Focus On
Diagnosis of acute compartment syndrome

Acute compartment syndrome (ACS) is defined by a critical pressure increase within a confined compartmental space, causing a decline in the perfusion pressure to the compartment tissue, which without timely diagnosis and treatment will lead to ischaemia, necrosis and ultimately permanent disability of the affected region. Management is with immediate fasciotomy and decompression of all tissues within the affected compartment.

Principles Of Diagnosis
The diagnosis of ACS throughout the literature often uses a combination of clinical signs and/or compartment pressure monitoring, with a recent systematic review on compartment syndrome of the forearm documenting the use of monitoring in 50% of cases. O’Toole et al. documented that compartment pressure monitoring was only used as the primary diagnostic tool in 11.7% of cases when they reviewed the notes of 386 tibial diaphyseal fractures at a large level I trauma centre. An older United Kingdom survey of compartment pressure monitoring revealed that over 50% of all consultant orthopaedic surgeons did not use monitoring within their institution.

A delay in the diagnosis and management of ACS leads to a prolonged time of inadequate perfusion and has been found to result in a poor outcome for the patient, as well as being associated with increased medical costs. A prompt diagnosis is necessary to minimise the risk in a predominantly young and active population of potentially devastating long-term complications such as muscle necrosis, contractures, neurological deficits, fracture nonunion, infection, chronic pain, and in the worst cases amputation and even death. Along with providing an improved patient outcome, an early diagnosis is associated with decreased indemnity risk for legal claims. A delay in diagnosis has been attributed to a lack of awareness for the condition, inexperience of the surgeon, general or regional anaesthesia, patients with polytrauma, soft-tissue injuries and the reliance solely on the clinical signs used to diagnose ACS.

Epidemiology And Demographic Risk Factors
Knowledge of the incidence, and an understanding of the demographic risk factors, is invaluable when assessing a patient for a suspected ACS. The annual incidence of ACS in the literature has been quoted as 3.1 per 100 000 population, with the incidence in males ten times that of females. The mean age ranges from 30 to 35 years with males affected at a significantly younger age than females. The most frequently affected sites are the leg and forearm, although the arm, hand, gluteal region, thigh, and foot and abdomen can all be affected.

Over two-thirds of all ACS presentations are associated with a fracture, with a tibial diaphyseal fracture accounting for a third of all ACS cases. In the early days of intramedullary nailing of tibial diaphyseal fractures there was some concern that the technique might cause an increased rate of ACS, but subsequent studies have documented no increase in incidence. The incidence of ACS associated with a fracture of the tibia or distal radius has been found to be significantly increased in patients under the age of 35 years at the time of injury. In a large study of 1403 fractures of the tibial shaft from Edinburgh, risk factors for developing ACS were identified as male gender and youth. Furthermore, in a recent study of 414 tibial fractures, risk factors for the development of ACS were young patients with diaphyseal fractures. A proposed explanation for this is related to the increased muscle size in these patients, and hence a reduced capacity for swelling. In elderly patients, the protective effects of an increased perfusion pressure (hypertension) and small atrophied muscles has been postulated.

Although commonly associated with fractures, it is important to appreciate that almost a quarter of ACS presentations arise in the absence of a fracture. The mean age of patients who develop an ACS associated with a soft-tissue injury is significantly older than those associated with a fracture. A variety of causes has been identified and includes crush injuries, crush syndrome, drug overdose and anti-coagulation therapy. ACS in the absence of fracture has been found to be associated with a delay to diagnosis and fasciotomy.

High-energy injuries including sports, road traffic accident and falls from height accounted for only half of all the modes of injury in one study of ACS. Although commonly perceived to be associated with high-energy injuries and open fractures, data has demonstrated an increased rate of ACS complicating closed low energy tibial diaphyseal fractures. This is perceived to be related to the ‘auto-decompression’ of the...
affected compartment at the time of a high energy injury. However, high energy fractures of the forearm and femur are associated with an increased rate of ACS, which is probably related to the high number of young males who sustain these injuries.\textsuperscript{15,16,43,48}

**Clinical Diagnosis**

Symptoms and signs associated with a diagnosis of ACS are pain out of proportion to the injury, pain on passive stretch, swelling, sensory disturbance and motor disturbance. Weakness or absence of peripheral pulses is not an associated sign as this indicates either a vascular injury or the late stages of ACS, in which scenario amputation is usually necessary.\textsuperscript{6} A clinical diagnosis can be made on a combination of these clinical signs. However, there is literature documenting the poor diagnostic performance characteristics of these signs,\textsuperscript{28} and they have been felt to be unreliable in the assessment of ACS in adults\textsuperscript{6,24,51,54,70} and in children.\textsuperscript{71}

