Zoest WJ, Sala HA, Hoogeveen AR, Scheltinga MR. Long-term results of surgical decompression of chronic exertional compartment syndrome of the forearm in motocross racers. Am J Sports Med. 2012;40(2):452-458.
27. Winkes MB, van Zantvoort AP, de Bruijn JA, et al. Fasciotomy for deep posterior compartment syndrome in the lower leg: a prospective study. Am J Sports Med. 2016; 44(5):1309-16.
28. Wisniewski SJ, Smith J, Patterson DG, Carmichael SW, Pawlina W. Ultrasound-guided versus nonguided tibiotalar joint and sinus tarsi injections: a cadaveric study. PM R. 2010;2(4):277-281.
29. Won SJ, Kim JY, Yoon JS, Kim SJ. Ultrasonographic evaluation of needle electromyography insertion into the tibialis posterior using a posterior approach. Arch Phys Med Rehabil. 2011;92(11):1921-1923.
30. Won SJ, Yoon JS. Approach for needle insertion into the tibialis posterior: an ultrasonography study Muscle Nerve. 2016; 53(4):528-31.
31. Yun JS, Chung MJ, Kim HR, et al. Accuracy of needle placement in cadavers: non-guided versus ultrasound-guided. Ann Rehabil Med. 2015;39(2):163-169.

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# CHAPTER 5

# FASCIOTOMY FOR LOWER LEG DEEP POSTERIOR CHRONIC EXERTIONAL COMPARTMENT SYNDROME: A PROSPECTIVE STUDY

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# ABSTRACT

**Background**
Patients with exercise-induced lower leg pain may suffer from deep posterior chronic exertional compartment syndrome (dp-CECS). Current evidence for the efficacy of surgery is based on retrospective studies. Effects of fasciotomy on symptoms associated with dp-CECS have not been systematically studied, and reasons for unsuccessful surgery are unknown.

**Purpose**
To report short- and-long term effects of fasciotomy on pain, tightness and cramps in a prospective cohort of patients with isolated dp-CECS.

**Methods**
Between September 2011 and January 2015, pain, tightness, cramps, muscle weakness and diminished sensation were scored (5-item verbal rating scale ranging from very severe [5 points] to absent [1 point]) in patients with dp-CECS before and after a fasciotomy. Outcomes were graded as excellent, good, moderate, fair or poor. Fair and poor cases were again analyzed during a follow-up visit in the outpatient department.

**Results**
Forty-four patients underwent surgery for isolated dp-CECS. Short-term follow-up (median, 4 months; range, 3-7 months) was complete in 42 of the 44 patients (95%; median age, 23 years; 23 male; 64 operated legs). Long-term follow-up (median, 27 months; range, 12-42 months) was complete in 34 of 37 patients (92%). Before surgery, exertional pain was very severe (27%) or severe (61%). Fasciotomy improved all symptoms, both in the short term (pain, 4.1 ± 0.6 vs. 2.3 ± 1.1; $P \leq .001$) and the long term (pain, 4.2 ± 0.6 vs 2.7 ± 1.3; $P \leq .001$). Levels of tightness, cramps, muscle weakness and diminished sensation demonstrated similar significant improvements. Short- and long-term symptom scores did not differ. The short term outcome was excellent in 29%, good in 29%, moderate in 21%, fair in 12% and poor in 10% of patients. In the long term, outcomes were similar (excellent, 12%; good, 35%; moderate, 24%; fair, 18%; and poor, 12%). An unsatisfactory outcome (fair or poor) was often caused by alternative types of CECS (e.g., anterior or lateral CECS) or to medial tibial stress syndrome. Based on this outcome, 76% of patients would opt for surgery again.

**Conclusion**
Fasciotomy was beneficial in 71% of patients with dp-CECS in the lower leg; 47% of study patients experienced a good to excellent outcome. Outcomes were stable in the long term. Persistent complaints were often caused by other untreated conditions.

# INTRODUCTION

Some athletes have exercise-related pain in the lower leg caused by chronic exertional compartment syndrome (CECS). The anterior compartment is most commonly affected. However, some patients develop high pressure in the deep posterior compartment (dp-CECS).[6,12,14] These patients typically report calf pain and tightness within half an hour after starting an activity such as running.[23] Initially, nonoperative regimens, including rest and physical therapy, may be tried. Adopting a forefoot-strike running technique may decrease symptoms and compartment pressures in anterior CECS.[7] If nonoperative treatments are unsuccessful, an invasive strategy is discussed.[22] In contrast to acute compartment syndrome, which necessitates emergency 4-compartment fasciotomy, selective compartment release is preferred on the basis of patient history and physical examination findings suggestive of CECS in combination with excessive muscle compartment pressure after a standard challenge. For dp-CECS, surgery involving an incision of fascias covering the superficial and the deep posterior compartments is considered the gold standard.[10,19,20]

Studies reporting on the efficacy of surgery for dp-CECS have been retrospective in design.[1,14,16-18,21-23] Postoperative results have often been reported in terms as "symptom-free during running", "significant improvement", or "pain disappeared".[10,15,23] Patients with dp-CECS usually report a combination of 5 cardinal symptoms: pain, tightness, cramps, muscle weakness, and loss of sensation.[4,8,22,23] Symptom improvement after fasciotomy is unknown, and reasons for unsuccessful surgery have not been investigated. The present study is the first to prospectively describe short- and long-term effects of fasciotomy on characteristic symptoms in patients with dp-CECS and to analyze the causes for failed surgery.



# METHODS

## General information and inclusion criteria

Máxima Medical Center (MMC), Veldhoven, The Netherlands, is a national referral center for sports induced extremity pain. Between September 2011 and January 2015, all patients diagnosed with dp-CECS as demonstrated by a typical history (exercise-induced pain along the inner border of the lower leg accompanied by tightness, cramps, weakness, diminished sensation, and symptom resolution at rest) and elevated intracompartmental pressure (ICP) immediately after symptom-provoking exercise were eligible for the present study. Patients were excluded if they suffered from other diseases possibly interfering with symptoms of CECS, if they had undergone recent (<3 months) surgery for lower leg entities other than CECS, if a recent history of lower leg fracture(s) was reported, if they were operated on for dp-CECS at their referring hospital, or if combined anterolateral CECS was present. The medical ethics committee of MMC approved this study.

## Dynamic ICP measurements

ICP measurements were performed by 2 sports medicine physicians using a slit catheter technique (Indwelling Slit Catheter Set; Stryker Instruments).[3,9,13] The leg position and details of needle and catheter placement have been previously published.[22] Symptoms were elicited during 5 minutes of treadmill running, starting with an 8-km/h speed and an 8% inclination. A tiptoe-walking maneuver was occasionally used in case running did not maximally provoke symptoms. Compartment pressures were recorded immediately after cessation and after 1 and 5 minutes. ICP cutoff points for the diagnosis were >15 mm Hg at rest, >30 mm Hg after 1 minute, or >20 mm Hg after 5 minutes of provocative exercise as are generally accepted.[14,18,22] The ICP values of the anterior tibial muscle compartment and/or lateral compartment were obtained simultaneously using a second catheter if these compartments were also symptomatic.

## Questionnaires

Before surgery, patients completed a dp-CECS questionnaire with the following items scored: symptom duration, provocative circumstances, level of sport, previous investigations, and treatment. Pain, tightness, muscle cramps, diminished sensation and muscle weakness were determined using a 5-item categorical verbal rating scale (VRS; 5 points = very severe; 4 points = severe; 3 points = moderate; 2 points = mild; 1 point = absent). We chose the VRS as it is less susceptible to scale failure compared to a visual analog scale.[11] Symptom frequency was scored as "always", "often", "half of the time", "sometimes", or "never". These scales represent the best equidistance on numeric scales allowing proper analysis.[2]

A second questionnaire addressing surgical complications, time to full recovery, time to return to sports, and residual symptoms as scored by the 5-item VRS is sent 3 months postoperatively.[21,22] The clinical outcome was scored using a 5-item VRS (poor, fair, moderate, good, excellent). A 4-item VRS was avoided because in an earlier study, some patients reported they were forced to choose either a negative (fair/poor) or positive (good/excellent) side or met criteria from different predefined grades.[18,22] Moreover, an odd number of items allowed for a more neutral response. If patients did not respond, they were contacted and asked to complete a digital form of the questionnaire. If patients required bilateral dp-CECS surgery, an additional questionnaire was sent 3 months after the second surgical procedure.

In May 2015, a final questionnaire addressing long-term results was sent to all patients who were at least 1 year out from surgery. All patients reporting a fair or poor outcome were invited for an outpatient re-evaluation. If desired, ICP measurements were repeated.

## Surgical procedure

After the diagnosis, patients were given the option by the sports medicine physician to consult the senior author (M.R.S.) who is experienced in performing fasciotomies (>500 patients with all types of CECS). They were informed on specific details of the surgical procedure and success rates, both by the surgeon and by a booklet. Informed consent was obtained. If bilateral dp-CECS was present, fasciotomies were performed at least 3 months apart. All operations were performed by the senior author.

Outpatient surgery was performed under general anesthesia or with a regional technique. A useful step-by-step surgical "how-to" for correct release of the deep posterior compartment has been previously reported.[23] A 15- to 20-cm stretch of the crural fascia was opened, and the soleus muscle was detached from the tibia. A separate fascia covering the flexor digitorum longus muscle was opened using scissors. Subsequently, the plane dorsomedial to the flexor digitorum longus muscle was systematically explored. The posterior tibial nerve that was located dorsal to the artery was visualized and served as a landmark representing the posterior tibialis muscle compartment. This muscle was always found to be enveloped by an ultrathin but exceedingly strong fascia that was opened using a knife and scissors (Figure 5.1). The length of this fasciotomy was between 15 and 20 cm. Exploration of the flexor hallucis longus muscle compartment was never performed. The skin was closed using standard techniques.



Postoperatively, patients wore compression stockings for 14 days. They were permitted to walk, but sports were not permitted during this 2-week time period. Wound inspection occurred 2 weeks postoperatively, followed by bicycling during week 3 and 4, light jogging during week 5 and 6, and sports of maximal intensity during week 7 and 8. A telephone consultation was performed 2 to 3 months postoperatively. After the short- and long-term questionnaires were obtained, patients with unsuccessful results were again invited for outpatient follow-up.

## Statistical analysis

Statistical analysis was performed using SPSS Windows version 17.0.1 (IBM Corp). Data were expressed as mean ± SD if normally distributed, or as median and range if not. A $\chi^2$ test compared categorical variables. For comparison of normally distributed preoperative and postoperative mean variables, a paired-samples *t* test was used. The relation between ICP characteristics and clinical outcomes was analyzed using a Kruskal-Wallis test. For comparison of short- and long-term symptom reductions, a paired-samples *t* test was used. For comparison of short- versus long-term outcomes (ordinal variables), a Wilcoxon signed-rank test was used. For all tests, $P \leq .05$ was considered significant.

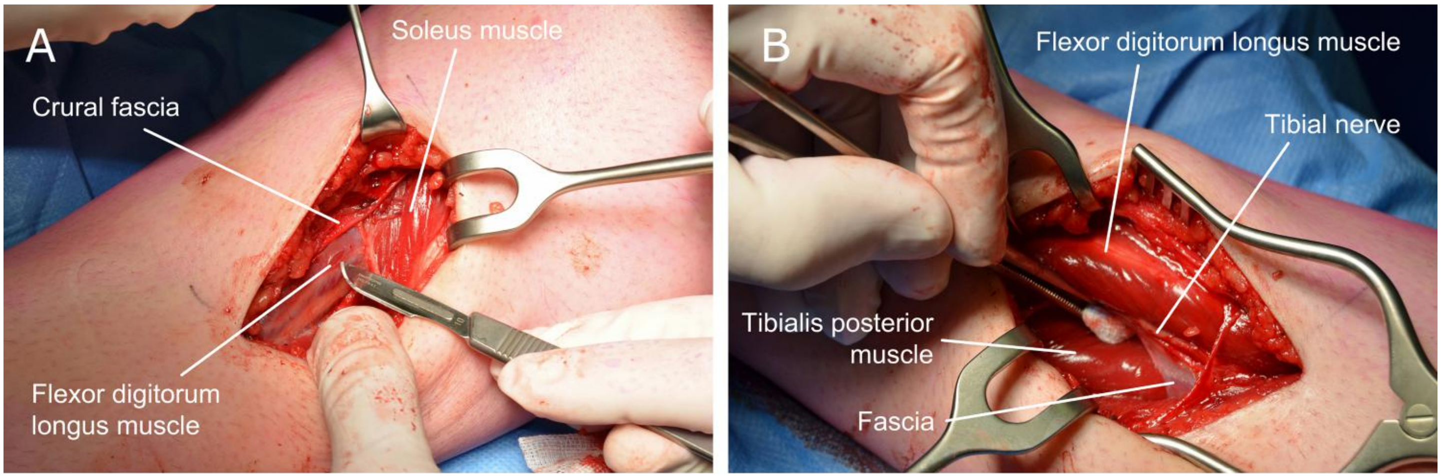


**FIGURE 5.1** Step-by-step surgical procedure in deep posterior chronic exertional compartment syndrome. (A) After opening the crural fascia and soleal detachment, the fascia covering the flexor digitorum longus muscle is visible. This fascia is opened proximally and distally using scissors. (B) Exploration of the plane dorsomedial to the flexor digitorum longus muscle reveals a thin but exceedingly strong separate fascia of the tibialis posterior muscle.

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# RESULTS

## Study characteristics

During the almost 3.5-year study period (September 2011 to January 2015), 722 ICP measurements were performed in 1143 compartments (433 lower leg deep posterior, 516 lower leg anterior, 143 lower leg peroneal/lateral, 45 lower arm extensor or deep flexor, 5 hand, and 1 upper thigh) of patients with symptoms suggested of CECS. A total of 91 patients were diagnosed with dp-CECS. During the study period, a total of 73 patients with a medial tibial stress syndrome (MTSS), having pain along the medial portion of the tibial bone, and normal ICP measurements were diagnosed. Of these, 21 underwent posterior fasciotomy, but results are not included in the present report.

Forty-seven of these 91 patients with dp-CECS were excluded because they were treated by their referring institution (n=25); chose nonoperative therapy (n=4); were still on the waiting list for surgery (n=2); suffered from a significant untoward event such as a knee tumor (n=1), cerebrovascular accident (1), or intramedullary osteosynthesis for a tibial fracture (n=1); or had anterolateral CECS requiring fasciotomy (anterior/dp-CECS, n=12; lateral/dp-CECS, n=1). Two of the remaining 44 patients with isolated dp-CECS not responding to phone calls or questionnaires after the 2-week postoperative wound inspection were also excluded. Therefore, the present study reports on 42 patients with isolated dp-CECS in the short term (follow-up rate, 95%). The study population was representative of the initial cohort (n=91) because the study group (n=42) and excluded group (n=49) were not significantly different (Table 5.1). Demographic data of both populations are listed in Table 5.1. For the ease of the reader, the patients lost to follow-up have been listed in the exclusion group.



All 42 patients had complete data sets of history, ICP values, preoperative symptom scores, 2-week postoperative outpatient findings and short-term symptom scores. At the final evaluation time point, 37 of these 42 patients were at least one year postoperatively. Long-term questionnaires were completed in 34 of these 37 patients (92%).

## History and previous treatment of patients with isolated dp-CECS

Provocative sports were soccer (n=18), running (15), military activities (2), korfball (2), field hockey (2), cycling (2), fitness (2), athletics (1), badminton (1), volleyball (1), handball (1), spinning (1), crossfit (1), rugby (1), mountain biking (1), fighting sports (1), tennis (1), or no sports (1). Patients had received rest (93%), physical therapy (89%), orthotics (76%) or icing (54%), but always to no avail. Eight patients (19%) reported chiropractics, acupuncture, dry needling, extracorporeal shock wave therapy, transcutaneous electrical nerve stimulation, trigger point therapy, or compression stockings. Seven patients (17%) had previously undergone successful fasciotomy of other compartments (5 bilateral anterior CECS, 2 unilateral dp-CECS; 3 of these 7 underwent surgery elsewhere). Demographics and ICP pressures of study population are reported in Table 5.1.

