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Acute Compartment Syndrome of the Foot: A Literature Review

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Abstract: Acute compartment syndrome is a surgical emergency that possesses a high risk of morbidity and mortality and can result in poor outcomes if left untreated. In the foot, it is classically a result of crush injuries but can occur in other high-energy mechanisms. Compartment syndrome accounts for less than 5% of limb cases. The current accepted anatomic model defines nine compartments within the foot, with surgical management based on this classification. Most authors advocate for decompressive fasciotomy in diagnosed compartment syndrome patients. However, diagnostic and treatment protocol continues to be debated as there is a lack of high-level of evidence guidelines regarding decision making. Nevertheless, this review provides current recommendations for diagnosis, pressure measuring, and management of compartment syndrome of the foot.

Key words: Compartment syndrome of the foot, acute compartment syndrome, decompressive fasciotomy, crush injury.

Compartment syndrome is a surgical emergency that possesses a high risk of morbidity and mortality and can result in poor outcomes if left untreated. This condition is a consequence of increased intracompartmental pressure often secondary to hemorrhage or edema that leads to damage of muscles, nerves, or vessels (1, 2). It was first described in the upper extremity by Richard von Volkmann in 1872, who years later noted the long-term effects of untreated compartment syndrome from cast applications (3). Shortly after, Hildebrand et al would make the connection of the condition to increased intracompartmental pressures (2). Prior to the 1980s, compartment syndrome of the foot was underrecognized until investigators noticed similarities of fixed foot deformities following severe trauma with that of Volkmann's findings in the upper extremity (4). Compartment syndrome of the foot is relatively uncommon and accounts for less than 5% of limb compartment syndrome cases (5). It has been noted that up to 6% of patients with foot injuries related to motorcycle accidents develop compartment syndrome of the foot (2). Compartment syndrome of the foot is classically associated with crush injuries but can also be seen in Chopart and Lisfranc fracture-dislocations, forefoot and midfoot trauma, and calcaneal fractures. Calcaneal fractures have been associated with 4.7-17% of foot compartment syndrome cases (1). Additional causes in the foot can be seen in other insult such as snakebites, inflammatory reactions, thermal burns, embolectomies, iatrogenic or traumatic arterial injuries, gunshot wounds, osteotomies, fracture, circumferential dressings, and casts (3).

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Pathophysiology

Muscle groups of the lower extremities, just like the rest of the body, are divided into compartments which

are separated by strong, inelastic, fascial membranes. These myofascial compartments are composed of finite volumes that possess limited ability for expansion (6). Compartment syndrome is the result of myofascial compartment pressure surpassing that of perfusion pressure (7). An increase in intracompartmental components, such as from muscle swelling, or a decrease in compartment volume can lead to a rise in intracompartmental pressure. This in turn can lead to tissue ischemia and subsequent necrosis (7). In the foot, compartment syndrome is typically caused by local insult such as trauma or from other causes such as those previously mentioned. When perfusion pressure is surpassed due to increased tissue and venous pressures, the arteriovenous gradient becomes disrupted and decreases (6). This compromises microvascular flow through capillaries and eventually results in ischemic changes to the surrounding tissue. Muscle tissue may sustain permanent damage if subjected to 4-8 hours of ischemia (6). Peripheral nerves may undergo irreversible damage after 4-6 hours of ischemia (5). Severity is dependent on the extent of compartment involvement and duration of ischemia. Muscle necrosis can lead to release of myoglobin and can lead to metabolic acidosis and hyperkalemia (6).

Anatomy

Literature has reported between three to ten compartments in the foot (5). While a consensus to an exact classification has not been agreed upon, the Manoli and Weber classification is currently being used in providing a model for diagnostic and surgical management of compartment syndrome of the foot. In 1990, Manoli and Weber injected gelatin into cadaveric foot specimens and observed their localization under cryopreservation (2). Their study identified nine anatomic compartments within the foot: medial, lateral, superficial, adductor, calcaneal, and four interosseous compartments. An additional dorsal compartment was identified by Reach et al with the use of high-resolution MRI (2, 5).

