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# Compartment Syndrome

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**ABSTRACT**

Acute Compartment Syndrome is a rare but potentially devastating condition that demands immediate intervention. Failure to diagnose and manage compartment syndrome promptly is associated with long term disability and litigation. Ongoing research looks set to introduce new techniques for compartment pressure monitoring and both the diagnosis and treatment of the condition are now the subject of national guidelines. In writing this, clinical review, we performed a Pub Med and Med Line Search using the words Compartment Syndrome and cited key papers historical papers in the field.

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## Introduction

Compartment Syndrome is associated with a dramatic increase in hydrostatic pressure within an osseofascial compartment. Blood flow within the compartment is soon compromised and ischaemia and later infarction soon follow.

The condition was first described in 1881 by the German Surgeon Richard Von Volkman who would also go on to describe its calamitous sequelae, Volkman's ischaemic contracture [1]. In modern times, it has become a significant source of litigation, economic compromise and functional disability [2-4]. The most serious and common form of compartment syndrome is acute which is usually associated with trauma. Chronic compartment is associated with repetitive activities and is a frequent problem in athletes and sportsmen.

This paper will focus on acute compartment syndrome only.

## The Demographics of Compartment Syndrome

A greater average muscle mass and a penchant for physical injury makes the condition ten times more common in men than women. **McQueen et al** noted that compartment syndrome was most commonly seen in a young adult male with 69% of the patients in her own series having sustained a fracture [5]. According to **Via** the mean age for acute compartment syndrome is 30 years in men and 44 in women. The most commonly involved anatomical regions are the leg followed by forearm, thigh and arm [6]. Of those patients that have sustained a fracture, about half have broken their tibia with about 3% of mid shaft forearm fractures progressing to compartment syndrome. In the lower limb, the anterior compartment of the leg is most commonly affected. **Sangdo** has shown that compartment syndrome is more common in *diaphyseal* tibia fractures rather than at the extremities of the same bone [7]. Involvement of the hand or the foot can occur, but this is more unusual. Compartment syndrome has also been described in the thigh but again, this is rare.

Working in modern Seattle, Lollo reported a series of over a hundred cases of compartment syndrome and noted that 15.3% of his patients presented without any obvious history of injury. More than a third of these had well established peripheral vascular disease although cases of necrotizing fasciitis, a ruptured Baker's cyst and rhabdomyolysis secondary to a decubitus ulcer were also noted. Compartment syndrome can also occur after a crush injury, even when there is no associated fracture. The condition has also been described when blood flow returns to a previous bloodless limb (for example, people rescued at the scene of an earthquake), with electrocution and following intravenous extravasation of fluid in a limb.

## Compartment Syndrome in Children

Compartment syndrome in the paediatric setting is very rare. For children under the age of ten years, compartment syndrome is usually caused by infection or vascular injury, while in those over 14, the aetiology is usually trauma or surgical positioning [8-10]. As in the adult population, paediatric compartment syndrome occurs predominantly in boys, especially in the adolescent male. In a meta-analysis of 233 children with compartment syndrome, **Lin** reported a 74% association with fracture. 88% of the patients in this series reported pain and 32% paraesthesia [11]. Mean time from injury to fasciotomy was 25.4 hours. The authors recommended a decompressing fasciotomy even if there is a prolonged time from injury at presentation since children have a better chance of long term recovery than adults.

**Signs and Symptoms of Compartment Syndrome**

**Traditionally, We Referred to the Signs of Compartment Syndrome as Being the 5 Ps**

*Pain, Pulselessness, Paraesthesia, Pallor, Paralysis*. However, if all five of these signs are well established at the time of presentation, then it may well be too late for any intervention to be effective and in practise, the clinician must be prepared to act much earlier than this.

In a conscious patient, the pain in the affected limb is out of proportion to the underlying injury. When the fracture is complicated by compartment syndrome, the patient complains of undue pain that does not respond to first line drugs. Passive extension of the toes or fingers is extremely painful. If the patient does not react to this manoeuvre then compartment syndrome is unlikely.