**TABLE 5.1**
Characteristics of patients with isolated dp-CECS and controls. The control group consisted of patients with dp-CECS who were not studied for reasons listed in the text.

| | Study group (n = 42) | Control group (n = 49) | *P* Value |
|---|---|---|---|
| Sex, male/female, n | 23/19 | 27/22 | .88 |
| Age, median (range), y | 23 (17-52) | 23 (14-61) | .97 |
| Symptom duration before diagnosis, median (range), mo | 24 (3-72) | 28 (6-300) | .27 |
| Resting pressure, mean ± SD (n), mm Hg | 20 ± 6 (41) | 18 ± 5 (48) | .24 |
| Immediately after provocative test | 43 ± 10 (40) | 41 ± 11 (49) | .37 |
| 1 minute after | 37 ± 8 (40) | 36 ± 11 (47) | .85 |
| 5 min after | 32 ± 9 (40) | 31 ± 9 (47) | .49 |
| Medial tibial stress syndrome, n | 6 | 4 | .36 |
| Anterior tibial compartment CECS, n | 0 | 24 | |
| Peroneal/lateral CECS, n | 0 | 1 | |
| Level of sports, n (%) | | | |
| International | 1 (2%) | 2 (4%) | |
| National | 6 (14%) | 7 (14%) | |
| Local competitive | 23 (55%) | 28 (57%) | |
| Social | 10 (24%) | 10 (20%) | |
| No sports | 2 (5%) | 2 (4%) | |

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## History of symptoms

The median time from the first symptom to diagnosis was 28 months (range 3 months to 25 years). 97% of patients reported that symptoms had started after completing an intense sports workout. Symptoms were experienced within 5 minutes of sport in 48% of patients and within 30 minutes in almost all (93%) patients. More than half of the patients (55%) were forced to terminate sports, but 37% were able to continue, albeit at a less intense level. Only 8% of patients performed at their desired level. The level of sports was mostly local competitive or social (Table 5.1). Symptoms were pain (27% very severe, 61% severe and 12% moderate) and tightness (32% very severe and 49% severe). Thirteen patients experienced exercise-induced tingling or dull sensations in the areas innervated by the medial and lateral plantar nerves. The levels of cramps and muscle weakness are depicted in Figure 5.2. Bilateral dp-CECS was seen in 76% of patients (32/42). The 7 patients who had previously undergone surgery for other compartments were asymptomatic in these compartments during the physical examination. Six patients with dp-CECS also demonstrated symptoms suggestive of MTSS, defined as painful palpation of the posteromedial border of the distal tibia over a length of at least 5 cm.[24]

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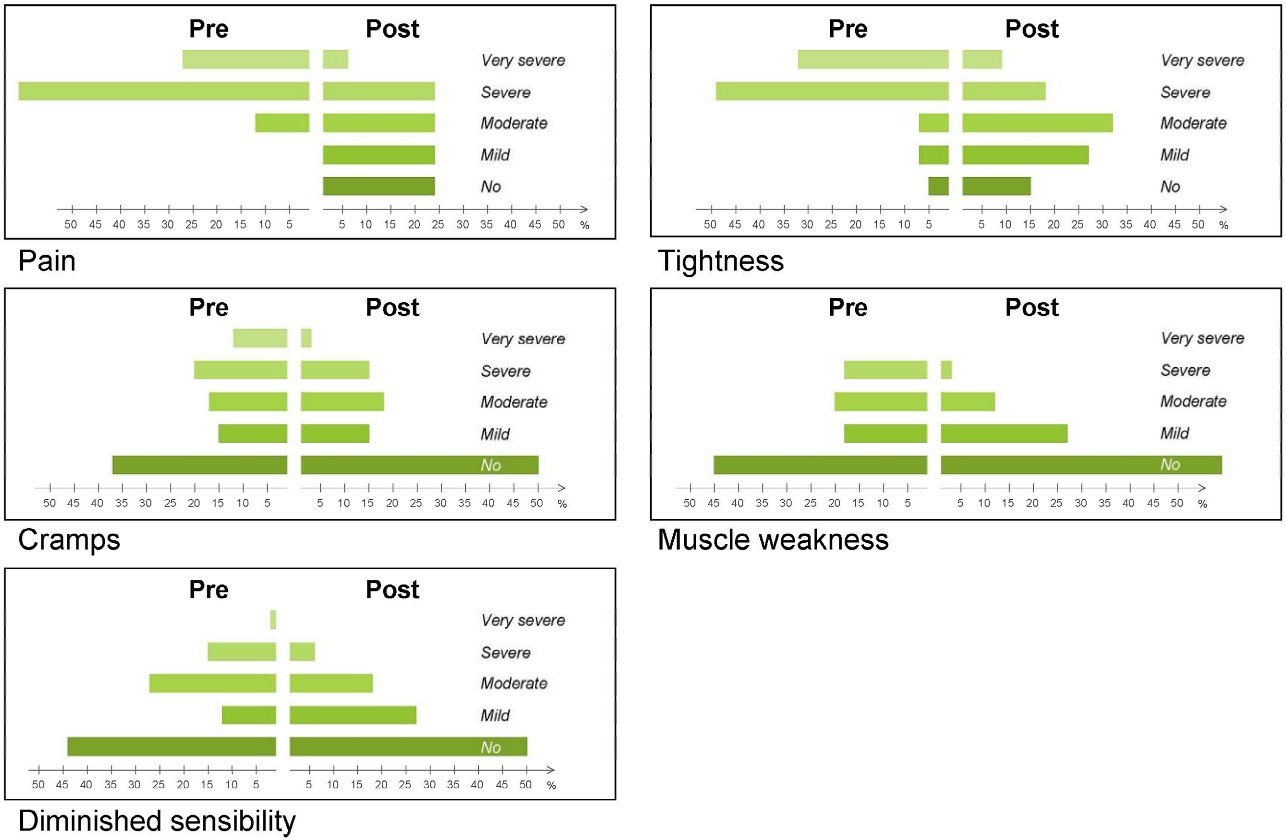


**FIGURE 5.2** Intensity of symptoms in 34 patients with isolated deep posterior chronic exertional compartment syndrome in the lower leg before and at least 1 year (median, 26 months) after a fasciotomy.

## Short-term outcomes

All 42 patients (64 legs) underwent fasciotomy; 22 (52%) were operated on for bilateral isolated dp-CECS. After a median 4 months (range, 3-7 months) of follow-up, a mean 1.8 ± 1 point drop in pain was reported (4.1 ± 0.6 vs. 2.3 ± 1.1; $P \leq .001$). Tightness also decreased significantly (3.1 ± 0.8 vs. 2.5 ± 1; $P = .003$), as did cramps (2.6 ± 1.5 vs. 1.7 ± 1.1; $P \leq .001$). Intensities of muscle weakness and diminished sensation as well as frequencies of symptoms were also significantly diminished after the fasciotomy. Interestingly, nearly all plantar paresthesias improved.

Self reported recovery from surgery was at a mean of 5 weeks (range, 2-14 weeks). Thirty-six percent of patients reported that they had returned to their highest (preinjury) levels of sporting activity, another 43% of patients were able to exercise but at a lower level than previously, and 12% were not engaged in sporting yet. The remaining 4 patients were either building up (2/42) or were hampered because of an unoperated contralateral dp-CECS (2/42).

The overall outcome was excellent in 29% (n=12), good in another 29% (n=12), moderate in 21% (n=9), fair in 12% (n=5) and poor in 10% (n=4). Pain reductions were 2.9, 2.0, and 1.7 points for excellent, good and moderate outcomes respectively, compared with 0.6 and 0.3 points for fair or poor outcomes. These improvements suggest that participants with excellent, good, and moderate outcomes constituted the success group. Clinical results were not different between men and women (65% good/excellent for men vs. 47% good/excellent for women; $P = .34$), nor was pain reduction ($P = .19$, Cohen effect size $d = 0.47$). Preoperative ICP values did not predict outcomes. The area under a 4-point pressure curve was not prognostic, as previously suggested.[22]

Twenty-two of the 42 patients were operated on for their contralateral dp-CECS in a second session. Postoperative results for this contralateral procedure were excellent (13%), good (38%), moderate (38%), fair (6%) and poor (6%).

An outpatient department analysis of unsuccessful patients (n=9) reporting a fair (n=5) or poor (n=4) outcome was performed (Table 5.2). Two patients were found to have symptoms associated with untreated compartments (1 with anterolateral CECS, 1 with lateral pain), whereas three additional patients had residual pain due to an associated MTSS. Interestingly, the 2 patients with untreated anterolateral compartments were asymptomatic regarding these compartments before the deep posterior compartment fasciotomy. One patient with a fair outcome experienced ankle edema, eventually improving after wearing compressive stockings. Three patients (2 with fair outcomes, 1 with a poor outcome) were still feeling pain in the decompressed deep posterior compartment. In contrast, 6 of these 9 unsuccessful patients did not experience pain in the operated deep posterior compartment.

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**TABLE 5.2**

Analysis of patients with an unsuccessful outcome in the short term (n=9) and long term (n=10) after fasciotomy for isolated dp-CECS.[a]

| Patient, male/female, age (yrs, baseline) | Level of sport at baseline | Short term result | Long term result | ICP (preoperative, immediately after challenge, in mm Hg) | ICP (long term postoperatively, immediately after challenge) | Condition causing residual symptoms | Treatment | Would undergo surgery again based on current outcome? |
|---|---|---|---|---|---|---|---|---|
| 1 M (42) | Social | Fair | Good | 54 (dp) | n.o. | Lower leg edema | Edema disappeared after use of compression socks | Yes |
| 2 M (45) | Local competitive | Excellent | Fair | 36 (dp) | 16 (dp)<br>24 (lat) | Residual pain lateral, possible peroneal nerve entrapment due to cyst | Refused further treatment | No |
| 3 M (20) | National competitive | Good | Fair | 36 (dp) | n.o. | Residual pain DP | Refused further evaluation | No |
| 4 F (26) | Local competitive | Moderate | Fair | 32 (dp)<br>19 (ant) | 15 (dp)<br>45 (lat)<br>45 (ant) | Lat-CECS | Improvement after fasciotomy lateral compartment (post-operative ICP 20 mm Hg) and 12kg weight loss | No |
| 5 F (25) | Local competitive | Fair | Fair | 40 (dp) | n.o. | Residual pain DP | Refused further evaluation | No |
| 6 F (32) | Social | Fair | Fair | 36 (dp) | 24 (dp)<br>45 (ant)<br>64 (lat) | New onset MTSS<br>New onset ant-CECS<br>New onset lat-CECS | Fasciotomy ant-CECS<br>Fasciotomy lat-CECS | Yes |
| 7 F (17) | Local competitive | Poor | Fair | 33 (dp) | n.o. | Persistent MTSS | Rest, minimal improvement | No |
| 8 M (28) | Social | Fair | Poor | 48 (dp)<br>24 (ant) | 28 (lat)<br>22 (ant) | Borderline lat-CECS | Refused additional treatment | No |
| 9 M (18) | Local competitive | Fair | Poor | 43 (dp) | n.o. | Redisual pain DP | Re-fasciotomy planned | Yes |
| 10 F (26) | Social | Poor | Poor | 32 (dp) | n.o. | Persistent pain DP | Refused further evaluation | No |
| 11 M (21) | Local competitive | Poor | Poor | 46 (dp) | n.o. | Persistent MTSS | Prolotherapy, minimal improvement | No |
| 12 F (20) | Social | Poor | Lost to follow-up | 35 (dp) | 19 (dp) | New-onset MTSS | Prolotherapy, dry needling, minimal effect Refused long term evaluation | - |

[a] Ant, anterior tibial compartment; CECS, chronic exertional compartment syndrome; dp, deep posterior compartment; F, female; ICP, intracompartmental pressure; lat, lateral compartment; M, male; MTSS, medial tibial stress syndrome.

## Long-term outcomes

The mean follow-up was 26 ± 10 months (median 27, range 12-42 months). Data from 34 of 37 patients who had reached the 1-year postoperative follow-up were available for analysis (response rate 92%; mean follow-up, 26 ± 9 months; range 12-42 months). 18 of these 34 patients were operated for bilateral dp-CECS in two sessions. During the follow-up period, one patient had revision surgery for recurrent dp-CECS, shortly after his primary operation.

A mean 1.6 ± 1-point drop in pain was reported (4.2 ± 0.6 vs. 2.7 ± 1.3; $P$<.001). Tightness had also decreased significantly (3.9 ± 1.2 to 2.8 ± 1.2; $P$<.001), as did muscle weakness (2.2 ± 1.2 to 1.6 ± 0.8; $P$=.003). Cramps and diminished sensation also improved, but changes were not significant (both $P$=.09). Symptom reductions did not differ at the short- and long-term follow-up time points ($P$=.10, .19, and .34 for pain, tightness, and muscle weakness, respectively). Frequencies of symptoms were all significantly diminished following fasciotomy.

The overall long-term outcome was excellent in 12% (4/34), good in 35% (12/34), moderate in 24% (8/34), fair in 18% (6/34) and poor in 12% (4/34). There was a trend of a less favorable outcome in the long term ($P$=.08); however, 76% of patients (26/34) reported that they would undergo surgery again based on their current outcome. Seven of the 8 patients reporting a moderate outcome would undergo surgery again, suggesting that most benefited from surgery. Clinical results were not different between men and women (good or excellent in 6/15 [men] vs. 10/19 [women]; $P$=.35, Cohen effect size $d$=0.16). Preoperative ICP values again did not predict outcomes. The area under a 4-point pressure curve was also not prognostic.[22] Twenty-nine percent of patients (10/34) reported that they had returned to their highest (preinjury) level of sporting activity. Another 47% of patients was able to exercise but at a lower level than previously whereas the remaining 23% was not engaged in sports.

An outpatient department analysis of patients reporting a fair (6/34, 18%) or poor (4/34, 12%) outcome is depicted in Table 5.2. Four patients (2 fair, 2 poor) had residual pain in their deep posterior compartment. Three of them accepted the situation and refused further diagnostics, the fourth opted for explorative refasciotomy (planned). Three additional patients (2 fair, 1 poor) suffered from recalcitrant MTSS, one of which was not present at baseline. Treatment (rest, physiotherapy and prolotherapy[5]) resulted in no to minimal improvement in all patients. One of these patients with MTSS also had anterolateral CECS and was planned for surgery. One patient with a poor outcome reported pain in his lateral compartment, with borderline elevated peroneal pressures. He refused further treatment. Another patient with a fair outcome had lateral CECS, and symptoms improved after fasciotomy combined with 12 kg of weight loss. Another patient with a fair outcome experienced exertional pain in his lateral compartment possibly because of peroneal nerve entrapment. Interestingly, 2 patients (1 fair, 1 poor) would opt for surgery again based on their outcome.

## Complications

Complications were registered in 4 of 64 legs (6% complication rate). One wound infection required clinical wound management including drainage and intravenous antibiotics. Three other patients developed a mild superficial wound infection, requiring oral antibiotics in 2. All 4 patients recovered uneventfully. Nerve damage or other complications were not observed.

# DISCUSSION

To our knowledge, all prior studies on surgery for dp-CECS in the lower leg were retrospective. Reported success rates varied from 33% to 65%, depending on the definition of success and follow-up.[21-23] In the present study, patients with dp-CECS, diagnosed using gold-standard dynamic ICP measurements, were followed prospectively in a single institution. The severity and frequency of 5 symptoms were quantified before and after fasciotomy. After a median 27 months' follow-up, a good or excellent result was achieved in 47% of the patients, whereas 71% benefited from surgery. An outpatient evaluation of the remaining 29% (n=10) reporting a fair or poor outcome demonstrated that pain in the decompressed deep posterior compartment was persistent in 4 (12%) patients. Conversely, other untreated types of CECS or MTSS caused residual lower leg pain in the remaining 6 unsuccessful patients.



Most studies recognize pain as a dominant symptom in dp-CECS. However, it is our experience that patients also report tightness, cramps, diminished sensation, and weakness. Patients completed a questionnaire investigating these symptoms before surgery, 3 months thereafter, and after more than 2 years. Follow-up was acceptable with a 95% short-term and 92% long-term response rate. Before surgery, 88% reported severe or very severe pain. However, more than three-quarters (81%) also experienced severe or very severe tightness. Muscle cramps, diminished sensation, and muscle weakness were felt by almost half of the population (49%, 44% and 38%, respectively). These data indicate that most patients with dp-CECS suffer from a spectrum of symptoms. Scoring these cardinal symptoms may contribute to decision making in doubtful cases and may allow for determining efficacy of future therapies.

It is controversial whether a physical examination has a role in the diagnosis of dp-CECS. However, executing a proper physical examination is important because palpation may identify concomitant entities such as CECS of the anterior or lateral compartment as these areas are often tender. Moreover, patients with dp-CECS may simultaneously harbor symptoms and signs of MTSS. The differential diagnosis of dp-CECS is extensive and difficult, and an incorrect diagnosis may lead to disappointing treatment results.[22,23] Alternative diagnoses may be of muscular origin (muscle strain, tendinopathy), vascular (popliteal artery entrapment syndrome, intermittent claudication, endofibrotic disease, cystic adventitial disease, deep vein thrombosis), bone/periosteum (stress fracture, MTSS, metabolic bone disease), nerve entrapment (peripheral neuropathies, dorsal root disease, herniated disk) or infectious (osteomyelitis) origin.[23] At the physical examination, signs of neurological disease or vascular syndromes including abnormal pedal pulse test results must be excluded. Is there a sign at the physical examination that possibly reflects the presence of dp-CECS? It is our experience that patients often do flinch if the lower leg is firmly grasped with one hand by the investigator, who is squeezing dorsomedial portions of the lower calf just medial to the Achilles tendon (Figure 5.3). Conversely, this test is negative after successful surgery. However, sensitivity and specificity of this subjective maneuver are not studied yet.

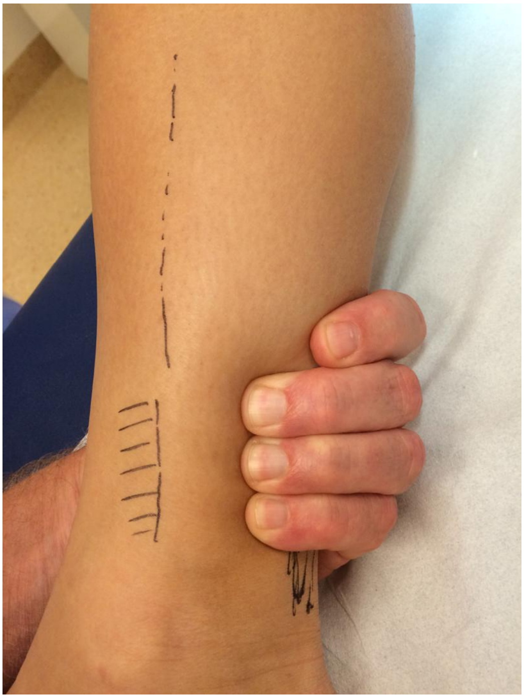

**FIGURE 5.3** Patients with isolated deep posterior chronic exertional compartment syndrome in the lower leg report pain if the hand of the investigator squeezes dorsomedial portions of the lower calf just medial to the Achilles tendon (marked using solid lines). The dotted line represents the medial tibial border.

Before surgery, 76% of patients had bilateral isolated dp-CECS. However, only 52% were operated bilaterally. There may be several explanations for this discrepancy. First, some may experience gradually diminishing contralateral symptom severity after successful ipsilateral surgery. Second, other patients may be reluctant to undergo surgery on the contralateral side if they are somewhat disappointed with the results of ipsilateral surgery. Third, some patients may want to postpone contralateral surgery for

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personal reasons related to their work situation. This finding must be communicated during preoperative counseling.

The present study has limitations. Seventeen percent of patients had previously undergone successful fasciotomy of other compartments. Inclusion of these patients may have caused selection bias as all were satisfied with their previous surgery. Conversely, it may be possible that there are patients with dp-CECS who choose not to undergo further treatment because of previous unsatisfactory results after fasciotomy of other compartments. It must also be appreciated that only patients with CECS were included. One may theoretically perform elective 4-compartment fasciotomy as routinely performed in acute compartment syndrome in these patients with CECS, although these studies were hitherto not performed. It is difficult to justify extensive surgery for asymptomatic compartments. Conversely, the downside of a preferred selective approach is the onset of CECS in previously untreated compartments and consequent multiple operations. Previously asymptomatic anterolateral compartments becoming symptomatic after successful posterior compartment fasciotomy also influenced success rates of the present population.