Clinical Evaluation

The five "P's" have classically been described as the signs and symptoms of compartment syndrome; pain, pallor, pulselessness, paresthesia, and paralysis. Unfortunately, these findings may be less reliable when trying to identify compartment syndrome in the foot. It is recommended that patients who are thought to be at risk of developing compartment syndrome of the foot have serial physical examinations performed (1, 6). Some studies have argued that pain has been the leading symptom of compartment syndrome that has been shown to be highly sensitive but nonspecific (2). Others have argued that pain out of proportion may not be reliable as many foot injuries produce considerable pain (5). A study by Myerson et al found in patients with compartment of the syndrome of the foot, 86% exhibited exacerbation of pain due to passive motion (6). However, utility of assessing for pain with passive dorsiflexion has become questionable as this test assesses mainly extrinsic musculature (1). In another study by Myerson et al, a decrease in two-point discrimination versus pinprick sensation was a more sensitive finding when assessing for sensory deficits (5, 6). Some studies have also noted that paresthesia may be unreliable as it may be difficult to determine if the nerve injury was secondary to the inciting injury or ischemia (1). Regarding pulses, some have argued that they have low sensitivity for diagnosis simply because they are extracompartmental (6). Muscles strength was also found to be a poor parameter as testing would be difficult secondary to pain from injury (5, 6). A consistent physical finding reported by several studies, including one by Fakhouri and Manoli, was tense swelling (1, 5).

While having a thorough history and physical examination are essential in diagnosing compartment syndrome, subjective findings may be difficult to appreciate under certain circumstances such as obtunded patients or in patients with severe head, spinal cord, or peripheral nerve injuries (1). Because of this, most authors agree that compartment pressure monitoring is the most reliable method for objective diagnosis in the foot (1, 5). Myerson et al recommends pressure monitoring in patients with significant foot swelling. They also noted that pressure changes can precede clinical signs and symptoms (5).

Noninvasive techniques such as contrast-enhanced ultrasound imaging and near-infrared spectroscopy have been described in recent literature though studies are limited. Additionally, cerebral pressure catheters and piezoelectrical probes have been described as potential measuring devices (2). A variety of invasive pressure measurement methods have historically been described such as the Whiteside's infusion technique, the Wick Catheter, and the Slit Catheter (3). In most hospitals today, commercial handheld manometers are the latest devices that make

measuring compartment pressures accurate, reproducible, and easy to perform (1). A common theme these invasive devices share is they measure compartmental pressures through the insertion of a cannula into a muscular compartment (2). A syringe and manometer connected to the cannula measures the force required to overcome compartmental resistance. This force is equal to the intracompartmental pressure (2).

Intracompartmental pressures are normally less than 8 mm Hg (2). Apart from clinical findings, threshold for diagnosis of compartment syndrome should rely on a differential pressure reading between diastolic blood pressure and intracompartmental pressure of less than 30 mm Hg (1, 8). Due to disagreement regarding the number of anatomical compartments of the foot, there is no consensus on which or how many compartments' pressures should be measured. However, one consistent finding most studies have observed was that the calcaneal compartment frequently demonstrated the highest pressure readings and should always be monitored (1, 2, 5, 6).