Ulmer\textsuperscript{28} performed a systematic review to determine the efficacy of four clinical signs in the diagnosis of ACS (Table II). He found that the sensitivity of clinical findings for diagnosing ACS to be low at 13\% to 19\%, with a specificity of 97\% (Table II), and concluded that all the signs are better at excluding than confirming a diagnosis. In this analysis, it was found that with only one positive sign, the odds of ACS being present never reached above 26\%. With three positive signs the odds were 93\%, however, the third sign was paresis. This is a late sign of ACS and it is not acceptable to wait for this to develop before making the diagnosis and instituting treatment. If the diagnosis is delayed until paresis is established only 13\% of patients will make a full recovery.\textsuperscript{35}

**Pain.** Severe pain that is out of proportion to the associated injury and refractory to analgesia is judged to be the primary symptom of ACS. However, pain is subjective, already present post injury, of variable intensity, can be reduced when affecting the deep posterior compartment, can be absent when there is a concomitant nerve injury, and has been found to have very poor sensitivity (Table II).\textsuperscript{13,16,22,28,72} It has also been proven to be inadequate when assessing children or in the patient with poly-trauma and suspected ACS.\textsuperscript{71,73} Pain on passive stretch is equally unreliable with comparable diagnostic performance characteristics (Table II).\textsuperscript{28,72,74} Badhe et al\textsuperscript{13} reported four cases of ACS in which any form of pain was absent, with diagnosis confirmed on subsequent fasciotomy.

**Swelling.** Although palpable swelling is a common presenting feature of ACS, it is a very subjective sign and is often hindered due to either the necessity of immobilisation masking the affected compartment or the fact that some compartments are deep and therefore difficult to assess.\textsuperscript{18,75}

**Paraesthesia.** This sign can be related to either nerve ischaemia as it runs through the affected compartment or can be related to a concomitant nerve injury.\textsuperscript{72,74} There were initial suggestions that this sign might be more useful than pain in the diagnosis of ACS\textsuperscript{75} but it has since been suggested this is a late sign.\textsuperscript{20} On analysis, sensitivity is even lower at 13\%, with a marginally increased specificity (98\%).\textsuperscript{28}

**Paralysis/Paresis.** This is a late sign of ACS and is the poorest performing clinical finding on diagnostic performance analysis.\textsuperscript{28} Positive pre-fasciotomy motor symptoms have been found to negatively influence the outcome in patients with compartment syndrome.\textsuperscript{12,35,48} with one study reporting that only 13\% of patients achieve a full recovery.\textsuperscript{35} Furthermore, there is noted difficulty in determining the presence of limb paralysis in a trauma patient who may have limited motor function due to pain.\textsuperscript{77}

**Compartment Pressure Monitoring**

Given the necessity for a timely diagnosis, the variable aetiology and presentation of ACS, as well as the poor performing diagnostic performance characteristics of the clinical signs at presentation, continuous intracompartmental pressure (ICP) monitoring in all at risk patients is recommended.\textsuperscript{6,13,15,23,28,31,74,79-81} Pressure monitoring has been proven to detect ACS prior to the onset of clinical signs in addition to reducing the time to fasciotomy and the development of subsequent sequelae.\textsuperscript{13,82} whilst not increasing the rate of fasciotomy or associated complications.\textsuperscript{59,83-85} McQueen, Christie and Court-Brown\textsuperscript{12} reviewed 25 patients (13 monitored, 12 not monitored) with tibial diaphyseal fractures that had been complicated by an ACS. They found a significant increase in the time from injury to fasciotomy (16

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<th>Table I. Conditions associated with the development of acute compartment syndrome\textsuperscript{15}</th>
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<tr>
<td><strong>Cause</strong></td>
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<td>Fracture</td>
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<td>Tibial diaphyseal fracture</td>
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<td>Diaphyseal forearm fracture</td>
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<td>Tibial plateau fracture</td>
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<td>Soft tissue</td>
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<td>Soft-tissue injury</td>
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<th>Table II. The diagnostic performance characteristics of the frequently employed clinical signs of acute compartment syndrome as found by Ulmer\textsuperscript{28} (PPV, positive predictive value; NPV, negative predictive value)</th>
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<tr>
<td><strong>Sign</strong></td>
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hour difference, p < 0.05), no complications in the monitored group compared with 83% in the non-monitored (p < 0.01), and a significant delay in tibial union in the non-monitored group (p < 0.05).