Defining success is also a matter of discussion. For instance, a previous study used 4 categories of outcomes (excellent, good, fair and poor).[18] Some of our earlier patients reported that an extra option (moderate) was missing in this classification. We therefore introduced a 5-item categorical outcome scale (excellent, good, moderate, fair or poor). A strict definition of the term "success" was thus avoided. However, one may reason that "success" is the sum of excellent, good and moderate outcomes (pain reductions of 2.9, 2.0, and 1.7 points, respectively). In support of this assumption, 7 of the 8 patients with a moderate outcome reported that they would undergo surgery again based on their results. In contrast, drops in pain levels in patients with fair and poor outcomes were a modest 0.6 and 0.3 points, respectively.



The currently performed fasciotomy was more extensive compared with other studies.[1,21] Before this study period, a poor result in 1 patient undergoing a fasciotomy of the crural fascia and flexor digitorum longus muscle fascia only was a strong prompt for us to additionally explore dorsal portions of the deep posterior compartment during a reoperation. After fasciotomy of the tibialis posterior muscle, the outcome was excellent in this patient. It was therefore decided to standardize our method to include fasciotomy of the tibialis posterior muscle. However, this more extensive type of surgery may possibly result in an increased risk of bleeding and cellulitis.

## CONCLUSION

This is the first prospective study on surgery for isolated dp-CECS in the lower leg with a long-term follow-up. If nonoperative measures in dp-CECS fail, fasciotomy of the crural fascia as well as flexor digitorum longus muscle and tibialis posterior muscle was found to diminish all 5 cardinal symptoms (pain, tightness, cramps, muscle weakness, and diminished sensation) associated with dp-CECS. Clinicians should re-examine patients with dp-CECS reporting limited success after fasciotomy as CECS of other compartments or MTSS may require treatment.

# REFERENCES


1. Biedert RM, Marti B. Intracompartmental pressure before and after fasciotomy in runners with chronic deep posterior compartment syndrome. *Int J Sports Med.* 1997;18(5):381-386.
2. Bocklisch F, Bocklisch SF, Krems JF. Sometimes, often, and always: exploring the vague meanings of frequency expressions. *Behav Res Methods.* 2012;44(1):144-157.
3. Boody AR, Wongworawat MD. Accuracy in the measurement of compartment pressures: a comparison of three commonly used devices. *J Bone Joint Surg Am.* 2005;87(11): 2415-2422.
4. Brennan FH jr, Kane SF. Diagnosis, treatment options, and rehabilitation of chronic lower leg exertional compartment syndrome. *Curr Sports Med Rep*. 2003 Oct;2(5):247-250.
5. Curtin M, Crisp T, Malliaras P, Padhiar N. The effectiveness of prolotherapy in the management of recalcitrant medial tibial stress syndrome: a pilot study. *Br J Sports Med.* 2011;45e1.
6. Detmer DE, Sharpe K, Sufit RL, Girdley FM. Chronic compartment syndrome: diagnosis, management, and outcomes. *Am J Sports Med.* 1985;13(3):162-170.
7. Diebal AR, Gregory R, Alitz C, Gerber JP. Forefoot running improves pain and disability associated with chronic exertional compartment syndrome. *Am J Sports Med*. 2012;40(5):1060-7.
8. Dunn JC, Waterman BR. Chronic exertional compartment syndrome of the leg in the military. *Clin Sports Med.* 2014;33(4):693-705.
9. Hammerberg EM, Whitesides TE, Jr., Seiler JG, 3rd. The reliability of measurement of tissue pressure in compartment syndrome. *J Orthop Trauma.* 2012;26(1):24-31.
10. Howard JL, Mohtadi NG, Wiley JP. Evaluation of outcomes in patients following surgical treatment of chronic exertional compartment syndrome in the leg. *Clin J Sport Med.* 2000; 10(3):176-184.
11. Loos MJ, Houterman S, Scheltinga MR, Roumen RM. Evaluating postherniorrhaphy groin pain: visual analogue or verbal rating scale? *Hernia.* 2008 Apr;12(2):147-51.
12. Martens MA, Backaert M, Vermaut G, Mulier JC. Chronic leg pain in athletes due to a recurrent compartment syndrome. *Am J Sports Med.* 1984;12(2):148-151.
13. McQueen MM, Duckworth AD, Aitken SA, Court-Brown CM. The estimated sensitivity and specificity of compartment pressure monitoring for acute compartment syndrome. *J Bone Joint Surg Am.* 2013;95(8): 673-677.
14. Pedowitz RA, Hargens AR, Mubarak SJ, Gershuni DH. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med.* 1990; 18(1):35-40.
15. Puranen J. The medial tibial syndrome. *Ann Chir Gynaecol.* 1991;80(2):215-218.
16. Rorabeck CH. Exertional tibialis posterior compartment syndrome. *Clin Orthop Relat Res.* 1986(208):61-64.
17. Rorabeck CH, Bourne RB, Fowler PJ. The surgical treatment of exertional compartment syndrome in athletes. *J Bone Joint Surg Am.* 1983;65(9):1245-1251.
18. Schepsis AA, Martini D, Corbett M. Surgical management of exertional compartment syndrome of the lower leg. Long-term followup. *Am J Sports Med.* 1993;21(6):811-817.
19. Slimmon D, Bennell K, Brukner P, Crossley K, Bell SN. Long-term outcome of fasciotomy with partial fasciectomy for chronic exertional compartment syndrome of the lower leg. *Am J Sports Med.* 2002;30(4):581-588.
20. Turnipseed WD. Diagnosis and management of chronic compartment syndrome. *Surgery.* 2002;132(4):613-617; discussion 617-619.
21. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR. Chronic deep posterior compartment syndrome of the leg in athletes: postoperative results of fasciotomy. *Int J Sports Med.* 2008;29(5):419-423.
22. Winkes MB, Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Compartment pressure curves predict surgical outcome in chronic deep posterior compartment syndrome. *Am J Sports Med.* 2012;40(8):1899-1905.
23. Winkes MB, Hoogeveen AR, Scheltinga MR. Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. *Br J Sports Med.* 2014; 48(22):1592-1598.

24. Yates B, White S. The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *Am J Sports Med.* 2004;32(3):772-780.

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# CHAPTER 6

# LONG-TERM RESULTS OF SURGICAL DECOMPRESSION OF CHRONIC EXERTIONAL COMPARTMENT SYNDROME OF THE FOREARM IN MOTOCROSS RACERS

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# ABSTRACT

**Background**
Chronic exertional compartment syndrome (CECS) is occasionally observed in the forearm flexor muscles of motocross racers. Long term results of fasciectomy and fasciotomy for this syndrome are scarce.

**Purpose**
To study the long term effects of two surgical techniques for forearm flexor CECS.

**Study Design**
Case Series; Level of evidence; 4.

**Methods**
A database of patients with forearm CECS who underwent surgery was analyzed. Long-term pain reduction (visual analog scale [VAS], 0-100) and efficacy were evaluated using a questionnaire.

**Results**
Data of 24 motocross racers were available for analysis. Intracompartmental pressures during rest, during provocation, and after 1 and 5 minutes of provocation were 15 ± 4, 78 ± 24, 29 ± 10, and 25 ± 7 mm Hg, respectively. Painful sensations in the forearm were reduced from 53 to 7 (median VAS, $P<.001$). Both fasciectomy (n=14) and fasciotomy (n=10) were equally effective. More than 95% (23/24) of the patients were satisfied with the postoperative result after a 5 ± 2 years' follow up.

**Conclusions**
Surgical fasciotomy and fasciectomy of the forearm flexor compartment are equally successful in motocross racers suffering from forearm CECS.

# INTRODUCTION

Intermittent extremity pain following repetitive muscle action in young adults without a history of cardiovascular disease may be because of the presence of a chronic exertional compartment syndrome (CECS). Chronic exertional compartment syndrome may develop in any muscle group covered by fascia and is most frequently demonstrated in anterior or posterior portions of the leg.[9,19,27] If nonoperative treatment fails, open or endoscopic fasciotomy or partial fasciectomy may prove successful.[10,30,32,40,41]

Lower leg CECS is relatively easily diagnosed, but the syndrome is often not considered in patients with forearm complaints. Symptoms are often mistakenly interpreted as caused by carpal tunnel syndrome with consequent unsuccessful surgical treatment.[43] However, patients characteristically report pain and muscle hardening as well as the inability to perform repetitive exercise referred to as "arm pump". Arm dysfunction occurs because of high levels of lactic acid in hypertrophied muscles enveloped by too tight compartmental fascias. As venous return is compromised, a subsequent disproportional rise in intracompartmental pressure ensues, with an ongoing vicious circle of local lactic acid accumulation and flexor forearm muscle dysfunction.[12,26]

In contrast to a substantial number of reports on lower leg CECS, studies addressing CECS in the forearm are scarce.[1,4,16,28,34] Chronic exertional compartment syndrome of the forearm may occasionally be observed in individuals participating in weightlifting, mountaineering, motocrossing or motor racing.[4,16] In a motocross race, both forearms are continuously exposed to heavy motor vibrations while maintaining balance at the rough tracks without an opportunity to relax. This may especially be true for the right forearm as it is constantly dealing with the throttle.[1]



Abnormal and persistent elevated intracompartmental pressure recorded by dynamic pressure measurements after cessation of strenuous exercise is widely recognized as the most objective diagnostic parameter of forearm CECS.[7,12,17,35] Data on long-term efficacy of surgery for forearm CECS are scarce.[6] Although the choice of performing an additional partial fasciectomy as first-line procedure remains controversial[39], there are some studies showing fasciectomy to be superior to subcutaneous fasciotomy in lower limb CECS as realignment and subsequent readherence of fascial edges may be prevented.[2,33,36-38] Some suggest that a partial fasciectomy is effective in cases of recurrent CECS after a fasciotomy.[2] However, data comparing fasciectomy and fasciotomy for forearm CECS are lacking.

In this study, we evaluated the long-term efficacy of surgical fasciotomy and partial fasciectomy for flexor forearm CECS in motocross racers. We hypothesized that long-term success rates were improved in patients with a partial fasciectomy.

# MATERIALS AND METHODS

## Patients

All demographic and clinical data of patients referred to the Department of Sports Medicine of the Máxima Medical Center, Veldhoven, The Netherlands, have been prospectively entered into a database since January 1996. The department serves as a referral center for the evaluation of sports-related injuries. Patients were extracted from this database and were deemed eligible for the study if their available sets of data containing patient history, physical examination results, and compartmental pressures were complete and were indicative of forearm CECS.

Long-term efficacy data were obtained using a questionnaire that was sent to all eligible individuals by mail. This retrospective questionnaire was designed to investigate additional characteristics before surgery, perioperative data, and long-term postoperative results. The list of questions was modified on the basis of a previous study on lower leg CECS.[40] Pain levels were measured using a visual analogue scale (VAS) consisting of a horizontal 100 mm line with the degree of pain quantified on the left as ‘pain absent’ (0 mm) and on the right as ‘excruciating pain’ (100 mm). The patients were instructed to put a cross on this line at the position representing their current perception of pain. Two typical examples were provided together with the questionnaire as a means of reducing the chance of scale failure. The VAS levels were categorized as severe (>70 mm), moderate (31-70 mm), mild (10-30) and no pain (<10 mm). Nonresponders received a second questionnaire or a reminder by telephone.

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## Dynamic intracompartmental pressure measurements

If history and physical examination findings were suggestive of forearm CECS, a dynamic intracompartmental pressure (ICP) measurement was performed. One investigator, a sports medicine physician (A.H.) with abundant experience in this technique (>600 lower leg ICP and >50 lower arm ICP) performed the measurements. The patients were sitting in an armchair with one arm lying flat on a table. Before introduction of the needle, a 1-$cm^2$ portion of overlying skin was infiltrated with 2 mL of 1% lidocaine. The needle of the slit catheter (Indwelling Slit Catheter Set; Stryker Instruments, Kalamazoo, Michigan) was inserted in the thickest proximal third part of the volar compartments,[15] in the midline between tendons of the palmaris longus and flexor carpi radialis muscles into the flexor digitorum profundus muscle. For the deep flexor compartment, the needle was aimed at the ulna at a $45^o$ angle.[25] Pressure measurement of the superficial flexor compartment was performed by retracting the catheter until the tip was located superficially.

Patients were instructed to palmar flex the wrist joint against resistance to ensure a correct position of the catheter. After the catheter was inserted, typical lower arm symptoms were provoked by repetitive palmar flexion of the wrist against resistance.

Compartmental pressure values were registered before, during, immediately after, and 1 and 5 minutes after the provocation using a pressure monitor device (Pressure Monitor Device 783547; Hewlett Packard, Palo Alto, California). Cutoff values were set at >10 mm Hg in rest and >20 mm Hg 1 and 5 minutes after provocation, as suggested by others.[3,4,31,44]

## Surgical technique and postoperative procedure

If signs and symptoms were suggestive for the presence of CECS, patients were informed on therapeutic options including nonoperative measures as well as surgical treatment. They all consented orally and in writing to a surgical procedure. The attending surgeon (E.L.) preferred an open fasciotomy combined with a partial fasciectomy using a tourniquet, whereas 2 surgeons (H.S. and M.S.) opted to perform a fasciotomy without a tourniquet through a restricted incision. Patients were operated under general anesthesia in a day care facility. They received 2500 IU of a low molecular weight heparin subcutaneously 1 hour before the surgical procedure as part of the hospital's standard operating procedure.

A fasciotomy was performed as follows. After sterile exposure, a 4- to 8-cm longitudinal incision over the flexor compartment was used to gain access to the superficial flexor compartment. Branches of the medial cutaneous nerve were identified and preserved. The subcutaneous fascia was freed from subcutaneous tissue over a 15- to 20-cm distance. Subsequently, this fascia was incised using a scalpel, and scissors or a fasciotome as described by Due and Nordstrand[11] were used to extend the fascial incisions "blindly" in proximal and distal directions (Figure 6.1). Blunt splitting of the flexor digitorum muscle was performed to allow access to the deep flexor muscles surrounding the ulna. The overlying fascia, if present, was also incised using a knife and scissors. One surgeon performed an additional 2 x 10-cm partial superficial fasciectomy in 14 patients through a somewhat larger 10- to 14-cm incision (Figure 6.2). The skin was closed in one layer followed by a compression bandage for 3 days. Patients were instructed to mobilize wrist and elbow joints from the first postoperative day and started full exercise after 2 weeks.

## Statistical analysis

Statistical analysis was performed using SPSS Statistics, Windows version 17.0.1 (Chicago, Illinois). The VAS scores were analyzed for skewness and kurtosis, and a Wilcoxon signed-rank test was used to compare the median preoperative and postoperative scores. A Mann-Whitney *U* test was used to compare VAS reductions in both surgical procedures. Data were expressed as mean ± standard deviation if normally distributed or as median and range. For all tests, $P \leq .05$ was considered significant.

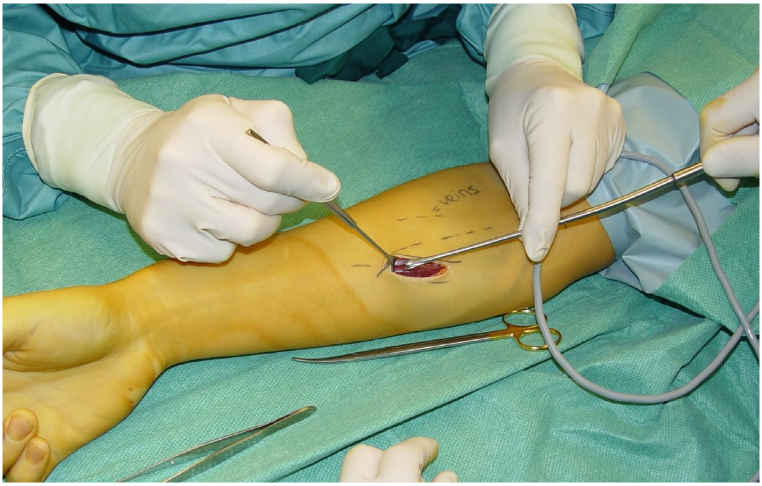


**FIGURE 6.1** Intraoperative view of a fasciotomy using a fasciotome through a minimally sized incision.

**FIGURE 6.2** Additional left arm superficial fasciectomy. The removed strip of fascia provides a clear view of the superficial volar compartment, showing the tendon of the palmaris longus muscle overlaying the flexor carpi radialis and the flexor digitorum superficialis muscle.

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## RESULTS

From January 2002 until April 2010, 46 patients with signs and symptoms suggestive of forearm CECS underwent surgery. Questionnaires from 9 patients (7 motocross riders, 1 weight lifter, 1 military recruit) were not obtained for reasons listed in the flow chart (Figure 6.3). Intracompartmental pressures were not available in 10 additional patients (9 motocross riders, 1 tennis player) leaving 27 patients eligible for analysis. As 3 patients received surgery for CECS because of provocational activities other than motocross (dog training, n=1; assembly line worker, n=1; fitness, n=1), a complete data set was available in 24 motocross riders (partial fasciectomy, n=14; fasciotomy, n=10). Demographic and clinical data of these 24 are listed in Table 6.1. Patients were all male participating in motocross competitions of various levels. Patients suffering from a bilateral syndrome (23/24) received bilateral surgery in a 1-stage procedure.

