

# Chapter 7

## Fasciotomy: Upper Extremity



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### Background

- Early fasciotomy is the standard of care for upper extremity compartment syndrome (UECS) and may prevent the development of irreversible contractures of forearm and hand musculature, a pathology initially described by Volkmann [1]. Compartment syndrome (CS) is a feared orthopedic complication and a common cause for permanent functional damage and limb loss as well as one of the most common causes for litigation in orthopedic surgery [2, 3].
- CS of the forearm is the second most common cause of CS in the extremities given the injury proneness of the upper extremity and hand as a prime organ of prehension and grasp [4]. Given this important physiologic function, one can argue that the functional loss due to an established CS is higher than that of the lower extremity.
- For UECS, a high level of alertness to clinical symptoms such as pain to passive stretch and increasing pain or analgesic requirements is key to not miss the diagnosis in the alert patient.
- UECS shares common etiologies for CS seen in other body areas: either an external reduction of CS size such as external pressure from casts, dressings, and gravity or increase in compartmental size as seen in bleeding and fracture displacement, microvascular barrier damage in ischemia, burn injury, and envenom-

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ations [4]. Several additional etiologies are pertinent to UECS such as iatrogenic extravasations of intravenous fluids, upper extremity arterial catheterizations [5], and electrical trauma [6].

- UECS is most commonly encountered in the forearm, which has three designated compartments (i.e., the lateral (mobile wad), the dorsal extensor, and the volar) of which contains the bulk of muscle mass in the flexor compartment. There are ten designated hand compartments which can be affected in hand compartment syndrome as seen, for instance, in crushing injuries (exploded hand syndrome), fractures and dislocations, as well as extravasations.
- When performing fasciotomies for UECS, special emphasis must be placed to decompress the muscles of the deep flexor compartment due to their non-redundant blood supply which makes them especially prone to ischemic damage [7].

## Recommendations

### *Pathophysiology*

Compartment Syndrome is a result of tissue ischemia which arises from a reduction of the pressure gradient between the vascular bed and the surrounding soft tissues which can become pressurized due to intracompartmental pressure rise or external pressure [8].

The severity of a CS has been described by several authors as dependent on time and amount of pressure as well as the degree of tissue injury [4]. Recommendations are to differentiate separate phases of CS, which may help guide treatment [4]. As such, pending nonestablished CS can be differentiated from the acute, reversible CS (within 8 hrs of trauma), and acute irreversible CS (later than 8 hrs). This is separated from late established CS and even later in the upper extremity Volkmann's contracture as a sequelae of CS. Independent from these acute traumatic conditions, chronic exertional CS can be seen as its own entity with different treatment modalities.

### *Diagnosis*

Given the importance of early intervention before irreversible damage has incurred, the diagnosis of CS in the upper extremity relies primarily on the recognition of clinical scenarios where a CS can be expected in combination with detection of early clinical signs such as pain to stretch – increasing pain out of proportion and increased analgesic needs. The classic signs of compartment syndrome (“5 or 6 Ps”) included late irreversible changes and are not recommended in diagnosing early compartment syndrome [9].

Pressure measurements – especially in the obtunded patient – remain an important adjunct to CS diagnosis. The absolute pressure theory as described by Matsen has been replaced by differential pressure models in which fasciotomy is indicated when the delta pressure, measured as the difference between the compartmental pressures and arterial or venous blood pressures, falls to 30 and 20 mmHg, respectively [10].

When using pressure measurement devices, the higher accuracy of side port or slit catheters as compared to straight catheters has been pointed out [11]. In addition, it was shown that pressures measured within a single compartment can vary significantly with regard to distance to fracture site [12]. So standardization of measurement methods and sites is recommended for repeat measurements. With regard to the most commonly affected deep flexor compartments in UECS, safe techniques for pressure measurement have been described [13].

## *Treatment*

Close observation with documented hourly repeat exams of a patient with concerns for a pending CS is mandatory. This includes removing all constrictive dressings and tight splints. As the provision of tissue oxygenation is key to prevention of a CS, medical optimization of a patient is of paramount importance. This includes full resuscitation, optimization of blood pressure and oxygenation, as well as keeping the extremity at slight elevation (heart level). Further elevation will reduce perfusion pressures, reduce differential pressures, and thereby increase tissue damage.

