Acute compartment syndrome of the limb

W. Köstler*, P.C. Strohm, N.P. Südkamp

Department für Orthopädie und Traumatologie, Klinik für Traumatologie, Universitätsklinikum Freiburg, Hugstetterstr. 55, 79106 Freiburg im Breisgau, Germany

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Introduction

Matsen defined the compartment syndrome as "a condition in which increased pressure within a limited space compromises the circulation and function of the tissues within that space." 24

Malgaigne was the first to describe compartment syndrome, and the first medical reference was by Volkmann 39 in 1881. Jepsen reported successful treatment by decompression 18 in an experimental study.

The abdominal compartment syndrome was first described by Baggot in 1951. 4 The increasing intra-abdominal pressure alters cardiovascular haemodynamics, respiratory mechanics and renal function.

In this review, only the aetiology, clinical signs, diagnosis and treatment of the limb compartment syndromes are discussed.

Aetiology and incidence

Most compartment syndromes are associated with traumatic insults, but the condition also occurs after reperfusion, following a period of ischaemia, burns, prolonged limb compression after drug abuse or poor positioning during prolonged surgical procedures (Table 1).

This classification, based on aetiology, is a simplification; in most cases, a combination of factors is responsible. 11,37

Orthopaedic

The most common fractures causing a limb compartment syndrome are those of the tibial shaft (40%) and of the forearm (18%). About 23% are caused by soft tissue injuries without fracture. 27,33

The incidence after closed tibial fractures ranges from 1 to 29%, while in open fractures, it is between 1 and 10%. A greater incidence in multifragmentary fractures is a reflection of the higher energy causing...
this type of fracture, resulting also in a more severe soft tissue injury.

It is important to recognise that open fractures can also develop a compartment syndrome, both in the closed compartments and those compartments opened by the injury.

**Vascular**

Any procedure revascularising the limb can result in a muscle compartment syndrome, the incidence ranging between 0 and 21%. In patients with combined popliteal artery and venous injuries, more than 50% require a fasciotomy.36

**Soft tissue**

Swelling of the soft tissue develops in contusion injury without fracture, especially in patients with a coagulopathy. Burns can also cause compartment syndrome.

In patients with altered consciousness due to drug or alcohol abuse, prolonged limb compression can lead to soft tissue injury and compartment syndrome.

**Iatrogenic**

The use of a pneumatic antishock garment, or military antishock trousers, may also lead to compartment syndrome. In combination with hypotension, normally the reason for its use, and with application for more than 30 min, the development of compartment syndrome should be borne in mind.2

Prolonged surgery, especially in the Trendelenburg position, sometimes causes compartment syndromes.7 In combination with poor positioning, it can also cause soft tissue necrosis, as a result of direct pressure.

**Pathophysiology**

The normal pressure in the muscle compartments is below 10–12 mm Hg (4–21).42 The compartmental perfusion pressure, which is the mean arterial pressure minus the compartment pressure, should be above 70–80 mm Hg.17,23. Both increasing the compartmental pressure and decreasing the perfusion pressure can lead to a compartment syndrome. Swelling of the injured muscle and soft tissue raises the intra-compartmental pressure, closing the lymphatic vessels and the small venules. Hypertension in the capillary bed and the compression of the arterioles in the later stages leads to an ischaemia, which further increases the pressure, and a vicious downward spiral becomes established.

In the reperfusion situation, there is a complex mechanism leading to vascular leakage. Although some factors, such as leucotrienes, tumour necrosis factor, free radicals and others, are known to play a part, the exact mechanism within the cell remains unclear.10

The ischaemia causes perifascicular and intra-fascicular oedema in the early stage presentation, which, without treatment, leads to atrophy and necrosis of the muscle fibres. The end result of an unchecked compartment syndrome includes neurological deficit, muscle necrosis and late fibrous contractures.

**Symptoms and signs**

The initial clinical signs of compartment syndrome are often subtle. Early diagnosis requires a high index of suspicion. Pain, usually out of proportion to the injury, can be the first indication of compartment syndrome. The six P’s, formerly emphasised by Mubarak and Rorabeck,, are very late signs, usually at an irreversible stage29 (Table 2).

