Title: Assessment and diagnosis of acute limb compartment syndrome: a literature review

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Abstract:

Background: Compartment syndrome is a collection of symptoms that signal increased pressure in the muscle compartment and results in compromised tissue perfusion. Failure to diagnose and treat the condition can result in permanent neurovascular deficit, tissue ischaemia, limb amputation and rhabdomyolysis.

Aims: The aim of the review was to determine the strength of the evidence regarding risk reduction and early detection of ALCS and to identify the gaps in the evidence.

Methods: Following a systematic search, literature about patient risk, risk reduction, clinical observation and compartment monitoring was identified and the methodological quality of studies was considered.

Findings: Diaphyseal fractures of the tibia are the most significant risk factor for compartment syndrome followed by fracture of the distal radius. The anterior compartment of the leg and the flexor compartment of the forearm are most affected. Other factors include calcaneal fractures, male gender, age <35 years, high energy trauma, soft tissue injuries (especially in patients with bleeding disorders), open fracture, limb compression due to traction, padding and casts and surgical management of

fractures. Males aged below 35 years who sustain a fracture of the lower leg or forearm should be monitored most carefully.

Clinical observations, together with compartment pressure monitoring, in patients at risk appears to be the best method of diagnosing the condition. Pain out of proportion to the injury and pain on passive muscle stretch are the most effective clinical observation in conscious patients. Paresis/paralysis, parasthesia and pallor may help in diagnosis but are late signs. The sensitivity and specificity of these symptoms in diagnosing ALCS is unclear and the approach to pain assessment is not considered in detail.

The Assessment and Diagnosis of Acute Limb Compartment Syndrome: A Literature Review

INTRODUCTION

Compartment syndrome (CS) refers to a collection of symptoms arising as a result of increased pressure in the muscle compartment that results in compromised tissue perfusion (Duckworth & McQueen, 2011; Foong, Jose, Jeffery, & Titley, 2011; McDonald & Bearcroft, 2010). The presentation may be acute, sub-acute or chronic. CS can develop in any area of the body that has a muscle compartment with little or no capacity for tissue expansion, for example in the buttocks, abdomen, hands, arms, legs or feet (Mabvuure, Malahias, Hindocha, Khan, & Juma, 2012). The focus of this review is Acute limb compartment syndrome (ALCS) which is considered "…a true orthopaedic emergency" (Tzioupis, Cox, & Giannoudis, 2009 pp433). Failure to diagnose and treat ALCS in a timely manner may result in ischemia, necrosis, neurological deficit and limb amputation (Duckworth & McQueen, 2011; Foong et al., 2011; Wall, Lynch, Harris, Richardson, Brand et al., 2010) as well as rhabdomyolyisis ─ a life-threatening medical emergency. ALCS is treated with fasciotomy and surgical decompression of the affected compartment (Duckworth & McQueen, 2011; Foong et al., 2011; Kostler, Strohm, & Sudkamp, 2004; McQueen, Christie, & Court-Brown, 1996).

The leg (Duckworth & McQueen, 2011; Kostler, Strohm, & Sudkamp, 2005 McQueen et al., 1996; McQueen, Gaston, & Court-Brown, 2000; Rorabeck & Macnab, 1976) and forearm (Botte & Gelberman, 1998; Duckworth & McQueen, 2011; Duckworth, Mitchell, Molyneux, White, Court-Brown et al., 2012; Kalyani, Fisher, Roberts, & Giannoudis, 2011) are reported to be the most frequently affected sites. Men are ten times more likely to be affected than women (Kalyani et al., 2011; McQueen et al., 2000).

Although an initial literature search revealed a large body of material related to ALCS assessment and management, a careful examination of this literature clearly demonstrated a dearth of empirical studies. Most of the evidence is based on case reports, case series, opinions, summary literature reviews and the views of clinicians. This provides little support to practitioners in their quest for evidence based practice. We conducted this review to fill this gap and in response to a call from the RCN Society of Orthopaedic and Trauma Nursing (RCN SOTN) UK, and to determine the strength of the evidence regarding risk reduction and early detection of ALCS.

Review Questions

The specific questions which this review aims to answer are:

1. Which patients are at risk of ALCS?
2. Can patients at risk of ALCS be stratified according to level of risk?
3. How can the risk of peripheral neurovascular deficit/compromise due to ALCS be reduced?
4. What clinical observations are most effective in diagnosing peripheral neurovascular deficit in conscious patients with ALCS?
5. Is compartment monitoring of value in diagnosing peripheral neurovascular deficit in ALCS?
6. When should concerns regarding peripheral neurovascular deficit in ALCS be escalated?

