Compartment Syndrome of the Lower Extremity

Martin H. Hessmann, Patrick Ingelfinger, Pol M. Rommens[1]

Abstract
Acute compartment syndrome of the lower extremity is a limb-threatening emergency that requires prompt surgical treatment. Early detection and decompression are necessary in order to avoid irreversible damage. In the lower extremity, compartment syndrome may occur around the pelvis, in the thigh, the lower leg or the foot. Acute compartment syndrome of the lower leg is most common. Sometimes, combined compartment syndromes of neighbouring skeletal regions are observed. In this review, the specific clinical symptoms as well as the anatomic and therapeutic characteristics of the acute compartment syndrome of the lower extremity are described.

Key Words
Compartment syndrome · Lower extremity · Soft tissue injury · Dermatofasciotomy · Surgery decompression

Eur J Trauma Emerg Surg 2007;33:589–99
DOI 10.1007/s00068-007-7161-y

Introduction

The acute compartment syndrome of the lower extremity is a surgical emergency and still a challenge for even the best clinicians. Though it is by far most often seen after injuries to the lower leg, compartment syndrome can occur in all other compartments of the lower extremity, including the gluteal compartment, the thigh and the foot. Failure to promptly identify and treat compartment syndrome leads to severe limb- and even life-threatening complications and gives all too often rise to a medical malpractice or negligence claim. Only the physician who is fully aware of the etiology and pathophysiology, the clinical symptoms, adjunctive diagnostic techniques and the appropriate treatment will prevent his patients from devastating complications.

This review presents current thoughts and findings regarding compartment syndrome of the lower extremity. Most importantly, it urges physicians to maintain a high level of suspicion of compartment syndrome when dealing with lower extremity injury.

Incidence

Compartment syndrome is the most important and following thrombosis, the most common complication associated with fractures and soft tissue injuries of the lower extremities [1]. The true incidence is not known. Whereas compartment syndrome in association with tibia fractures is well documented in literature, only small series or individual case reports exist in the thigh [2–8], the foot [9–13] or the gluteal region [14–19].

The incidence of compartment syndrome in association with fractures of the tibia varies widely and ranges from 1 to 29% [20–25]. The incidence may be underestimated since this pathology may remain undetected in severely traumatized and/or unconscious patients.

McQueen et al. [26] retrospectively looked at 164 patients with acute compartment syndrome. Sixty-nine percent of the patients had an acute fracture. Fractures of the tibia were most common (36%). Isolated severe soft-tissue injury without fracture was observed in 23.2% of cases. Ten percent of these patients were taking anticoagulants or suffered from bleeding disorder.

It is important to be aware that open fractures are as likely to develop compartment syndrome as closed fractures. DeLee [27] found that 6% of patients with open tibia fractures developed compartment syndrome, compared to only 1.2% in closed fractures. Blick et al. [24] reported even a 9.1% incidence in 198

[1]Department of Trauma Surgery, Johannes Gutenberg-University, Mainz, Germany.

Received: November 7, 2007; accepted: November 8, 2007; Published Online: November 21, 2007

open fractures of the tibia. They concluded that an open wound does not provide adequate decompression. McQueen [28] in a prospective study of 116 patients with tibia fractures found that there was no significant difference in tissue pressure between open and closed fractures.

Etiology

Compartment syndrome of the lower extremity may be caused by a wide variety of pathologies (Table 1). They include specific problems that:

(1) Decrease the intra-compartmental volume,
(2) increase the compartmental content
(3) cause external pressure and/or compression.

Those problems may occur separately or in combination.

Table 1. Etiology of the acute compartment syndrome of the lower extremity.

Decreased compartment volume	Closure of fascial defects
	Application of excessive traction to fractured limbs [23, 25, 30]
Increased compartment content	Trauma
Vascular injury	Tibial fracture
Bleeding disorder	Femoral fracture
Increased capillary pressure/filtration	Knee dislocation
Increased capillary permeability	Ankle fracture/dislocation
Diminished serum osmolarilty	Foot fracture/dislocation
Tumor	Surgery
	Total knee arthroplasty [31–34]
	Total hip arthroplasty [8, 16, 35, 36]
	Arthroscopy [37–39]
	Intensive use of muscles (exercise induced CS) [40–45]
	Post ischemic reperfusion [46, 47]
	Anticoagulants [48–50]
	Diabetes mellitus [51–53]
	Hypothyroidism [54]
	Leukemia [55]
	Sickle cell anemia [56]
	Nephritic syndrome [57]
	Venous obstruction [58]
	Popliteal cysts [59]
	Burns [60–64]
	Snakebites [65, 66]
	Cold [67]
Externally applied pressure	Tight casts, dressing [68, 69]
	Lying on limb (lithotomy position) [70–74]

According to Matsen [29] two prerequisites are needed for the development of a compartment syndrome:

(1) A surrounding envelope with limited elastic capacities (skin, fascia, external elastic or non-elastic dressings/casts)
(2) An increased tissue pressure within that envelope (that may be caused either by a decrease in the volume or an increase in the content).

In the lower extremity, the acute compartment syndrome is mainly caused by trauma. However, specific surgical procedures such as intramedullary nailing or traction in an acute fracture situation may contribute to the progression of an impending compartment syndrome to a manifest compartment syndrome. Therefore, the indications and the potential benefit for those procedures should be analyzed critically in patients with severe soft tissue damage and – in case of doubt – alternative procedures such as external fixation should be considered. Postoperatively, careful clinical re-evaluation in regular time distances is mandatory, since acute compartment syndrome may also develop during the early postoperative course.

Intramedullary Nailing

Several authors reported on elevated compartment pressures in association with intramedullary (IM) nailing of tibia shaft fractures. Moed et al. [75] observed changes in intracompartmental pressure during reaming in an experimental study on animals. However, changes in pressure were transient and pressure values returned to normal or even below baseline after removal of the reamer out of the medullary canal. During nail insertion, pressure values rose again and this time, they remained elevated mainly in the anterolateral compartment. The authors concluded that compartment syndrome is a potential complication of closed IM nailing and they suggested peri- and intra-operative tissue pressure monitoring.

Mawhinney et al. [76] reported on three cases of compartment syndrome of the tibia after closed IM nailing. Peak pressures were reached after two reaming cycles.

Based on these observations, unreamed nailing has been recommended in tibial fractures with associated (impending) compartment syndrome [23, 75–77]. Tornetta and French [23] in a prospective case control study examined the changes in compartmental pressure in the anterior compartment of the tibia in 58 acute fractures that were fixed with unreamed nails. The highest-pressure values were observed during manual fracture reduction (20–58 mmHg; mean 34 mmHg) as well as during nail insertion (15–56 mmHg; mean 26 mmHg). However, pressure returned to baseline values immediately after nail insertion in all cases (mean 13.8 mmHg). The authors concluded that nailing without reaming is safe because it raises the IM pressure only momentarily. They suggested that prolonged pre- or intra-operative traction should however be avoided.

