Foot Compartment Syndrome: Diagnosis and Management

Andrew Dodd, MD
Ian Le, MD, FRCSC

Abstract

Although uncommon, foot compartment syndrome (FCS) is a distinct clinical entity that typically results from high-energy fractures and crush injuries. In the literature, the reported number of anatomic compartments in the foot has ranged from 3 to 10, and the clinical relevance of these compartments has recently been investigated. Diagnosis of FCS can be challenging because the signs and symptoms are less reliable indicators than those of compartment syndrome in other areas of the body. This may lead to a delay in diagnosis. The role of fasciotomy in management of FCS has been debated, but no high-level evidence exists to guide decision making. Nevertheless, emergent fasciotomy is commonly recommended with the goal of preventing chronic pain and deformity. Surgical intervention may also be necessary for the correction of secondary deformity.

Foot compartment syndrome (FCS) is relatively uncommon. Although isolated foot injuries result in FCS in only 2% of cases, orthopaedic surgeons must remain aware of this clinical entity because it can result in negative sequelae. FCS accounts for <5% of limb compartment syndrome cases.

Typically, FCS is the result of high-energy injuries to the foot such as crush injuries, Lisfranc fracture-dislocations, midfoot and forefoot trauma, and calcaneal fractures. FCS can also develop after a tibial fracture secondary to the communication between the deep posterior compartment of the leg and the calcaneal compartment of the foot.

The most commonly cited etiology is a high-energy fracture of the calcaneus, which results in FCS in up to 10% of cases. However, data from a study by Thakur et al suggest that this patient population may be undertreated because only 1% of patients with isolated calcaneal fractures and suspected FCS underwent a fasciotomy.

Stiffness, chronic disability, deformity, and pain are some of the complications associated with untreated FCS (Table 1). Necrosis of the intrinsic muscles of the foot can lead to ischemic contractures that may result in claw toe, hammer toe, and pes cavus. Neurovascular injury can also cause chronic pain and an insensate foot with secondary neuropathic pathology (eg, chronic ulceration, joint destruction).

Pathophysiology

Compartmant syndrome is caused by increasing pressure secondary to hemorrhage or edema within an anatomic compartment bound by inelastic fibrous tissue. Pressures rise until capillary perfusion pressure is exceeded, resulting in ischemia, soft-
tissue compromise, and subsequent necrosis followed by fibrosis and contracture of the compartment’s contents.1,4

Claw toe is the most common sequela of FCS and develops when the extrinsic musculature overpowers the weak or scarred intrinsic foot muscles, whereas cavus deformity is the result of scarred and contracted plantar structures.2 In the setting of intra-articular calcaneal fracture, claw toe develops after the fracture hematoma in the deep central compartment of the foot raises pressures and compresses the medial and lateral plantar neurovascular bundles.12,13 This results in ischemic insult to the interosseous muscles and quadratus plantae muscle, which derive their blood supply from the medial and lateral plantar arteries.

Acute compartment syndrome can also cause ischemic neuropathy and chronic neuropathic pain.17 Peripheral nerves may undergo irreversible damage after 4 to 6 hours of ischemia.17 Symptoms of neuropathic pain include numbness, spontaneous pain, allodynia, and hyperalgesia.18 Neuropathic pain is associated with poor general health and a decrease in many quality of life measurements.19 Management of neuropathic pain is difficult and the outcomes are generally poor. Multimodal drug therapy is often necessary.20 Frink et al21 reported high rates of sensory disturbance and pain at rest in patients treated for lower limb compartment syndrome. To our knowledge, no studies have examined the prevalence or natural history of neuropathic pain in the setting of acute FCS.

| Table 1 |
| Potential Complications Associated With Untreated Foot Compartment Syndrome |
| Chronic pain | Insensate foot | Foot and ankle stiffness |
| Claw toe deformity | Hammer toe deformity | Cavus foot deformity |
| Neuropathic pain | Neuropathic ulceration |

Anatomy

Understanding of the myofascial compartments of the foot continues to evolve. Early reports identified four fascial compartments: medial, lateral, central, and interosseous.22-24 Myerson25 described methods for surgical decompression of these compartments.

Manoli and Weber26 performed infusion studies and reported that the foot could be divided into nine anatomic compartments, with the central compartment divided into superficial central and deep central (or calcaneal) compartments. They also increased the number of interosseous compartments from one to four, adding a compartment for the adductor hallucis muscle. New decompression techniques using multiple incisions were recommended based on the increased number of compartments.26

Guyton et al27 questioned the validity of previous gelatin infusion studies in defining anatomic compartments and accurately measuring them without image guidance. The authors performed infusion studies using CT guidance with simultaneous compartment pressure monitoring, focusing on the distinction between the superficial and deep central compartments. They demonstrated active fluid communication between the two compartments as pressures rose above 10 mm Hg. In addition, they commented on the difficulty of inserting an infusion needle into the superficial central compartment even with CT guidance.