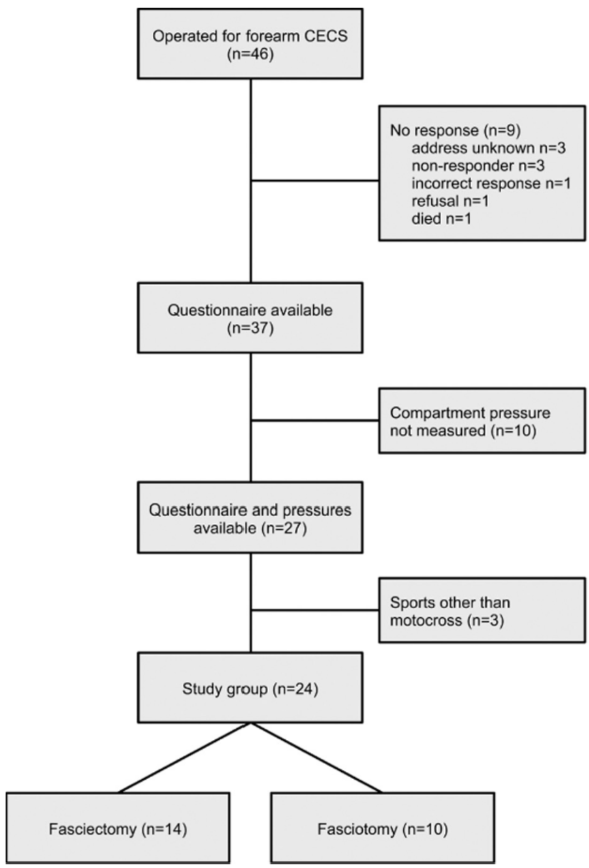


**FIGURE 6.3** Flow chart of patients with forearm chronic exertional compartment syndrome.

**TABLE 6.1**
Characteristics of patients operated for forearm chronic exertional compartment syndrome.

| Characteristic | |
|---|---|
| Sex, male/female, n | 24/0 |
| Age, mean ± standard deviation, y | 34 ± 8 |
| Height, mean ± standard deviation, cm | 181 ± 6 |
| Weight, mean ± standard deviation, kg | 80 ± 9 |
| Body mass index, mean ± standard deviation | 24 ± 3 |
| Sporting time, mean (range) h/wk | 5 (2-14) |
| Level of motocross, n | International: 7 |
| | National: 9 |
| | Local: 8 |

The patient's history was characterized by pain as a principal presenting symptom. More than three quarters (n=21) suffered from moderate (n=13) to severe (n=8) pain during racing. However, almost half of these (11/21) also experienced pain during normal activities in daily life. Pain levels were similar in both forearms. Accompanying symptoms were loss of muscle strength (moderate, n=6; severe, n=12) and cramps (moderate, n=4; severe, n=10). Moreover, 13 patients reported substantial loss of hand sensibility. These symptoms typically started around 7 minutes (range, 2-15 minutes) after starting the race. Most patients (n=18, 75%) mentioned that these symptoms limited their performance, whereas 21% (n=5) were unable to continue riding. Half of the motocross riders (n=12) mentioned that these complaints diminished after quitting riding, usually after about 12 minutes (range, 1-30 minutes). In contrast, the other half experienced pain even up to the following day.



## Compartmental pressures

Intracompartmental pressure measurements were performed in all 24 patients. Mean values during rest were 15 ± 4 mm Hg (range, 9-22 mm Hg). Provocation resulted in a more than 4-fold rise up to 78 ± 24 mm Hg (range, 25-120 mm Hg). Immediately after cessation, pressures declined to 35 ± 9 mm Hg (range 20-52 mm Hg). Values remained substantially above the 20-mm Hg threshold at the 1-minute (29 ± 10 mm Hg; range, 10-45 mm Hg) and 5-minute time points (25 ± 7 mm Hg; range, 10-38 mmHg)(Figure 6.4).

## Functional results after surgery

All individuals were able to ride their motocross cycles 4 weeks after surgery (range, 2-12 weeks). Fifteen patients reported that their level of sports improved after surgery compared to the level before, whereas 9 patients did not experience any change in performance.

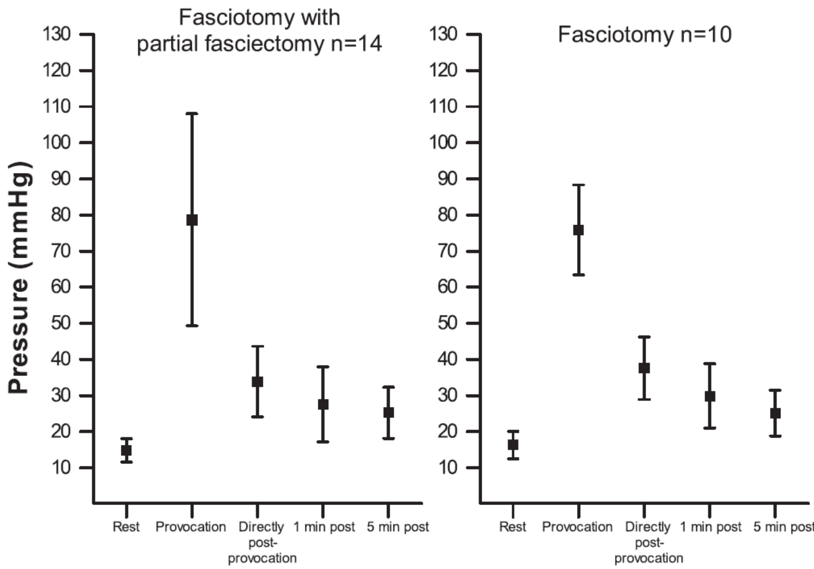


**FIGURE 6.4** Intracompartmental pressures in 2 groups of patients with forearm chronic exertional compartment syndrome (mean ± standard deviation).

Pain scores are reported in Figure 6.5. Overall median VAS scores decreased from 53 (range, 0-100) to 7 (range, 0-40)(*P*<.001). In the fasciectomy group (n=14), median scores improved from 50 (range, 1-100) to 5 (range, 0-33) (*P*=.001) and in the fasciotomy group from 71 (range, 0-92) to 24 (range, 0-40) (n=10; *P*=.028). Differences in preoperative pain, postoperative pain and reduction in pain between the two groups were not significant (p=0.83, p=0.10, and p=0.66, respectively). Some 20 patients (83%) were very satisfied with the outcome, whereas 3 were fairly satisfied (fasciotomy n=2, fasciectomy n=1) after a 5-year follow-up. One individual did not benefit from surgery (fasciotomy).

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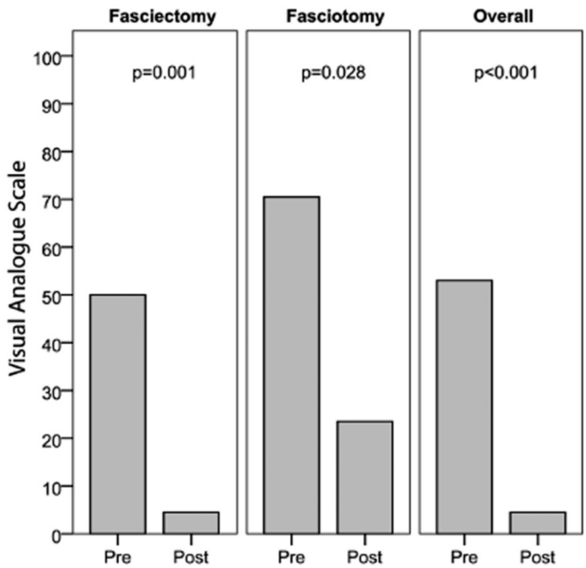


**FIGURE 6.5** Pain scores before and after surgery (fasciectomy,n=14, *P*=.001; and fasciotomy, n=10, *P*=.028) (overall *P*<.001).

## DISCUSSION

Few studies have been performed on forearm CECS. Because its incidence is low, most studies are case reports or small cohort studies. Overall, some 69 patients have been reported in the literature (Table 6.2).[1,3,4,6,8,13,14,16,18,20-24,28,29,34,42,44] Some professions or hobbies are associated with forearm CECS including weight training,[4,21] climbing,[6,44] manufacture assembly working,[28] and motocross riding or motor racing.[1,6,16,22,23,44] The present study is the largest cohort of patients with forearm CECS due to motocross. The results indicate that partial fasciectomy or fasciotomy are both successful procedures in the long term.

The origin of forearm CECS in motocross is debated. Some have suggested that the extensive use of gas handles during motocross may lead to forearm flexor compartment overuse.[1] However, the present study demonstrates that almost all individuals (23/24) reported complaints on both arms with identical VAS scores. It is therefore believed that CECS results from the continuous correction and stabilization of both intensely vibrating bars of the steering wheel. As there is little opportunity for forearm muscle relaxation during a race, capillary perfusion may be impaired by the ongoing pressure elevations.[1]

**TABLE 6.2**
Review of literature.

| Lead Author (Year of Publication) | No. of Participants | Provocative Activity | Intervention | Success |
|---|---|---|---|---|
| Bird (1983) | 1 | Weight lifting | Fasciotomy | Yes |
| Imbriglia (1984) | 1 | Strenuous work | Fasciotomy | Yes |
| Kutz (1985) | 1 | Normal exercise | Fasciotomy | Yes |
| Pedowitz (1988) | 1 | Assembly working | Fasciotomy | Yes |
| Allen (1989) | 1 | Motocross | Fasciotomy | Yes |
| Wasilewski (1991) | 1 | Athletics | Fasciotomy | Yes |
| Kouvalchouk (1993) | 2 | Motocross | Fasciotomy | Yes |
| Söderberg (1996) | 2 | Carpenter (n=1)<br>Motor mechanic (n=1) | Fasciotomy | 100% |
| Berlemann (1998) | 1 | Tennis | Fasciotomy | Yes |
| Garcia Mata (1999) | 1 | Motocross | Fasciotomy | Yes |
| Jawed (2001) | 1 | Weight lifting | Fasciotomy | Yes |
| Hider (2002) | 1 | Lifting, driving | Fasciotomy | Yes |
| Goubier (2003) | 2 | Motocross | Fasciotomy | 100% |
| Zandi (2005) | 6 | Wheelchair athletics (n=1)<br>Motocross (n=1)<br>Manual working (n=1)<br>Climbing (n=1)<br>Turner (n=1)<br>Water skiing (n=1) | Fasciotomy and partial fasciectomy | 100% |
| Jeschke (2006) | 1 | Motocross | Fasciotomy | Yes |
| Piasecki (2008) | 1 | Sprint kayaker | Fasciotomy | Yes |
| Fontes (2003) | 25 | Sportsmen (n=23)<br>Musicians (n=2) | Endoscopically assisted fasciotomy | 88% |
| Croutzet (2009) | 8 | Motocross | Mini-open fasciotomy | 63% |
| Brown (2011) | 12 | Motocross (n=5)<br>Manual worker (n=3)<br>Climbing/windsurfing (n=1)<br>Crane driver (n=1)<br>Martial arts (n=1)<br>Rowing (n=1) | Fasciotomy | Median improvement 88% |

The present study used a modified questionnaire evaluating symptoms before surgery as well as after surgery. By choosing such a study design, the phenomenon of recall bias is possible. Furthermore, it was a priori assumed that the central (preoperative) symptom was pain. The portion of the questionnaire evaluating the postoperative situation scored pain exclusively but not other symptoms such as strength, cramps or sensibility, although these symptoms appeared abundantly present before to the operation. During the analysis, this omission was regretted, but the fact that 23 of 24 patients were very (n=20) or fairly (n=3) satisfied suggests that surgery also exerted beneficial effects on strength, cramps or sensibility in the long term.

It is widely acknowledged that the diagnosis CECS is determined by measurements of ICP. Therefore, it was decided to exclude patients that were just operated on the basis of a suggestive history and physical examination but without a diagnostic intracompartmental pressure measurement (n=10). Although not in the scope of this study, operative results in this 10 patient subgroup appeared less successful with a median 26-point VAS reduction compared to a 46-point reduction in the 24 patients reported in the present study. This finding again demonstrates that ICP is the single most objective diagnostic parameter in CECS.[7,12,17,35,41] In contrast to lower legs, cutoff compartment pressure values in forearm CECS necessitating surgical treatment are less well defined.[3,31,44] Dynamic compartmental measurements using a slit catheter are superior whereas single-needle measurements are probably obsolete.[5] The most important diagnostic criterion for forearm CECS may be the slope of decreasing pressures over time, as suggested by others.[31] Normal values were not obtained in the present study for ethical reasons.

The optimal surgical procedure for forearm CECS is unknown. Depending on the preference of our attending surgeons, some patients received a fasciotomy whereas others underwent a partial fasciectomy. As both groups reported similar success, one may decide to perform the least invasive technique. If symptoms are residual or recur over time, one may choose to perform a partial removal of the fascia. Another study in lower leg CECS also found no difference between the two techniques on the long term.[33]

# REFERENCES


1. Allen MJ, Barnes MR. Chronic compartment syndrome of the flexor muscles in the forearm: a case report. *J Hand Surg Br.* 1989; 14(1):47-48.
2. Bell S. Repeat compartment decompression with partial fasciectomy. *J Bone Joint Surg Br.* 1986;68(5):815-817.
3. Berlemann U, al-Momani Z, Hertel R. Exercise-induced compartment syndrome in the flexor-pronator muscle group: a case report and pressure measurements in volunteers. *Am J Sports Med.* 1998;26(3):439-441.
4. Bird CB, McCoy JW Jr. Weight-lifting as a cause of compartment syndrome in the forearm: a case report. *J Bone Joint Surg Am.* 1983;65(3):406.
5. Boody A, Wongworawat MQ. Accuracy in the measurement of compartment pressures: a comparison of three commonly used devices. *J Bone Joint Surg Am.* 2005;87(11):2415-2422.
6. Brown JS, Wheeler PC, Boyd KT, Barnes MR, Allen MJ. Chronic exertional compartment syndrome of the forearm: a case series of 12 patients treated with fasciotomy. *J Hand Surg Eur Vol.* 2011;36(5):413-419.
7. Brukner P, Kahn K. *Clinical Sports Medicine*. 2nd ed. McGraw-Hill; 2001.
8. Croutzet P, Chassat R, Masmejean EH. Mini-invasive surgery for chronic exertional compartment syndrome of the forearm: a new technique. *Tech Hand Up Extrem Surg.* 2009;13(3):137-140.
9. David V, Thambiah J, Kagda FH, Kumar VP. Bilateral gluteal compartment syndrome: a case report. *J Bone Joint Surg Am.* 2005;87(11):2541-2545.
10. de Fijter W, Scheltinga MR, Luiting MG. Minimally invasive fasciotomy in chronic exertional compartment syndrome and fascial hernias of the anterior lower leg: short- and long-term results. *Mil Med.* 2006;171(5):399-403.
11. Due J Jr., Nordstrand K. A simple technique for subcutaneous fasciotomy. *Acta Chir Scand.* 1987;153(9):521-522.
12. Edwards PD, Meyerson MS. Exertional compartment syndrome of the leg: steps to expedient return to activity. *Phys Sportsmed.* 1996;24(4):31-46.
13. Fontes D, Clement R, Roure P. [Endoscopic aponeurotomy for chronic exertional compartmental syndrome of the forearm: report of 41 cases]. *Chir Main.* 2003;22(4): 186-196.
14. Garcia Mata S, Hidalgo Ovejero A, Martinez Grande M. Bilateral, chronic exertional compartment syndrome of the forearm in two brothers. *Clin J Sport Med.* 1999;9(2):91-99.
15. Gelberman RH, Garfin SR, Hergenroeder PT, Mubarak SJ, Menon J. Compartment syndromes of the forearm: diagnosis and treatment. *Clin Orthop Relat Res.* 1981;161: 252-261.
16. Goubier JN, Saillant G. Chronic compartment syndrome of the forearm in competitive motor cyclists: a report of two cases. *Br J Sports Med.* 2003;37(5):452-453; discussion 453-454.
17. Harries M, Stanish WD, Micheli LJ. *Oxford Textbook of Sports Medicine*: Oxford University Press; 1994.
18. Hider SL, Hilton RC, Hutchinson C. Chronic exertional compartment syndrome as a cause of bilateral forearm pain. *Arthritis Rheum.* 2002;46(8):2245-2246.
19. Holmes GB Jr. Quantitative determination of intermetatarsal pressure. *Foot Ankle.* 1992; 13(9):532-535.
20. Imbriglia JE, Boland DM. An exercise-induced compartment syndrome of the dorsal forearm: a case report. *J Hand Surg Am.* 1984;9A(1):142-143.
21. Jawed S, Jawad AS, Padhiar N, Perry JD. Chronic exertional compartment syndrome of the forearms secondary to weight training. *Rheumatology (Oxford).* 2001;40(3):344-345.
22. Jeschke J, Baur EM, Piza-Katzer H. [Chronic compartment syndrome of the flexor muscles in the forearm due to motocross]. *Handchir Mikrochir Plast Chir.* 2006;38(2):122-125.
23. Kouvalchouk JF, Watin Augouard L, Dufour O, Coudert X, Paszkowski A. [Chronic stress-related compartment syndrome of the forearm]. *Rev Chir Orthop Reparatrice Appar Mot.* 1993;79(5):351-356.
24. Kutz JE, Singer R, Lindsay M. Chronic exertional compartment syndrome of the forearm: a case report. *J Hand Surg Am.* 1985;10(2):302-304.
25. McCarthy DM, Sotereanos DG, Towers JD, Britton CA, Herndon JH. A cadaveric and radiologic assessment of catheter placement for the measurement of forearm

compartment pressures. *Clin Orthop Relat Res.* 1995(312):266-270.
26. Mohler LR, Styf JR, Pedowitz RA, Hargens AR. Intracompartmental pressure and intramuscular PO2 in chronic compartment syndrome of the leg. *J Bone Joint Surg Am.* 1997;79(6):844-849.
27. Orava S, Rantanen J, Kujala U. Fasciotomy of the Posterior Femoral Muscle Compartment in Athletes. *Int J Sports Med.* 1998;19(1):71-75.
28. Pedowitz RA, Toutounghi FM. Chronic exertional compartment syndrome of the forearm flexor muscles. *J Hand Surg Am.* 1988;13(5):694-696.
29. Piasecki DP, Meyer D, Bach BR, Jr. Exertional compartment syndrome of the forearm in an elite flatwater sprint kayaker. *Am J Sports Med.* 2008;36(11):2222-2225.
30. Rorabeck C, Fowler P, Nott L. The results of fasciotomy in the management of chronic exertional compartment syndrome. *Am J Sports Med.* 1988;16(3):224-227.
31. Rydholm U, Werner CO, Ohlin P. Intracompartmental forearm pressure during rest and exercise. *Clin Orthop Relat Res.* 1983(175):213-215.
32. Schepsis AA, Martini D, Corbett M. Surgical management of exertional compartment syndrome of the lower leg. Long-term followup. *Am J Sports Med.* 1993;21(6):811-817; discussion 817.
33. Slimmon D, Bennell K, Brukner P, Crossley K, Bell SN. Long-term outcome of fasciotomy with partial fasciectomy for chronic exertional compartment syndrome of the lower leg. *Am J Sports Med.* 2002;30(4):581-588.
34. Soderberg TA. Bilateral chronic compartment syndrome in the forearm and the hand. *J Bone Joint Surg Br.* 1996;78(5):780-782.
35. Styf J, Korner L, Suurkula M. Intramuscular pressure and muscle blood flow during exercise in chronic compartment syndrome. *J Bone Joint Surg.* 1987;69(2):301-305.
36. Turnipseed W, Detmer DE, Girdley F. Chronic compartment syndrome. An unusual cause for claudication. *Ann Surg.* 1989;210(4):557-562; discussion 562-553.
37. Turnipseed WD. Diagnosis and management of chronic compartment syndrome. *Surgery.* 2002;132(4):613-617; discussion 617-619.
38. Turnipseed WD. Clinical review of patients treated for atypical claudication: a 28-year experience. *J Vasc Surg.* 2004;40(1):79-85.
39. Tzortziou V, Maffulli N, Padhiar N. Diagnosis and management of chronic exertional compartment syndrome (CECS) in the United Kingdom. *Clin J Sport Med.* 2006;16(3):209-213.
40. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR. Chronic deep posterior compartment syndrome of the leg in athletes: postoperative results of fasciotomy. *Int J Sports Med.* 2008;29(5):419-423.
41. Verleisdonk EJ, Schmitz RF, van der Werken C. Long-term results of fasciotomy of the anterior compartment in patients with exercise-induced pain in the lower leg. *Int J Sports Med.* 2004;25(3):224-229.
42. Wasilewski SA, Asdourian PL. Bilateral chronic exertional compartment syndromes of forearm in an adolescent athlete. Case report and review of literature. *Am J Sports Med.* 1991;19(6):665-667.
43. Weinstein SM, Herring SA. Nerve problems and compartment syndromes in the hand, wrist, and forearm. *Clin Sports Med.* 1992;11(1):161-188.
44. Zandi H, Bell S. Results of compartment decompression in chronic forearm compartment syndrome: six case presentations. *Br J Sports Med.* 2005;39(9):e35.