METHODS

Eligibility Criteria

Any empirical study that explored ALCS was considered for possible inclusion. Included studies had to be: (a) based on empirical data (primary study or literature/systematic review); (b) written in English; (c) published in a peer reviewed journal; and (d) published between January 1981-December 2012. Studies related to chronic compartment syndrome and compartment syndrome in compartments other than upper/lower limbs were not included in the review. Articles published in any language other than English were excluded.

Data Sources

A comprehensive literature search using the search engines MEDLINE, CINAHL, Embase, the Cochrane Library and Joanna Briggs Library was performed. Keywords used in the search included compartment syndrome, limb compartment syndrome, limb AND compartment AND syndrome, arm AND compartment syndrome, thigh AND compartment syndrome, leg AND compartment syndrome, foot and compartment syndrome, forearm AND compartment syndrome, arm AND compartment syndrome, hand AND compartment syndrome. A search was also conducted using Google and Google Scholar to identify studies not published in indexed journals. The reference list of each article was scrutinized to identify studies that may not have been listed in the searched databases.

Study Selection and Data Extraction:

The initial search resulted in the identification of 1490 potentially relevant articles. A scan of titles and abstracts helped in narrowing this to 228 articles. A further detailed and careful review of the titles and abstracts resulted in the selection of 58 papers. The full text was retrieved for all of these and after a careful review of each article 32 were selected. Two independent reviewers read these 32 articles, including 10 literature reviews which were included in the review. Studies focusing on ALCS with varied purposes and focus were included in the review to ensure examination of literature in relation to each review question.

Any study (systematic review, randomized control trials, observational studies, validation studies, and published guidelines) meeting the inclusion criteria and exploring compartment syndrome in relation to upper or lower limb, in adults or children, was included. We used the critical appraisal tools of the Critical Appraisal Skills Programme (CASP http://www.casp-uk.net/) to assess the quality of the studies. A data extraction template was constructed to record relevant information such as purpose, research design, sampling method, sample characteristics, data collection method, method of data analysis, results of the study, limitations and comments by the first reviewer. Data from the included studies were abstracted by one author, which were then subsequently reviewed and confirmed by another member of the review team.

FINDINGS

Study Characteristics: Primary Studies:

Studies were conducted to examine risk factors of ALCS (McQueen et al., 2000; Park, Ahn, Gee, Kuntz, & Esterhai, 2009) in patients with upper limb (Blakemore, Cooperman, Thompson, Wathey, & Ballock, 2000) and lower limb fractures (Blick, Brumback, Poka, Burgess, & Ebraheim, 1986; Kierzynka & Grala, 2008; Kosir, Moore, Selby, Cocanour, Kozar et al., 2007; Mithofer et al., 2004). Some studies explored clinical outcome or effects of ALCS (Cascio, Pateder, Wilckens, & Frassica, 2005; Frink et al., 2007; Vaillancourt, Shrier, Vandal, Falk, Rossignol et al., 2004; White, Howell, Will, Court-Brown, & McQueen, 2003) and others focused on the contribution of compartment pressure monitoring (Al-Dadah, Darrah, Cooper, Donell, & Patel, 2008; Harris, Kadir, & Donald, 2006; Janzing & Broos, 2001; McQueen et al., 1996; McQueen & Court-Brown, 1996; Ozkayin & Aktuglu, 2005). We also included a study that examined the effect of anaesthesia on diagnosis of ALCS (Davis, Harris, Keene, Porter, & Manji, 2006) and another exploring current practices of clinicians in the management of ALCS (Wall, Richardson, Lowe, Brand, Lynch et al., 2007). There were only two studies that focused on children with upper limb (Blakemore et al., 2000) or lower limb fractures (Ferlic, Singer, Kraus, & Eberl, 2012).

The majority (n=9) of studies were based on retrospective design (Blakemore et al., 2000; Blick et al., 1986; Cascio et al., 2005; Ferlic et al., 2012; McQueen et al., 1996; Mithofer et al., 2004; Park et al., 2009; Uslu et al., 1995; Vaillancourt et al., 2004). Seven studies used a prospective design (Al-

Dadah et al., 2008; Frink et al., 2007; Janzing & Broos, 2001; Katz et al., 2008; Kosir et al., 2007; McQueen & Court-Brown, 1996; Ozkayin & Aktuglu, 2005), including one randomized control trial of continuous pressure monitoring versus usual care (Harris et al., 2006). Two studies used a case control design (Kierzynka & Grala, 2008; White et al., 2003). However, in many studies, the study design was not described clearly. We also included two recent descriptive quantitative studies in the review that used postal surveys as a data collection method (Davis et al., 2006; Wall et al., 2007). The sample size of the studies ranged from 13 to 108. Authors tend to report the number of sample/patients/records reviewed to determine inclusion in the study. A critique of the quality of studies will be presented later in the report. Table 1 gives details of the 22 included studies.

