Chapter 1
Diagnostic Dilemma for the Orthopedic Surgeon

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Background

1. Compartment syndrome is associated with serious long-term morbidity.
2. Appropriate treatment is invasive and involves its own risks.
3. The presentation of compartment syndrome is variable.
4. The diagnosis of compartment syndrome relies largely on clinical findings.
5. Pressure monitoring may provide supplemental but imperfect diagnostic guidance.

The diagnosis and management of compartment syndrome represents a dilemma for clinicians. A major cause of concern in treating compartment syndrome is the potentially devastating outcome if not treated effectively. Compartment syndrome results in ischemia within a fascial compartment that eventuates into necrosis of the tissues it encompasses. Sequelae of missed compartment syndrome include loss of function, contracture of joints, limb deformity, and painful neuropathies [1, 2]. These complications persist and significantly reduce quality of life. In light of this, the timely diagnosis and treatment of compartment syndrome is a focus of orthopedic surgery training. However, an inconsistency in practice remains. O'Toole et al. [3] demonstrated a wide variation between orthopedic surgeons, even within a single practice of orthopedic trauma specialists at a level I trauma center. A diagnostic rate of compartment syndrome for tibia fractures ranged from 2% to 24% depending on the surgeon who was on call. This demonstrates the lack of consensus and clarity with regard to diagnosis.

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The prognosis is grave in cases of missed compartment syndrome, but there are even severe repercussions for a diagnosis delayed by a matter of hours. If the treating surgeon correctly recognizes compartment syndrome, but attempts late release of the fascia over a necrotic compartment, the patient is subject to a high risk of infection and life-threatening complications [4]. Sheridan and Matsen report an infection rate of 46%, and an amputation rate of 21% after fasciotomy was delayed by 12 hours [5]. Only 2% of those patients treated on a delayed basis had a normal functioning extremity at final follow up, compared to 68% in those treated earlier. Reperfusion after severe muscle necrosis may further increase systemic effects. As myonecrosis develops and reperfusion is achieved, myoglobin is released into circulation, further contributing to myoglobinuria, metabolic acidosis, and hyperkalemia. This may lead to renal failure, shock, and cardiac events [6, 7]. Although fascial release is the appropriate treatment of acute compartment syndrome, clinicians must be aware of the dangers of late surgical intervention.

In addition to the serious consequences of missed or delayed treatment of acute compartment syndrome, clinicians and patients may face complications even in the setting of treatment with the correct technique and timing. A retrospective study looking at the long-term outcomes of fasciotomy placement by Fitzgerald et al. does not convey a completely benign procedure [8]. Reviewed outcomes of 164 patients over an 8-year period showed pain (10%), altered sensation (77%), dry skin (40%), pruritis (33%), discoloration (30%), swelling (13%), and muscle herniation (23%). Scarring of the extremities caused patients to keep extremity covered (23%), changed hobbies (28%), and even changed occupation (12%). Fasciotomy sites may also require the patient to undergo multiple interventions of attempted wound closure or grafting. In the setting of operative fractures, the placement of fasciotomy incisions may complicate surgical approach and increase risk of infection and nonunion of fracture sites.

In addition to the issues relating to the morbidity, complications, and time pressure of compartment syndrome, the diagnosis itself is rarely straightforward. Patients may present following a typical injury and exhibit classic symptoms, but they will likely include a constellation of positive and negative findings. The diagnostic dilemma of acute compartment syndrome is always present because it is a clinical diagnosis. The classic signs and symptoms of acute compartment syndrome are often listed as the 5 or 6 “Ps” including some variation of pain, pressure, pulselessness, paralysis, paresthesia, and pallor [1, 2, 5, 9]. Early descriptions of diagnosis of compartment syndrome begin with those of ischemic contracture in the upper extremity by Volkmann, followed by more recent observations in the lower extremity, such as those described by Seddon [1]. However, while describing the diagnostic “Ps” of compartment syndrome, Seddon noted that they were absent in over half of the cases he reviewed [10]. These diagnostic findings may simply be unavailable in a timely manner. Pain out of proportion or in response to passive stretch may be an early indicator for compartment syndrome, but is unreliable in cases where a patient is obtunded or experiencing a neural deficit. Other signs, such as pallor or paralysis, may be delayed to the point of being useless.