# CHAPTER 7

# MOTORCYCLE RACER WITH UNILATERAL FOREARM FLEXOR AND EXTENSOR CHRONIC EXERTIONAL COMPARTMENT SYNDROME

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BMJ CASE REP. 2016 APRIL 14.

## SUMMARY

We discuss a case of a 26-year-old man, a motorcycle racer, who presented with progressive pain, weakness and swelling of his right forearm and loss of power in his index finger, experienced during motor racing. Chronic exertional compartment syndrome (CECS) of both flexor and extensor compartments of his forearm was diagnosed by dynamic intracompartmental muscle pressure measurements. After fasciotomies, all symptoms were resolved and the patient was able to improve on his preinjury racing skills, without any limitations. A literature review and a surgical 'how-to' for correct release of the extensor and deep flexor compartments of the forearm are provided.

## BACKGROUND

Chronic exertional compartment syndrome (CECS) is a disabling condition that is most commonly observed in the legs. Repetitive intense muscle activity during sports is thought to cause increased intracompartmental blood volume, hypertrophy and oedema, leading to inappropriately elevated muscle compartment pressures because of a too tightly enveloping fascia. As venous return is hampered, lactate accumulation results in pain and muscle weakness. As most patients of these conditions are fanatic sports participants, conservative regimens including rest are often rejected. Fasciotomy of the affected compartments should be considered.

CECS is almost always diagnosed in the lower legs. The forearm is rarely affected. Only a few case reports and small case series have been reported. If present, a bilateral lower arm flexor muscles CECS is diagnosed in 95% of cases.[4,16,33] A combined unilateral lower arm extensor and flexor CECS is exceedingly rare with an unknown incidence. Moreover, pictures of the surgical release of the extensor compartment have not been reported before.



## CASE PRESENTATION

A 26-year-old man, a track motorcyclist, presented to our sports medicine department, with a 1-year history of progressive weakness of his right index finger, accompanied by pain, weakness and swelling of the right forearm. He reported that symptoms were more prominent towards the end of races. More recently, he had noticed that pain already started within 5 min after the start of a race. He was not able to finish his last few races due to this severe discomfort. Pain intensity appeared to be related to the number of braking manoeuvres. Frequent and intensive braking, especially required on short tracks with multiple curves, caused swelling, tightness and tense muscle compartments in his right forearm. As a result, he could no longer control the hand brake lever, and he was also unable to flex his index finger. Moreover, he felt progressive numbness of the palmar portions of his right hand. The swelling and tightness usually disappeared within 1 hour after racing. However, numbness and weakness of the hand was present until the day after. Other sports such as swimming and weight lifting did not provoke any right lower arm discomfort. Hitherto, medication, rest, ointments and physiotherapy were to no avail.

## INVESTIGATIONS

On inspection, both forearms appeared normal. Skin sensation, motor function as well as ulnar and radial arterial pulsations of both arms were normal. Provocation of the flexor and extensor muscles of both forearms using fitness grippers resulted in tense flexor and extensor muscle compartments on the right side only. However, right-sided weakness of the index finger could not be evoked.

Carpal tunnel syndrome was excluded by a nerve conducting study. A questionnaire scoring symptoms frequently associated with CECS suggested the presence of chronic compartment syndrome.[33] As a combined lower arm flexor and extensor CECS was assumed, intracompartmental pressures (ICP) of both muscle compartments of the right forearm were obtained as reported earlier.[10] Values in the deep flexor compartment were 16 mm Hg during rest, which increased to 40 mm Hg immediately after maximal provocation using fitness grippers, and 36 and 35 mm Hg at 1 and 5 min thereafter, respectively. Pressures in the extensor compartment were also elevated (16, 34, 32 and 28 mm Hg, respectively).

## DIFFERENTIAL DIAGNOSIS



The differential diagnosis of upper extremity exertional pain is extensive and includes syndromes of muscular/tendon origin (tenosynovitis, muscle strain, forearm CECS, contusion, intersection syndrome), bone/periosteum (epicondylitis, stress fracture, little league elbow), nerves (thoracic outlet syndrome, pronator syndrome, entrapment syndromes), vascular (Paget-Schroetter syndrome or effort thrombosis, intermittent vascular claudication, vascular compression syndromes) or of an infectious origin (osteomyelitis). As the results of the patient's history-taking and physical examination were highly suggestive of lower arm CECS, most of these potential alternative conditions were ruled out by physical examination. Nerve conduction studies and EMG excluded nerve entrapment and neuromuscular disease. Duplex ultrasound and CT/MR angiography are suitable for the detection of vascular compression syndromes but were not performed, since the index of suspicion was too low.

## TREATMENT

After informed consent, the patient underwent a fasciotomy of both lower arm compartments in day care. After induction of general anaesthesia and sterile exposure, an 8 cm longitudinal incision just ulnar to the midline on the volar aspect of the lower arm allowed access to the superficial flexor compartment (Figure 7.1). Branches of the medial cutaneous nerve were identified and preserved. The subcutaneous fascia covering the flexor carpi ulnaris, flexor digitorum superficialis and flexor carpi radialis muscles was freed from subcutaneous tissue and opened over a length of 15-20 cm. The plane between the carpi ulnaris and digitorum superficialis muscles was used to gain access to the deep flexor muscles enveloping the ulnar bone. The ulnar nerve overlying this deep fascia covering the flexor digitorum profundus and flexor pollicis longus muscle was identified and preserved (Figure 7.1C).

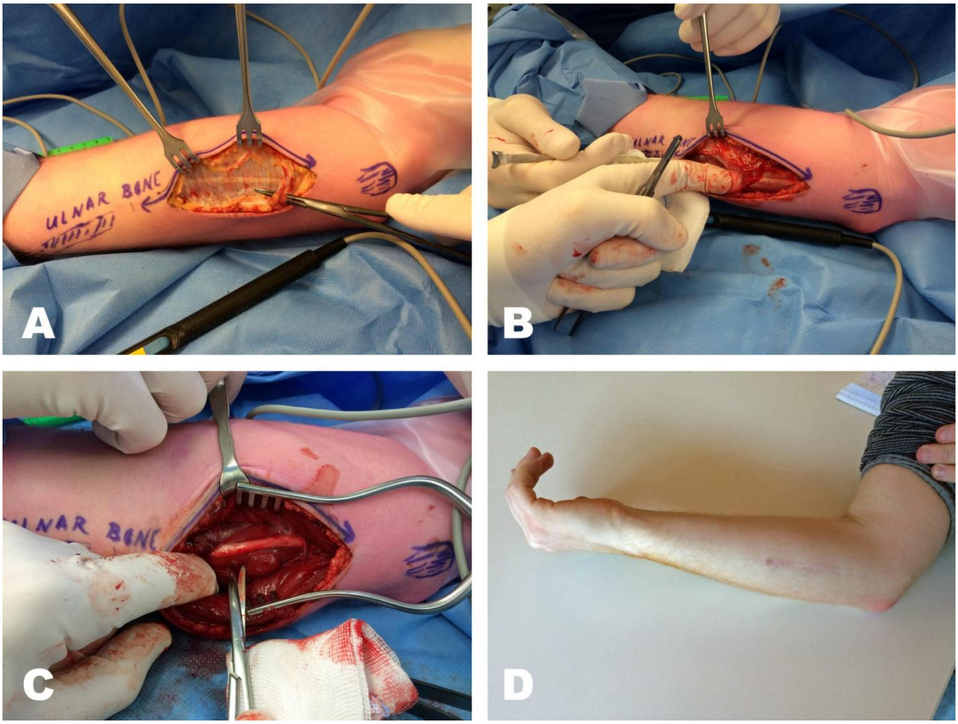


**FIGURE 7.1** Superficial and deep fasciotomy for chronic exertional compartment syndrome of the flexor side of the forearm. An 8-cm longitudinal incision on the volar aspect of the proximal forearm allowed exposure to the superficial volar fascia covering the flexor carpi ulnaris, flexor digitorum superficialis and flexor carpi radialis muscles (A and B). After superficial fasciotomy, blunt splitting of the plane between the flexor carpi ulnaris and flexor digitorum superficialis muscles gained access to the deep compartment. A thick ulnar nerve is identified. After opening the deep compartment, muscle tissue of the flexor digitorum profundus popped out (C). One year after surgery, the patient reported widening of the volar incisional scar (D).

The deep flexor fascia was incised using a knife and scissors. Subsequently, a 6 cm longitudinal incision over the proximal portions of the superficial extensor compartment allowed access to the superficial fascia that was freed from subcutaneous tissue. Two separate fasciae covering the extensor digitorum and extensor carpi ulnaris muscles were opened in both, proximal and distal directions (Figure 7.2). Using superficial muscle retraction, the extensor carpi radialis fascia was identified and opened. Both surgical wounds were closed using standard techniques.

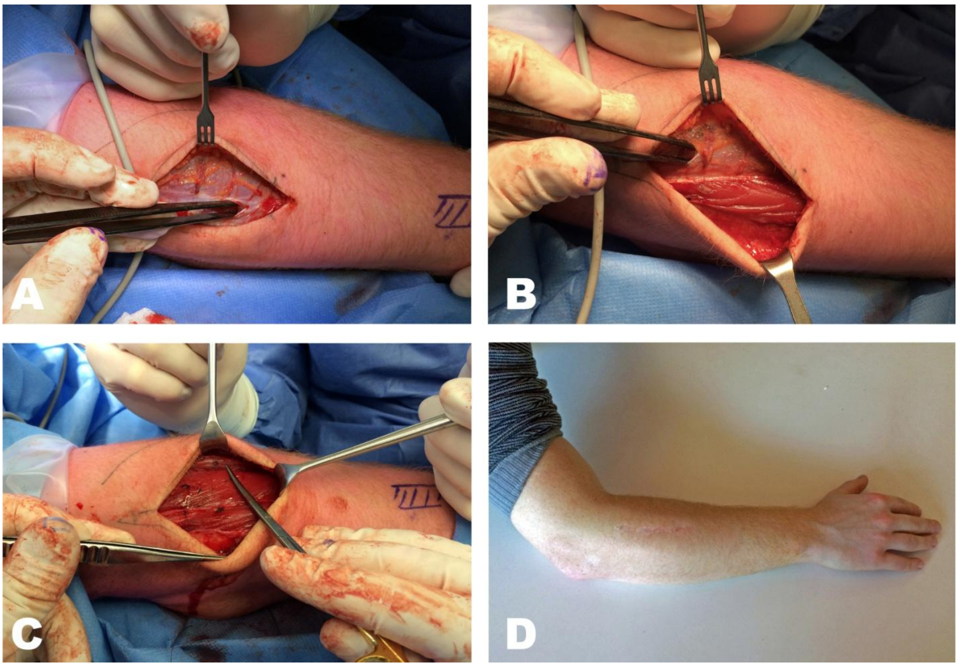

**FIGURE 7.2** Fasciotomy for chronic exertional compartment syndrome of the extensor aspect of the forearm. A 6 cm proximal longitudinal incision was used to expose the superficial fascia. Two separate fasciae covering the extensor carpi ulnaris (A) and extensor digitorum (B) muscles were opened in both directions. Subsequently, a fasciotomy of the extensor carpi radialis muscle (C) was performed. Panel D demonstrates the incisional scar one year after surgery.



## OUTCOME AND FOLLOW-UP

Recovery was uneventful. After 6 weeks, the patient was able to start training again at the preoperative level. Within 3 months, he was no longer hampered by lower arm symptoms and was able to perform at a higher competitive level. One year after surgery, he again completed the CECS symptom questionnaire (Figure 3). Results indicated that the exertional pain and tightness had completely resolved. Repetitive finger strength remained maximal throughout each race, and hand sensibility also remained normal (Figure 7.4). However, the patient reported that the volar incisional scar unattractively widened during the first months after surgery.

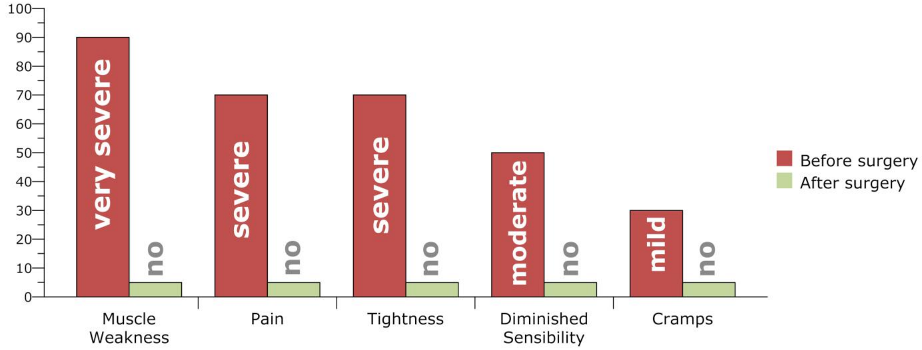


**FIGURE 7.3** Results of chronic exertional compartment syndrome questionnaire before and 1 year after fasciotomy of both deep flexor and extensor lower arm muscles in a motor cyclist.


**FIGURE 7.4** The patient throttling his motorcycle 1 year after surgery.

# DISCUSSION

CECS of the forearm is a relatively rare but well documented subtype of CECS. The first report of forearm CECS was published in 1983.[28] At present (January 2016), a total of 319 cases are described in the literature.[1-9,11-21,23-28,30-34] The extensor compartment is affected in just 25% of cases (n=80), whereas a combined extensor/flexor CECS is present in only 17%. Sports causing forearm CECS are mostly motocross (72%) and motorcycle racing (9%). However, rowing,[12,21] climbing,[6] kayaking,[24] swimming,[30] tennis[3] and baseball,[27] and activities such as truck driving,[14,20] working on an assembly line[23,26] and carpentry[31] may incidentally also lead to lower arm CECS.

The gold standard for the diagnosis of forearm CECS is provided by a dynamic ICP measurement. Currently, there is no consensus on cut-off criteria. However, pressures of ≥15 mm Hg at rest and/or ≥30 mm Hg at 1 min after exercise and/or ≥20 mm Hg 5 min after exercise are generally accepted limits, as suggested by Pedowitz *et al*.[22] However, it must be appreciated that these criteria were originally based on values in suspected lower leg CECS. Others propose resting pressures >10 mm Hg and a pressure normalisation time exceeding 15 min as abnormal.[8,9] Deep flexor compartment pressures between 15-30 mm Hg during recovery after maximal stress testing are also highly suggestive of CECS, as well as an ICP above 30 mmHg.[4,29] However, it must be realised that the diagnosis of CECS should always be based on a combination of the patient's history, physical examination results and ICP's.

The pathophysiology of lower arm CECS is somewhat unclear. However, forearm CECS is often bilateral (95%) and found more commonly in motocross racers.[4,16,33] The bilaterality is thought to result from a constant effort by both arms to maintain motor stability on uneven soil. Our patient also reported bilateral symptoms in earlier days when he was practising off-road motocross. However, the syndrome later became unilateral, once he had shifted to motorcycling on asphalt tracks. A repetitive flexion-extension manoeuvre that is required for handling the throttle probably put a disproportionate stress on his right lower arm. A so called 'quick shifter' allowed his left hand to easily change gears without a need to touch either the clutch or throttle, explaining why the flexor-extensor CECS syndrome was limited to his right lower arm only.

Once the diagnosis of forearm CECS is likely, cessation of symptom-provoking activities may alleviate symptoms. However, most athletes reject this option.[4,9] If conservative therapies are unsuccessful, surgery including a fasciotomy or a fasciectomy often provides good to excellent results.[26] The optimal surgical approach is debated. Some favour a wide open or a minimally open operation, whereas others promote an endoscopic release, all having similar beneficial results.[2,16,33] Complication rates are frequently not reported. However, long-term widening of the volar incisional scar is often reported, as was also found in the present patient.[4,7,8,34]

## LEARNING POINTS

– Chronic exertion compartment syndrome (CECS) of the forearm is usually bilateral (95%) and of a flexor type (75%), and is often found in motocross and motorcycle racers.
– Unilateral combined extensor/flexor CECS in forearm CECS is exceedingly rare.
– Combined surgery for forearm CECS types yields excellent results.
– A possible long-term effect of surgery for forearm CECS is widening of incisional scars.