Reach et al28 further investigated the anatomic compartments of the foot using high-resolution MRI. The authors found a 10th compartment in addition to the 9 compartments described by Manoli and Weber.26 The 10th compartment is bounded by the skin and contains the extensor digitorum brevis and the extensor hallucis brevis in a newly described dorsal compartment.

In a cadaver study of the myofascial compartments of the foot, Ling and Kumar8 dissected 13 feet and found three vertical fibrous septae in the hindfoot that, along with the plantar aponeurosis, form the compartments of the foot (Figure 1). These results were substantially different from those of prior studies. The septae bound compartments identified as medial, intermediate, and lateral. Skin and subcutaneous tissue compose the medial border of the medial compartment. As such, only the intermediate and lateral compartments are rigidly bound by fascia on all sides. The authors found no evidence of a thick fascial layer between the previously described superficial central and deep central (calcaneal) compartments, finding only a thin and often incomplete filmy layer of tissue instead. They concluded that the intermediate and lateral compartments are the only compartments that need surgical decompression and recommended a single plantar-based surgical approach to do so. These findings conflict with those of Stotts et al29 who reported on an isolated medial compartment syndrome in the foot that required surgical decompression, which suggests that the medial compartment is capable of developing pressures sufficient to warrant decompression.

Ling and Kumar8 attempted to qualify the clinical importance of the foot compartments with regard to surgical decompression and concluded that only two rigidly bound
compartments exist, which may suggest that the clinical sequelae of FCS are a result of injury to the medial and lateral plantar arteries and nerves that traverse the newly termed intermediate compartment. More research is needed to confirm or refute these conclusions, including prospective studies comparing the new decompression technique described by the authors with more aggressive releases of all nine compartments of the foot.

**Diagnosis and Physical Examination**

Although diagnosis of FCS is established clinically and follows the same principles as those for diagnosis of compartment syndrome in other areas of the body, the signs and symptoms of FCS tend to be less reliable.\(^1,4\) Patients who present with high-energy fractures and severe crush injuries to the foot are at risk of developing FCS and should be monitored serially.\(^1,2\) Open fractures and wounds do not result in reliable decompression of myofascial compartments and the presence or development of compartment syndrome cannot be ruled out in the setting of these injuries.\(^1\)

Pain associated with FCS has been described as a severe, relentless burning that encompasses the entire foot.\(^12\) Determining whether the pain is out of proportion to the injury is difficult given the severe trauma typically involved.\(^1\) Indications of a developing FCS include progressive pain despite immobilization of the foot and increasing analgesic requirement.\(^1,2,13\)

In a series of 12 cases of FCS, Fahour and Manoli\(^30\) reported that the most consistent physical finding was tense swelling. Other authors agree that although the presence of tense swelling is not necessarily diagnostic, it is suggestive of FCS.\(^11,13,31\) Substantial pain with passive dorsiflexion of the toes is a common physical finding, but it may be present in the absence of compartment syndrome.\(^1,2,11,13,30\) Passive dorsiflexion of the toes decreases the volume of the interosseous compartments, which exacerbates pain.\(^2\) Sensory changes can be nonspecific, with the most sensitive findings being decreased two-point discrimination and decreased light touch on the plantar aspect of the foot and toes. Decreased pin-prick sensation is a less sensitive finding.\(^1,2,11,13,30,31\) Motor strength and the presence or absence of palpable pulses are poor indicators of a developing compartment syndrome.\(^2\) Serial examinations are helpful to observe changes in pain patterns and sensory findings.\(^2\)

**Compartment Pressure Monitoring**

FCS can be difficult to diagnose based on physical findings; therefore, most authors agree that compartment pressure monitoring is the most reliable method for objective diagnosis of FCS.\(^1,2,4,5,11,13,30,32\) Myerson\(^1\) recommends liberal use of pressure monitoring because increased pressures often precede clinical signs and symptoms. Some authors advocate liberal pressure monitoring for any foot trauma with significant swelling.\(^1,30\) Benefits of pressure monitoring include the ability to monitor the trend of the compartment pressures and to document adequate decompression after fasciotomies.\(^1,13\)