McQueen and Court-Brown [28] used continuous compartment pressure monitoring during reamed and unreamed nailing of tibial fractures. Reaming in their series did not affect the incidence of compartment syndrome.

Traction and Limb Positioning During Surgery

Traction as well as limb positioning during surgery (lithotomy position) have been shown to affect both the compartment volume and the intra-compartmental pressure. Traction and limb positioning therefore may contribute to the development of an acute compartment syndrome.

Shakespeare and Henderson [78] described compartmental pressure changes during calcaneal traction in tibia fractures. Pressure in the anterior and deep posterior compartments increased linearly with increasing traction. Increased pressure persisted during the time that traction was applied. Based on these observations, it was suggested to reduce weight during traction. Traction should be sufficient only to render the patient comfortable and to maintain correct limb alignment. Excessive traction is likely to increase the risk of compartmental ischemia.

Compartment syndromes (mainly of the lower leg) have been described in association with prolonged limb positioning in flexion, elevation, and abduction during surgery (Lloyd-Davies or lithotomy position) [71, 78, 78–81]. The combined effects of direct compression, compressive circumferential bindings or stockings, sequential inflatable devices, and relative elevation of the limb contribute to increase compartment pressure, decrease compartment volume, and decrease blood flow. The combination of these factors in the end may lead to the formation of an acute compartment syndrome [79, 82].

Diagnosis

History

Successful management of compartment syndrome of the lower extremities requires early diagnosis and immediate treatment in order to minimize the risk of late sequelae. The mechanism of injury and associated risk factors must be assessed. A high index of suspicion in patients that are at risk is considered to be the most important diagnostic tool. Especially in young male patients, an increased incidence of this pathology has been observed [26]. Mc Queen et al. [26] suggested that older people have smaller muscle volumes due to hypotrophy. They also are less likely to sustain high-energy injuries. Their relatively higher blood pressure moreover may provide tolerance for higher tissue pressures.

In unconscious or polytraumatized patients, the typical clinical signs and symptoms such as severe pain, numbness and motoric dysfunction are difficult to assess [24]. Additionally, specific anesthesiological procedures (local nerve blocks, epidural anesthesia, and other forms of intra- and postoperative regional anesthesia) may hamper clinical evaluation [83–85]. The use of local anesthetics combined with narcotics during epidural anesthesia has been shown to increase the likelihood of missed compartment syndromes and is not recommended in the at risk patient [86–88].

Physical Examination

Thorough serial clinical examinations are the cornerstone for diagnosis. Most errors are caused by a lack of thoroughness, not a lack of knowledge! The clinical diagnosis is made on a constellation of physical symptoms and signs. Similar as in other anatomic regions,

(1) pain out of proportion and pain on passive stretching
(2) tense and swollen compartments, sometimes with blister formation
(3) weakness of the muscles (paresis)
(4) and numbness or paresthesia [89–92]

are the typical clinical symptoms. Those clinical symptoms may be missed in a superficial clinical evaluation when only one or two compartments of the extremity are involved. It is important to mention that palpable peripheral arterial pulses (A. tibialis posterior, A. dorsalis pedis) do not exclude an acute compartment syndrome, since the increased intracompartimental pressure primarily affects the venous and capillary vascular system (see pathophysiology).

Compartment Pressure Measurement

Particularly in those patients where a reliable clinical examination is not possible, tissue pressure measurement is a useful diagnostic adjunct [91]. Whereas some investigators advocate compartment pressure measurements as a principal criterion for early diagnosis [28, 93, 94], there still is no consensus regarding the compartment pressure for which fasciotomy should be performed. Two competing concepts are in use:

(1) Measurement of the absolute compartment pressure (ACP): values higher than 30–40 mmHg require decompression.
(2) Calculation of the differential pressure (ΔP = diastolic blood pressure – absolute compartment pressure): pressures lower than 30 mmHg require fasciotomy.

The second concept relies on Whiteside's theory, that states that blood pressure can decrease or increase the effect of ACP on the tissue perfusion [93, 95]. However, most data are derived from lower leg studies and no specific pressure thresholds have been defined for the gluteal, thigh or foot compartments.

Diagnosis in clinical practice is established mainly by the clinical symptoms and signs [96, 97]. Pressure monitoring is rarely performed outside specialized units. The results of a survey in the United Kingdom demonstrated that in 1998, less than 50% of hospitals had dedicated measuring devices [98]. Furthermore, departments with a device for pressure measurement seldom used it to its full potential. Possible reasons for not monitoring pressure include faith in own clinical skills, lack of experience in positioning sensors, lack of knowledge of whether pressures need to be measured at different sides within each fascial space, and the unknown accuracy of the monitors available [99].

Treatment

The goal of treatment of the acute compartment syndrome in the lower limb is to avoid irreversible damage of the muscles and neurovascular structures by prompt decompression of all involved compartments, thereby restoring local blood flow and soft tissue oxygenation.

Non-operative Management

Every surgeon should be aware that immediate surgical decompression by dermatofasciotomy is the only effective method of treatment. In patients with an impending or true compartment syndrome, the following immediate measures are useful as a so-called "first aid to hypoxic cells" [100].

- Casts or occlusive dressings should be split completely. Cast padding or circumferential dressings should be released around their entire circumference.
- The affected limb should be placed at the level of the heart. Elevation is contraindicated because it decreases arterial blood flow and narrows the arterial venous pressure gradient and thus worsens the ischemia [100–102, 102].
- Ensure that the patient is normotensive, as hypotension reduces perfusion pressure and facilitates tissue injury [26, 103].

Surgical Decompression by Dermatofasciotomy

Surgical decompression is the gold standard in the treatment of the acute compartment syndrome. Prompt intervention is crucial for tissue salvage and functional recovery. Ischemia tolerance of muscle tissue without irreversible damage is 4–6 h (see pathophysiology) [104].

Thorough knowledge concerning the specific regional anatomical features is mandatory in order to achieve complete decompression of all muscle compartments and in order to reduce the surgery-related morbidity. Iatrogenic damage to the muscles and the neurovascular structures must be strictly avoided. Incisions must be planned with care in order to minimize the risk of skin necrosis and/or excessive scar formation.

Wound Management

Fasciotomy wounds are covered by artificial skin (e.g. Epigard®) or by vacuum sealing. After 2–3 days, local swelling usually decreases. Continuous traction is then applied to the skin margins in order to achieve progressive wound closure (Figure 1). Elastic loops (e.g. vessel loops) are used for skin approximation: at the end of the dermatofasciotomy procedure, vessel loops are fixed in a shoelace fashion with staples at the wound edges. Patients have to be carefully checked in order to avoid a rebound compartment syndrome. As soon as the wound edges approach, definitive wound closure is performed. Continuing skin traction is a useful technique in order to reduce the need of skin grafting.