# REFERENCES


1. Allen MJ, Barnes MR. Chronic compartment syndrome of the flexor muscles in the forearm: a case report. *J Hand Surg Br.* 1989;14(1):47-48.
2. Barrera-Ochoa S, Haddad S, Correa-Vazquez E, et al. Surgical Decompression of Exertional Compartment Syndrome of the Forearm in Professional Motorcycling Racers: Comparative Long-term Results of Wide-Open Versus Mini-Open Fasciotomy. *Clin J Sport Med.* 2015.
3. Berlemann U, al-Momani Z, Hertel R. Exercise-induced compartment syndrome in the flexor-pronator muscle group. A case report and pressure measurements in volunteers. *Am J Sports Med.* 1998;26(3):439-441.
4. Brown JS, Wheeler PC, Boyd KT, Barnes MR, Allen MJ. Chronic exertional compartment syndrome of the forearm: a case series of 12 patients treated with fasciotomy. *J Hand Surg Eur Vol.* 2011;36(5):413-419.
5. Croutzet P, Chassat R, Masmejean EH. Mini-invasive surgery for chronic exertional compartment syndrome of the forearm: a new technique. *Tech Hand Up Extrem Surg.* 2009;13(3):137-140.
6. Drouet A, Jaquin O, Guilloton L, Dumas P, Volckmann P, Ribot C. [Anterior compartment syndrome of the forearm caused by exercise: unusual cause of recurrent episodes of acute effort rhabdomyolysis]. *Rev Med Interne.* 2001; 22(4):394-397.
7. Fontes D, Clement R, Roure P. [Endoscopic aponeurotomy for chronic exertional compartmental syndrome of the forearm: report of 41 cases]. *Chir Main.* 2003;22(4):186-196.
8. Garcia-Mata S. Chronic exertional compartment syndrome of the forearm in adolescents. *J Pediatr Orthop.* 2013;33(8): 832-837.
9. Garcia Mata S, Hidalgo Ovejero A, Martinez Grande M. Bilateral, chronic exertional compartment syndrome of the forearm in two brothers. *Clin J Sport Med.* 1999;9(2):91-99.
10. Gelberman RH, Garfin SR, Hergenroeder PT, Mubarak SJ, Menon J. Compartment syndromes of the forearm: diagnosis and treatment. *Clin Orthop Relat Res.* 1981(161):252-261.
11. Goubier JN, Saillant G. Chronic compartment syndrome of the forearm in competitive motor cyclists: a report of two cases. *Br J Sports Med.* 2003;37(5):452-453; discussion 453-454.
12. Harrison JW, Thomas P, Aster A, Wilkes G, Hayton MJ. Chronic exertional compartment syndrome of the forearm in elite rowers: a technique for mini-open fasciotomy and a report of six cases. *Hand (N Y).* 2013;8(4):450-453.
13. Hider SL, Hilton RC, Hutchinson C. Chronic exertional compartment syndrome as a cause of bilateral forearm pain. *Arthritis Rheum.* 2002;46(8):2245-2246.
14. Hijjawi J, Nagle DJ. Endoscopic-assisted Fascial Decompression for Forearm Exertional Compartment Syndrome: A Case Report and Review of the Literature. *Hand (N Y).* 2010;5(4):427-429.
15. Imbriglia JE, Boland DM. An exercise-induced compartment syndrome of the dorsal forearm--a case report. *J Hand Surg Am.* 1984;9a(1):142-143.
16. Jans C, Peersman G, Peersman B, Van Den Langenbergh T, Valk J, Richart T. Endoscopic decompression for chronic compartment syndrome of the forearm in motocross racers. *Knee Surg Sports Traumatol Arthrosc.* 2014.
17. Jawed S, Jawad AS, Padhiar N, Perry JD. Chronic exertional compartment syndrome of the forearms secondary to weight training. *Rheumatology (Oxford).* 2001;40(3):344-345.
18. Jeschke J, Baur EM, Piza-Katzer H. [Chronic compartment syndrome of the flexor muscles in the forearm due to motocross]. *Handchir Mikrochir Plast Chir.* 2006;38(2):122-125.
19. Kouvalchouk JF, Watin Augouard L, Dufour O, Coudert X, Paszkowski A. [Chronic stress-related compartment syndrome of the forearm]. *Rev Chir Orthop Reparatrice Appar Mot.* 1993;79(5):351-356.
20. Kumar PR, Jenkins JP, Hodgson SP. Bilateral chronic exertional compartment syndrome of the dorsal part of the forearm: the role of magnetic resonance imaging in diagnosis: a case report. *J Bone Joint Surg Am.* 2003;85-a(8):1557-1559.
21. O'Heireamhoin S, Baker JF, Neligan M. Chronic exertional compartment syndrome of the forearm in an elite rower. *Case Rep Orthop.* 2011;2011:497854.

22. Pedowitz RA, Hargens AR, Mubarak SJ, Gershuni DH. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med.* 1990;18(1):35-40.
23. Pedowitz RA, Toutounghi FM. Chronic exertional compartment syndrome of the forearm flexor muscles. *J Hand Surg Am.* 1988;13(5):694-696.
24. Piasecki DP, Meyer D, Bach BR, Jr. Exertional compartment syndrome of the forearm in an elite flatwater sprint kayaker. *Am J Sports Med.* 2008;36(11):2222-2225.
25. Pozzi A, Pivato G, Kask K, Susini F, Pegoli L. Single portal endoscopic treatment for chronic exertional compartment syndrome of the forearm. *Tech Hand Up Extrem Surg.* 2014;18(3):153-156.
26. Pritchard MH, Williams RL, Heath JP. Chronic compartment syndrome, an important cause of work-related upper limb disorder. *Rheumatology (Oxford).* 2005;44(11):1442-1446.
27. Raphael BS, Paletta GA, Jr., Shin SS. Chronic exertional compartment syndrome of the forearm in a major league baseball pitcher. *Am J Sports Med.* 2011;39(10):2242-2244.
28. Rydholm U, Werner CO, Ohlin P. Intracompartmental forearm pressure during rest and exercise. *Clin Orthop Relat Res.* 1983(175):213-215.
29. Schoeffl V, Klee S, Strecker W. Evaluation of physiological standard pressures of the forearm flexor muscles during sport specific ergometry in sport climbers. *Br J Sports Med.* 2004;38(4):422-425.
30. Seiler JG, 3rd, Hammond KE, Payne SH, Ivy R. Bilateral exertional compartment syndrome of the forearm: evaluation and endoscopic treatment in an elite swimmer. *J Surg Orthop Adv.* 2011;20(2):126-131.
31. Soderberg TA. Bilateral chronic compartment syndrome in the forearm and the hand. *J Bone Joint Surg Br.* 1996;78(5):780-782.
32. Wasilewski SA, Asdourian PL. Bilateral chronic exertional compartment syndromes of forearm in an adolescent athlete. Case report and review of literature. *Am J Sports Med.* 1991;19(6):665-667.
33. Winkes MB, Luiten EJ, van Zoest WJ, Sala HA, Hoogeveen AR, Scheltinga MR. Long-term results of surgical decompression of chronic exertional compartment syndrome of the forearm in motocross racers. *Am J Sports Med.* 2012;40(2):452-458.
34. Zandi H, Bell S. Results of compartment decompression in chronic forearm compartment syndrome: six case presentations. *Br J Sports Med.* 2005;39(9): e35.

# CHAPTER 8

# SUMMARIZING DISCUSSION, CONCLUSIONS AND FUTURE PERSPECTIVES

# SUMMARIZING DISCUSSION

Some athletes may suffer from exercise-related pain in the lower leg or forearm because of the presence of a chronic exertional compartment syndrome (CECS). CECS is defined as a painful condition in which abnormally increased intramuscular pressure during exercise impedes local blood flow and impairs neuromuscular function of the tissue within the muscle compartment.[2,19,28] CECS may present in all muscles covered by fascia. This thesis focuses on diagnostic and surgical aspects of a subtype of CECS occurring in flexor portions of the lower and upper extremity termed deep posterior CECS (dp-CECS) and forearm flexor CECS.

A patient with CECS typically experiences progressive pain forcing premature termination of the provocative exercise. Pain is often accompanied by tight feelings, muscle cramps and weakness, or altered sensibility. The exercise-related pain projects in medial portions of the calf and is predominantly observed in runners and soccer players. In contrast, forearm CECS is characterized by a squeezing tightness of the forearm and loss of force in finger flexion and is almost exclusively diagnosed in motocross racers. A general overview describing historical aspects, relevant anatomy, diagnosis and treatment of these two subtypes of CECS is provided in **chapter 1**. This chapter also contains the general and specific aims and outline of this thesis.

A systematic literature review is reported in **chapter 2** allowing insight into the surgical management of lower leg dp-CECS. A search identified 7 level III evidence studies reporting on a total of 131 patients with dp-CECS. The review concluded that current treatment modalities are highly clinician-dependent. Surgical procedures ranged from a superficial crural fasciotomy to multiple fasciotomies of separate fascias within the deep posterior lower leg compartment. Length and number of incisions, detachment of the soleus muscle, release of the deep posterior compartment, additional release of the tibialis posterior muscle or treatment of overlying fascia (fasciotomy/fasciectomy) were highly variable and surgeon dependent. Prolonged high intracompartmental pressures (ICP) levels of the muscle following provocation were associated with postoperative success. Outcomes after surgery were suboptimal with success rates ranging from 30% to 65%. Different aspects such as suboptimal selection of patients possibly having (overlap with) medial tibial stress syndrome (MTSS) or popliteal artery entrapment syndrome (PAES), inaccurate interpretation of intracompartmental pressure readings during a standardized provocative test or incomplete surgery may all contribute to these suboptimal operative success rates. In the review we presented a step-by-step surgical "how-to" for release of the deep flexor compartment of the lower leg.

One may hypothesize that characteristics of ICP determines success of treatment. The study presented in **chapter 3** aimed to answer whether preoperative ICP values in dp-CECS were related to functional outcome after surgery or even may predict treatment outcome. Compared to 31 previous reports on dp-CECS including mostly heterogenic and small study populations, the present study includes the largest series of patients with dp-CECS, with clear descriptions of preoperative deep flexor compartment pressures and postoperative outcomes. In this study, 52 dp-CECS patients with complete preoperative pressure data sets were available for analysis. All responded to a questionnaire regarding pre- and postoperative symptom levels (pain, muscle cramps, tightness, diminished sensibility and muscle weakness) and were asked to judge their 3-months postoperative clinical outcome as excellent, good, fair or poor. Successful surgery was defined as an excellent or good outcome, whereas fair and poor outcomes were considered 'not successful'. The short-term success rate was 52% (27/52, 14% excellent, 38% good). It was found that a larger 'area under a preoperative 4-point pressure curve' predicted outcome (excellent, 127 ± 28 mm Hg; good, 113 ± 25 mm Hg; fair, 100 ± 22 mm Hg; poor, 88 ± 15 mm Hg; $P$=.005) and was indicative of success (OR 1.04; 95% C.I., 1.01-1.08). However, no reliable cut-off pressures were found to differentiate good/excellent patients from the fair/poor ones. Moreover, these associations disappeared on the long term. Pressure values directly after the provocative exercise were the most important of all 4 timed readings. Delay in diagnosis was related to poor outcome. It was concluded that patterns of compartment pressures following a standard challenge may possibly help the physician in clinical decision making.

Diagnosing dp-CECS starts with the insertion of an ICP pressure catheter allowing to obtain dynamic pressure measurements of the compartment of interest. An insertion is usually done 'freehand', meaning 'guided by anatomic landmarks', although some advice the assistance of ultrasound. The catheter is ideally inserted in the tibialis posterior muscle (TP). Only two previous studies in cadaveric lower limbs aimed at determining the accuracy of needle placement in the deep posterior compartment.[14,23] However, analysis of *in vivo* accuracy of catheter insertion in healthy individuals possibly having dp-CECS has never been performed. Although the most commonly used technique for measuring compartment pressures includes the insertion of a plastic pressure catheter, some studies describe multiple static compartment measurements using a hand held monitor device with a metal needle, which is not suitable for proper MRI analysis.[1] However, a plastic catheter that temporarily remains in situ during the provocative treadmill test potentially allows for imaging using MRI. The study in **chapter 4** is the first to analyze whether such a free hand catheter insertion results in accurate positioning in the TP as confirmed by MRI in individuals with possible dp-CECS. In this study, 24 patients with possible dp-CECS underwent insertion of pressure catheters into central portions of the TP using a standard puncturing technique guided by lower leg anatomical landmarks. After timed pressure measurements directly after a standardized treadmill exercise test, lower leg MRI scans were performed and evaluated by two musculoskeletal radiologists. Catheter tip placement was termed optimal (in TP), suboptimal (in deep posterior compartment but outside TP), or inaccurate (outside of deep posterior compartment). Catheter tip placement appeared optimal in 10 patients (42%), whereas suboptimal placement was achieved in 9 (37%). Five procedures were inaccurate (transition zone between deep and superficial compartment, n=3; in the superficial lower leg compartment, n=2). Signs of a hematoma were found in 38% of the patients although these were not clinically relevant. This study clearly illustrates that standard palpation guided insertion of pressure catheters for dp-CECS lacks accuracy. Optimizing insertion technique may improve the diagnostic accuracy for dp-CECS and may aid in patient selection benefitting from surgery.

Based on experience obtained from earlier retrospective studies, we prospectively analyzed the effect of surgery regarding the 5 cardinal symptoms associated with dp-CECS (pain, tightness, cramps, muscle weakness, and loss of sensation), complication rates and possible causes for failed surgery in **chapter 5**. This study was the first to prospectively describe short- and long-term effects of a fasciotomy for dp-CECS. Between September 2011 and January 2015, a homogeneous group of 44 patients with isolated dp-CECS was studied. Fasciotomy improved all symptoms, both in the short term (3 months) and in the long term (a minimal 12 months after surgery). Fasciotomy was beneficial in 71% of patients, whereas 47% of patients termed their long-term outcome "good" to "excellent". Based on this outcome, 76% of patients would opt for surgery again. Persistent complaints were often caused by other untreated subtypes of CECS or MTSS as was diagnosed during a new evaluation of patients reporting limited success. An important lesson was learned: sport physicians or surgeons should thoroughly re-examine patients who do not benefit from dp-CECS surgery.

Chapter 6 and 7 discusses the second part of this thesis focusing on the treatment of forearm CECS. In **Chapter 6**, a study on long term results of surgical decompression of forearm CECS in a homogeneous group of motocross racers is presented. At the time of publication, this study represented the largest series of patients with forearm CECS as diagnosed with ICP. Two surgical techniques for treatment of forearm flexor CECS were compared in a nonrandomized model, a fasciotomy with or without an additional fasciectomy. Data of 24 motocross racers with forearm flexor CECS were available. Overall VAS scores for pain significantly decreased from 53 (range, 0-100) to 7 (range, 0-40). Fasciotomy (n=14) and fasciectomy (n=10) were equally successful on the long term. In contrast, operative results of an excluded group of patients (n=10), operated on the basis of a suggestive history and physical examination but not verified by ICP appeared less successful with a median 26-point VAS reduction. After a 5 ± 2 years' follow up, the vast majority of patients (95%, 23/24) were satisfied with the end result.

**Chapter 7** presents a case of a motorcycle racer with an uncommon type of unilateral combined flexor and extensor forearm CECS. One year after surgery, all preoperative symptoms completely disappeared. A systematic review revealed that forearm CECS is usually bilateral and of flexor type (75%) and is often found in motocross and motorcycle racers. A combined flexor/extensor forearm CECS is extremely rare.

## CONCLUSIONS OF THIS THESIS

1. Quality of studies reporting on surgery for lower leg dp-CECS is limited and prospective data are lacking. Diagnostic criteria and surgical techniques are highly diverse whereas surgical success rates are disappointingly low (30-65%).
2. Short-term success rates after surgery for dp-CECS are related to preoperative pressure curves in a retrospectively analyzed patient population.
3. Palpation guided catheter placement for tibialis posterior muscle pressure measurement is suboptimal in more than half of the individuals with suspected lower leg dp-CECS.
4. Fasciotomy is beneficial in 71% of patients with lower leg dp-CECS. Nearly half of the patients experience a good/excellent outcome on the long term. Persistent complaints are often caused by other untreated conditions.
5. Fasciotomy or fasciectomy of the forearm flexor compartment are equally successful in motocross racers suffering from forearm CECS.

## FUTURE PERSPECTIVES

The initial treatment of dp-CECS is non-surgical including rest, physical therapy and orthotics. If these noninvasive approaches fail, a surgical procedure entailing a fasciotomy is considered gold standard. This invasive treatment is based on the finding that opening of the enveloping fascial muscle layer relieves pathologically high intracompartmental pressures. Elevated muscle pressures are believed to cause the pain and are generally considered the 'cornerstone' in the pathophysiology of CECS. However, an intricate knowledge of all mechanisms that are involved in CECS is currently lacking. More understanding of the pathophysiologic basis of dp-CECS and the mechanism of pain are needed as these new insights may possibly result in a transition from surgical treatments towards noninvasive options such as gait pattern adaptations. This noninvasive novel tool recently demonstrated promising results for anterior CECS.[3-6]

Incidences of dp-CECS among the general population and in certain sports are unknown. Some have estimated that up to one of seven young athletes with exercise-related lower leg pain suffers from a type of lower leg CECS.[16] Specific numbers for dp-CECS are not available at the moment. The true prevalence may be underestimated as a substantial portion of athletes probably decrease their sports activity to a level that they can handle and therefore never seek medical attention. Moreover, awareness may be low in trainers and general practitioners who are confronted with a patient with exercise induced lower leg pain who reports that rest fails.[21] In contrast to anterior CECS, the differential diagnosis of exercise-related pain in medial and deep aspects of the lower leg is extensive. Therefore, dp-CECS may not be the first diagnosis doctors think of as also illustrated by the mean 2 years delay as demonstrated in the present thesis.