Study Characteristics: Literature Reviews

Ten reviews were also included. We evaluated the included articles using the critical appraisal guidelines for systematic review provided by CASP (Critical Appraisal Skills Programme http://www.casp-uk.net/) and SIGN (Scottish Intercollegiate Guidelines Network http://www.sign.ac.uk). We excluded only one review (Wright, 2009) which duplicated findings from another review (Wright, 2008).

Insert table 1 near here

We considered that it was important to include these reviews as most of them summarized evidence from case reports and case series which we considered to provide useful clinical information and a broader evidence base. No review, however, provided any clear and specific research question, leading to unclear and uncertain conclusions. Most of the reviews relied on PubMed (MEDLINE) as the only search engine to identify relevant articles (Hayakawa, Aldington, & Moore, 2009; Kalyani et al., 2011; Shadgan et al., 2008; Wall et al., 2010). Only one review (Mar, Barrington, & McGuirk, 2009) reported using more than two search engines and one did not specify the use of any search engine (Garner & Handa, 2010). The majority (n=8) of the reviews provided information about search terms used to identify papers and six studies provided information about inclusion/ exclusion criteria. Two reviews (Garner & Handa, 2010; Wright, 2008) did not mention inclusion or exclusion criteria and the review by Wall et al. (2010) only mentioned exclusion criteria. Of the 10 included reviews, four failed to report the final number of studies included in the review (Garner & Handa, 2010; Tiwari, Haq, Myint, & Hamilton, 2002; Wall et al., 2010; Wright, 2008). Information about assessment of the quality of studies, detail of the included studies and method of synthesising data from included studies was often missing. Most reviews (Garner & Handa, 2010; Kalyani et al., 2011; Ojike et al., 2010; Shadgan et al., 2008; Tiwari et al., 2002; Wall et al., 2010; Wright, 2008) lacked reporting the critique methods of the included studies. In all reviews, the authors summarised the evidence from studies but failed to critique strengths and weaknesses of included studies. In only two reviews (Hayakawa et al., 2009; Mar et al., 2009), some degree of critique is presented, but a more robust critique would have been useful.

Risk Factors

Out of 32 included empirical papers, 13 primary studies (n=22) and seven review papers (n=10) identified risk factors of ALCS in the studied population. Box 1 summarises the risk factors for ALCS. One study that is often cited as evidence of predisposing factors for ALCS is the study by McQueen et al. (2000) which identified tibial diaphyseal fracture as a major risk factor for ALCS associated with 36% (n=164) of all cases, followed by fracture of the distal radius. The anterior compartment of the leg and the flexor compartment of the forearm are reported in other studies to be most affected by ALCS (Tiwari et al., 2002). Tibial (Blick et al., 1986; Ferlic et al., 2012; Frink et al., 2007; Hayakawa et al., 2009; Kalyani et al., 2011; McQueen et al., 2000; Tiwari et al., 2002; Wall et al., 2010) and forearm (Blick et al., 1986; Hayakawa et al., 2009; Kalyani et al., 2011; McQueen et al., 2000; Park et al., 2009; Tiwari et al., 2002) and calcaneal fractures (Kierzynka & Grala, 2008) are also identified as risk factors in other studies.