Specific Compartment Syndromes of the Lower Extremity

Compartment Syndrome Around the Pelvis

Compartment syndrome around the pelvis is a rare condition. Neuromuscular dysfunction in the area of

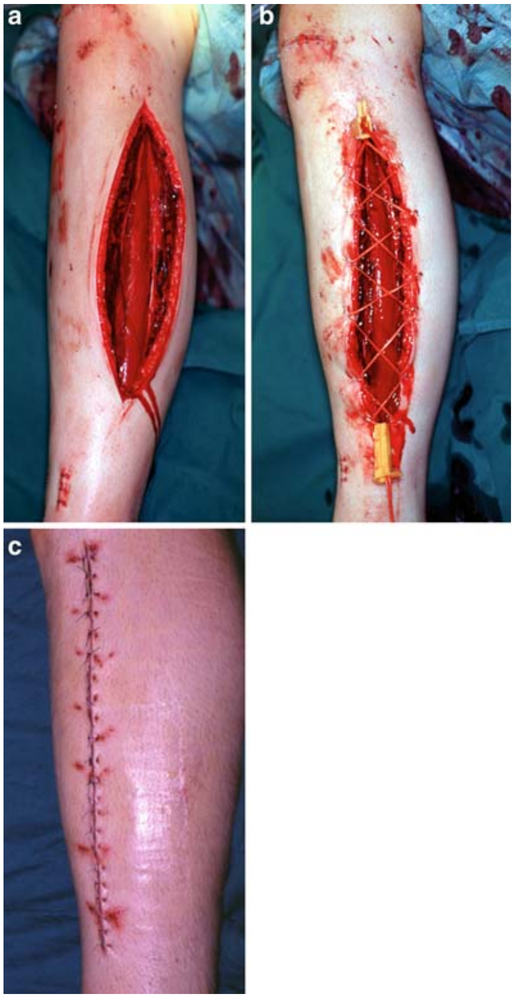

Figure 1. Dermatofasciotomy defect of the lower leg a) after decompression, b) during skin approximation using elastic loops and c) after secondary skin closure by suture after 8 days.

the sciatic and/or the femoral nerve in an acute post-traumatic situation should however arouse suspicion for this complication.

Anatomy

Compartments around the pelvis include the gluteal compartments and the compartment of the iliopsoas muscle. While the gluteal region is often considered as a single unit, it should be understood in the context of its three compartments, separated by individual surrounding non-distensible fascia structures. In a cadaver study, Owen et al. [105] showed these three compartments in the gluteal region: the compartment of the gluteus maximus muscle, the compartment of the gluteus medius and minimus muscle and the compartment of the tensor fasciae latae muscle. The fascia of the gluteal region is the fascia lata of the thigh. The fascia lata splits into two layers to encompass the gluteus maximus muscle posteriorly and the tensor fascia lata muscle anteriorly. Between these two compartments, the combined fascia overlies the gluteus medius and minimus. The sciatic nerve does not lie within the fascial envelope. However, the nerve is located in close relationship to the short external rotators of the hip (M. piriformis, Mm. gemelli, Mm. obturatorii). This location predisposes to compression and loss of function in the development of a compartment syndrome. The diagnosis of compartment syndrome must be considered in any patient with sciatic nerve dysfunction in a setting of gluteal trauma [106].

The iliacus and psoas muscles on the inside of the pelvis are embedded between the iliac wing and the iliac fascia. The femoral nerve, originating from the lumbar plexus (L2–L4) pierces the iliopsoas muscle and runs towards the lacuna musculorum. In this area, the blood supply of the nerve is suboptimal. Compartment syndrome of the iliopsoas muscle may cause ischemic dysfunction of the femoral nerve. Clinical symptoms are palsy of the quadriceps muscle and loss of sensation in the suprapatellar area, as well as in the anterior part of the lower leg towards the medial side of the foot (saphenus nerve). Diagnosis of the iliopsoas compartment syndrome is difficult. CT-scans are useful to demonstrate diffuse edema and swelling or subfascial hematoma.

Surgical technique

The gluteal compartment may be exposed and decompressed, by two alternative approaches. Henry [107] described a ''question-mark-shaped'' incision whereas Janzing [108] described a posterior curved incision similar as to the posterior approach to the hip joint. The ''Henry-incision'' starts at the posterior superior iliac spine and turns down over the greater trochanter to the level of the inferior gluteal fold. The incision described by Janzing is smaller, lies at the superolateral edge of the gluteus maximus and runs distally to the greater trochanter. Decompression of the gluteus maximus muscle requires fasciotomy and multiple epimysiotomies [108]. The superolateral edge of the gluteus maximus is then separated from the iliotibial tract. This enables exposure of the underlying muscles, with minimal risk of damage to the neurovascular structures. Reflection of the gluteus maximus must be performed with great care to protect the superior gluteal artery which extends directly into the deep aspect of the gluteus maximus after passing between the gluteus medius and piriformis muscle [18]. Decompression of the gluteus medius and minimus muscles, which are both embedded in a tight osteofibrous compartment, is an essential part of the surgical procedure. In case of sciatic nerve palsy, the nerve needs to be exposed and decompressed.

Compartment Syndrome of the Thigh

Anatomy

In the thigh there are three main osseofascial compartments. These are the anterior compartment, that contains the extensor muscles, the superficial femoral vessels and the saphenus nerve, the posterior compartment with the flexor muscles and the sciatic nerve and the medial or adductor compartment that contains also the deep femoral vessels. The lateral intermuscular septum divides the anterior and posterior compartment laterally; the medial and posterior intermuscular septa are much thinner.

Surgical technique

The anterior and posterior compartments are approached through a single lateral incision. The skin incision starts at the level of the greater trochanter and runs down towards the lateral femoral condyle. After incision of the fascia lata, the lateral intermuscular septum, that separates the flexor from the extensor muscles is exposed by anterior retraction of the vastus lateralis muscle and incised widely. The adductor compartment cannot be addressed from lateral. It therefore needs a separate incision on the medial side for decompression [108].

Compartment Syndrome of the Lower Leg

Compartment syndrome of the lower leg is most frequently observed. It usually occurs in association with fractures of the tibia but it may also be caused by severe soft tissue trauma without additional osseous lesions.