Remember that these signs can be elicited only in the fully conscious patient. Early diagnosis is difficult in patients with CNS compromise, the very young and the very old, and in patients with substance abuse. To distinguish between ischaemic pain and pain caused by a fracture, contusion, or muscle injury can sometimes be very difficult. The presence of distal pulses never excludes compartment syndrome.

In the leg, with its four compartments (anterior, lateral, deep posterior and superficial posterior), the deep peroneal nerve lies in the anterior

**Table 1 Causes of acute compartment syndromes**

<table>
<thead>
<tr>
<th>Category</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthopaedic</td>
<td>Fractures and fracture surgery</td>
</tr>
<tr>
<td>Vascular</td>
<td>Arterial and venous injuries</td>
</tr>
<tr>
<td></td>
<td>Reperfusion injury</td>
</tr>
<tr>
<td></td>
<td>Haemorrhage</td>
</tr>
<tr>
<td></td>
<td>Phlegmasia caerulea dolens</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>Crush injury</td>
</tr>
<tr>
<td></td>
<td>Burns</td>
</tr>
<tr>
<td></td>
<td>Prolonged limb compression</td>
</tr>
<tr>
<td>Iatrogenic</td>
<td>Puncture in anticoagulated patients</td>
</tr>
<tr>
<td></td>
<td>Use of a pneumatic antishock garment</td>
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<tr>
<td></td>
<td>casts and circular dressings</td>
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<tr>
<td></td>
<td>Pulsatile irrigation</td>
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<tr>
<td>Occasional</td>
<td>Snakebite</td>
</tr>
<tr>
<td></td>
<td>Overuse of muscles</td>
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</table>
compartment (Fig. 1). Its sensory territory is confined to the web space between the first and the second toes and it subserves active dorsiflexion of the toes. The superficial peroneal nerve runs through the lateral compartment and supplies sensation to the dorsum of the foot, except the first web space. The posterior tibial nerve lies in the deep posterior compartment, providing sensation of the plantar surface of the foot, its motor function being flexion of the toes. The superficial posterior compartment can be examined by testing sural nerve sensation along the lateral border of the foot.

Diagnosis

For a good clinical outcome, early diagnosis is of paramount importance. In patients with early symptoms, such as increasing pain, paraesthesiae and pain on passive stretching, careful and frequent assessment is necessary. If this is impossible, then prophylactic fasciotomy may well be indicated. It is certainly recommended in patients with an interrupted arterial supply lasting more than 4–6 h, in patients who are unconscious, or have peripheral nerve injuries, and in patients who undergo open fracture fixation near a compartment at risk.

Laboratory parameters

Seriously elevated levels of creatinine phosphokinase (CPK) may indicate severe muscle damage, or ischaemia. In absence of clinical signs, it could indicate an unsuspected compartment syndrome. For early diagnosis, it is clearly not helpful.

Compartment pressure

If the diagnosis is clinically evident, it is not necessary to measure the compartment pressures. This should be undertaken only when the clinical signs are unclear, and in patients whose consciousness level is impaired.

Measurement by saline injection was first done by French and Prince in 1962. Both needle techniques and catheter techniques require a bubble-free column of saline, and the tip may become blocked by muscle and blood clot. The catheter systems provide a continuous pressure recording for up to 24 h.

Moed and Thorderson compared the slit catheter, side-ported needle and simple needle techniques in a canine model. The values with the simple needle techniques were constantly higher than those with the other techniques. With the side-ported needle, it is not possible to measure continuously. Rorabeck et al. and McQueen et al. advocate the use of the slit catheter as the most accurate method. Uliasz et al. compared the Stryker instrument with the IV pump and Whitesides’ method. The latter failed to produce reliable results, the others gave comparable results.

Despite most surgeons agreeing that pressure measurement is the standard method, only about 50% of the hospitals in the UK and Germany have the technical equipment to do this, according to investigations of Williams and Sterk. It should be mentioned that it is important to measure all muscle compartments in a limb suspected of acute compartment syndrome.

