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The Pathophysiology, Diagnosis and Current Management of Acute Compartment Syndrome

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Abstract: Acute compartment syndrome (ACS) is a surgical emergency warranting prompt evaluation and treatment. It can occur with any elevation in interstitial pressure in a closed osseo-fascial compartment. Resultant ischaemic damage may be irreversible within six hours and can result in long-term morbidity and even death. The diagnosis is largely clinical with the classical description of 'pain out of proportion to the injury'. Compartment pressure monitors can be a helpful adjunct where the diagnosis is in doubt. Initial treatment is with the removal of any constricting dressings or casts, avoiding hypotension and optimizing tissue perfusion by keeping the limb at heart level. If symptoms persist, definitive treatment is necessary with timely surgical decompression of all the involved compartments. This article reviews the pathophysiology, diagnosis and current management of ACS.

Keywords: Compartment pressure monitoring, compartment syndrome, fasciotomy, ischaemic contracture, myofascial compartment.

INTRODUCTION

Richard von Volkmann first described compartment syndrome in 1881 [1]. He suggested that paralysis and contracture came simultaneously as a result of an interruption to the blood supply of the affected muscles. The first surgeon to reproduce ischaemic contracture in animals was Paul Jepson in 1924 [2] whilst working at the Mayo Foundation. He also demonstrated that prompt surgical decompression could prevent these contractures. Acute compartment syndrome (ACS) is now considered a surgical emergency warranting prompt evaluation and treatment.

PATHOPHYSIOLOGY

ACS is defined as 'a critical pressure increase within a confined compartmental space causing a decline in the perfusion pressure to the tissue within that compartment' [3-6]. It can occur with any elevation in interstitial pressure within an osseo-fascial compartment. Tissue perfusion is proportional to the difference between capillary perfusion pressure (CPP) and the interstitial fluid pressure.

When fluid enters a fixed volume compartment, for example from bleeding, both the tissue and venous pressure increase. When this exceesds the CPP, capillary collapse with ensuing muscle and nerve ischaemia occur. A similar reduction occurs in the CPP when the compartment size decreases (e.g. external compression) due to an increase in intracompartmental pressure, as well as a reduction in the arteriolar pressure. Fig. (**1**) below displays the cycle of events and the development of acute compartment syndrome.

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Compartment syndromes can arise in any area of the body that has little or no capacity for tissue expansion.

The commonest cause of all ACSs are tibial shaft fractures with a range from 2-9% [7, 8]. After the leg, the next commonest location is in the forearm, but almost any compartment can be affected: arm [9], thigh [10], foot [11], buttock [12], hand [13], and abdomen [14]. Poor patient positioning in unconscious patients for long periods of time can also contribute to the aetiology of ACS [15].

Any internal or external event that increases intra-compartmental pressure can cause a compartment syndrome. Table **1** below shows some of the more common causes.

Table 1. Common causes of ACS.

Fracture	Burns
Crush injury	Infection
Injection injury	Bleeding disorders
Penetrating trauma	Arterial injury
Constrictive dressings	Reperfusion
Casts	Extravasation of drugs

The incidence is thought to be 3.1 per 100000 population, with males ten times more commonly affected than females [16, 17].

OUTCOME

Prognosis is dependent on a number of factors:

- Injury severity.
- Duration of ischaemia.

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then allows identification of the anterior intermuscular septum. The anterior and lateral compartments can then be released taking care to avoid the superficial peroneal nerve just posterior to the intermuscular septum. The medial incision is made about 2 cm behind the medial tibial border, ensuring a sufficient skin bridge (>5 cm) between the two incisions. Blunt dissection allows visualisation of the fascia. A transverse incision can then be made between the deep and superficial compartments. Both compartments can then be fully decompressed. The soleus is firmly adherent to the posterior tibia and may need to be released to adequately decompress the deep compartment.

THIGH

The thigh has three compartments (Fig. **5**):

1. Anterior compartment consisting of the quadriceps muscles
2. Posterior compartment consisting of the hamstring muscles
3. Medial compartment consisting of the adductor muscles

A single lateral incision is usually adequate to decompress the thigh as the medial compartment is only rarely involved. A long lateral incision is used spanning the length of the thigh. The fascia lata is incised in line of its fibres and the anterior compartment decompressed. The vastus lateralis can be retracted anteriorly to allow access to the posterior compartment for further decompression. As mentioned it is rare to need to decompress the medial compartment but if necessary a separate medial incision can be used (Fig. **5**).