Anatomy

In the lower leg, there are four compartments that are embedded between the osseous structures of the tibia and fibula and between tight fibrous fascial structures (anterior, lateral, deep posterior and superficial posterior). The anterior and the deep posterior compartments are most commonly affected. Especially the deep posterior compartment is difficult to expose and decompress surgically. Since it contains important structures like the flexor tendons of the toes and the tibial nerve, inadequate decompression inevitably will lead to persistent functional impairment. The anterior compartment contains the deep peroneal nerve. Nerve palsy will impair dorsiflexion of the foot and the toes. Its sensory territory is confined to the web space between the first and second toe.

Surgical technique

Fasciotomy can be performed either by a single lateral incision or by a combined medial and lateral approach. Whatever method is used, it is strongly recommended that all four lower leg compartments are opened completely [109–111].

Subcutaneous fasciotomy is dangerous and cannot be recommended in the acute trauma situation since the skin can form the limiting boundary. Another disadvantage of percutaneous fasciotomy is that the deep posterior compartment is difficult to reach and not always adequately decompressed [109].

The length of the skin incisions however is still a matter of debate. Some authors favor limited incisions, claiming low morbidity, while others recommend long incisions, emphasizing that these are required to decompress affected compartments adequately. Olson and Glasgow pointed [115] out that the bulk of the musculature in the superficial posterior compartment is located proximally and requires a proximal extension to the incision for adequate decompression. In contrast, the bulk of the deep posterior musculature is located in the distal half of the lower limb. The authors therefore recommended wide incisions.

Patman [116] used multiple small skin incisions for decompression in fasciotomy for vascular causes. He advocated long skin incisions only if there was massive soft tissue swelling, paralysis or borderline function of muscles, or if muscle necrosis was encountered. Jensen and Sandermann [114] compared subcutaneous and open fasciotomy. Five of 39 limbs that had subcutaneous fasciotomy still showed signs of compartment syndrome and all five patients required reoperation with long skin incisions. In contrast, all patients with open fasciotomies had adequate decompression. Mubarak et al. [111, 117] used an incision 15 cm long and found that the skin incision alone reduced the ICP by 5–9 mmHg. Cohen et al. [118] evaluated the effect of the length of the fasciotomy wound, using a double-incision technique. Wide fascial releases were performed through limited 8 cm incisions in eight cases of post-traumatic lower extremity compartment syndrome. In nine of 29 compartments the pressure remained greater than 30 mmHg. Lengthening the skin incisions to an average of 16 cm decreased intracompartmental pressures significantly. Based upon these observations, generous skin incisions are generally recommended.

Single Incision Fasciotomy

Skin incision is made directly over the fibula within 5 cm of either end [112]. The septum between the anterior and lateral compartment is identified. This is most easily done by a transverse incision of the lateral fascia. Both compartments are subsequently decompressed completely. Care should be taken not to injure the superficial peroneal nerve distally. Lateral compartment musculature is elevated from the posterior intramuscular septum. Incision of this intramuscular septum provides access to the lateral portion of the superficial posterior compartment. The final step is to divide the origins of the soleus muscle from the fibula and to release the deep posterior compartment by incising it directly behind the fibula. Compared to the double-incision technique, single incision fasciotomy is less traumatising and gives better cosmetic results. Furthermore it leaves the long saphenous vein unexposed, which can be advantageous if later reconstructive vascular surgery is required [113, 114]. A disadvantage of the single incision approach is that the deep posterior compartment is difficult to access and decompress.

The fibulectomy–fasciotomy which has also been described as a single incision procedure is not recommended any more, since proper decompression of all four compartments can be achieved without resecting the fibula [109–111]. Resection of the fibula should be strictly avoided in case of an associated fracture of the tibia.

Double Incision Fasciotomy

This technique requires a medial and a lateral incision (Figure 2). The superficial and deep posterior compartments are decompressed through a medial longitudinal approach placed 1–2 cm posterior to the medial border of the tibia. The anterior and the peroneal compartment are decompressed by a second longitudinal incision placed 2 cm anterior to the anterior border of the fibula. The accurate placement of these incisions is essential [97]. The medial incision must be placed anterior to the posterior tibial artery in order to avoid injury to the perforating vessels that supply the skin. Incising the skin too anteriorly exposes the tibia and any underlying fracture. Extending the lateral incision too far posterior distally may expose the peroneal tendons. Exposure of bone or tendons increases the risks of delayed healing and infections [97]. It is important to remember that the anterior skin bridge between the two incisions should be at least 7 cm in order to avoid skin necrosis. Undermining skin margins also impairs vascularization. Skin necrosis of the anterior lower leg is a devastating complication since it exposes the tibia widely. In such a situation, extensive soft tissue reconstruction procedures often are inevitable.

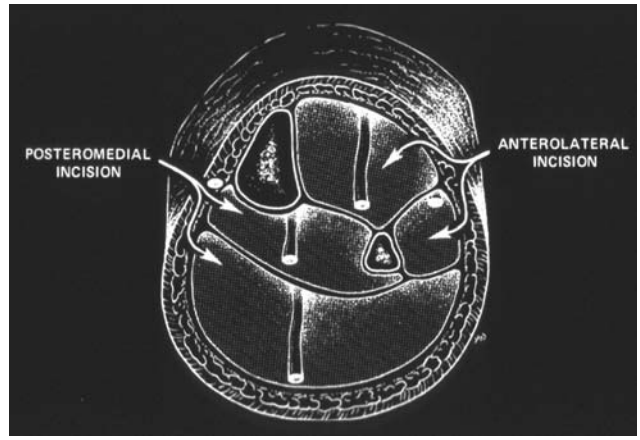

Figure 2. Medial and lateral approach to the four compartments of the lower leg. The anterolateral incision gives access to the anterior and the lateral compartment. The posteromedial incision allows decompression of the deep posterior and the superficial posterior compartments.

The advantage of the double incision technique is that it allows for adequate decompression of the deep posterior compartment. In comparison to the single incision approach the procedure is more quick and it carries less risk of damaging neurovascular structures. The disadvantage is that it requires two separate incisions. However, two incisions add little to morbidity and influence neither the complication rate nor the late functional result.

Compartment Syndrome of the Foot

Anatomy

Manoli and Weber [119] 1990 described nine compartments in the foot. Previously, it was thought that there were only four compartments. Three compartments run the entire length of the foot (medial, lateral, superficial). Five compartments are contained within the forefoot (adductor and four interossei). The ninth compartment that contains the quadratus plantae muscle and the lateral plantar neurovascular bundle is called the ''calcaneal'' compartment in order to emphasize its hindfoot location [119]. Claw toe deformity following calcaneus fracture appears to be due to late contracture of the quadratus plantae muscle in the calcaneal compartment.