In general, absolute compartment pressures >30 mm Hg are an indication for emergent decompression.\(^1,2,4,12,20,32\) This indication is supported by the findings of Mittlmeier
in a study of 17 patients with calcaneal fractures, 12 of whom had central compartment pressures >30 mm Hg. Seven of the 12 patients with pressures >30 mm Hg developed ischemic contractures, whereas 5 with pressures <30 mm Hg did not develop contractures. Serial measurements should be performed in patients with compartment pressures between 20 and 30 mm Hg.\textsuperscript{5,32} Systemic hypotension decreases the tolerance for increased compartmental pressures, and pressures within 10 to 30 mm Hg of the diastolic blood pressure are an indication for decompression.\textsuperscript{2,12} The calcaneal compartment of the foot consistently demonstrates the highest pressures; therefore, this compartment should always be monitored.\textsuperscript{2,11,12} The calcaneal compartment is approximately 60 mm distal to the most prominent aspect of the medial malleolus.

Aside from the importance of measuring the pressure of the compartment containing the quadratus plantae muscle, no consensus exists on measurement of pressures in particular compartments or the number of compartments that should be measured.\textsuperscript{2,11,12} Myerson\textsuperscript{1} suggested measuring the central and interosseous compartments; however this recommendation was based on the four-compartment model of the foot. More recently, methods for measurement of 9 or 10 compartments in the foot have been described.\textsuperscript{2,4,33} Ling and Kumar\textsuperscript{8} suggest that only the intermediate and lateral compartments require pressure monitoring; these are the only compartments that the authors recommended decompressing. No evidence currently exists to substantiate a recommendation on how many compartments’ pressures should be measured because a firm understanding of the number of clinically important compartments in the foot is lacking. The calcaneal (ie, intermediate) compartment has consistently demonstrated the highest compartment pressure readings; therefore, it is reasonable to suggest that an attempt should always be made to measure this compartment’s pressure.

Several authors have described techniques for measuring the pressure of the central compartment. Myerson and Manoli\textsuperscript{12} describe a method that entails entering the skin perpendicular to the foot at a point 3.8 cm distal to the tip of the medial malleolus. In a second method, the entry is made through the skin just below the base of the first metatarsal, passing above the abductor hallucis to a depth of 1.5 in.\textsuperscript{1} In a high-resolution MRI study of the compartments of the foot, Reach et al\textsuperscript{33} describe specific needle placement landmarks (Figure 2). When entry to the calcaneal compartment is required, they recommend a needle entry point approximately 60 mm distal to the most prominent aspect of the medial malleolus, inserted to a depth of approximately 24 mm.\textsuperscript{33} The authors describe entry points and depths for all 10 foot compartments.
Nonspecific findings on physical examination contribute to the difficulty in diagnosing FCS. Compartment pressure monitoring should be considered standard for establishing a diagnosis of FCS. Increasing pain and sensory disturbances in a tense, swollen foot should prompt measurement of compartment pressures.

**Acute Management**

Initial management of suspected compartment syndrome entails the removal of all restrictive dressings, elevation of the extremity to the level of the heart, and prevention of systemic hypotension as well as serial examinations and compartment pressure monitoring. If diagnosis of FCS is established, urgent decompressive fasciotomies should be considered. Although most authors advocate the use of acute compartment releases, we believe that this management option remains controversial. To date, no studies have compared early decompression versus delayed management of FCS, and most recommendations in the literature are based on level IV and V evidence. Complication rates associated with each treatment pathway are also poorly described in the literature, making it difficult to compare outcomes.

Early decompression and fasciotomy carries the risk of wound infection and the potential need for soft-tissue coverage. Delayed treatment presumably results in a higher rate of deformity and the sequelae listed in Table 1. Chronic pain is a common result of high-energy foot trauma and may or may not be related to ischemic insult to the peripheral nerves of the foot. Without high-quality prospective studies, it is difficult to determine whether one treatment pathway is superior to another; thus, further investigation is necessary.

**Fasciotomy**

When acute FCS is diagnosed, emergent decompressive fasciotomy should be performed to prevent ischemic contracture. In the setting of lower limb compartment syndrome, the best clinical results are achieved when fasciotomy is performed early; the potential benefits of this procedure decrease the longer the decompression is delayed from the time of diagnosis.

The high complication rate associated with delayed fasciotomy has prompted the suggestion that compartment releases should not be done if diagnosis is delayed >8 hours. However, it is not always possible to know when the initial signs and symptoms of compartment syndrome arose.

In a study of 17 patients with intra-articular calcaneal fractures and 12 with calcaneal compartment pressures documented at >30 mm Hg, Mittlmeier et al reported poor outcomes in patients with FCS treated without fasciotomy. Seven of the 12 patients with pressures >30 mm Hg developed symptomatic plantar contractures, claw toe deformity, or both.