A major challenge is to increase our understanding of the anatomy of the lower leg, especially with respect to the possible existence of an illustre 'fifth subcompartment' in the deep posterior compartment. Most anatomy studies relied on findings in anatomic specimens of random senior patients.[7,8] However, it is highly doubtful whether these findings are representative for an average (dp-) CECS patient who is often a young and healthy person. Because it is impossible to standardly perform an extensive exploration of the lower leg anatomy during surgery in CECS populations, future studies should use modalities such as CT or MRI to answer these questions. Focus on deep posterior compartment anatomy and the possible presence and extension of fascial blades is needed. Outcomes of these studies would possibly guide in choosing type of fasciotomy, currently varying from a simple crural fascia release to an in-depth exploration and additional releases of all subcompartments of the deep posterior compartment. A randomized controlled trial between simple fasciotomy and extensive deep posterior compartment fasciotomy is preferred but difficult to accomplish. Interestingly and in contrast to previous studies in random anatomic lower leg cadaveric specimens, our MRI study found that a separate tibialis posterior muscle fascia was visible in all 24 living patients.[26]

Currently, an important shortcoming in the diagnostic work-up of dp-CECS is a lack of consensus regarding ICP criteria.[25] Commonly used cut off points are derived from studies on anterior compartment pressure readings.[17,22,24,27] Because deep posterior compartment pressures are generally lower compared to values observed in the anterior compartment,[13,15,18] one may hypothesize that using the generally accepted ant-CECS pressure criteria for the diagnosis of dp-CECS may result in false negative diagnoses. Some even suggest that ICP values are not valid to diagnose CECS at all, predominantly because of the large overlap between asymptomatic and symptomatic individuals possibly leading to large numbers of false positive diagnoses.[20] Future studies should explore the possibility of analyzing ICP signals and patterns during rest and exercise. Additionally, studies on improved accuracy of pressure catheter placement using ultrasound and the influence of catheter depth on pressure registrations (pull back techniques) are required.[10]

Apart from measuring absolute values of ICP, recent studies have observed the presence of pulse-synchronous intramuscular pressure oscillations in ant-CECS patients suggesting decreased compartment compliance due to abnormally elevated compartment pressures.[11,12] The amplitude of oscillations was found to correlate with absolute ICP levels during abnormally elevated ICP in experimental human models. A high sensitivity for abnormally elevated ICP in patients was observed in ant-CECS, but similar findings have yet to be confirmed in dp-CECS.

A fasciotomy is currently considered gold standard for the treatment of recalcitrant dp-CECS. All patients report the use of unsuccessful nonoperative treatment regimens prior to surgery. However, effects of these treatments have never been consistently studied. Rest, physical therapy, icing, shockwave therapy and NSAIDs all focus on symptom relief but possibly fail to address the underlying pathophysiologic basis of the disease. A more extensive knowledge of noninvasive treatments is needed. Recent studies have confirmed that some types of noninvasive therapies possibly are valid alternatives in certain subtypes of CECS. For instance, a modification to a forefoot running pattern may yield good results in anterior CECS.[4-6] This treatment is based on the finding that altering muscle contraction load were found to lower intramuscular pressures in the anterior muscle compartment.[9] Running patterns such as forefoot strike, mid-foot strike or heel strike may be analyzed by a video analysis system such as Optogait. A study on running patterns in asymptomatic and symptomatic CECS patients using such a system is currently underway. These studies may lead the way to an effective nonoperative treatment for dp-CECS.

# REFERENCES


1. Aweid O, Del Buono A, Malliaras P, et al. Systematic review and recommendations for intracompartmental pressure monitoring in diagnosing chronic exertional compartment syndrome of the leg. *Clin J Sport Med.* 2012; 22(4):356-370.
2. Blackman PG. A review of chronic exertional compartment syndrome in the lower leg. *Med Sci Sports Exerc.* 2000;32(3 Suppl):S4-10.
3. Breen DT, Foster J, Falvey E, Franklyn-Miller A. Gait re-training to alleviate the symptoms of anterior exertional lower leg pain: a case series. *Int J Sports Phys Ther.* 2015;10(1):85-94.
4. Diebal AR, Gregory R, Alitz C, Gerber JP. Effects of forefoot running on chronic exertional compartment syndrome: a case series. *Int J Sports Phys Ther.* 2011;6(4):312-321.
5. Diebal AR, Gregory R, Alitz C, Gerber JP. Forefoot running improves pain and disability associated with chronic exertional compartment syndrome. *Am J Sports Med.* 2012;40(5):1060-1067.
6. Helmhout PH, Diebal AR, van der Kaaden L, Harts CC, Beutler A, Zimmermann WO. The Effectiveness of a 6-Week Intervention Program Aimed at Modifying Running Style in Patients With Chronic Exertional Compartment Syndrome: Results From a Series of Case Studies. *Orthop J Sports Med.* 2015;3(3):2325967115575691. eCollection 2015.
7. Hislop M, Tierney P. Anatomical variations within the deep posterior compartment of the leg and important clinical consequences. *J Sci Med Sport.* 2004;7(3):392-399.
8. Hislop M, Tierney P, Murray P, O'Brien M, Mahony N. Chronic exertional compartment syndrome: the controversial "fifth" compartment of the leg. *Am J Sports Med.* 2003;31(5):770-776.
9. Kirby RL, McDermott AG. Anterior tibial compartment pressures during running with rearfoot and forefoot landing styles. *Arch Phys Med Rehabil.* 1983;64(7):296-299.
10. Nakhostine M, Styf JR, van Leuven S, Hargens AR, Gershuni DH. Intramuscular pressure varies with depth. The tibialis anterior muscle studied in 12 volunteers. *Acta Orthop Scand.* 1993;64(3):377-381.
11. Nilsson A, Zhang Q, Styf J. Using the Amplitude of Pulse-Synchronous Intramuscular Pressure Oscillations When Diagnosing Chronic Anterior Compartment Syndrome. *Orthop J Sports Med.* 2014;2(11): 2325967114556443. eCollection 2015.
12. Nilsson A, Zhang Q, Styf J. The amplitude of pulse-synchronous oscillations varies with the level of intramuscular pressure in simulated compartment syndrome. *J Exp Orthop.* 2015;2(1):3. Epub 2015 Feb 25.
13. Ogunlusi JD, Oginni LM, Ikem IC. Normal leg compartment pressures in adult Nigerians using the Whitesides method. *Iowa Orthop J.* 2005;25:200-202.
14. Peck E, Finnoff JT, Smith J, Curtiss H, Muir J, Hollman JH. Accuracy of Palpation-Guided and Ultrasound-Guided Needle Tip Placement Into the Deep and Superficial Posterior Leg Compartments. *Am J Sports Med.* 2011;39(9): 1968-74.
15. Pedowitz R, Hargens A, Mubarak S, Gershuni D. Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *Am J Sports Med.* 1990;18(1):35-40.
16. Qvarfordt P, Christenson JT, Eklof B, Ohlin P, Saltin B. Intramuscular pressure, muscle blood flow, and skeletal muscle metabolism in chronic anterior tibial compartment syndrome. *Clin Orthop Relat Res.* 1983(179): 284-290.
17. Schepsis AA, Martini D, Corbett M. Surgical management of exertional compartment syndrome of the lower leg. Long-term followup. *Am J Sports Med.* 1993;21(6):811-817.
18. Staudt JM, Smeulders MJ, van der Horst CM. Normal compartment pressures of the lower leg in children. *J Bone Joint Surg Br.* 2008;90(2):215-219.
19. Styf J, Korner L, Suurkula M. Intramuscular pressure and muscle blood flow during exercise in chronic compartment syndrome. *J Bone Joint Surg.* 1987;69(2):301-305.
20. Tiidus PM. Is intramuscular pressure a valid diagnostic criterion for chronic exertional compartment syndrome? *Clin J Sport Med.* 2014;24(1):87-88.
21. Turnipseed WD. Diagnosis and management of chronic compartment syndrome. *Surgery.* 2002;132(4):613-617; discussion 617-619.
22. van Zoest WJ, Hoogeveen AR, Scheltinga MR, Sala HA, van Mourik JB, Brink PR. Chronic deep posterior compartment syndrome of the leg in athletes: postoperative results of

fasciotomy. *Int J Sports Med.* 2008;29(5):419-423.
23. Wiley JP, Short WB, Wiseman DA, Miller SD. Ultrasound catheter placement for deep posterior compartment pressure measurements in chronic compartment syndrome. *Am J Sports Med.* 1990;18(1):74-79.
24. Winkes MB, Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Compartment pressure curves predict surgical outcome in chronic deep posterior compartment syndrome. *Am J Sports Med.* 2012;40(8):1899-1905.
25. Winkes MB, Hoogeveen AR, Scheltinga MR. Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. *Br J Sports Med.* 2014; 48(22):1592-1598.
26. Winkes MB, Tseng CM, Pasmans HL, van der Cruijsen-Raaijmakers M, Hoogeveen AR, Scheltinga MR. 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.* 2016;44(10):2659-2666.
27. Winkes MB, van Zantvoort AP, de Bruijn JA, et al. Fasciotomy for Deep Posterior Compartment Syndrome in the Lower Leg: A Prospective Study. *Am J Sports Med.* 2016; 44(5): 1309-16.
28. Zhang Q, Jonasson C, Styf J. Simultaneous intramuscular pressure and surface electromyography measurement in diagnosing the chronic compartment syndrome. *Scand J Med Sci Sports.* 2011; 21(2):190-195.

8

# NEDERLANDSE SAMENVATTING (DUTCH SUMMARY)

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# DUTCH SUMMARY (NEDERLANDSE SAMENVATTING)

Sommige sporters ontwikkelen inspanningsgebonden spierpijn door een zogenaamd ‘chronisch compartimentsyndroom’ (CECS, chronic exertional compartment syndrome). CECS wordt gedefinieerd als een ziektebeeld waarbij tijdens inspanning sprake is van te hoge spierdrukken, hetgeen gepaard gaat met verslechterde doorbloeding waardoor verminderde spier- en zenuwfunctie in het aangedane spiercompartiment ontstaat. Dit ziektebeeld kan ontstaan in elke spier of spiergroep die door een bindweefselvlies (‘fascie’, ‘de-spier-z’n-jassie’) wordt omgeven.

Dit proefschrift richt zich op diagnostiek en chirurgische behandeling van twee CECS subtypen: het diepe flexoren compartimentsyndroom van het onderbeen (dp-CECS), en het onderarmflexoren CECS.

Patiënten met CECS ervaren progressieve inspanningsgebonden pijn hetgeen noodzaakt tot het stoppen van de provocatieve inspanning. De pijn kan gepaard gaan met een strak gevoel, krampen, zwakte of huidgevoelsveranderingen. In het dp-CECS wordt de pijn diep in de kuit ervaren, en dit subtype wordt frequent gezien bij hardlopers en voetballers. Een onderarm-CECS daarentegen kenmerkt zich door een samenknijpend strak gevoel in de onderarm met krachtverlies tijdens vingerbuiging en wordt vrijwel altijd bij motocrossracers vastgesteld. Een samenvattend overzicht betreffende historie, anatomie, diagnose en behandeling van deze CECS subtypen alsmede doelen van dit proefschrift worden weergegeven in **hoofdstuk 1**.

Een systematic literatuurreview over de chirurgische behandeling van dp-CECS wordt beschreven in **hoofdstuk 2**. Deze review levert 7 level III evidence studies, waarbij in totaal slechts 131 patiënten met dp-CECS worden beschreven. De conclusie is dat de chirurgische behandeling voor dit ziektebeeld zeer divers is. De ingreep varieert van slechts een oppervlakkige crurale fasciotomie tot multipele fasciotomieën van de diverse spieren die zich in het diepe flexoren onderbeencompartiment bevinden. Ook lengte en aantal incisies, wel/niet los prepareren van de soleusspier, wel/niet een fasciotomie van het diepe posterieure compartiment, wel/niet additionele fasciotomie van de musculus tibialis posterior evenals het wel/niet klieven (fasciotomie) of wegsnijden (fasciectomie) van de fascie variëren sterk. Verhoogde spierdrukken na provocatie zijn gerelateerd aan postoperatief succes. Echter, het resultaat na chirurgie is suboptimaal, waarbij de succesratio’s variëren van 30-65%.

Verschillende aspecten zoals suboptimale patiëntenselectie (mogelijk gelijktijdige lijdend aan mediaal tibiaal stress syndroom (MTSS) of popliteal arterial entrapment syndrome (PAES), inaccurate interpretatie van spierdrukken tijdens en na een provocatieve test evenals incomplete fasciotomie, kunnen alle bijdragen aan dit suboptimaal resultaat. In de review wordt een stap-voor-stap chirurgische ‘hoe-te-doen’ gepresenteerd voor een ons inziens correcte fasciotomie bij dp-CECS.

Voortvloeiend uit het feit dat pathologisch verhoogde spierdrukken de basis zijn voor de CECS diagnostiek zou men verwachten dat de absolute hoogte van spierdrukken (in mm Hg) voorspellend zal zijn voor operatiesucces. **Hoofdstuk 3** poogt te beantwoorden of preoperatieve spierdrukken gerelateerd zijn aan postoperatief operatieresultaat, en mogelijk voorspellend zijn voor succes. In tegenstelling tot 31 eerdere dp-CECS studies die veelal klein en heterogeen zijn, omvat de huidige studie de grootste serie patiënten met dp-CECS. Ook zijn preoperatieve 4-punts drukcurves en postoperatieve uitkomsten duidelijk omschreven.

Tweeënvijftig patiënten met dp-CECS beantwoordden een vragenlijst betreffende postoperatieve symptomen als pijn, strak gevoel, spierkramp, krachtsverlies, sensibiliteitsveranderingen. Ze classificeerden hun 3-maanden postoperatieve uitkomst als uitstekend, goed, matig of slecht. Succesvolle chirurgie werd gedefinieerd als uitstekend of goed, en niet-succesvolle chirurgie als matig of slecht. Het kortetermijn succes was 52% (27/52, 14% uitstekend, 38% goed). De 'area under the pressure curve' bleek gerelateerd aan postoperatieve uitkomst (uitstekend, 127 ± 28 mm Hg; goed, 113 ± 25 mm Hg; matig, 100 ± 22 mm Hg; slecht, 88 ± 15 mm Hg; P = .005) en succes (OR 1.04; 95% C.I., 1.01-1.08). Echter, de studie vond geen betrouwbare afkapwaarden voor spierdrukken die preoperatief konden voorspellen of het resultaat uitstekend/goed, of matig/slecht zou worden. Bovendien bleken drukken niet gerelateerd aan het langetermijnresultaat. Van de vier drukregistraties (druk in rust, direct na provocatie, en 1 en 5 minuten na), bleken de drukken direct na provocatie de uitkomst het beste te voorspellen. 'Doctor's delay' bleek gerelateerd aan een slechtere uitkomst. Deze studie concludeerde dat spierdrukpatronen na een gestandaardiseerde provocatietest mogelijk kunnen bijdragen aan de workup van dp-CECS.

De diagnose dp-CECS wordt gesteld met behulp van een 'dynamische' spierdrukmeting, waarbij met een holle naald een plastic drukmeetkathetertje wordt gepositioneerd in het te meten spiercompartiment. Plaatsing wordt meestal verricht 'uit de vrije hand' op basis van anatomische grenzen. Sommigen echter adviseren om de katheter te plaatsen met de hulp van echografie. De katheter wordt idealiter gepositioneerd in de musculus tibialis posterior (TP). Slechts twee (kadaver-) studies zijn verricht naar accuraatheid van plaatsing van de druknaald in dit diepe TP compartiment. Bepaling van *in vivo* accuraatheid van katheterplaatsing in het diepe TP compartiment in patiënten met een mogelijke dp-CECS is nooit verricht.

Hoewel bij de meeste drukmetingen gebruik wordt gemaakt van een plastic drukkatheter ten behoeve van een dynamische drukmeting, beschrijven sommige studies een statische drukmeting waarbij op verschillende meetmomenten een metalen druknaald wordt ingebracht met een in de hand gehouden meetapparaatje. Deze statische methode is niet geschikt voor het visualiseren middels magnetic resonance imaging (MRI). Een af te koppelen plastic katheter welke in situ blijft daarentegen is uitermate geschikt om zo af te beelden. De studie in **hoofdstuk 4** is de eerste waarin de accurate positie van een uit de vrije hand ingebrachte katheter met behulp van MRI werd geanalyseerd. In deze studie ondergingen 24 patiënten met een mogelijke dp-CECS een spierdrukmeting. De katheter was uit de vrije hand midden in de spierbuik van de musculus tibialis posterior (TP) geplaatst. Na de drukmeting ondergingen de patiënten, met de katheter nog in de spier aanwezig, een MRI scan.

De scans werden geëvalueerd door twee geblindeerde radiologen. Plaatsing van de kathetertip werd geclassificeerd als optimaal (midden in de TP), suboptimaal (in het diepe posterieure compartiment maar niet in de TP), of inaccuraat (buiten het diepe posterieure compartiment). Plaatsing bleek optimaal in 10 patiënten (42%), terwijl een suboptimale plaatsing werd verkregen in 9 patiënten (37%). Vijf drukmetingen bleken zelfs inaccuraat (overgangszone tussen diepe posterieure en oppervlakkige posterieure compartiment, n=3; tip gelegen in het oppervlakkige compartiment, n=2). Tekenen van een hematoom werd gezien op 38% van de scans, alhoewel deze nooit klinisch relevant waren. Deze studie concludeerde dat het uit de vrije hand inbrengen van een katheter voor drukmeting in het diepe flexoren compartimentsyndroom onvoldoende accuraat is. Het optimaliseren van de techniek van inbrengen resulteert wellicht in een hogere diagnostische accuraatheid en helpt wellicht bij de indicatiestelling voor chirurgie.