The calcaneal compartment communicates with the deep posterior compartment of the lower leg through the retinaculum behind the medial malleolus, following the neurovascular and tendinous structures. Injuries such as calcaneus fractures, tibia fractures and crush injuries may result in combined compartment syndromes of the calcaneal and the deep posterior leg

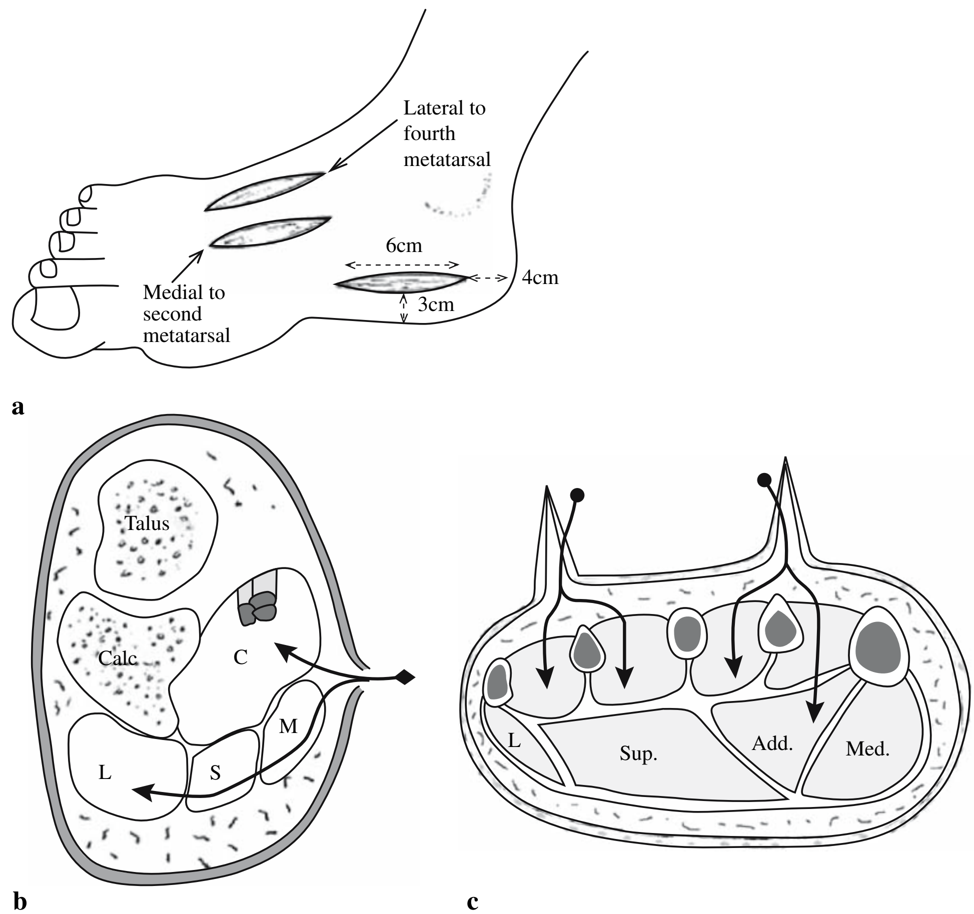

Figure 3. a) Release of foot compartments requires both dorsal and medial plantar incisions (taken from [124]). b) The medial incision allows access to the medial (M), superficial (S), calcaneal (C), and lateral (L) compartments (taken from [124]). c) Dorsal incisions allow release of the interossei and adductor compartments (taken from [124]).

compartment [11, 119, 120]. This necessitates monitoring of the deep posterior leg compartment in conjunction with calcaneal compartment measurements. Adequate release of the calcaneal compartment may include release of the distal tarsal tunnel through extension of the medial incision posteriorly [121, 122].

Surgical technique

Various techniques have been described for adequate decompression. The choice of approach depends upon the surgeon's preference as well as on other planned surgical procedures, such as internal fracture fixation. Pre-existing soft-tissue injury also has to be considered. Three incisions are generally necessary in order to decompress all nine compartments (Figure 3). With identification of the calcaneal compartment, investigators realized that a purely dorsal approach might be inadequate for the release of this compartment. To ensure adequate release of forefoot and hindfoot compartments, Myerson [123] recommended combined dorsal and medial plantar incisions. The hindfoot incision starts at the medial side of the calcaneus just anterior to the abductor hallucis origin and extends distally parallel to the plantar surface. Following medial compartment fasciotomy, the abductor hallucis is reflected superiorly to expose the intermuscular septum. Care must be taken at this point to avoid damage to the neurovascular bundle (lateral plantar nerve and vessels) just deep to the fascia.

Splitting the intermuscular septum medial to the abductor hallucis allows decompression of the calcaneal compartment. Caution is advised at the distal end of the incision in order to avoid damage to the medial plantar nerve at the distal end of the calcaneal compartment. To decompress the forefoot, two incisions are required: one is made over the second and the other over the fourth metatarsal shaft. The thin dorsal fascia is opened, followed by elevation of the interspace muscles from the medial aspect of the second metatarsal. This exposes the fascia of the adductor, which is then incised longitudinally. Release of the lateral interosseous compartments is accomplished through the lateral dorsal incision via longitudinal fasciotomies [121, 122, 124].