Absent peripheral pulses are a *late* sign in compartment syndrome and for those patients in which dorsalis pedis and tibialis pulses are absent, the condition may be so advanced that the limb is beyond salvage. It must also be understood that the converse, (i.e. the presence of intact peripheral pulses) does little to reassure us that compartment syndrome is absent.

As pressures increase, the limb begins to feel tense. If the limb is concealed within a plaster cast or some other brace, such tissue tension may be difficult to judge. Merely removing a plaster cast from a swollen limb significantly reduces the compartment pressure and cutting the circumferential wool layer reduces it further. Keeping the limb at the same level of the heart has also been shown to convey an advantage [12].

The diagnosis of compartment syndrome is much more difficult in patients with concomitant nerve palsy or the unconscious with the unconscious, ventilated patient being particularly difficult to assess.

When the history and physical signs are strongly in favour of compartment syndrome then some surgeons would advocate an immediate fasciotomy. By far the most common location for compartment syndrome is the leg with the anterior compartment being the most at risk.

There are 3 Anatomic and 4 Functional Compartments in the Leg Anterolateral, Anterior and two distinct functional compartments (superficial and deep) within the posterior compartment. In practise, all four compartments require distinct surgical release since any one compartment can develop compartment syndrome in isolation.

Not all surgical procedures will result in success with the single most important prognostic factor in compartment syndrome is the *time delay* between diagnosis and fasciotomy [13]. Recognised sequelae to acute compartment syndrome include Volkman's ischaemic contracture and rhabdomyolysis with myoglobin release and subsequent kidney failure. The process of surgical release in itself is not without risk with injury to the peripheral nerves being a recognised complication of compartment release.

**The Physiology and Anatomy of Compartment Syndrome**

Arterial pressure falls off steadily throughout the arterial tree. In the brachial artery (where we would normally apply a blood pressure cuff) the physician may observe a pressure of 120/80mmHg. However, with persistent branching, the pressure in each successive vessel will fall. Relatively small increases in hydrostatic pressure within a closed osseo-fascial compartment are enough to block the flow of blood within the small arterioles that supply the capillary beds. The fact that larger and more central vessels still retain a pulse in no way guarantees that the smaller vessels have not shut down, nor that the muscles are not yet infarcted.

It should be remembered that the degree of muscle damage is determined both by the duration of ischaemia and the magnitude of the intra-compartmental pressure with higher pressures causing very rapid tissue damage.

Compartment syndrome of the thigh is rare and often associated with a missed diagnosis and amputation [14]. It is also associated with high energy injury, and a significant mortality rate. Knab - working in Chicago - reported a high prevalence of penetrating trauma in compartment syndrome of the thigh [15].

**Compartment Syndrome in the Hand and Foot**

Compartment syndrome in the hand and foot is something of a rarity.

BOAST 14 guidelines in this area state that there is no consensus on the optimum incisions for compartment syndrome in the hand or foot although a number of incisions have been described [16].

**Continuous Monitoring in Suspected Compartment Syndrome**

In the unconscious or ventilated patient, the diagnosis of compartment syndrome becomes particularly difficult. Lacerations and/or a crush injury to the peripheral nerves further confuse the clinical picture. Whilst most patients will recover both consciousness and sensation after fracture fixation, many trauma surgeons are reluctant to use spinal or local anaesthetic for pain relief in the limb at this could easily downgrade the critical important symptom of pain in the immediate post-operative period.

Pressure within the compartment that is more than 30mmHg above the diastolic blood pressure is associated with compartment syndrome. Tissue perfusion pressure is defined as diastolic pressure minus the compartment pressure and is used by many units.

There is spatial and temporal variation in intramuscular pressure following trauma. Heckman showed that pressure within the same compartment is significantly higher within 5cms of the fracture site [17]. In his study of 20 patients, the highest pressures were recorded in the anterior and the deep posterior compartments. Similarly, Nakhostine placed three separate pressure monitoring catheters in specific locations in each of 12 healthy volunteers [18]. The pressure recorded varied considerably with the exact position of the catheter within the same compartment. It appears that pressure within the muscle increases centripetally as we approach the centrally lying tendon. The authors went on to recommend that in future studies relating to compartment pressure there should be a consensus on where pressure monitoring catheters are placed.