The pressure gradient within the fascial compartment exceeds perfusion pressure in order for compartment syndrome to set in. It is not often possible to specify when this threshold is reached, but we do know that the clinician only has a limited amount of time by that point. This threshold and the amount of time before irreversible damage is done has been a focus of study. A clear relationship between compartment pressure and blood pressure has been established with the use of animal models and observations of intra-compartmental pressures, tissue histology, oxygenation, and magnetic resonance spectroscopy [11, 12]. A study by Heckman et al. documented complete irreversible ischemic infarction of skeletal muscle by inducing elevated intra-compartmental pressures for 8 hours [8]. Variable recovery may be expected with earlier intervention. The threshold at which ischemia begins is difficult to predict. It may coincide with the traumatic event or set in insidiously. McQueen et al. [13] reported the average treatment of compartment syndrome 7 hours after manipulation and fixation in 13 cases with continuous monitoring and a delayed onset as late as 24 hours postoperatively. A late-onset variety of compartment syndrome has been reported as late as 4 days after an inciting event [6, 14].

Another factor adding to diagnostic difficulty of compartment syndrome is the myriad of injuries and conditions that may precede its onset. A classic scenario of acute compartment syndrome in the lower extremity is the result of a closed tibial shaft fracture [2, 15, 16]. However, compartment syndrome may develop with a huge variety of situations. Possible etiologies may include open and closed fractures, vascular injury, burns, intravenous access leakage, contusion, coagulopathies, constrictive dressing, patient positioning during surgery, drug overdose or animal bites [17]. Therefore, clinicians cannot rely on specific presentation factors to rule out developing compartment syndrome. The most common causes of acute compartment syndrome, as described in a series presented by McQueen et al. [18], was fracture (69%) followed by soft tissue injury without fracture (23.2%). The most common fractures observed were tibial diaphysis (36%) and distal radius (9.8%).

Compartment syndrome is a stressful situation for the patient and clinician. There exists a combination of significant morbidity, risks of invasive intervention, time limitations, and variations in presentation. Unfortunately, there is also the awareness that compartment syndrome and its sequelae are the source of a significant amount of litigation [19–21]. The prospect of undergoing a medical malpractice claim or suit is daunting and can be especially draining for physicians unaccustomed to the medicolegal process. It will likely create a significant cost in time, energy, finances, and emotional burden [22]. Orthopedic surgeons are a medical specialty at relatively higher risk of encountering medicolegal claims [23]. Given the high morbidity to patients, awards for plaintiffs or settlements may be large. One national database review of suits involving compartment syndrome found an average award for settlements out of court to be over 1 million dollars and average verdict awards for plaintiffs to be over 2 million dollars [17]. A review of claims involving compartment syndrome by Bhattacharyya and Vrahas found the average time commitment to resolve a claim to be 5.5 years [17].

Recommendations

The diagnosis of compartment syndrome is largely based on clinical judgment, history, and physical exam. Patient history in regard to mechanism of injury may be helpful in identifying factors that would increase risk of soft tissue injury such as crushing or high energy trauma. History may also include other medical risk factors such and coagulopathies or infusion injury. Findings on the exam typically focus on the presence of pain, pressure, pulselessness, paralysis, paresthesia, and pallor. These findings are especially instructive if they correspond to a specific compartment in question. The presence of firmness versus compressibility of a compartment is advantageous as it does not require consciousness or cooperation of a patient and may be the earliest manifestation of compartment syndrome. It is important to note that acute compartment syndrome is not a static process and cannot be adequately ruled out in a suspected case based on a single evaluation. Rather, it is advisable to include serial examinations, typically spaced 1–2 hours apart to ensure any changes may be detected and addressed in a timely manner [16].