Another risk factors is male gender (Blick et al., 1986; Frink et al., 2007; Kalyani et al., 2011; McQueen et al., 2000; Tiwari et al., 2002; Wall et al., 2010). It is speculated that young men are more likely to sustain high energy injuries (McQueen et al., 2000) and that young patients may have greater muscle mass with greater potential for swelling in relatively non-compliant fascia in limited space (McQueen et al., 2000; Park et al., 2009). It is also speculated that there is a difference in the thickness and stiffness of the fascia between younger and older patients making younger patients prone to the development of ALCS following injury (Park et al., 2009). Further risk factors inlcude age <35 years (Blick et al., 1986; Ferlic et al., 2012; McQueen et al., 2000; Park et al., 2009; Tiwari et al., 2002; Wall et al., 2010), high energy trauma (Ferlic et al., 2012; Ozkayin & Aktuglu, 2005; Tiwari et al., 2002; Wall et al., 2010) soft tissue injuries (Blick et al., 1986; Frink et al., 2007; McQueen et al., 2000; Ojike et al., 2010; Tiwari et al., 2002; Wall et al., 2010) (especially in patients with bleeding disorders) (McQueen et al., 2000; Ojike et al., 2010; Tiwari et al., 2002; Wall et al., 2010), open fracture (Ferlic et al., 2012; Ojike et al., 2010; Tiwari et al., 2002) and closed fractures (Ferlic et al., 2012; Kalyani et al., 2011). Other factors cited are prolonged limb compression due to traction, cotton padding and plaster casts (Tiwari et al., 2002; Wall et al., 2010; Wright, 2008) and following drug overdose (Tiwari et al., 2002; Wall et al., 2010), operative treatment of fractures with intramedullary nailing (Tiwari et al., 2002), anticoagulation therapy (McQueen et al., 2000; Ojike et al., 2010; Tiwari et al., 2002) and automated blood pressure monitoring (Wright, 2008).

Following drug overdose patients who are unconscious may lie on a limb for a long period of time, leading to unrelieved compression of the limb compartments. It is probable that this may also be the case following other causes of unconsciousness. Additional causes mentioned include penetrating trauma (Kalyani et al., 2011; Mithofer et al., 2004), vascular injuries (Kalyani et al., 2011; Wright, 2008), complications of intravenous and intraosseous infusions (Kalyani et al., 2011; Wright, 2008), tourniquet use (Kalyani et al., 2011), haemophilia (Kalyani et al., 2011), burns (Kalyani et al., 2011; Wright, 2008) and arterial injury (Kalyani et al., 2011; Wright, 2008). In children, supracondylar fracture of the humerus (Kalyani et al., 2011), radial fracture and crush injury (Kalyani et al., 2011; Wright, 2008) are cited as risk factors for ALCS. It is also suggested that crush injury to the foot in children with concurrent fractures may lead to foot ALCS (Tiwari et al., 2002).

Insert box 1 near here

Only one study (McQueen et al., 2000) directly reported risk factors of ALCS. The majority of studies involved patients with tibial fractures or patients at risk of developing ALCS. From the available evidence, it appears that males aged under 35 years who sustain a fracture of lower leg or forearm or higher energy trauma resulting in soft tissue injury are at greatest risk of developing ALCS and should, therefore, be monitored carefully. Wall et al. (2010) suggested high risk patients should be monitored for ALCS and after a careful examination of the available literature, we believe that the same criteria should be used to identify high risk patients. We found no literature which advised whether patients at risk of ALCS can be stratified according to level of risk.

Insert box 2 near here

Prevention of ALCS

Only two studies considered prevention of ALCS (Wall et al., 2010; Wall et al., 2007). Wall et al., (2007) explored the management of acute, traumatic compartment syndrome of the leg by 264 orthopaedic surgeons in Australia. They asked the respondents to rate the usefulness of various measures to prevent acute limb compartment syndrome in patients with leg injuries using a scale of 0-9 with 0 representing 'not at all useful' and 9 representing 'extremely useful'. The authors reported median usefulness, interquartile range and number of respondents. Removal of bandages and casts was rated as a highly useful measure in minimizing risk of ALCS with a median of 8 and usefulness interquartile range of 6-9 (n = 261) (Wall et al., 2007, p. 735). Other measures explored included ensuring that the patient is normotensive (median=5; usefulness interquartile range of 3-7; n = 259), elevating the injured leg (median=5; usefulness interquartile range of 3-7; n = 261), positioning injured leg at heart level (median=5; usefulness interquartile range of 3-7; n = 250), applying ice to the injured leg (median=4; usefulness interquartile range of 2-6; n = 258), applying high flow oxygen (median=3; usefulness interquartile range of 2-5; n = 252) and compression bandaging of the injured leg (median=0; usefulness interquartile range of 0-2; n = 257). Wall et al. (2010), while offering clinical practice guidelines, acknowledge that there is no proven method of preventing ALCS. However, using the evidence from experimental studies in human and animals with artificially raised compartment pressure (Garfin, Mubarak, Evans, Hargens, & Akeson, 1981; Weiner & Styf, 1994; Wiger, Zhang, & Styf, 2000), the authors recommend removal of circumferential bandages, positioning of limb at heart level and maintaining the ankle in the neutral position (Wall et al., 2010). They also recommend keeping the patient normotensive and administering high flow oxygen in patients with optimal oxygen saturation to optimise perfusion pressure and oxygen supply to affected compartment. Wall et al., (2010) suggest failure of these preventive methods should prompt fasciotomy to prevent ALCS. Box 5 summarises the preventive measures identified.