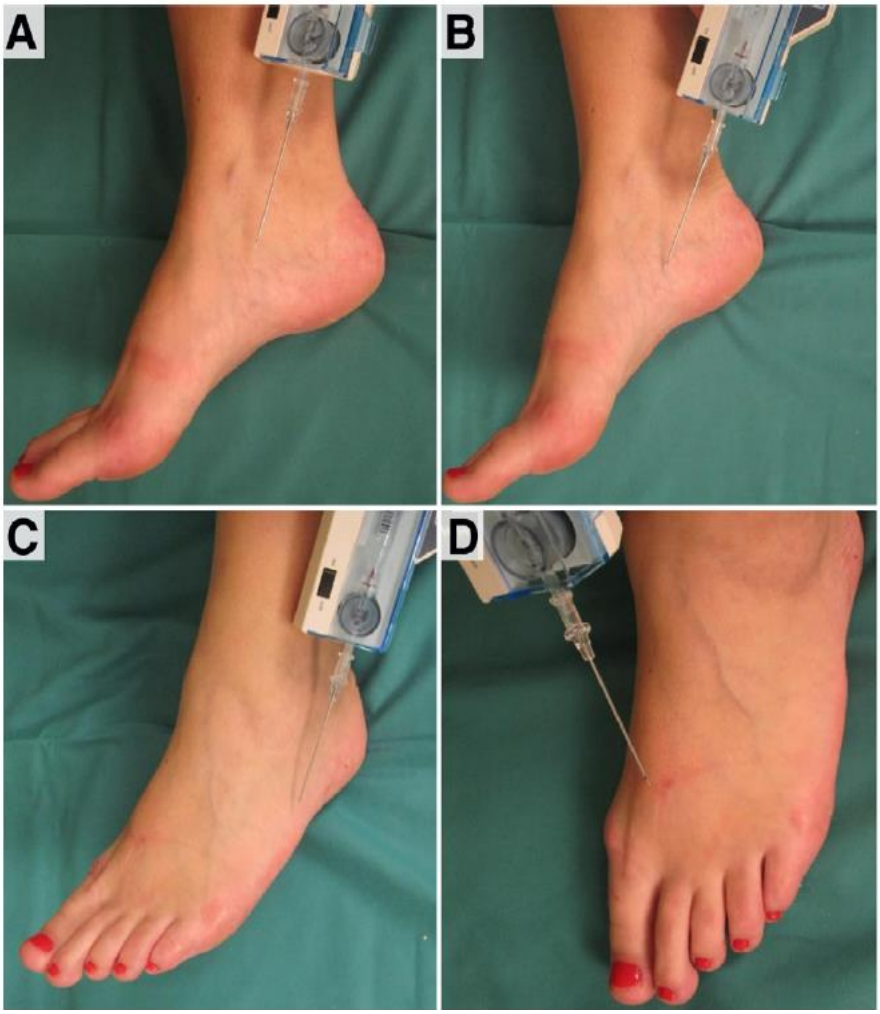

FIGURE 1. Needle insertion sites to measure intracompartmental pressures of the (A) medial and calcaneal compartments, (B) superficial compartment, (C) lateral compartment, and (D) interosseous and adductor compartments (Lutter *et al.* 2019)

Based on Manoli and Weber's classification, nine anatomic compartments of the foot can be measured. The needle insertion site for the medial compartment is located 4 cm below the medial malleolus (FIGURE 1A). As mentioned, the calcaneal compartment would typically show high pressure values, so more attention should be given towards measuring this compartment. Deep within the medial compartment insertion site, the calcaneal compartment can also be accessed (FIGURE 1A). The superficial compartment can be measured ventrally and plantarly by penetrating the flexor digitorum brevis muscle (FIGURE 1B). The lateral compartment can be reached just plantar to the fifth metatarsal (FIGURE 1C). Each of the interosseous spaces can be accessed from the dorsum of the foot (FIGURE 1D). Additionally, deeper insertion from this site can be used to measure the adductor compartment (2).

Management

Immediate management of suspected compartment syndrome involves removal of any restrictive dressings, bandages, or casts (2, 8). The limb should be laid flat or slightly elevated to a maximum of 10% above the level of the patient's heart. This is recommended in order to prevent any decreases in arteriovenous pressure which can impair circulation to the affected region (2).

When acute compartment syndrome of the foot is diagnosed, most authors advocate for decompressive fasciotomy. No studies have compared early decompression to delayed management of compartment syndrome of the foot (2). Fasciotomies carry the risk of wound infection and potential need for soft-tissue coverage while delayed

management holds risks such as ischemic contractures, chronic pain, and neuropathy. Secondary closure typically occurs 5-7 days after fasciotomy, with roughly 65% of cases requiring skin grafting after fasciotomy (6). For forefoot and midfoot fracture fixation, definitive stabilization acutely is recommended if primary closure is possible. Fixation of calcaneal fractures are typically delayed 10-14 days to allow for decrease in swelling. (6).