Myerson reviewed the results of 14 cases of FCS treated with decompressive fasciotomy. In nine cases, the releases were performed through two dorsal incisions; a single medial incision was used in five. In three cases, wounds were closed acutely with split-thickness skin excision coverage, eight required delayed split-thickness skin grafting, and three (all medial) were closed with delayed primary closure. Only one case required a free tissue transfer. At the latest follow-up, four patients were symptom free and six reported only occasional discomfort in the foot. Only one patient developed a claw toe deformity.

In a review of 12 cases of FCS treated with fasciotomy, Fakhoury and Manoli reported good results. Decompression was performed through a single medial incision in six cases, medial and double dorsal incisions in four, and medial plus dorsal and lateral incisions in two. Split-thickness skin grafting was necessary in four cases. At an average follow-up of 21 months, no wound infections or wound complications were reported. No ischemic contractures developed; however, eight patients had some discomfort and stiffness in the foot.

Currently, the three-incision approach is most commonly used for decompressive fasciotomy in the foot (Figure 3). This recommendation is based on the nine-compartment model of the foot described by Manoli and Weber. A medial incision is made starting 4 cm anterior to the posterior aspect of the heel and 3 cm superior to the plantar surface of the foot. This incision is carried distally for approximately 6 cm. Through this medial approach, the medial, superficial and deep central, and lateral compartments are released (Figure 3). Two dorsal incisions are used, one just medial to the second metatarsal and one just lateral to the fourth metatarsal to ensure an adequate skin bridge. The interosseous and adductor compartments are released through these dorsal incisions.

An alternative to the standard dorsal incisions was described by Dunbar et al. They used a “piecrusting” technique in which multiple stab incisions are made over the intermetatarsal spaces followed by blunt dissection with a hemostat. The goal is to reduce the need for skin grafts, which are often required with longer incisions on the dorsum of the foot.

Ling and Kumar recommend a plantar-based, single-incision fasciotomy. The incision begins 5 cm distal...
to the posterior aspect of the heel on the non–weight-bearing instep and extends 5 cm distally. The authors felt that this single incision could be used to decompress the intermediate and lateral compartments, which they believe is sufficient to decompress the foot. Data are lacking to support the use of this approach in a clinical setting.

Stabilization or repair of forefoot and midfoot fractures at the time of decompression is recommended to reduce further soft-tissue trauma. Definitive management of calcaneal fractures should be delayed until soft-tissue swelling has receded.\textsuperscript{2,10,30} Dorsal incisions commonly require split-thickness skin graft coverage 5 to 7 days after the fasciotomy is performed. The medial incision can often be closed primarily or with delayed primary closure.\textsuperscript{2,10,32}

Complication rates associated with fasciotomy for FCS have been reported to be lower than those for untreated FCS.\textsuperscript{5} Nevertheless, a paucity of data exists in the current literature with regard to complication rates of both acute fasciotomy and untreated FCS. In their study of 12 cases of FCS treated with fasciotomy, Fakhouri and Manoli\textsuperscript{10} documented no infections and no wound complications. In his series of 14 feet with FCS treated with fasciotomy, Myerson\textsuperscript{32} reported dorsal skin necrosis in one patient, and one patient required a free gracilis tissue flap for coverage. The medial-based fasciotomy incision places the medial calcaneal branch of the posterior tibial nerve at risk of injury; however, the rate of injury has not been documented.\textsuperscript{2}

For management of acute FCS, we recommend the use of the three-incision approach (one medial incision, two dorsal incisions), with a full decompression of all nine compartments performed. Currently, the nine-compartment model of the foot is the most accepted model described in the literature.\textsuperscript{26} The “pie-crusting” technique described by Dunbar et al\textsuperscript{35} may provide similar decompression of the dorsal foot compartments with a decreased need for skin grafting. Additional studies comparing this approach and other approaches, such as that described by Ling and Kumar,\textsuperscript{8} are needed.