Al-Dadah et al. compared 109 patients with a tibial diaphyseal fracture who underwent continuous ICP monitoring (fasciotomy rate 15.6%, time to fasciotomy 22 hours) with a historical control group of 109 patients who were assessed using clinical signs alone (fasciotomy rate 14.7%, time to fasciotomy 23 hours). Although they found no significant increase in the fasciotomy rate, they did not demonstrate a significant difference in terms of clinical outcome or time to fasciotomy.

Harris, Kadir and Donald performed a randomised trial of 200 consecutive tibial fractures comparing monitored and non-monitored patients. The primary outcome measure was the presence of late sequelae by six months after injury. According to the protocol, monitored patients underwent continuous ICP monitoring for 36 hours (no cases of ACS) and the non-monitored group received standard clinical assessment (five cases of ACS). They documented no difference between groups regarding the complication rates recording 27 soft-tissue complications and 29 nonunions in the 177 patients available for review. A criticism of this study is that like was compared with like as the indication for fasciotomy in alert patients in both groups was clinical symptoms and signs. Furthermore, issues regarding timing were ignored. For the ICP monitoring to be compared accurately with clinical symptoms and signs it must be the primary indication for fasciotomy.

Methods of ICP monitoring (Table III). Techniques for ICP monitoring include indirect measures using the needle manometer with or without the infusion of saline into the compartment, the wick catheter, the slit catheter or the solid state transducer intracompartmental catheter (STIC) with or without the transducer at the tip. Collinge and Kuper performed a clinical study in 26 patients with suspected ACS (31 limbs, 97 compartments) to compare three ICP monitoring devices (STIC, electronic transducer-tipped catheter, modified Whitesides needle). They concluded all techniques were comparable but not completely reliable for ICP monitoring in trauma patients.

Innovative techniques include near infrared spectroscopy, which is a direct non-invasive measure of tissue oxygenation and has demonstrated good correlation with ICP measurements in both experimental and human studies, though further work is required.

Technique and placement. Whichever method of ICP monitoring is employed, appropriate placement is within or on the affected compartment using an aseptic technique. In the presence of an associated fracture, the device should be
placed within 5 cm of the level of the fracture to give accurate readings.\textsuperscript{6,80,102,103}

In the leg, the anterior compartment is routinely used as it is the most frequently affected and accessible.\textsuperscript{69,83} However, despite being potentially difficult to manage and uncomfortable for the patient, some authors do recommend monitoring the deep posterior compartment as well given the associated risk of missing an isolated deep ACS.\textsuperscript{18,102} We would routinely recommend this if there is a clinical reason to suspect its presence. For other suspected compartment syndromes of the lower limb, the anterior compartment of the thigh is recommended as it has been found to be most frequently affected.\textsuperscript{13,69,82,101} In the case of a suspected foot ACS, the interosseous compartments are suggested, with consideration of the calcaneal compartment in hindfoot injuries.\textsuperscript{51,54,55}

The forearm is the most commonly affected site in the upper limb and measurement of the flexor compartment is routine.\textsuperscript{6,23,69,102,103} Again, in the suspected case of a rare isolated dorsal ACS, that compartment should be measured.\textsuperscript{16} The anterior compartment of the arm and the interosseous compartment of the hand are the recommended placements for ICP monitoring for the remainder of the upper limb.\textsuperscript{6,41,43,44}

**Threshold and timing for decompression.** Evidence has demonstrated that the normal ICP of healthy muscle is 10 mmHg.\textsuperscript{107} Much of the literature attempting to determine the threshold pressure for decompression has focused on whether to use ICP alone or whether to consider the ICP in relation to perfusion pressure. Despite initial studies suggesting an absolute ICP of 30-50 mmHg to be the threshold,\textsuperscript{12,44,68,75,83,87,108} it is now recognised that a patient’s tolerance to the ICP is dependent on perfusion, or the systemic blood pressure.\textsuperscript{69,103,109,111} Whitesides et al\textsuperscript{103} was the first to suggest using an animal model, with ranges from 10 mmHg to 35 mmHg considered diagnostic.\textsuperscript{103,111,112} However, there is now experimental and clinical work suggesting a pressure difference or delta pressure ($\Delta P =$ diastolic pressure – intra-compartmental pressure) of less than or equal to 30 mmHg should be considered diagnostic.\textsuperscript{13,69,82,103} McQueen and Court-Brown\textsuperscript{69} studied 116 patients with tibial diaphyseal fractures who underwent continuous pressure monitoring of the anterior compartment for 24 hours. The use of a $\Delta P$ of $\leq 30$ mmHg as a threshold for fasciotomy led to no missed cases of ACS, no unnecessary fasciotomies and no complications in any patients.\textsuperscript{69} White et al\textsuperscript{113} validated the clinical use of a $\Delta P$ of $\leq 30$ mmHg in a study of 101 patients followed for over a one year period. They found no significant difference in muscle power or return to function in 41 patients with an absolute pressure of over 30 mmHg and a $\Delta P$ over 30 mm Hg for more than six hours continuously, with the 60 patients who had absolute pressures of less than 30 mmHg.\textsuperscript{101}