Insert box 3 near here

Diagnosis of ALCS

Prompt diagnosis and subsequent management of the problem is crucial (Hayakawa et al., 2009; Kalyani et al., 2011; Shadgan et al., 2008; Ulmer, 2002) as "the early identification of compartment syndrome can significantly reduce the physical, financial and vocational disability experienced by injured patient" (Shadgan et al., 2008, p. 586). The evidence identifies clinical observations together with compartment pressure monitoring as the most effective way of diagnosing ALCS (Al-Dadah et al., 2008; Blakemore et al., 2000; Garner & Handa, 2010; Kalyani et al., 2011; Kosir et al., 2007; McQueen & Court-Brown, 1996; Ozkayin & Aktuglu, 2005; Park et al., 2009; Tiwari et al., 2002; Wall et al., 2010; Wall et al., 2007).

Clinical observations

The clinical features identified in the literature include pain, pressure, paraesthesia, pulselessness and paralysis (Garner & Handa, 2010; Hayakawa et al., 2009; Mar et al., 2009; Tiwari et al., 2002; Ulmer, 2002; Wall et al., 2010; Wall et al., 2007). The most common sign that should alert a clinician is reported to be pain out of proportion to injury and pain on passive stretch of the related muscles (Cascio et al., 2005; Frink et al., 2007; Garner & Handa, 2010; Harris et al., 2006; Ozkayin & Aktuglu, 2005; Wall et al., 2010; Wall et al., 2007). Swelling and tenseness of the limb (Ozkayin & Aktuglu, 2005) was identified as another important indicator of ALCS. Paraesthesia, paresis/paralysis and pulselessness are considered to be late signs of ALCS (Garner & Handa, 2010; Tiwari et al., 2002; Wall et al., 2010; Wall et al., 2007; Wright, 2008). Box 4 summarises the clinical features of ALCS.

Insert box 4 near here

Kosir et al., (2007) used a predetermined screening tool to assess lower extremity compartment syndrome in critically ill trauma patients. They screened patients on admission and every four hours and, thereafter, for the first 48 hours. The examination included measurement of lower leg circumference (4 cm below the tibial tuberosity). The authors assessed pain using a 1-10 numerical pain rating scale (Kosir et al., 2007). They assessed calf pain at rest and pain on passive stretch (foot in plantar flexion and dorsal extension). The vascular examination included palpation and doppler assessment of the pulses of dorsalis pedis and posterior tibial arteries on a scale of 1-4, where 1 represented non-palpable and negative pulses on doppler assessment; 2 represented non palpable and positive pulses on doppler assessment; 3 represented diminished pulses and 4 represented palpable pulses. A neurological examination was conducted to examine motor as well as sensory components. Motor function was assessed by dorsal flexion of the foot (deep peroneal nerve), and plantar flexion of the foot (tibial nerve). A motor strength scale from 1-6 was used. Sensory function was assessed by testing between first second toe web space (deep peroneal nerve) and on the sole of the foot (tibial nerve) using a scale of 1-3 where 1 represented absent sensation. 2 represented diminished sensation and 3 represented normal sensation. In patients who were considered high risk and when physical examination was considered suspicious and unreliable the compartment pressure of anterior and deep posterior calf was also measured using an 18 gauge needle. The authors acknowledged that prompt diagnosis of ALCS requires a high level of suspicion and vigilant evaluation and re-evaluation. They believed that "clinical findings alone are an unreliable determinant of the presence of ALECS…"(Kosir et al., 2007, p. 273). It is important to note that the authors could not measure leg circumference in 51% (n=45) of cases due to postoperative casts, splints or dressings. In addition, pain assessment and neurological examination were unobtainable in 69% (n=45) due to the patient's neurological or sedation status. The recommended length of the screening period was shortened from 48 hours to 24 hours because all cases were diagnosed within 18 hrs. However, the authors identified physical examination as "…notoriously inaccurate" (Kosir et al., 2007, p. 274) and on completion of the study decided not to use physical examination as part of the screening tool. Despite this, the clinical features are consistently identified in other studies as useful, but it is important to conduct further multicentre prospective research to determine the effectiveness of these features in relation to developing an effective 'gold standard' screening tool.