FOREARM

The forearm can be anatomically divided into three compartments (Fig. **6**):

1. Mobile wad comprising brachioradialis, extensor carpi radialis longus and brevis muscles
2. Volar compartment comprising superficial and deep flexors
3. Dorsal compartment containing the extensor muscles

Pronator quadratus may be described as a separate compartment.

A volar Henry approach provides exposure to adequately decompress the flexor compartments and the mobile wad. The incision is started 1 cm proximal and 2 cm lateral to the medial epicondyle extending to the mobile wad. It is carried distally to the midline down to the proximal wrist crease. Median nerve decompression is always performed at the same time. To decompress the dorsal compartment a single straight incision from the distal aspect of the lateral epicondyle aiming to the centre of the wrist (Thompson's approach) can be utilised.

HAND

The hand has ten separate osseo-fascial compartments:

- Four dorsal interossei
- Three palmar interossei
- The thenar and hypothenar compartments
- Adductor pollicis

Fasciotomy is achieved using a four-incision technique (Fig. **7**). One is on the radial side of the thumb releasing the thenar compartment. Two dorsal incisions are made over the index metacarpal and over the ring metacarpal. These incisions are used to release the dorsal and volar interossei. Adductor pollicis can also be reached using the index metacarpal incision. The hypothenar muscles are released using an incision at the ulna aspect of the little finger.

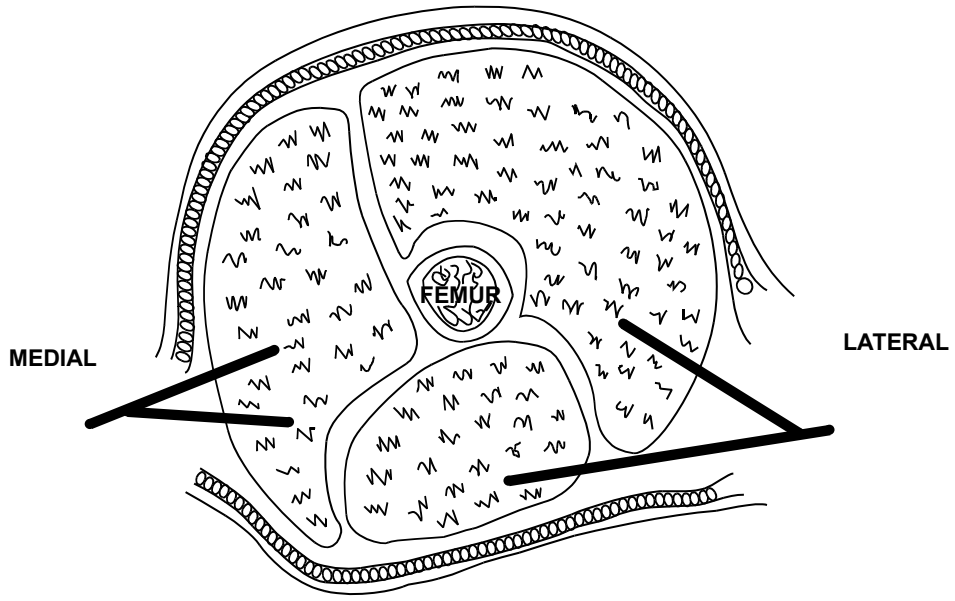

Fig. (5). Approaches for thigh fasciotomy.