Table 2 Symptoms and signs of acute compartment syndrome

<table>
<thead>
<tr>
<th>Symptom and sign</th>
<th>Refs</th>
</tr>
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<tbody>
<tr>
<td>Pain (spontaneous and disproportionate)</td>
<td>20,33</td>
</tr>
<tr>
<td>Pain on passive stretching of the involved muscles</td>
<td>31,33</td>
</tr>
<tr>
<td>Swollen and tense compartment</td>
<td>12,15</td>
</tr>
<tr>
<td>Rapid progression of these signs over a short time period</td>
<td>13,43</td>
</tr>
<tr>
<td>Paraesthesia (initially affecting two point discrimination)</td>
<td>13,43</td>
</tr>
<tr>
<td>Pulselessness (usually in vascular injury)</td>
<td>15,21</td>
</tr>
<tr>
<td>Paralysis (late symptom)</td>
<td>15,21</td>
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![Figure 1](image-url) The four muscle compartments and their important, traversing structures.
Other methods

Willy et al. 42 showed the easy and highly accurate use of transducer tipped probes. They work without the artefacts associated with saline-column systems. It is also possible to measure the partial pressure of oxygen in the muscle with catheters, although this method is not routinely used clinically, as the critical levels of tissue oxygenations have not yet been defined or validated, and its worth has to be proven. Theoretically, it should be helpful to measure the oxygen saturation in the tissue, since the pressure is only an indirect measure of tissue damage and perfusion.

Near-infrared spectroscopy can measure the levels of muscle haemoglobin and myoglobin. The method is applied percutaneously, but the limited measurement depth of about 40 mm is a problem, especially for the deep posterior compartment in the leg. Most studies with this technique were done in chronic compartment syndromes; the value in patients with an evolving acute compartment syndrome remains unclear. With further technical improvements, it may offer a rapid, non-invasive tool in the future.16,22

MRI can show the tissue changes in established compartment syndrome, but fails to identify changes in an imminent compartment syndrome without neurological deficit. It is not possible to decide if the swelling and oedema are correlated with a soft tissue injury itself, or represent signs of an evolving compartment syndrome.32

Laser Doppler flowmetry and scintigraphy have only been evaluated in chronic compartment syndromes.

Critical pressure

More important than improving the technical devices is to improve the guidelines for interpretation of the results and their clinical relevance.

The critical level of the absolute intra-compartmental pressure remains undecided. In the literature, levels ranging from 30 to 50 mm Hg are proposed.1,29,31 Experimental studies have shown a big difference between individuals, when correlating absolute pressure levels, clinical signs, nerve function (EMG) and oxygen levels in the muscle tissue.42 At a level of 50 mm Hg of intra-compartmental pressure, some healthy volunteers had no decrease in oxygen saturation in the muscle; others showed a decrease to nearly zero. The decrease in the muscle response started at 30 mm Hg, but at a level of 50 mm Hg there was still one volunteer with no measurable muscular response. It is clear that the definition of an absolute critical level of the intra-compartmental pressure is not possible.

Whitesides introduced the concept that the level of intra-compartmental pressure which causes ischaemic compromise is related to the perfusion pressure.40 This "delta p" pressure, comparable to the CPP in brain injury, is the diastolic pressure minus the intra-compartmental pressure. The most commonly cited Δp is less than or equal to 30 mm Hg. In studies using Δp, unnecessary fasciotomies were avoided and no significant complications occurred.26

The time factor is more critical for the neural structures than it is for the muscle, but it is important to remember that there is a dynamic relationship between the level of the intra-compartmental pressure and the duration of elevated pressure. The longer the delay to fasciotomy, the worse the outcome. If the delay is more than 12 h, bad results are inevitable.

Treatment

Surgical therapy

If compartment syndrome is suspected, all circumferential dressings should be removed, normal blood pressure should be achieved by dealing with any cause of hypotension. The extremity should not be elevated, but kept at heart level, in order to maintain perfusion in the compartment. Supplementary oxygen, to improve the tissue oxygenation, is helpful.