Ulmer (2002), in a meta-analysis, used Bayes' theorem to calculate the predictive value of the main clinical features (pain, paraesthesia, paresis, pain on passive movement) and found that the sensitivity of clinical findings in diagnosing ALCS was only between 13-19%. The positive predictive value of clinical findings was 11-15%, whereas, the specificity and negative predictive value was 97-98%. The author concluded that, due to the high specificity and low sensitivity of these clinical features, it would be appropriate to use these features to exclude the diagnosis of ALCS in conscious patients. The low positive predictive value of these clinical features suggests that, on their own, these features are poor indicators of ALCS but the authors believed that the odds of ALCS increase in the presence of more than one clinical feature. The odds of ALCS in the presence of two, three and four symptoms were identified as 68%, 93 % and 98% respectively. The study by Ulmer (2002) is the only study that explored the sensitivity and specificity (important aspects when considering the validity of diagnostic tests) of the clinical features in the diagnosis of ALCS.

Compartment Pressure Monitoring

Compartment pressure monitoring (CPM) is identified as the most useful method in the diagnosis of ALCS in most of the studies reviewed (Blick et al., 1986; Frink et al., 2007; Harris et al., 2006; Janzing & Broos, 2001; Kosir et al., 2007; McQueen et al., 1996; McQueen & Court-Brown, 1996; Ozkayin & Aktuglu, 2005; Wall et al., 2010; Wall et al., 2007). This involves placing a cannula or catheter into the relevant limb compartment and using an electronic monitor to record pressure readings in the compartment (Shadgan et al., 2008; Tiwari et al., 2002). CPM is recommended as an adjunct to assessment of clinical features unless the diagnosis is obvious (Kosir et al., 2007; Mar et al., 2009; McQueen & Court-Brown, 1996). CPM is recommended as a diagnostic method in patients who are unconscious, uncooperative or confused because it does not rely on patient reported symptoms.

The benefits of CPM are said to outweigh associated risks as failure to monitor may lead to a missed diagnosis (McQueen & Court-Brown, 1996).

The normal compartment pressure is 10-12 mmHg, although may be different in different compartments (Garner & Handa, 2010). Pain and paraesthesia occurs at pressures between 20-30 mmHg. “Compartmental perfusion pressure (mean arterial pressure minus compartment pressure) should not exceed 70-80mmHg” (Garner & Handa, 2010, p. 476). The literature recommends consideration of fasciotomy when the intra-compartmental pressure (ICP) is above >30 mmHg (Blick et al., 1986; McQueen et al., 1996; McQueen & Court-Brown, 1996; McQueen et al., 2000). ICP can be read as an absolute value or as a derived value (ΔP) i.e. perfusion pressure (Diastolic blood pressure – Absolute compartmental pressure (ACP) = ΔP) (McQueen & Court-Brown, 1996). Perfusion pressure (ΔP) is considered to be more reliable as it accounts for physiological variation and helps to avoid unnecessary fasciotomies in patients who can tolerate high pressure (Garner & Handa, 2010). Differential pressure or perfusion pressure appears to be superior in diagnosing ALCS (Ozkayin & Aktuglu, 2005). Janzing and Broos (2001) recommended that only those patients who are either symptomatic or are difficult to assess should be subjected to ICP measurement. They concluded that, when used with clinical symptoms, or as a second measurement after one hour, ΔP had excellent specificity but low sensitivity and that, therefore, its use may result in missed diagnosis (Janzing & Broos, 2001). Other studies also recommended the use of compartment pressure monitoring only in unconscious patients (Al-Dadah et al., 2008; Harris et al., 2006). Wall et al., (2010) suggest monitoring CPM every four hours for a minimum of 24 hours after injury in unconscious or uncooperative patients. They maintained, however, that a high degree of suspicion is required for all unconscious patients with limb injuries. Various methods which can be used to measure ICP are discussed in the literature including; Wick catheter, simple needle manometry, infusion technique, slit catheter, central venous pressure manometer, side ported needle and fibreoptic transducer (Garner & Handa, 2010; Tiwari et al., 2002).

Other diagnostic methods

There is some evidence for the use of other methods such as raised serum creatine kinase (CK) levels in patients with thigh compartment syndrome (Mithofer et al., 2004). A review by Shadgan et al. (2008) explored the use of biomarkers such as myoglobin (MB) levels, CK levels, fatty acid binding protein levels (FABP), lactic acid levels, magnetic resonance imaging (MRI), ultrasound, scintigraphy, laser doppler flowmetry, near infrared spectroscopy, pulse oximetry, hardness measurement techniques, direct nerve stimulation, vibratory sensation and tissue ultrafiltration in detection of ALCS. They concluded that, although various methods seem to provide promising opportunities for the diagnosis of ALCS, further research is needed to determine their effectiveness.