**Delayed Management**

The natural history of nonsurgically managed FCS includes potential development of ischemic contractures, neuropathy, deformity, and chronic pain.\textsuperscript{7,36,37} The goal of management is to achieve a functional, plantigrade, and pain-free foot.\textsuperscript{7,10} Lesser toe deformities, cavus foot deformity, neuropathic pain, and ulceration secondary to deformity and sensory disturbance are common problems that must be addressed.\textsuperscript{2,10,36,37}

Claw toe, the most common deformity associated with FCS, develops due to intrinsic muscle weakness and extrinsic muscle overpull. Interosseous muscle injury, denervation, and ischemic contracture of the quadratus plantae muscle, which inserts onto the flexor digitorum longus tendon, result in hyperextension of the metatarsophalangeal (MTP) joints and flexion of the interphalangeal
joints. Less commonly, hammer toe can develop in the setting of ischemic contracture in the interosseous and lumbral muscles. Cavus deformity is also common, occurring as a result of fibrosis and contracture of the plantar intrinsic muscles and soft tissues. Additional sequelae include neuropathic changes, neuro- pathic pain due to ischemic nerve injury, nerve compression symptoms from fibrosis and contracture, and insensate areas of the foot with subsequent ulcerations.

Management of Sequelae Associated With FCS

Nonsurgical
Nonsurgical management of complications associated with FCS is most likely to be successful in patients with mild, flexible deformities with no neuropathy or static neuropathic symptoms. Toe deformities and cavus foot deformity may initially be managed with passive mobilization and stretching. Shoe wear modification (eg, deep toe box) is also recommended. Custom orthotics may be beneficial for management of cavus foot deformity. In insensate areas of the foot, appropriate skin care to avoid pressure ulcers is also important.

Surgical
In patients with more advanced deformity, progressive neuropathic symptoms, or failed nonsurgical treatment, surgical intervention may be indicated. Soft-tissue procedures, osteotomies, arthrodesis, and amputation are options that should be considered depending on clinical circumstances. Correction of deformity and maintenance of the correction are the goals of surgical intervention. Progressive neuropathic symptoms may indicate ongoing nerve compression in contracted fibrotic tissues. Nerve conduction velocity studies can help distinguish between ongoing nerve compression and static ischemic nerve injury. In cases of nerve compression, neurolysis of the tibial nerve and its distal branches may be helpful.

Management of claw toe deformity is based on whether the deformity is flexible or rigid. Flexible deformities are passively correctable at the interphalangeal and MTP joints, whereas rigid deformities are not. Flexible deformities can often be managed with flexor tenotomies and extensor tendon lengthening. Flexor-to-extensor tendon transfer (Girdlestone-Taylor procedure) also can be used, although we infrequently perform this procedure. In cases of rigid deformity, which are far more common than flexible deformities, arthrodesis is recommended. We recommend proximal interphalangeal arthrodesis with MTP arthrotenomy or even a metatarsal shortening osteotomy, if necessary. This is often supplemented by extensor tendon lengthening and flexor tenotomies.

Initially, cavus deformity associated with FCS should be managed with soft-tissue procedures (eg, plantar fascia release, long flexor tendon lengthening or release, scar tissue excision) followed by osteotomies or selective arthrodesis, if necessary. In cases of cavus and concomitant claw toe deformity, extensor digitorum longus tendon transfer to the metatarsal necks addresses both deformities. If the correction is inadequate, a forefoot or midfoot dorsal closing wedge osteotomy or arthrodesis may be considered. At our institution, we proceed with soft-tissue balancing before any bony procedures. If soft-tissue procedures do not provide adequate correction, we perform dorsal closing wedge osteotomy through the midfoot. In the setting of degenerative changes, deformity correction with midfoot or hindfoot arthrodesis is most effective.

Amputation can serve as a salvage option in cases of severe deformity, pain, and ulceration. Poor vascular supply may also play a role in the choice of amputation over reconstruction. We do not consider amputation a failure of treatment. For a functionless, insensate foot with the sequelae of ulceration and infection, amputation is an effective management option.

Summary
FCS is an uncommon diagnosis, accounting for <5% of limb compartment syndromes. A high index of suspicion for FCS must be maintained in the setting of a high-energy injury to the foot (e.g., severe crush injury). Physical examination findings may be unreliable for diagnosis; therefore, compartment pressure monitoring is essential. Controversy exists regarding acute versus delayed management of FCS, and further research on the outcomes of acute fasciotomy versus delayed management is necessary. Acute management, if chosen, typically consists of emergent decompressive fasciotomies using a three-incision technique. Reconstruction options include deformity correction, nerve decompression, and, in severe cases, amputation. Further research is also needed to determine the optimal decompression technique to avoid chronic FCS, which can result in deformity, dysfunction, and chronic pain.

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References

Evidence-based Medicine: Levels of evidence are described in the table of
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Contents. In this article, references 3 and 5 are level II studies. References 6, 16, 21, 30, 32, and 34 are level IV studies. References 1, 2, 4, 7, 9-14, 17-20, 29, 31, and 35-38 are level V expert opinion.

References printed in bold type are those published within the past 5 years.