Equivalent to the debates between number of anatomic compartments and measuring pressures, empiric treatment remains controversial. For the foot, several approaches have been described including the plantar approach, dorsal approach, medial-plantar approach, medial approach, and the lateral approach (2). For the plantar approach, an incision is made over the first metatarsal. With the abductor hallucis muscle retracted, the other compartments can be reached. The dorsal approach, described by Mubarak and Owen, requires two incisions: medial to the second metatarsal and lateral to the fourth metatarsal. It is helpful to be mindful of the distance between the two incisions to minimize the risk of tissue necrosis. The medial-plantar approach utilizes a 6 cm medial incision that is parallel to the plantar aspect of the foot overlying the origin of the abductor hallucis muscle. This incision allows access to all compartments once the abductor hallucis is retracted and fascia separated. The medial approach is started 4 cm anterior to the posterior aspect of the heel and 3 cm superior to the plantar surface of the foot. This incision is extended distally approximately 6 cm. The lateral approach, initially described by Echtermeyer et al in 1982, starts at the lateral malleolus and continues dorsally to the heads of the fourth and fifth metatarsals. (2, 5). The most commonly used approach utilizes a combination of the medial and dorsal approaches (FIGURE 2 and 3). The medial approach allows for the release of the medial, superficial, calcaneal, and lateral compartments. The dorsal approach allows for the interossei and adductor compartment release (5, 6). Dorsal incisions often require split-thickness skin grafts. Wounds post-fasciotomy are either covered with vacuum therapy or left open, possibly using the shoelace technique to favor delayed closure (2). To reduce the need for skin grafts, Dunbar et al (9) described a "pie-crusting" technique which utilizes multiple stab incisions made over the dorsal aspect of the intermetatarsal spaces [(FIGURE 4) (5, 6)]. In acute cases, primary closure should be avoided as this can induce a rebound

FIGURE 2. Illustration demonstrating the three-incision fasciotomy. Blue arrows in the cross section indicate entrances into medial, superficial, central, lateral, and deep central compartments. (Dodd *et al* 2013)

compartment syndrome (10). For vacuum therapy, circumferential application of film dressing should be avoided as this can cause an increase in pressure (2).

Complications and Sequelae.

Surgical and delayed management of compartment syndrome of the foot are not without complication. Infection rates for delayed primary closure or split-thickness skin graft application following fasciotomy, with or without negative pressure wound therapy, is reported to be about 20% (1).

A study by Mittlmeier et al observed development of symptomatic plantar contractures or claw toe deformities in patients with compartment syndrome of the foot that were treated without fasciotomy (5). Myerson reviewed 14 cases of compartment syndrome of the foot treated with decompressive fasciotomy and noted that only one patient had developed a claw toe deformity (5).