It is the combination of clinical findings and CPM which makes the prompt diagnosis of ALCS possible. Clinical findings (Pressure, Paraesthesia, Paralysis, Pale, and Pulselessness), as discussed earlier, provide an important insight into the patient's condition in relation to tissue perfusion in the affected compartment. It is important to remember that the high specificity and low sensitivity of clinical features make them more appropriate in excluding ALCS in conscious patients. It is also important to remember that the odds of ALCS increase in the presence of more than one clinical feature. It is argued that CPM in such situations can provide a definitive diagnosis. In unconscious patients who are unable to articulate their symptoms, however, raised CPM may be the only way to identify ALCS.

DISCUSSION AND CONCLUSIONS

Review of the available evidence clearly reinforces current trends in practice. However, it is also important to take into account in any clinical decisions that the available evidence is scarce and is of not good quality.

Findings suggest that male patients under 35 years of age and who present with tibial or forearm fracture or soft tissues injuries as a result of high energy injury are at risk of developing ALCS

(McQueen et al., 1996; McQueen & Court-Brown, 1996; McQueen et al., 2000; Wall et al., 2010).. Anatomical differences between younger and older patients are postulated as the reasons that both young men and younger patients generally are more prone to the development of ALCS following injury (McQueen et al., 2000; Park et al., 2009). Further multi-centre and larger studies to explore risk factors ALCS in patients would be useful. Patients with bleeding disorders and/or on anticoagulation therapy are also considered at high risk of developing ALCS (McQueen et al., 1996; McQueen & Court-Brown, 1996; McQueen et al., 2000; Wall et al., 2010) as they have a greater risk of substantial bleeding into the compartment.

To reduce the risk of peripheral neurovascular deficit/ compromise due to ALCS, high risk patients should be subjected to careful monitoring of clinical findings and CPM (Hayakawa et al., 2009; Janzing & Broos, 2001; Shadgan et al., 2008; Wall et al., 2010). Pain out of proportion to injury and pain on passive muscle stretch appear to be the most effective clinical observations. In addition, paresis/paralysis, paraesthesia and pallor help in diagnosing peripheral neurovascular deficit in conscious patients with ALCS (Garner & Handa, 2010; Hayakawa et al., 2009; Ulmer, 2002) but are considered to be late signs of the condition that potentially compromise timeliness of intervention. These clinical observations are more effective when used in excluding the diagnosis rather than making the diagnosis as these observations have higher specificity than sensitivity (Ulmer, 2002; Wall et al., 2010; Wall et al., 2007) and it is important to consider that the evidence related to use and efficacy of clinical findings is very limited. Further systematic and rigorous studies are required to determine the effectiveness of clinical findings in the diagnosis of ALCS. This should include exploring the reliability, validity and efficacy of the screening methods and frequency of assessment suggested to date using appropriate diagnostic research methods.

Use of CPM in conjunction with clinical observations appears to be effective in the diagnosis of ALCS (Wall et al., 2010; Wall et al., 2007). In unconscious patients, use of CPM appears to be very effective in diagnosing ALCS (Wall et al., 2010; Wall et al., 2007) because of the difficulty in using patient-reported symptoms such as pain. CPM appears to be most relied on and effective method in prompt diagnosis of ALCS and, therefore, reducing the risk of peripheral neurovascular deficit. The presence of clinical findings and raised ICP, especially ΔP (Hayakawa et al., 2009; Wall et al., 2010), in conscious patients and raised ICP in unconscious patients, could be an indication of ALCS and, therefore, requires urgent medical review/intervention. Although there is wide variation in critical pressure recommended for the diagnosis, CPM <30 mmHg appears to be widely considered as appropriate (Hayakawa et al., 2009).

Analysis of the available evidence clearly reflects a need of further robust research studies considering various aspects of ALCS, including the identification of risk factors, diagnosis, prevention and management. More robust and rigorous studies based on multi-centre prospective research designs are needed. Appropriate diagnostic research methods need to be employed for this. Quantitative and qualitative exploration of the role of junior medical staff, nurses and other practitioners in the diagnosis of ALCS would also be beneficial. This should include consideration of clinician's experience and education and their role in the development of effective assessment and monitoring practice.