If medical optimization is unsuccessful or the patient presents with an acute CS, fasciotomy must be performed as emergent procedure to decompress tissues and salvage tissue function.

General recommendations for the upper extremity are similar to concepts of fasciotomy elsewhere in the body in that surgical decompression must be performed through adequate incisions which parallel the length of the fasciotomy incisions. Care must be taken not to add morbidity by injuring cutaneous branches in the forearm (e.g., MABC/LABC) and to decompress all components of the compartment. Given the importance of maintaining joint motion in the upper extremities and protecting important neurovascular bundles which could be exposed by nonjudicious incisions, recommendations are to perform curvilinear incisions and to avoid crossing flexion creases in a straight fashion.

At the brachium level, three compartments are described: the volar (anterior) compartment containing the biceps and brachialis and coracobrachialis, which is released through an anterior or anterolateral approach, the posterior compartment with the three heads of the triceps, and the deltoid compartment – the latter two can be decompressed through a posterolateral approach taking care to release the tight epimysium of the deltoid compartment.

In the more common forearm compartment syndrome, care must be taken to decompress both the superficial and deep components of the volar flexor compartment. This includes the investing fascia of individual fascial compartments in the deep

flexor muscles (PQ, FDP, FPL). Proximally, the lacertus fibrosus must be released as a possible site of compression as well as distally the carpal tunnel. The dorsal extensor compartment is approached through a dorsal midline straight incision – the mobile wad can usually be released via either the volar or dorsal approaches.

When releasing the forearm, consideration to progressive swelling-induced exposure of released neurovascular bundles must be taken into account. While the standard extended Henry type of release with Brunner style zigzag extension into the carpal tunnel and antecubital fossa may be adequate, flap creating exposures which maximize a radial-based forearm flap and ulnar to radial dissection across the flexor crease of the wrist may optimize median nerve coverage as well as preserve the option for later radial artery-based flap coverage in complex soft tissue defects of the hand. Specific injury patterns such as burn or electrical trauma may need additional release of eschar and neurovascular bundles.

For compartment syndromes of the hand and fingers, standardized incisions are necessary to minimize morbidity given the tight skin envelope and complex anatomical content of these compartments. On the volar side, longitudinal incisions paralleling the radial and ulnar border of thenar and hypothenar eminences are described to optimize the release of these muscle compartments and protect neurovascular bundles. Commonly, carpal tunnel releases for UECS are performed as extensile approaches to connect to the forearm fasciotomy but can also be done in isolation, in which case the carpal tunnel must be released 4–5 cm into the volar forearm fascia. On the dorsal side, the release of the interosseous spaces is usually performed via two longitudinal incisions overlying the first and second as well as third and fourth interosseous spaces. These incisions parallel the metacarpal shafts, and care must be taken to preserve a wide enough skin bridge. When releasing finger compartments, additional morbidity by accidentally damaging dominant sensory nerves must be avoided. As such, radial incisions are performed on the thumb and index finger and ulnar incisions on the index long and ring fingers. These unilateral, midaxial incisions traverse the Cleland ligament – the dorsal roof of the neurovascular bundle – and thus release compression around these structures.

After fasciotomies for UECS, special care must be taken to ensure functional rehabilitation is started soon. This includes splinting the extremity (especially hand) in a functional position in the operating room and starting with early therapy including edema care and coverage once second look procedures confirm a viable wound bed [14]. Early coverage of important functional units takes precedent and can include flap and/or skin graft coverage as well as dynamic wound closure techniques. In all instances, the creation of a secondary iatrogenic compartment syndrome by overly tight closing compartments must be excluded [6].

## Limitations and Pitfalls

Unfortunately, the correct diagnosis and early treatment of every CS at a function recoverable stage appears to be still an elusive target. This may be explained by the complex multifactorial etiology of CS and the progressive nature of the

disease which can be easily missed unless there is accurate documentation and standardized handover between care teams.