In navolging van de eerdere retrospectieve studie zoals beschreven in hoofdstuk 3, werd in **hoofdstuk 5** een prospectieve studie verricht naar het effect van chirurgie op de vijf kardinale symptomen van een dp-CECS (pijn, strak gevoel, spierkramp, spierzwakte en verminderd huidgevoel), complicaties en oorzaak van falen. Deze studie is de eerste in zijn soort die prospectief korte- en langetermijnresultaten beschrijft na een fasciotomie voor dp-CECS. Tussen september 2011 en januari 2015 werd een homogene groep van 44 patiënten met een geïsoleerd dp-CECS bestudeerd. Een fasciotomie verbeterde alle symptomen, zowel op de korte termijn (3 maanden) als op langere termijn (minimaal 12 maanden na chirurgie). 71% van de patiënten had baat bij de fasciotomie terwijl 47% hun langetermijnuitkomst als 'goed' of 'uitstekend' rapporteerde. 76% van de patiënten gaf aan opnieuw deze operatie te verkiezen, als zij op voorhand dit resultaat wisten. Bij hernieuwd poliklinisch lichamelijk onderzoek bleken persisterende klachten veelal te berusten op onbehandelde subtypen CECS of een MTSS. Een belangrijke conclusie van deze studie is, dat de ontevreden patiënt recht heeft op een hernieuwde evaluatie van zijn onderbeenklachten.

**Hoofdstuk 6 en 7** vormen het tweede deel van dit proefschrift en focussen op de chirurgische behandeling van onderarm-CECS. **Hoofdstuk 6** gaat over de langetermijn effecten van chirurgische decompressie van een onderarmen-CECS in een homogene groep van motocrossers. Ten tijde van publicatie betrof dit de grootste serie van patiënten met dit ziektebeeld, vastgesteld met dynamische spierdrukmetingen. Twee chirurgische technieken voor de behandeling van onderarm flexoren CECS werden niet-gerandomiseerd vergeleken: een fasciotomie met of zonder een aanvullende fasciëctomie. 24 motocrossers werden geanalyseerd. De visual analoge scale (VAS, spreiding 0-100) voor pijn tijdens inspanning daalde gemiddeld van 53 naar 7. Fasciotomie (n=14) en fasciëctomie (n=10) bleken op de lange termijn beiden even succesvol. Vergeleken met deze studiegroepen, bleken de operatieve resultaten van een geëxcludeerde groep (n=10, geopereerd op basis van anamnese en lichamelijk onderzoek alleen, maar niet bevestigd met drukmeting) veel minder succesvol (mediaan 26 punten daling in VAS). Na gemiddeld 5 jaar was 95% tevreden met het eindresultaat.

**Hoofdstuk 7** beschrijft het geval van een motorrijder met een ongewoon subtype CECS, namelijk een eenzijdig gecombineerde flexoren-extensoren onderarm CECS. Eén jaar na chirurgie waren alle symptomen verdwenen. Een systematische review concludeerde dat een onderarm-CECS meestal tweezijdig is, meestal van het flexoren type (75%), terwijl het bijna altijd motocrossers of motorracers betreft. Een gecombineerd flexoren-extensoren onderarm CECS is extreem zeldzaam.

## CONCLUSIES

1. De kwaliteit van studies over het chronische compartiment syndroom van de diepe flexoren in het onderbeen (dp-CECS) is beperkt. Diagnostische criteria en chirurgische technieken blijken zeer divers, hetgeen de matige operatieresultaten (30-65% succes) waarschijnlijk deels verklaart.
2. In een retrospectief geanalyseerde patiëntpopulatie met dp-CECS blijkt het kortetermijnsucces na chirurgie gerelateerd aan preoperatieve spiercompartiment-drukken.
3. Het uit de vrije hand inbrengen van drukkatheters voor meting van de tibialis posterior druk blijkt suboptimaal in meer dan de helft van de patiënten met een verdenking op dp-CECS.
4. 71% van de patiënten met dp-CECS heeft baat bij een fasciotomie terwijl bijna de helft op de lange termijn een goed of uitstekend resultaat rapporteert. Persisterende klachten worden vaak veroorzaakt door andere subtypes CECS, of door MTSS.
5. Fasciotomie en fasciëctomie zijn even succesvol als behandeling voor het onderarmflexoren CECS bij motocross racers.

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# VALORISATIE

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# VALORISATIE

Een compartimentsyndroom is een ziektebeeld waarbij te hoge druk in een door een vlies afgesloten spiercompartiment de functie en vitaliteit van die spieren bedreigt. Meestal ontstaat dit binnen enige uren, bijvoorbeeld door spierzwelling als gevolg van een onderbeenbreuk. In dit geval is snelle ontlasting (decompressie) van de spieren middels een operatie vereist om onomkeerbaar weefselversterf te voorkomen. Dit proefschrift laat deze acute vorm van compartimentsyndromen verder buiten beschouwing. Er bestaat een variant van een compartimentsyndroom waarbij verhoogde drukken optreden door belasting van de betreffende spieren: in de onderbenen vaak door lopen of hardlopen. De drukken normaliseren meestal als de spieren niet meer belast worden. Soms kan door herhaalde sportieve activiteiten een chronische situatie van verhoogde druk ontstaan (chronic exertional compartment syndrome, CECS). Het voor u liggende proefschrift gaat over dit CECS.

CECS kenmerkt zich door pijn, een strak gevoel en spierkrampen die optreden na het starten van een lichamelijke inspanning en veelal verdwijnen na enige tijd rust. Van oudsher wordt in de praktijk onderscheid gemaakt tussen verschillende spiercompartimenten waarin CECS kan ontstaan. Het meest frequent zijn de voorste (anterior) en diepe achterste (deep posterior) spiercompartimenten van het onderbeen aangedaan (respectievelijk ant-CECS en dp-CECS in dit proefschrift). Minder frequent is het laterale onderbeencompartiment aangedaan waar de peroneus musculatuur zich bevindt (per-CECS) en uiterst zelden het oppervlakkige achterste onderbeencompartiment. CECS is het meest frequent beschreven in het onderbeen, maar kan optreden in iedere spier of spiergroep met een fascie, bijvoorbeeld de onderarm (onderarm-CECS). In dit geval kan weer onderscheid gemaakt worden in buig- en strekspieren, gelegen in een oppervlakkig en een diep compartiment.

Patiënten met CECS zijn meestal gezonde, sportende individuen. Behalve jonge leeftijd zijn geslacht (man), afwezigheid van eerdere aandoeningen aan het symptomatische ledemaat, type sport en pijn bij palpatie van de spiercompartimenten geassocieerd met CECS. Typische provocatieve sporten zijn hardlopen, schaatsen (ant-CECS), voetbal (dp-CECS) en motocross (onderarm CECS). De onbekendheid met CECS onder artsen, paramedici en ook sporters vormt het grootste probleem voor (h)erkenning en adequate behandeling. De meest bekende CECS variant is het ant-CECS, ook al vanwege de relatief simpele diagnose en behandeling. In sommige kringen, zoals militairen of hardlopers, heeft ant-CECS relatief veel aandacht gekregen. Echter, ant-CECS wordt wel verward met bot- en botvlies gerelateerde ziektebeelden en daarom soms foutief "shinsplints" genoemd.

Dit proefschrift behandelt een aantal relevante vraagstukken over diagnostiek en chirurgische behandeling van een ander type CECS, namelijk het CECS in de diepe buigspieren van het onderbeen (dp-CECS) en die van de onderarm. Deze variant is, mede door een brede differentiaaldiagnose (“DD”, een lijst van mogelijke aandoeningen waaraan een bepaalde patiënt zou kunnen lijden), maar ook door technisch lastige spierdrukmetingen, moeilijk te diagnosticeren.

Vergeleken met een ant-CECS, waarbij de DD relatief simpel is (vermoeidheidsbreuk (stressfractuur), spierherniatie, botvliesirritatie of slagader-verkalking), is deze bij een dp-CECS veel uitgebreider. Wanneer bij pijn van de kuit aan een dp-CECS gedacht wordt, dienen ziektebeelden op andere terreinen zoals spier/pezen (spiercontusie, tendinopathie), bloedvaten (slagaderlijke beknelling in de knieholte, slagaderverkalking, diep veneuze trombose), bot/botvlies (stress fractuur, mediaal tibiaal stress syndroom [shin splints]), zenuwbeknelling (perifere zenuw-beknelling, rughernia) en infectie (osteomyelitis) te worden overwogen.

De afdeling Sportmáx in Máxima Medisch Centrum, Veldhoven, fungeert als landelijk verwijscentrum voor inspanningsgebonden pijn aan de ledematen bij sporters. In de laatste jaren is veel ervaring opgedaan met het verrichten van dynamische drukmetingen in diverse spiercompartimenten, om de diagnose CECS te bevestigen of te verwerpen. De ieder jaar toenemende stroom CECS patiënten vormt een uitstekende mogelijkheid om onderzoek te verrichten om diagnostiek, behandeling en bekendheid van CECS te verbeteren. Dit proefschrift is een bundeling van zes wetenschappelijke artikelen betreffende diagnostiek en chirurgische behandeling van dp-CECS in het onderbeen en CECS in de onderarm. Resultaten werden gepresenteerd op nationale en internationale congressen. Aangezien de meeste patiënten via een sportarts de diagnose krijgen, werd besloten deze artikelen aan te bieden aan internationale sportgeneeskundige bladen met duidelijke affiniteit voor chirurgie. Dat er interesse op het hoogste wetenschappelijke nivo was blijkt uit het feit, dat 5 van de 6 artikelen in de 'Eredivisie' van internationale sportbladen zijn gepubliceerd.

Los van een meer gecompliceerde diagnostiek door de uitgebreide DD, is ook de behandeling van dp-CECS (het chirurgisch openleggen van de fascie, een zgn. 'fasciotomie') lastiger dan bij een ant-CECS. Een dp-CECS wordt door velen gezien als de lastigst te behandelen CECS variant waarbij regelmatig een teleurstellend operatieresultaat wordt verkregen. In het beginstadium van dit promotieonderzoek werden na behandeling door middel van een fasciotomie in de literatuur in louter retrospectieve series succespercentages tussen de 30 tot 65% gerapporteerd. In een prospectieve serie patiënten die een fasciotomie hebben ondergaan voor dp-CECS (een primeur in de internationale literatuur), had 71% van onze patiënten profijt gehad van een fasciotomie. Een belangrijke les uit deze studie was dat patiënten die een matig of slecht resultaat rapporteerden, bij poliklinische follow-up eigenlijk alleen last bleken te hebben van nog onbehandelde andere typen CECS of een mediaal tibiaal stress syndroom. Ook kwamen wij tot de conclusie dat consensus ontbreekt over wat nu eigenlijk 'succes' is. Is dit een terugkeer naar onbeperkte en ongehinderde sport-beoefening? Is dit volledig pijnvrij worden na een operatie? Voor een topsporter zal bijvoorbeeld 90% klachtenvermindering als onvoldoende worden ervaren, terwijl dit bij een recreatieve sporter wel als succes ervaren kan worden. Wanneer succes goed gedefinieerd wordt, zal het mogelijk worden om behandelingsresultaten van verschillende onderzoeken onderling te vergelijken.

Dat dp-CECS en onderarm-CECS voor velen onbekend terrein zijn, blijkt uit het geringe aantal medische publicaties, maar ook uit het feit dat veel patiënten pas na een aanzienlijk "doctor’s delay" uiteindelijk de diagnose krijgen. Uit ons onderzoek is gebleken dat gemiddeld 37 maanden na ontstaan van de eerste klachten pas de diagnose CECS werd gesteld. Voorafgaand aan de diagnose is 80% van de patiënten één of meerdere malen met dit probleem bij de huisarts geweest en heeft 90% van de patiënten een eerder consult bij een sportarts gehad. Negen van de 10 patiënten gaf aan meerdere fysiotherapeutische behandelingen te hebben ondergaan zonder enig resultaat, en respectievelijk 25% en 50% van de patiënten bleek met deze klachten naar een chirurg of orthopedisch chirurg geweest, zonder dat de juiste diagnose werd gesteld. Eénderde van de patiënten onderging een röntgenfoto van het onderbeen, één op de drie een MRI scan en één op de acht een botscan. Landelijke incidentiecijfers van CECS zijn niet bekend, maar dit proefschrift maakt het meer dan aannemelijk dat de maatschappelijke kosten teruggedrongen kunnen worden als dit ziektebeeld een grotere bekendheid krijgt en daarmee overbodig beeldvormend onderzoek achterwege gelaten kan worden. Gelukkig is wereldwijd de aandacht voor het ziektebeeld CECS gestaag aan het toenemen, gegeven de toename van de medische publicaties van gemiddeld 10 per jaar in de jaren '90, tot 50+ in 2016.

Concluderend toont dit proefschrift aan dat dp-CECS en onderarm-CECS voor velen nog onbekende pijnsyndromen zijn, die goed chirurgisch te behandelen zijn. De postoperatieve resultaten na een onderbeensfasciotomie in onze recente prospectieve studie lijken beter dan eerdere retrospectieve studies deden vermoeden. Er is behoefte aan een duidelijke definitie van behandelings “succes”, en het is gebleken dat bij patiënten met een onvoldoende operatieresultaat gezocht moet worden naar alternatieve onbehandelde diagnoses. Een toegenomen bekendheid van dit ziektebeeld zal gepaard gaan met een afname van maatschappelijke kosten.

# DANKWOORD

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# DANKWOORD

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# LIST OF PUBLICATIONS

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1. **Winkes MB**, Loos MJ, Scheltinga MR, Teijink JA. Dialysis catheter placement via the left internal jugular vein: risk of brachiocephalic vein perforation. J Vasc Access 2016 May 17. DOI:10.5301/jva.5000566.

2. **Winkes MB,** Tseng CM, Pasmans H, Hoogeveen AR, Scheltinga MR. MRI verified accuracy of intracompartmental pressure measurements in the deep posterior compartment of the lower leg. Am J Sports Med 2016 Oct;44(10): 2659-2666.

3. **Winkes MB**, Teijink JA, Scheltinga MR. Motorcycle racer with unilateral forearm flexor and extensor chronic exertional compartment syndrome. BMJ Case Rep. 2016 Apr 14;2016.

4. **Winkes MB**, Wienhoven J, Groetelaers R, Poeze M. Traumacasus: Val door dak. Nieuwsbrief Netwerk Acute Zorg Limburg 2016;3:4-7.

5. **Winkes MB,** van Zantvoort AP, de Bruijn JA, Smeets JS, van der Cruijsen M, Hoogeveen AR, Scheltinga MR. Fasciotomy for deep posterior compartment syndrome in the lower leg: A prospective study. Am J Sports Med 2016 May;44(5):1309-16.

6. de Bruijn JA, van Zantvoort AP, **Winkes MB**, Raaymakers L, van der Cruijsen-Raaijmakers M, Hoogeveen AR, Scheltinga MR. Feasibility and safety of an operative tool for anterior chronic exertional compartment syndrome treatment. Foot Ankle Int. 2015 Dec;36(12):1475-82.

7. van Zantvoort AP, de Bruijn JA, **Winkes MB**, Dielemans JP, van der Cruijsen M, Hoogeveen AR, Scheltinga MR. Isolated chronic exertional compartment syndrome of the lateral lower leg: A case series. Orthop J Sports Med. 2015 Nov;3(11): 2325967115617728.

8. **Winkes MB**, Hoogeveen AR, Scheltinga MR. Is surgery effective for deep posterior compartment syndrome of the leg? A systematic review. Br J Sports Med. 2014 Dec; 48(22):1592-8.

9. **Winkes MB**, Scheltinga MR. Invaginatie van het jejunum door een gemetastaseerd longcarcinoom. Medisch Journaal. 2013; 42(2):71.

10. **Winkes MB**, Luiten EJT, van Zoest WJF, Sala HA, Hoogeveen AR, Scheltinga MR. Long term results of surgical decompression of chronic exertional compartment syndrome of the forearm in motocross racers. Am J Sports Med. 2012 Feb; 40(2):452-458.

11. **Winkes MB**, Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Compartment pressure curves predict surgical outcome in chronic deep posterior compartment syndrome. Am J Sports Med. 2012 Aug; 40(8):1899-905.

12. **Winkes MB,** Hoogeveen AR, Houterman S, Giesberts A, Wijn PF, Scheltinga MR. Drukmetingen voorspellen operatiesucces bij het chronisch compartimentsyndroom van de diepe flexoren in het onderbeen. Medisch Journaal. 2012; 41(3):50-56.

13. **Winkes MB**, Luijten AAPM. Een vrouw met plotse braakneigingen. Tijdschr. voor geneeskunde. 2011; 67(21):1028-1029.

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# CURRICULUM VITAE

CV

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Michiel Winkes werd geboren op 12 januari 1987 in Rotterdam. In 2005 behaalde hij zijn Atheneum diploma aan het Mgr. Frencken College te Oosterhout (Noord Brabant). Datzelfde jaar werd gestart met de studie geneeskunde aan de Universiteit van Maastricht. Tijdens deze studie volgde hij coschappen in o.a. Kampala (Oeganda) en Jakarta (Indonesië). In het laatste jaar van de studie begon Michiel aan de wetenschappelijke stage naar chronisch compartimentsyndromen in het Máxima Medisch Centrum, Veldhoven, onder leiding van dr. M.R.M. Scheltinga, chirurg, en dr. A.R. Hoogeveen, sportarts. Na het behalen van het artsexamen in oktober 2011, werd gestart als ANIOS (arts, niet in opleiding tot specialist) op de spoedeisende hulp en in oktober 2012 als ANIOS op de intensive care. Het onderzoek naar compartiment-syndromen ging gestaag door en werd al snel een promotietraject met internationale presentaties, waaronder in Londen en Rome. In juli 2013 begon Michiel in opleidingsregio Maastricht aan de opleiding tot algemeen chirurg in het Máxima Medisch Centrum (Veldhoven/Eindhoven), opleiders dr. R.M.H. Roumen en dr. M.R. Scheltinga, wat in juli 2015 werd voortgezet in Maastricht Universitair Medisch Centrum, opleider prof. dr. L.P.S. Stassen. In juli 2016 ging hij terug naar het Máxima Medisch Centrum. Daar zal hij in juli 2017 starten met de differentiatie traumachirurgie (differentiatieopleider drs. P.V. van Eerten). Michiel woont samen met zijn vriendin Dorien Coenen in Eindhoven.