If the Δp is below 30 mm Hg, and/or clinical signs are present, fasciotomy of all relevant compartments is the treatment of choice and should be performed as an emergency. Prophylactic fasciotomy is recommended in patients with vascular injuries, who have had a warm ischaemia time of more than 4—6 h, patients with ligation of the major veins in the popliteal region or the distal thigh and patients with crush injuries.

In the lower leg, a four-compartment fasciotomy is recommended (Fig. 2). This can be performed by different techniques: with a single lateral incision, with or without fibulectomy or by a double incision technique, using medial and lateral incisions.19,30 In the acute situation, the skin incision must be long enough to ensure that all underlying muscle is decompressed; so-called “percutaneous” fasciotomies are dangerous and are not recommended.

The single incision technique allows adequate exposure of all four compartments;8 fibulectomy should be avoided, especially in patients with complex tibial fractures.
The skin incision is made directly over the fibula. A transverse incision is made in the fascia to identify the inter-muscular septum between the anterior and lateral compartments and to identify the superficial peroneal nerve. Longitudinal fasciotomies of the anterior, the lateral and the superficial dorsal compartments are then performed. The final step is to divide the origins of the soleus from the fibula and then, directly behind the fibula, release the deep posterior compartment.

With the double incision technique, the posterior compartments are opened from medially, and the anterior and lateral compartments from the lateral side. Its advantage is the possible use of local anaesthesia, even at the bedside; its disadvantage is the need for two separate incisions.

For temporary wound coverage, hypoallogenic materials, such as Epigard or Vacuseal, can be used (Figs. 3a and b), followed by early definitive closure using split skin grafting. Recently, in the authors’ department, since elastic bands have been used to close the wound incrementally, the necessity for skin grafting has decreased and has only been mandated in a few cases (Fig. 4).

In patients with fractures and muscle compartment syndrome, osteosynthesis is recommended, the technique depending on the fracture localisation, the patient’s status and the quality of the soft tissue. If possible, definitive fracture surgery should be undertaken at the time of fasciotomy.

In the thigh, all three compartments can be decompressed via a lateral incision. In order to prevent muscle hernia, the authors favour two parallel incisions in the fascia lata, with an intervening bridge of at least 4–5 cm. The fracture

Figure 2 Generous releases are necessary for complete decompression of all four lower leg muscle compartments.
causing the compartment syndrome is fixed definitively at the same time, provided the patient is physiologically stable.

In the forearm, volar and dorsal incisions are necessary. A complete forearm fasciotomy requires decompression of each nerve and muscle. When in combination with fractures, definitive stabilisation, usually with plates, is recommended. The implants should be covered by vital muscle. If the clinical status of the hand remains unclear, the volar incision should be extended into the palm and the carpal tunnel released.

In patients who develop sepsis, it is important to remember that all necrotic tissue has to be excised. Renal function should be monitored and renal failure prevented.

**Hyperbaric oxygen**

In patients with crush injuries, Bouachour et al. showed that adjunctive hyperbaric therapy was associated with significantly better wound healing after fasciotomy. There are also some experimental data that show better functional results. It is our impression, in patients with clinically borderline symptoms, for example, after intramedullary nailing, that immediate hyperbaric therapy in the first 2 days often renders fasciotomy unnecessary, but further studies are necessary.

**Drug therapy**

Mannitol, as a hyperosmotic diuretic, has been shown to reduce the incidence of compartment syndrome after revascularisation. Additionally, free radical scavengers are thought to have beneficial effects. In animal studies, the effects are variable and their use in humans is not established.

**Summary**

The final clinical outcome of an untreated compartment syndrome is the replacement of muscle with scar tissue. This produces a severe fibrous contracture and a neuropathy of any peripheral nerve traversing the compartment, leading to serious dysfunction. Once this stage is reached, it is never possible to restore normal function.

For early detection of muscle compartment syndrome, it is necessary to educate those taking care of patients at risk, especially in the early symptoms and signs.

Monitoring of intra-compartmental pressure should be routine in unconscious, sedated and uncooperative patients. If the $\Delta p$ remains less than 30 mm Hg, in the presence of clinical signs and despite conservative measures, fasciotomy should be performed as an emergency to preserve the function of the limb.

**References**

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