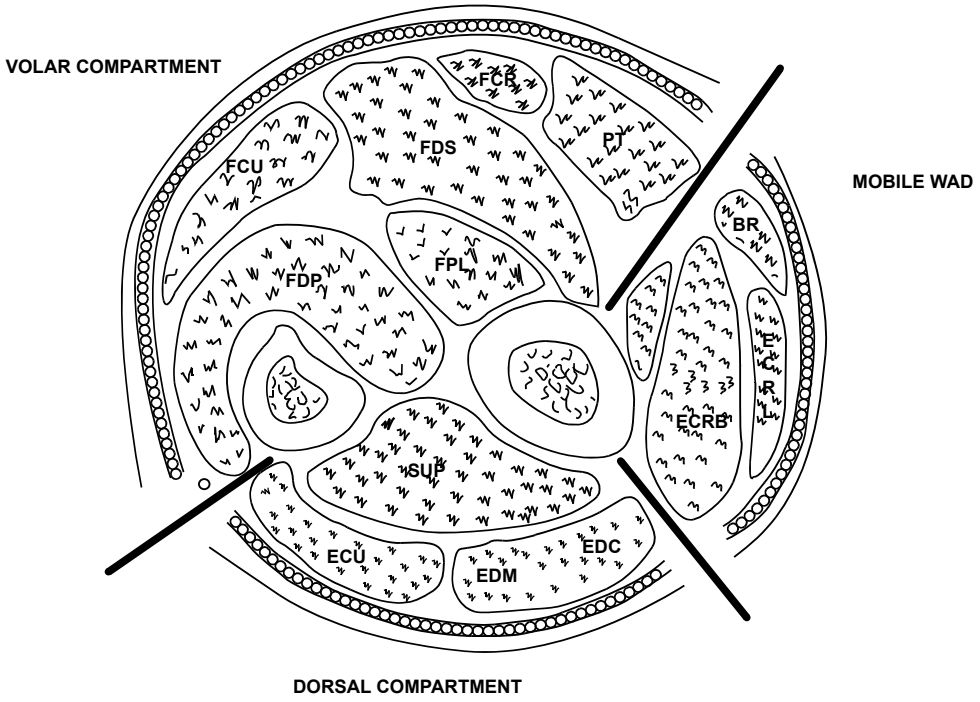

Fig. (6). Compartments of the forearm.

FOOT

Foot compartment syndrome is controversial both in terms of anatomy and in terms of treatment. Some authors advocate four compartments (medial, lateral, central and interosseous); others have expanded on this creating nine:

- Medial
  - abductor hallucis
  - flexor hallucis brevis
- Lateral
  - abductor digiti minimi
  - flexor digiti minimi brevis

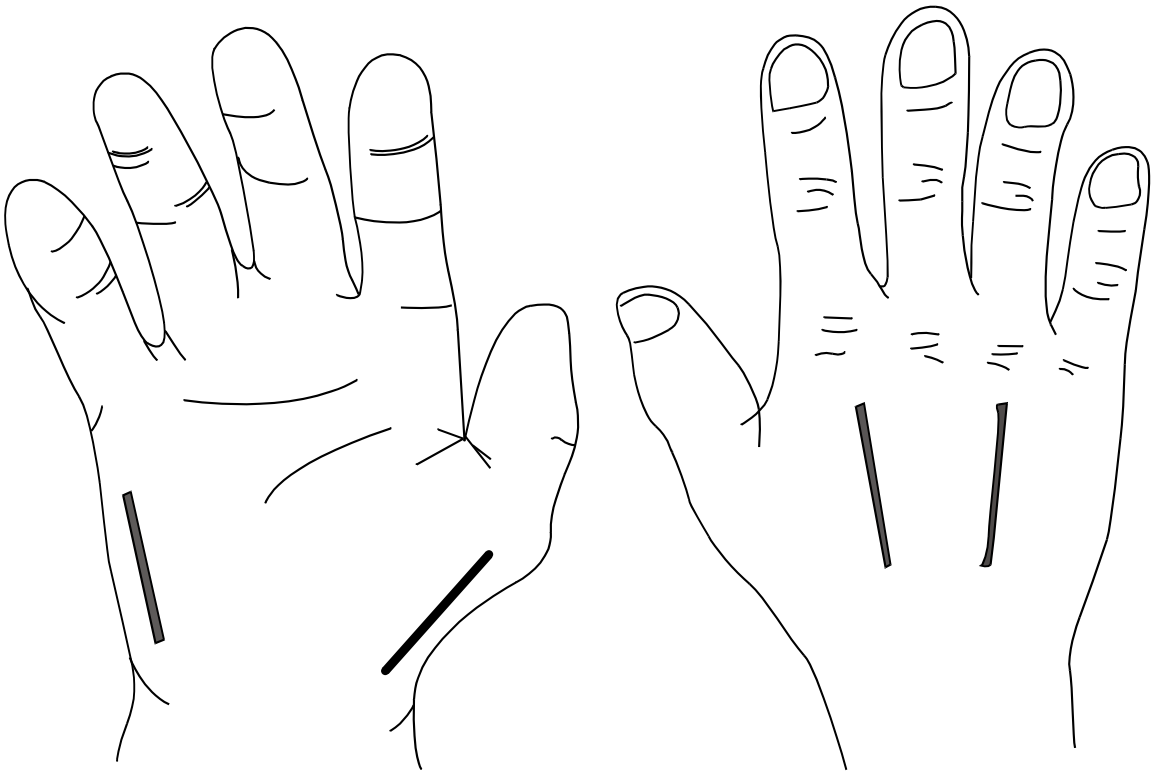

Fig. (7). The four incisions to decompress the hand.