In view of the paucity and poor quality of the existing evidence and the need to offer guidance for practice, it is recommended that a consensus approach to the development of practice guidelines is considered. Although this approach is considered to provide a relatively low level of evidence, the highly important nature of the clinical problem requires that sound guidance is developed using the best method available until such time as sufficient numbers of robust studies have been conducted. This guidance can, at present, only be offered through a systematic approach to ascertaining consensus from a carefully selected group of clinical experts and based on the existing literature as well as clinical expertise and experience. An alternative or adjunctive approach to consensus may be to use Delphi methods to explore clinicians' views of best practice.

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Box 1: Causes of ALCS

Orthopaedic	Tibial fracture
	Forearm fracture
	Calcaneal fracture
	Closed fracture
	Open fracture
	Nailing procedures
	Soft tissue injury in patients with bleeding disorders and on anticoagulation therapy
Others	Ischaemia- reperfusion injury
	Haemorrhage
	Phlegmasia caerulea dolens
	Vascular puncture in patients with bleeding disorders
	Intravenous/ arterial drug injection
Soft tissue injury	Prolonged limb compression due to e.g. traction, plaster cast
	Crush injury
	Burns

Box 2: High risk patients who should be assessed for ALCS

- Males aged <35 years with fractures of the tibia/ radius/ ulna
- High energy injuries resulting in open fractures or soft tissue injuries
- Males <35 years of age with bleeding disorders or on anticoagulants who sustained soft tissue injuries
- Patients with crush injuries
- Patients with prolonged limb compression (due to plaster casts, drug overdose and other causes of unconsciousness)
- Children with lower or upper limb fractures

Box 3: Measures to prevent ALCS

Removing circumferential bandages and casts
Positioning the affected limb at heart level
Elevating the injured leg
If the leg is injured, the ankle should be maintained in the neutral position
Ensuring that the patient is normotensive
Administering high flow oxygen if oxygen saturation is suboptimal

Box 4: Clinical features of ALCS

Pain	Pain out of proportion to injury Pain on passive stretching of the muscles of the compartment
Pressure	Swelling and tenseness of the limb/ firm to touch
Paraesthesia	Decreased sensation, numbness; diminished two point discrimination
Paralysis	Inability to use the muscle (e.g. foot drop)
Pallor	The limb appears different in colour and may feel cold
Pulselessness	Absent or weak pulses

Table 1: Details of the 22 included studies

	Author	Year	Country	Design & data collection	Population	Sample Size
1	Blick et al.,	1986	USA	Retrospective record review	Patients with Tibial fracture	198
2	Uslu et al.,	1995	Turkey	Retrospective record review	Patients with trauma and at risk of compartment syndrome	27
3	McQueen et al.,	1996	UK	Retrospective review	Patients with Tibial fracture complicated with ACS	25
4	McQueen & Court Brown	1996	UK	Prospective observation	Patients with Tibial diaphyseal fractures	116
5	McQueen et al.,	2000	UK		Patients with acute compartment syndrome	164
6	Blakemore et al.,	2000	USA	Retrospective review	Children with upper extremity long bone fracture	978
7	Janzing & Broos	2001	Belgium	Prospective observation	Patients with Tibial fracture	97
8	White et al	2003	UK	Case control	Patients with Tibial diaphyseal fractures	101 (40 cases)
9	Vailncourt	2004	Canada	historical cohort record review	Patients who had fasciotomy for ACS	76
10	Mithofer	2004	USA	Retrospective record review	Patients with thigh compartment syndrome	28
11	Ozkayin & Aktuglu	2005	Turkey	Prospective observation	Patients with Tibial diaphyseal fractures at risk of developing ACS	39
12	Cascio et al.,	2005	USA	Retrospective record review	Patients who had fasciotomy for ACS	28
13	Davis et al	2006	Canada	Postal Survey Questionnaire	Anaesthetists	243
14	Harris et al.,	2006	Australia	Randomised Control Trial	Patients with Tibial fracture	200
15	Kosir et al	2007	USA	Prospective observation	Shock Trauma intensive care patients	45
16	Wall et al.,	2007	Australia	Postal Survey	Surgeons and Registrars	286
17	Frink et al.,	2007	Germany	Prospective observation	Patients who had fasciotomy for ACS	26
18	Katz et al.,	2008	USA	Prospective observation	Trauma patients presenting to the emergency department	164
19	Kierzynka & Grala	2008	Poland	Case control	Patients with calcaneal fractures	13
20	Al-Dadah et al.,	2009	UK	Prospective Cohort	Patients with Tibial fracture	218
21	Park et al.,	2009	USA	Retrospective Cohort review	Patients with Tibial fracture	414
22	Ferlic et al.,	2012	Austria	Retrospective record Review	Children with lower leg fracture	1028