References

1. Schmit-Neuerburg KP. The compartment syndrome as a sequela of trauma. Chirurg 1988;59:713–21.
2. Mithoefer K, Lhowe DW, Vrahas MS, Altman DT, Erens V, Altman GT. Functional outcome after acute compartment syndrome of the thigh. J Bone Joint Surg Am 2006;88:729–37.
3. Kuri JA, Difelice GS. Acute compartment syndrome of the thigh following rupture of the quadriceps tendon. A case report. J Bone Joint Surg Am 2006;88:418–20.
4. Lee AT, Fanton GS, McAdams TR. Acute compartment syndrome of the thigh in a football athlete: a case report and the role of the vacuum-assisted wound closure dressing. J Orthop Trauma 2005;19:748–50.
5. Sancineto C, Monzon DG. Compartment syndrome of the thigh: an unusual complication after spinal surgery. J Spinal Disord Tech 2004;17:336–8.
6. Burns BJ, Sproule J, Smyth H. Acute compartment syndrome of the anterior thigh following quadriceps strain in a footballer. Br J Sports Med 2004;38:218–20.
7. Best IM, Bumpers HL. Thigh compartment syndrome after acute ischemia. Am Surg 2002;68:996–8.
8. Mai DD, MacDonald SJ, Bourne RB. Compartment syndrome of the right anterior thigh after primary total hip arthroplasty. Can J Surg 2000;43:226–7.
9. Stotts AK, Carroll KL, Schafer PG, Santora SD, Branigan TD. Medial compartment syndrome of the foot: an unusual complication of spine surgery. Spine 2003;28:E118–E120.
10. Myerson MS, Berger BI. Isolated medial compartment syndrome of the foot: a case report. Foot Ankle Int 1996;17:183–5.
11. Myerson M, Manoli A. Compartment syndromes of the foot after calcaneal fractures. Clin Orthop Relat Res 1993;142–50.
12. Mittlmeier T, Machler G, Lob G, Mutschler W, Bauer G, Vogl T. Compartment syndrome of the foot after intraarticular calcaneal fracture. Clin Orthop Relat Res 1991;241–8.
13. Bonutti PM, Bell GR. Compartment syndrome of the foot. A case report. J Bone Joint Surg Am 1986;68:1449–51.
14. Kumar V, Saeed K, Panagopoulos A, Parker PJ. Gluteal compartment syndrome following joint arthroplasty under epidural anaesthesia: a report of 4 cases. J Orthop Surg (Hong Kong) 2007;15:113–7.
15. Heyn J, Ladurner R, Ozimek A, Vogel T, Hallfeldt KK, Mussack T. Gluteal compartment syndrome after prostatectomy caused by incorrect positioning. Eur J Med Res 2006;11:170–3.
16. Somayaji HS, Hassan AN, Reddy K, Heatley FW. Bilateral gluteal compartment syndrome after total hip arthroplasty under epidural anesthesia. J Arthroplasty 2005;20:1081–3.
17. Roth JS, Newman EC. Gluteal compartment syndrome and sciatica after bone marrow biopsy: a case report and review of the literature. Am Surg 2002;68:791–4.
18. Bleicher RJ, Sherman HF, Latenser BA. Bilateral gluteal compartment syndrome. J Trauma 1997;42:118–22.
19. Yoshioka H. Gluteal compartment syndrome. A report of 4 cases. Acta Orthop Scand 1992;63:347–9.
20. McQueen MM, Christie J, Court-Brown CM. Acute compartment syndrome in tibial diaphyseal fractures. J Bone Joint Surg Br 1996;78:95–8.
21. McQueen MM, Christie J, Court-Brown CM. Compartment pressures after intramedullary nailing of the tibia. J Bone Joint Surg Br 1990;72:395–7.
22. Court-Brown CM, Byrnes T, McLaughlin G. Intramedullary nailing of tibial diaphyseal fractures in adolescents with open physes. Injury 2003;34:781–5.
23. Tornetta P III, French BG. Compartment pressures during nonreamed tibial nailing without traction. J Orthop Trauma 1997;11:24–7.
24. Blick SS, Brumback RJ, Poka A, Burgess AR, Ebraheim NA. Compartment syndrome in open tibial fractures. J Bone Joint Surg Am 1986;68:1348–53.
25. Mullett H, Al-Abed K, Prasad CV, O'Sullivan M. Outcome of compartment syndrome following intramedullary nailing of tibial diaphyseal fractures. Injury 2001;32:411–3.
26. McQueen MM, Gaston P, Court-Brown CM. Acute compartment syndrome. Who is at risk?. J Bone Joint Surg Br 2000;82:200–3.
27. DeLee JC, Stiehl JB. Open tibia fracture with compartment syndrome. Clin Orthop Relat Res 1981;175–84.
28. McQueen MM, Court-Brown CM. Compartment monitoring in tibial fractures. The pressure threshold for decompression. J Bone Joint Surg Br 1996;78:99–104.
29. Mabee JR, Bostwick TL. Pathophysiology and mechanisms of compartment syndrome. Orthop Rev 1993;22:175–81.
30. Janzing H, Broos P, Romnens P. Compartment syndrome as complication of skin traction, in children with femoral fractures. Acta Chir Belg 1996;96:135–7.
31. Hailer NP, Adalberth G, Nilsson OS. Compartment syndrome of the calf following total knee arthroplasty – a case report of a highly unusual complication. Acta Orthop 2007;78:293–5.
32. Kort NP, van Raay JJ, van H Jr.. Compartment syndrome and popliteal vascular injury complicating unicompartmental knee arthroplasty. J Arthroplasty 2007;22:472–6.
33. Haggis P, Yates P, Blakeway C, et al. Compartment syndrome following total knee arthroplasty: a report of seven cases. J Bone Joint Surg Br 2006;88:331–4.
34. Bezwada HP, Nazarian DG, Booth RE Jr. Compartment syndrome following total knee arthroplasty: a case report. Am J Orthop 2005;34:386–8.
35. Marsh A, Johnstone D, Stott D. Compartment syndrome as a complication of positioning for revision hip arthroplasty – a case report. Acta Orthop Scand 2000;71:527–9.
36. Nadeem RD, Clift BA, Martindale JP, Hadden WA, Ritchie IK. Acute compartment syndrome of the thigh after joint replacement with anticoagulation. J Bone Joint Surg Br 1998;80:866–8.
37. Krysa J, Lofthouse R, Kavanagh G. Gluteal compartment syndrome following posterior cruciate ligament repair. Injury 2002;33:835–8.
38. Siegel MG. Compartment syndrome after arthroscopic surgery of the knee. A report of two cases managed nonoperatively. Am J Sports Med 1997;25:589–90.
39. Fruensgaard S, Holm A. Compartment syndrome complicating arthroscopic surgery: brief report. J Bone Joint Surg Br 1988;70:146–7.
40. Klodell CT Jr, Pokorny R, Carrillo EH, Heniford BT. Exercise-induced compartment syndrome: case report. Am Surg 1996;62:469–71.
41. Esmail AN, Flynn JM, Ganley TJ, Pill SG, Harnly H. Acute exercise-induced compartment syndrome in the anterior leg. A case report. Am J Sports Med 2001;29:509–12.
42. Middleton DK, Johnson JE, Davies JF. Exertional compartment syndrome of bilateral feet: a case report. Foot Ankle Int 1995;16:95–6.
43. Levine WN. Exercise-induced compartment syndrome. Am J Knee Surg 1995;8:119.
44. Presnal BP, Heavilon JA. Exercise-induced acute compartment syndrome of the thigh. Case report. Am J Knee Surg 1995;8:77–9.