The fear of delayed fasciotomies and the possible risk of adverse outcomes to patients as well as litigation to institution and provider may result in an overly broad indication of fasciotomies which if done improperly can add significant morbidity to an already traumatized limb [15]. This concern may be especially applicable to the noncooperative, obtunded patient as well as in the young pediatric populations where it may be difficult to elicit clinical signs of CS. It is not surprising that especially in the pediatric patient population, there is a higher rate of plaintiff verdicts [2].

From a legal perspective, one of the main concerns and causes for successful plaintiff verdicts in the treatment of CS appears to be a late release of an established CS defined as later than 8 hrs post documentation of a CS [16]. At this point, it becomes easier for the plaintiff counsel to argue that the incurred damage was due to the late intervention and independent of a prior trauma [2]. While late intervention is a common pitfall seen in CS, also in the upper extremity, a common pitfall lies in the inadequate release of a CS. This can be seen in failure to release adjacent structures which can be affected by CS – here the incomplete release of neurovascular bundles in the AC fossa and carpal tunnel need to be stressed. Also the failure to completely release deep flexor compartments in the forearm and inadequate incisions across flexor creases commonly result in avoidable morbidity. Of special legal concern is the occurrence of an iatrogenic CS, which in the setting of an upper extremity surgery can be seen after tight fascial closures of forearm fractures or attempts of early closure of fasciotomy incisions. The release of established and irreversible CS is associated with high infection rates and limb loss and does not add benefit [17]. Here consideration for a midterm release of forearm and hand contractures should take precedent [18].

## Future Directions

While fasciotomies appear to remain the standard surgical treatment for established CS, standardization of technique to minimize morbidity is an ongoing effort.

Future research is directed at improving diagnostic tools and minimizing delays in treatment as well as optimizing wound care to facilitate early closure to prevent secondary limb injuries [19].

Similar to the active research of breakthrough pain in cancer patient care [20], a future research direction may be aimed toward improved and possibly automated detection of inadequate analgesia as an early sign of evolving CS. Going one step further, earlier research demonstrated that predictive algorithms can be developed to alert clinicians to the heightened risk for developing a CS [21] in patients with specific injury diagnosis and scenarios such as increased blood loss, vascular injury, and open fractures. While this may seem trivial to the specialized clinician, missed compartment syndromes continue to occur, and every option to prevent these should be utilized.

There is ongoing research into the development of improved pressure sensors as well as combined sensors for tissue pH, muscle microvascular blood flow, and oxygenation [22–24]. This includes measuring perfusion pressure with photoplethysmography and near-infrared spectroscopy-pH probes [23]. An interesting novel but experimental method is the use of ultrafiltration catheters to measure in real time the accumulation of muscle injury markers such as CK and LDH [25].

It appears possible that advances in these different diagnostic avenues can improve our skills in rapid detection and treatment of the CS at an early stage.

### Take-Home Message

- Surgeon must be alert to possible development of a compartment syndrome even before clinical symptoms have set in and in certain circumstances perform prophylactic fasciotomies (high energy segmental fractures, ischemia-reperfusion trauma, obtunded patients).
- The deep flexor muscles of the forearm are especially injury prone to ischemia and compressive damage due to more limited vascular supply (angiosome concept) and separate investing fascia.
- In electric trauma and burn injury, perform separate release of neurovascular structures and constricting eschar.
- Any diagnosed CS needs emergent fasciotomy. This procedure must be performed in a standardized way to protect key functional structures (e.g., NV bundles, tendons, and joints). In the upper extremity, special care must be taken to protect these structures from prolonged exposure and secondary compression due to swelling of fasciotomy flaps or compression from unreleased fascial septal structures including the bicipital aponeurosis.
- Early functional rehabilitation including splinting and compression therapy is essential in the treatment of upper extremity compartment syndrome and must start after fasciotomy.
- Communication of all team members nursing staff, resident team, and provider is essential to avoid delay in care. All findings must be documented and closely monitored in cases of suspected but not established compartment syndromes.

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