Measurement of compartment pressures can be a useful tool in situations where the clinical picture is muddled. There are multiple techniques described for pressure monitoring, including slit catheter, wick catheter, infusion, and side port needle devices. Commercially available side-port needle devices have gained popularity with their ability to measure multiple compartments and ease of use [8, 14]. As the development of ischemia is dependent upon a differential between compartment pressure and perfusion pressure, the threshold at which compartment pressures should be considered dangerous is often described in comparison to diastolic pressures. This differential, commonly described as ΔP, was described in canine models with a critical pressure being within 20 mmHg of diastolic pressure, resulting permanent abnormalities noted in muscle tissue. In a prospective study, McQueen and Court-Brown observed 116 patients with tibial diaphyseal fractures who underwent continuous anterior compartment pressure monitoring for 24 hours [24]. They noted absolute pressures reaching as high as 50 mmHg in multiple patients, but only three met a fasciotomy threshold criteria of ΔP less than 30 mmHg. No other patients were noted to develop compartment syndrome, resulting in a ΔP less than 30 mmHg being widely accepted as a threshold for surgical intervention.

Limitations and Pitfalls

Although clinical findings are important in diagnosis of acute compartment syndrome, the predictive value of individual findings is low. One analysis of 4 prospective studies involving 132 cases of compartment syndrome found that the positive predictive value of individual findings such as pain, paresthesia, and paresis was low at 11–15%, but the likelihood of successful diagnosis did increase with multiple clinical findings. However, the negative predictive value was as high as 98% [25]. Therefore, the presence of individual clinical findings was not as useful as noting the absence of such findings, to rule out the presence of compartment syndrome.

The use of local nerve blocks, epidural or regional anesthesia, is not recommended in the setting of possible compartment syndrome. Local anesthetics may mask pain from increasing compartment pressures or neurologic symptoms that would usually alert clinicians [26]. Additionally, the use of epidural anesthesia may increase the risk of developing compartment syndrome as sympathetic blockade will increase local blood flow and possibly exacerbate intracompartmental pressure increases [27, 28].

In situations where clinical findings of compartment syndrome may be unreliable, needle compartment pressure monitoring is often useful to evaluate an impending compartment syndrome. In these cases, a ΔP less than 30 mmHg will indicate the possible need for fasciotomy. However, compartment pressure monitoring is not a panacea for challenging clinical scenarios. As demonstrated by Heckman et al., compartment pressures taken from a few centimeters away from fracture site yield unreliable results [15]. One study observing 48 consecutive patients with tibial shaft fractures who were not suspected of developing compartment syndrome underwent pressure measurement of all four lower leg compartments [29]. There was an observed false-positive rate of 35% with the standard threshold of ΔP less than 30 mmHg. Depending upon a single compartment pressure as a sole criteria of surgical intervention would therefore result in unnecessary surgery and morbidity. This reinforces the necessity of clinical observations and judgment that provide context and correct diagnosis compartment syndrome.

Future Directions

The goal of future improvements in the diagnosis of compartment syndrome will obviously focus on increased accuracy, speed, and ease of diagnosis. The current state of practice requires clinical judgment resulting from experience and training. Although the use of pressure monitoring provides a more objective finding, it is a technique that is dependent upon technique and a limited understanding of the threshold of ischemic changes within extremities. Other modalities to better predict and measure intracompartmental pressures will likely improve our ability to diagnose and treat compartment syndrome.

Take-Home Message
The diagnosis and management of suspected compartment syndrome is a troubling situation for any clinician. The risks for long-term morbidity are present even with the most attentive and thorough evaluation. One must be suspicious not only in cases of high-energy trauma and crush injuries but also in unusual circumstances when patients show concerning signs of pressure and pain. The use of compartment pressure monitoring is a useful supplemental tool, but surgeons should be hesitant to base management solely on a single pressure measurement. Clinical judgment and close monitoring are the best tools we have to treat patients presenting with suspected compartment syndrome.

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