45. Abramowitz AJ, Schepsis AA. Chronic exertional compartment syndrome of the lower leg. Orthop Rev 1994;23:219–25.
46. Defraigne JO, Pincemail J. Local and systemic consequences of severe ischemia and reperfusion of the skeletal muscle. Physiopathology and prevention. Acta Chir Belg 1998;98:176–86.
47. Pua BB, Muhs BE, Cayne NS, Dobryansky M, Jacobowitz GR. Bilateral gluteal compartment syndrome after elective unilateral hypogastric artery ligation and revascularization of the contralateral hypogastric artery during open abdominal aortic aneurysm repair. J Vasc Surg 2005;41:337–9.
48. Griffiths D, Jones DH. Spontaneous compartment syndrome in a patient on long-term anticoagulation. J Hand Surg (Br) 1993;18:41–2.
49. Oseto MC, Edwards JZ, Acus RW, III. Posterior thigh compartment syndrome associated with hamstring avulsion and chronic anticoagulation therapy. Orthopedics 2004;27:229–30.
50. McLaughlin JA, Paulson MM, Rosenthal RE. Delayed onset of anterior tibial compartment syndrome in a patient receiving low-molecular-weight heparin. A case report. J Bone Joint Surg Am 1998;80:1789–90.
51. Smith AL, Laing PW. Spontaneous tibial compartment syndrome in Type 1 diabetes mellitus. Diabet Med 1999;16:168–9.
52. Coley S, Situnayake RD, Allen MJ. Compartment syndrome, stiff joints, and diabetic cheiroarthropathy. Ann Rheum Dis 1993;52:840.
53. Pamoukian VN, Rubino F, Iraci JC. Review and case report of idiopathic lower extremity compartment syndrome and its treatment in diabetic patients. Diabetes Metab 2000; 26:489–92.
54. Hsu S, Thadhani RI, Daniels GH. Acute compartment syndrome in a hypothyroid patient. Thyroid 1995;5:305.
55. Veeragandham RS, Paz IB, Nadeemanee A. Compartment syndrome of the leg secondary to leukemic infiltration: a case report and review of the literature. J Surg Oncol 1994;55:198–200.
56. Hieb LD, Alexander AH. Bilateral anterior and lateral compartment syndromes in a patient with sickle cell trait. Case report and review of the literature. Clin Orthop Relat Res 1988;190–3.
57. Sweeney HE OF. Bilateral anterior compartment syndrome in association with the nephrotic syndrome: a case report. Arch Intern Med 1965;116.
58. Van Der Loo B, Banyai-Falger S, Koppensteiner R, Banyai M. An unusual consequence of deep vein thrombosis. Int Angiol 2002;21:277–9.
59. Dunlop D, Parker PJ, Keating JF. Ruptured Baker's cyst causing posterior compartment syndrome. Injury 1997;28:561–2.
60. Berky M, Novak J. Bilateral anterior tibial compartment syndrome following burn of lower extremities (author's transl). Magy Traumatol Orthop Helyreallito Seb 1980;23:44–7.
61. Caruso DM, King TJ, Tsujimura RB, Weiland DE, Schiller WR. Primary closure of fasciotomy incisions with a skin-stretching device in patients with burn and trauma. J Burn Care Rehabil 1997;18:125–32.
62. Counce JS, Cone JB, McAlister L, Wallace B, Caldwell FT Jr. Surgical complications of thermal injury. Am J Surg 1988;156:556–7.
63. Demling RH. The burn edema process: current concepts. J Burn Care Rehabil 2005;26:207–27.
64. Justis DL, Law EJ, MacMillan BG. Tibial compartment syndromes in burn patients. A report of four cases. Arch Surg 1976;111: 1004–8.
65. Ertem K, Esenkaya I, Kaygusuz MA, Turan C. Our clinical experience in the treatment of snakebites. Acta Orthop Traumatol Turc 2005;39:54–8.
66. Kouyoumdjian JA, Polizelli C. Snake bites by *Bothrops moojeni*: correlation of the clinical picture with the snake size. Rev Inst Med Trop Sao Paulo 1989;31:84–90.
67. Fowler PJ, Willis RB. Vascular compartment syndromes. Can J Surg 1975;18:157–61.
68. Large TM, Frick SL. Compartment syndrome of the leg after treatment of a femoral fracture with an early sitting spica cast. A report of two cases. J Bone Joint Surg Am 2003; 85-B:2207–10.
69. Hawkins BJ, Bays PN. Catastrophic complication of simple cast treatment: case report. J Trauma 1993;34:760–2.
70. Chow CE, Friedell ML, Freeland MB, Dejesus S. A pitfall of protracted surgery in the lithotomy position: lower extremity compartment syndrome. Am Surg 2007;73:19–21.
71. Wassenaar EB, van den Brand JG, van der Werken C. Compartment syndrome of the lower leg after surgery in the modified lithotomy position: report of seven cases. Dis Colon Rectum 2006;49:1449–53.
72. Raza A, Byrne D, Townell N. Lower limb (well leg) compartment syndrome after urological pelvic surgery. J Urol 2004; 171:5–11.
73. Bocca G, van Moorselaar JA, Feitz WF, van der Staak FH, Monnens LA. Compartment syndrome, rhabdomyolysis and risk of acute renal failure as complications of the lithotomy position. J Nephrol 2002;15:183–5.
74. Tuckey J. Bilateral compartment syndrome complicating prolonged lithotomy position. Br J Anaesth 1996;77:546–9.
75. Moed BR, Strom DE. Compartment syndrome after closed intramedullary nailing of the tibia: a canine model and report of two cases. J Orthop Trauma 1991;5:71–7.
76. Mawhinney IN, Maginn P, McCoy GF. Tibial compartment syndromes after tibial nailing. J Orthop Trauma 1994;8:212–4.
77. Georgiadis GM. Tibial shaft fractures complicated by compartment syndrome: treatment with immediate fasciotomy and locked unreamed nailing. J Trauma 1995;38:448–52.
78. Shakespeare DTHN. Compartmental pressure changesduring calcaneal traction in tibialfractures. J Bone Joint Surg Br 1982;64:498–9.
79. Zappa L, Sugarbaker PH. Compartment syndrome of the leg associated with lithotomy position for cytoreductive surgery. J Surg Oncol 2007.
80. Brinker A, Doehn C. Compartment syndrome following surgery in the lithotomy position. Anaesthesia 2007;62:98.
81. Yanazume S, Yanazume Y, Iwamoto I, Tsuji T, Yoshinaga M, Douchi T. Severe leg compartment syndrome associated with dorsal lithotomy position during radical hysterectomy. J Obstet Gynaecol Res 2006;32:610–2.
82. Goldsmith AL, McCallum MI. Compartment syndrome as a complication of the prolonged use of the Lloyd–Davies position. Anaesthesia 1996;51:1048–52.
83. Hyder N, Kessler S, Jennings AG, De Boer PG. Compartment syndrome in tibial shaft fracture missed because of a local nerve block. J Bone Joint Surg Br 1996;78:499–500.
84. Ananthanarayan C, Castro C, McKee N, Sakotic G. Compartment syndrome following intravenous regional anesthesia. Can J Anaesth 2000;47:1094–8.
85. Strecker WB, Wood MB, Bieber EJ. Compartment syndrome masked by epidural anesthesia for postoperative pain. Report of a case. J Bone Joint Surg Am 1986;68:1447–8.
86. Tang WM, Chiu KY. Silent compartment syndrome complicating total knee arthroplasty: continuous epidural anesthesia masked the pain. J Arthroplasty 2000;15:241–3.