It should be noted that much of the above work does not include children and was carried out solely in association with ACS of the leg. Other regions of the body may have different pressure thresholds but in the absence of evidence to the contrary it seems reasonable to retain the threshold of a $\Delta P$ of 30 mmHg. Furthermore, in children, the mean arterial pressure rather than the diastolic pressure has been suggested a more appropriate measure to calculate the $\Delta P$ as the diastolic pressure is often lower in this group of patients.\textsuperscript{113}

Confusion in the literature regarding time to fasciotomy relates to the definition of the start point. Time to fasciotomy has been found to correlate with outcome,\textsuperscript{60,13,18,20} with six to 12 hours quoted as critical in both clinical and experimental studies.\textsuperscript{83,108,114,115} The variation is likely to be due to varying pressure levels. It is probable that a lower pressure can be tolerated for a longer period of time and vice versa.\textsuperscript{108,115} We would suggest that time to fasciotomy would be most accurately determined as time from admission as this is closest to the time of injury.\textsuperscript{5,23,69} Time from diagnosis is not relevant as once the diagnosis has been made, urgent fasciotomy should be performed without delay.

When using ICP monitoring, the trend and duration of pressure measurements are important to consider when determining the appropriate point to perform fasciotomy.\textsuperscript{6,62} By employing a protocol of fasciotomy to be carried out based on the trend of readings over a two hour period, authors have found a reduction in the time to fasciotomy and complications whilst not increasing the rate of fasciotomy.\textsuperscript{69} One study has suggested overtreatment can occur with continuous ICP monitoring,\textsuperscript{116} although this study does not consider the trend over time. A diagnosis of ACS should not be made on the basis of a single reading. Another consideration is the effect of anaesthesia on blood pressure. Kakar et al\textsuperscript{117} performed a prospective cohort study of 242 tibial fractures treated with intramedullary nail fixation under GA. When calculating the $\Delta P$ using ICP monitoring, they found the pre-operative diastolic pressure correlated well with the post-operative pressure, with a significant difference seen in the intra-operative pressure (mean difference 18 mmHg, $p < 0.05$).\textsuperscript{117} They concluded that fasciotomy should not be performed on an isolated $\Delta P$ measurement intra-operatively and that serial measurements are recommended.

**Future Work**

The literature would benefit from further long-term outcome studies examining the usefulness and effect of ICP monitoring, as well as data on the diagnostic performance characteristics of ICP monitoring. Further work is needed to determine the critical $\Delta P$ for other regions of the body and in children, as well as more data on the innovative techniques of ICP monitoring.
Large prognostic prospective studies would help identify and clarify high-risk patients. Optimally, adequately powered prospective randomised controlled trials of continuous ICP monitoring versus clinical signs would provide level 1 evidence. However, several issues arise with this. Firstly, for ICP monitoring to be effective it needs to be the primary indicator for fasciotomy including consideration of time factors. Secondly, during the conduct of any such trial there is a high risk of changing behaviour by encouraging more stringent and frequent examination of the patient than is normal practice, thus biasing the results. Thirdly, there is no gold standard reference for diagnosing ACS and the incidence in the literature is quoted as well below 30%,[55,57,63] In this situation, statistical methodology including latent class analysis and Bayes theorem should be used when determining the diagnostic performance characteristics of the clinical tests used.

Conclusions
In conclusion, acute compartment syndrome can occur following either a fracture or soft tissue injury, with males and youth being most at risk. Because of the poor diagnostic performance characteristics of the clinical diagnosis, we would recommend continuous compartment pressure monitoring as the prime diagnostic tool in the following situations:

- All patients with tibial diaphyseal fractures
- All patients with high-energy tibial pilon and plateau fractures
- All young patients with high-energy forearm or femoral injuries, with or without an associated fracture
- All patients with soft tissue swelling suggestive of compartment syndrome, irrespective of age, gender or causality
- All patients at risk who are unable to co-operate with clinical assessment (e.g. patients with polytrauma, ventilated patients, children)

Until further evidence is available, we would recommend the slit catheter technique for continuous ICP monitoring, with a ΔP of ≤ 30 mmHg diagnostic of ACS using a trend of readings over a two hour period.

 References

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