Objective measurements of compartment syndrome are clearly dependent on our ability to measure blood pressure. It has been demonstrated that blood pressure itself varies significantly during the course of a patient's stay in hospital. Kakar et al looked at pre-operative, intra-operative and post-operative blood pressure measurements in patients receiving a tibial nail [19]. Diastolic pressure was, on average, 18mm Hg lower on table than before surgery. These workers concluded that pre-operative pressures were the best to compare the intramuscular pressure differential to.

Stryker manufacture a commonly pressure measuring device with a disposable syringe and a digital read out (Stryker Surgical, USA). However, pressure within an individual compartment can vary over time and some authors have questioned the viability of a single pressure reading using the Stryker kit [20]. It seems reasonable to suggest that continuous pressure monitoring may give a more reliable result.

McQueen has demonstrated that continuous compartment pressure monitoring has a high specificity and sensitivity for compartment syndrome. In a series of 979 patients, there was an estimated sensitivity of 94% and an estimated specificity of 98% for acute compartment syndrome. All 979 patients in this series were actually monitored [21].

One obvious risk of continuous compartment pressure monitoring is that it might lower our threshold for performing surgery and that in effect, some patients would receive unnecessary surgery. Al-Dadah looked at his compartment release figures before and after introducing continuous muscle pressure monitoring and found that monitoring did not affect his release rate [22].

**New and Alternative Investigations in Compartment Syndrome**
Continuous compartment pressure monitoring is an invasive procedure that requires some degree of skill on the clinician and carries a theoretical risk of infection. It would be greatly advantageous to be able to objectively diagnose compartment syndrome by some other mechanism.

Valdez et al looked at a formula for measuring three parameters derived from a blood sample and tried to correlate these to the diagnosis of compartment syndrome [23]. A model combining maximal Creatinine Kinase level greater than 4,000 U/L, maximal chloride level greater than 104 mg/dl, and a minimal BUN level of less than 10 mg/dl has a 100% association with Compartment Syndrome. This study was performed on 97 patients all of whom had been admitted with a fracture of the tibia.

Near infra-red spectroscopy monitoring has been investigated as an alternative to the traditional, more-invasive forms of pressure monitoring, but the technique remains controversial. Normal peripheral oxygenation appears to exclude compartment syndrome. Similarly, normal hyperaemia is consistent with absence of acute compartment syndrome [24,25].

Ultrasound has also been proposed as a means of non-invasive compartment pressure monitoring but this research is still at an early stage [26,27].

It has also been suggested that plasma myoglobin levels could be used as a marker of compartment syndrome. Comparing patients who received an acute compartment release in those who had a fracture and those who had compartment syndrome without fracture, Nilsson et al noted that intra-compartmental pressures were actually higher in the non-compartment groups as was p myoglobin [28].

Doro performed an animal study for compartment pressure and monitored intramuscular glucose and partial pressure of oxygen within the limb [29]. In this study, there was a dip in O2 and glucose levels quite soon after compartment syndrome was induced when compared to the contralateral, normal limb of the same animal. This suggest that intramuscular glucose levels might be useful to monitor impaired metabolism in acute compartment syndrome. Again, this should be regarded as early work.

**Indications for surgery**
A clinical diagnosis of compartment syndrome demands urgent surgical intervention with release of all affected compartments.

BOAST recommends that if the absolute intra-compartmental pressure exceeds 40mmHg then a fasciotomy should be performed with the delay between the decision to operate and surgery being less than one hour. When surgery is performed to remove necrotic tissue, a second procedure should be performed at 48 hours to reassess tissue viability.

It seems reasonable to suggest that guidelines of this kind can make the process of decision taking easier, especially in a scenario where clinicians are conscious of the high risk of litigation. However, Bodansky looked at several trauma centres in the North West of England and failed to find a difference in management before and after the introduction of BOAST10 guidelines [30].

**Surgical Technique**
Compartment release has been performed through two skin incisions in the leg followed by a deeper and extended incision through the deep fascia. In the calf, there is significant risk of damaging adjacent structures with both foot drop and reduced foot eversion being recognised complications. All four compartments should be individually released.