87. Smith PN, Rampersaud R, Rorabeck CH. Incipient compartment syndrome of the thigh following total knee arthroplasty. J Arthropl 1997;12:835–8.
88. Dunwoody JM, Reichert CC, Brown KL. Compartment syndrome associated with bupivacaine and fentanyl epidural analgesia in pediatric orthopaedics. J Pediatr Orthop 1997;17:285–8.
89. Rorabeck CH, Macnab L. Anterior tibial-compartment syndrome complicating fractures of the shaft of the tibia. J Bone Joint Surg Am 1976;58:549–50.
90. Halpern AA, Nagel DA. Anterior compartment pressures in patients with tibial fractures. J Trauma 1980;20:786–90.
91. Elliott KG, Johnstone KJ. Diagnosing acute Compartment Syndrome. J Bone Joint Surg (Br) 2003;85-B:625–32.
92. Ulmer T. The clinical diagnosis of compartment syndrome of the lower leg: are clinical findings predictive of the disorder? J Orthop Trauma 2002;16:572–7.
93. Ogunlusi JD, Oginni LM, Ikem IC. Compartmental pressure in adults with tibial fracture. Int Orthop 2005;29:130–3.
94. Whitesides TE, Heckman MM. Acute Compartment Syndrome: update on diagnosis and treatment. J Am Acad Orthop Surg 1996;4:209–18.
95. Whitesides TE, Haney TC, Morimoto K, Harada H. Tissue pressure measurements as a determinant for the need of fasciotomy. Clin Orthop Relat Res 1975;43–51.
96. Heemskerk J, Kitslaar P. Acute compartment syndrome of the lower leg: retrospective study on prevalence, technique, and outcome of fasciotomies. World J Surg 2003;27:744–7.
97. Pearse MF, Harry L, Nanchahal J. Acute compartment syndrome of the leg. BMJ 2002;325:557–8.
98. Williams PR, Russell ID, Mintowt-Czyz WJ. Compartment pressure monitoring – current UK orthopaedic practice. Injury 1998;29:229–32.
99. Roach R, Perkins R. Acute compartment syndrome. J Bone Joint Surg Br 2000;82:932–3.
100. Mars M, Hadley GP. Raised intracompartmental pressure and compartment syndromes. Injury 1998;29:403–11.
101. Matsen FA 3rd, Wyss CR, Krugmire RB Jr, Simmons CW, King RV. The effects of limb elevation and dependency on local arteriovenous gradients in normal human limbs with particular reference to limbs with increased tissue pressure. Clin Orthop Relat Res 1980;150:187–95.
102. Styf J, Wiger P. Abnormally increased intramuscular pressure in human legs: comparison of two experimental models. J Trauma 1998;45:133–9.
103. Matsen FA. Compartmental Syndromes. Seattle: University of Washington; updated 10 February 2005. http://www.orthop.washington.edu.ubproxy.ub.uni-frankfurt.de/faculty/Matsen/compartmental.2005.
104. Williams AB, Luchette FA, Papaconstantinou HT, Lim E, Hurst JM, Johannigman JA, Davis K Jr. The effect of early versus late fasciotomy in the management of extremity trauma. Surgery 1997;122:861–6.
105. Owen CA, Woody PR, Mubarak SJ, Hargens AR. Gluteal compartment syndromes: a report of three cases and management utilizing the Wick catheter. Clin Orthop Relat Res 1978; 132:57–60.
106. Hayden G, Leung M, Leong J. Gluteal compartment syndrome. ANZ J Surg 2006;76:668–70.
107. Henry AK. Extensile exposure. Churchill Livingstone, New York, 1987 189.
108. Janzing H, Broos P. Fasciotomies of the limbs: how to do it? Acta Chir Belg 1998;98:187–91.
109. Matsen FA III, Winquist RA, Krugmire RB Jr. Diagnosis and management of compartmental syndromes. J Bone Joint Surg Am 1980;62:286–91.
110. Rorabeck CH. The treatment of compartment syndromes of the leg. J Bone Joint Surg Br 1984;66:93–7.
111. Mubarak SJ, Owen CA. Double-incision fasciotomy of the leg for decompression in compartment syndromes. J Bone Joint Surg Am 1977;59:184–7.
112. Cooper GG. A method of single-incision, four compartment fasciotomy of the leg. Eur J Vasc Surg 1992;6:659–61.
113. Gawenda M, Prokop A, Walter M, Erasmi H. The compartment syndrome with special reference to vascular surgery aspects. A patient sample of the Cologne University Clinic 1981 to 1991. Zentralbl Chir 1992;117:432–8.
114. Jensen SL, Sandermann J. Compartment syndrome and fasciotomy in vascular surgery. A review of 57 cases. Eur J Vasc Endovasc Surg 1997;13:48–53.
115. Olson SA, Glasgow RR. Acute compartment syndrome in lower extremity musculoskeletal trauma. J Am Acad Orthop Surg 2005;13:436–44.
116. Patman RD. Compartmental syndromes in peripheral vascular surgery. Clin Orthop Relat Res 1975;103–10.
117. Mubarak SJ, Owen CA, Hargens AR, Garetto LP, Akeson WH. Acute compartment syndromes: diagnosis and treatment with the aid of the wick catheter. J Bone Joint Surg Am 1978; 60:1091–5.
118. Cohen MS, Garfin SR, Hargens AR, Mubarak SJ. Acute compartment syndrome. Effect of dermotomy on fascial decompression in the leg. J Bone Joint Surg Br 1991;73:287–90.
119. Manoli A, Weber TG. Fasciotomy of the foot: an anatomical study with special reference to release of the calcaneal compartment. Foot Ankle 1990;10:267–75.
120. Manoli A. Compartment syndromes of the foot: current concepts. Foot Ankle 1990;10:340–4.
121. Myerson MS. Experimental decompression of the fascial compartments of the foot – the basis for fasciotomy in acute compartment syndromes. Foot Ankle 1988;8:308–14.
122. Myerson MS. Management of compartment syndromes of the foot. Clin Orthop Relat Res 1991;239–48.
123. Myerson M. Diagnosis and treatment of compartment syndrome of the foot. Orthopedics 1990;13:711–7.
124. Fulkerson E, Razi A, Tejwani N. Review: acute compartment syndrome of the foot. Foot Ankle Int 2003;24:180–7.

Address for Correspondence
Priv.-Doz. Dr. Martin H. Hessmann
Department of Trauma Surgery
Johannes Gutenberg-University
Langenbeckstrasse 1
55131 Mainz
Germany
Phone (+49/6131) 17-2845, Fax -6687
e-mail: Hessmann@unfall.klinik.uni-mainz.de