- Interosseous (x4)
- Central (x3)
  - superficial
    - flexor digitorum brevis
  - central
    - quadratus plantae
  - deep
    - adductor hallucis
    - posterior tibial neurovascular bundle

Traditional treatment involves urgent fasciotomy using the following incisions (Fig. **8**):

- 2 dorsal incisions overlying the 2nd and 4th metatarsals. Care is needed to maintain an adequate skin bridge. The superficial fascia is divided and the interossei are elevated off the metatarsals. Blunt dissection can then be continued through the central, medial and lateral compartments.
- A medial incision along the inferior border of the 1st metatarsal or a calcaneal incision beginning posteromedially towards the 1st metatarsal will allow more extensive decompression of the central compartment, which may be helpful with hindfoot involvement.

More recently, however, some authors now suggest a 'supervised neglect' approach accepting the inevitable deformity and clawing and suggesting reconstruction at a later date to avoid the high risk of potential surgical complications.

DELAYED FASCIOTOMY

Fasciotomy after 8 hours in cases of ACS is controversial. The myoneural damage is irreversible at this stage and the increased risks may outweigh any potential benefit. Finkeltstein *et al.* described five patients with an average of 56 hours delay from the diagnosis in whom a fasciotomy was performed. One died from multi-organ failure, the remaining four required a later amputation [42]. Williams *et al.* found a rate of infection of 28% when fasciotomy was delayed more than twelve hours.

Where the diagnosis has been missed or delayed supportive renal treatment should be considered and surgery delayed until the morbidity has been declared and reconstruction can be planned. The evidence for this has generally come from traumatic cases. In certain cohorts (particularly haemophiliacs) this may not necessarily be the case and anecdotal evidence suggests better outcomes with delayed fasciotomy as clotting deficiencies are addressed prior to surgery.

WOUND MANAGEMENT AND WOUND COMPLICATIONS

Management of fasciotomy wounds remains controversial. Most advocate leaving the wounds open with delayed primary closure or skin grafting within 7-10 days when the compartment syndrome has completely resolved. A second look and debridement is usually necessary at 48-72 hours. Interim coverage can be achieved with simple absorbent dressings, semi-permeable membranes, vessel loops in a 'bootlace' pattern or with negative pressure dressings, which can be helpful in allowing later closure [44].

Fasciotomies are not benign procedures and there are multiple associated complications [45]:

- Altered sensation within the margins of the wound (77%)
- Dry, scaly skin (40%)
- Pruritus (33%)
- Discolored wounds (30%)
- Swollen limbs (25%)
- Tethered scars (26%)
- Recurrent ulceration (13%)
- Muscle herniation (13%)
- Pain related to the wound (10%)
- Tethered tendons (7%)
- Chronic venous insufficiency due to impaired calf muscle pumps [46].

Fig. (8). Incisions for foot fasciotomy.

COMPARTMENT SYNDROME IN HAEMOPHILIA

The lack of a clear aetiology or conspicuous traumatic injury both contribute to a potential diagnostic difficulty in haemophiliacs. In many cases the diagnosis of a bleeding disorder may not be known. The role of fasciotomy in haemophilia has been downplayed and care focuses on haemostatic manoeuvres in the first instance [47]. The absent clotting factor should be substituted and specialist haematological input sought. If these manoeuvres fail, fasciotomy is often performed to prevent muscle necrosis and future joint contracture. Caution should, however, be advised as surgical decompression can be catastrophic if the bleeding cannot be controlled and there is a higher than average amputation rate in haemophiliacs [48, 49].

MEDICO-LEGAL PITFALLS

ACS is a common cause of litigation. In nearly all cases, compartment pressures are never measured. Other potential pitfalls include malpositioning of the compartment pressure monitor, equipment errors and failure to correlate pressure reading with the clinical findings.

CONCLUSION

ACS is a surgical emergency and a high level of suspicion is needed in all potential cases. Compartment pressure monitoring may aid in the diagnosis, with a delta pressure of 30 mmHg or below suggestive of ACS. The definitive treatment is prompt surgical decompression of all the involved compartments. A delay of more than six hours is associated with irreversible myoneural damage and timing is crucial. Delayed fasciotomy after 8-10 hours is associated with significantly increased risks which may outweigh any potential benefit.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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