Since compartment syndrome is not a condition that the surgeon encounters on a regular basis, it is worth reviewing the recommended locations for the incisions before operating.

During surgery to the forearm, the deep flexor compartment of the forearm must be released separately due the non-redundant blood supply. Given the importance of the hand to human function, it can be argued that upper limb compartment syndrome is an even more devastating injury than the equivalent condition in the lower limb.

A high proportion of compartment syndrome surgery result in wounds that are impossible to close, even after a protracted period of elevation. Split skin graft is often performed to achieve skin cover over the exposed muscle.

**Role of Hyperbaric Oxygen for Compartment Syndrome**
Abdullah has reported treating compartment syndrome using hyperbaric oxygen [31]. Hyper baric oxygen is not widely available but various experiments have been performed. In particular, hyperbaric oxygen has been used when compartment syndrome has occurred in conjunction with carbon monoxide poisoning.

**Late Surgery**
Glass et al have looked at the results of surgical decompression in patients who are deemed to have presented late [32]. In these circumstances the actual operation represents a second physiological insult to the body and it has been suggested that if some of these cases could be managed conservatively they would actually have a lower late amputation rate. The evidence here remains sparse and of poor quality. Finkelstein looked at 5 cases where fasciotomy occurred more than 35 hours after the original injury (average delay was 56 hours) and observed one death and four late amputations. Given this particularly bleak outcome they suggest that one should consider conservative management in some late presentations of compartment syndrome [33].

**Outcomes following Compartment Syndrome**

Both compartment syndrome itself and the process of surgical release are associated with the risk of adverse outcomes.

Persistent pain is one of the most common long term outcomes [34]. Compartment release is often followed by fibrotic contracture, deformity and pain from nerve compression.

Reverte et al reviewed the literature on compartment release following tibial fractures and concluded that when compartment release is performed in the presence of a tibial fracture than the mean time to union increases by nearly 5 weeks. Delayed or non-union occurred in 55% of those patients who had received a compartmental release versus 17.8% of tibial fractures that did not receive a compartment release [35].

Lollo looked at 108 patients who had received compartment release in Seattle. At 12 months follow up, 69.2% of patients had returned to work. Almost one in five had a drop foot and a similar figure had foot numbness. 12.9% of patients had an eventual amputation with the vast majority of these being male [33].

When rhabdomyolsis occurs in the setting of acute lower extremity trauma compartment release tsai et al reported AKI as occurring in up to 40% of patients [36].

**Amputation in Compartment Syndrome.**

Amputation is a recognised sequelae to compartment syndrome, especially following late diagnosis. Perhaps inevitably, amputation is associated with a high rate of litigation4. Working in Seattle, Lollo reported a 12.5% amputation rate in 108 patients with compartment syndrome in Seattle. The amputees in this series had a 69.2% return to work. Of those patients requiring amputation, two thirds had an associated vascular injury9. Male sex was a risk factor for amputation and poor outcome. Foot drop occurred in 18% of patients and osteomyelitis in 10.2%.

**Litigation**

Bhattacharya et al evaluated 19 malpractice claims in the United States relating to compartmental syndrome [2]. The most common cause of successful litigation was a delay of more than 8 hours from the onset of the condition to surgery. Marchesi et al looked at 66 cases and reported that 32% of cases that found against the physician were based on an inappropriate delay to surgery [37].

Working in the United States, Depasse et al looked at 139 cases of compartment syndrome where there was an actual court case. Their study noted that doctors were more likely to lose a lawsuit "if the patient was a woman or child or if acute compartment syndrome developed as a complication of a surgical procedure" [38].

**Conclusion**

Compartment syndrome is an extremely serious complication in trauma and orthopaedics with a high rate of complication and litigation. It demands close attention and sound clinical judgement. In our own unit, compartment pressure is monitored on the ward for 24 hours after admission. However, data from instrumentation should not be regarded as a substitute for good clinical acumen and if the picture deteriorates then fasciotomy may be indicated on clinical signs alone [39].

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