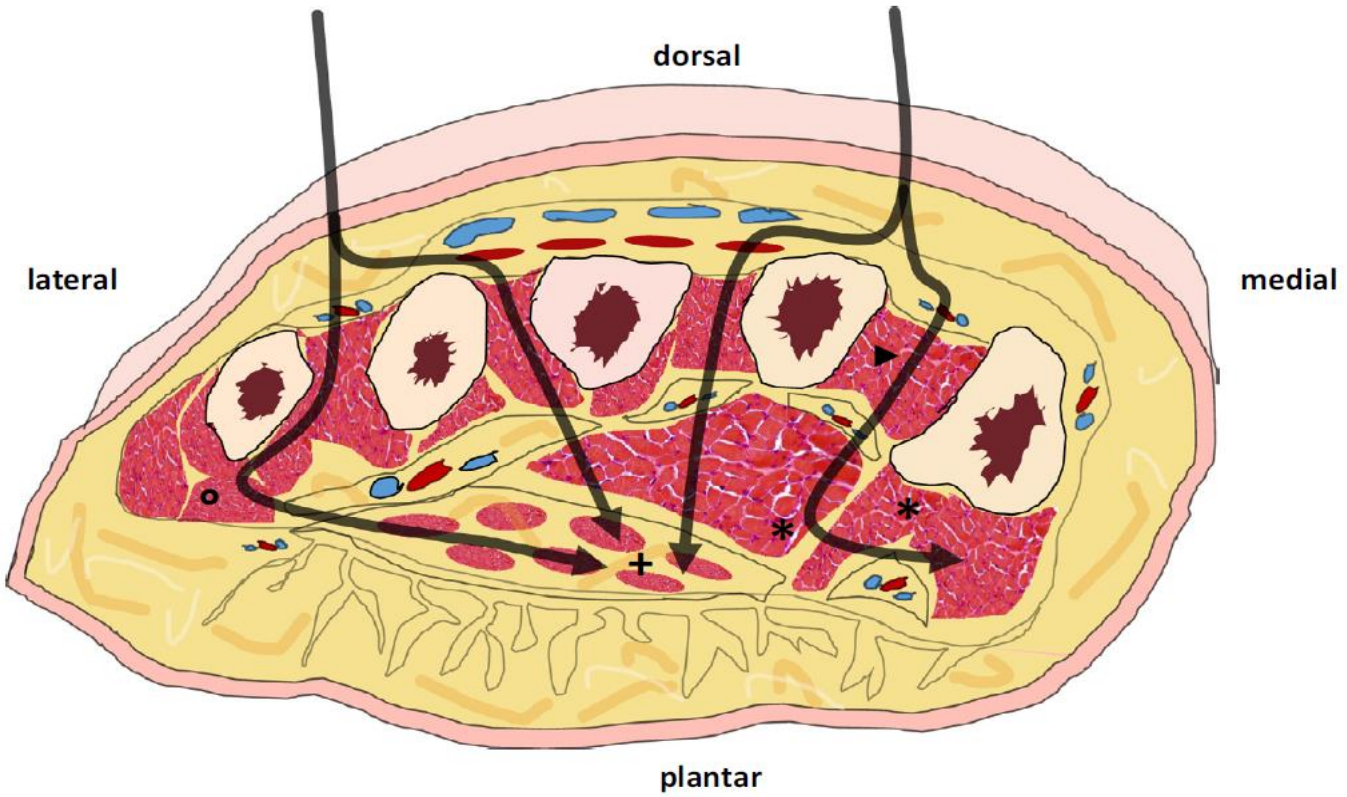

FIGURE 3. Fasciotomy approach for dorsal incisions: Black arrows indicate approaches. *, medial and adductor compartments; +, superficial compartments; °, lateral compartments; ►, interosseous compartments (Lutter *et al.* 2019).

Another study by Fakhouri and Manoli consisting of 12 cases of compartment syndrome of the foot treated with fasciotomy yielded no wound infection, wound complications, or ischemic contractures (5). Of note, patients in the Myerson and the Fakhouri and Manoli studies did note discomfort and stiffness in the foot at follow-up. 10% of patients with these symptoms were able to return to their preinjury state after fasciotomy (6).

With delayed management, especially a missed diagnosis of compartment syndrome in the foot, potential outcomes include development of ischemic contractures, neuropathy, deformity, and chronic pain (1). Hammertoe and claw toe deformities are the most common ischemic contractures and have been noted to occur up to 13 months following injury (1). Imbalances between intrinsic and extrinsic musculature are responsible for these deformities (1, 5). Cavus foot deformity is also a common sequelae of delayed treatment of acute compartment syndrome and occurs as a result of fibrosis and contracture of the plantar intrinsic musculature and soft tissue (5). Reported treatments of sequelae can include nerve decompression, soft tissue release, tendon transfers, osteotomies, and fusions (5, 6). Chronic pain, neuropathic pain, numbness, allodynia, and hyperalgesia are additional complications that can arise (5). Alterations in foot structure from deformity may affect gait. In combination with neuropathic changes, these can lead to the development of ulcerations. In this subset of patients, amputation may be the definitive option for sequelae management (6). In those with mild, flexible deformities, shoe gear modifications and custom foot orthoses are recommended. With neuropathic patients, monitoring high pressure areas and skin care are important in preventing ulcerations (5).

Summary

Acute compartment syndrome of the foot is a pathologic condition that is caused by increases in intracompartmental pressures that typically result from high-energy injuries. Delay in treatment or a missed

FIGURE 4. Pie crusting technique described by Dunbar *et al.* 2007 (9).

diagnosis can lead to irreversible cell death that is often associated with poor long-term outcomes. Controversy still exists in regards to diagnosis and treatment. Diagnosis is made through history and clinical examination but can be aided by the use of manometers. High clinical suspicion and serial examinations are recommended for high risk patients. Guidelines in literature for treatment remain inconsistent, likely due to the debate regarding the number of foot compartments and their clinical relevance for decompression. The current accepted model by Manoli and Weber recognizes nine compartments in the foot. When acute compartment syndrome is diagnosed, most authors advocate for decompressive fasciotomy utilizing a combination of medial and dorsal approaches. Complications may still arise following decompression including pain, discomfort, and stiffness. Delayed management or missed diagnosis can lead to irreparable tissue damage and poor functional outcomes which may also require surgical intervention. Current literature on compartment syndrome of the foot remains limited and could benefit from prospective and randomized controlled studies that focus on treatment modalities and their outcomes. These studies could generate empiric guidelines for diagnosis and treatment of compartment syndrome of the foot.

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