Compartment Syndromes and Fasciotomies of the Extremities

Mark W. Bowyer

Introduction:

All surgeons caring for patients with trauma to the extremities, or practicing vascular surgery must be able to recognize and surgically treat compartment syndromes. This entity results from a variety of causes. The final outcome is increased compartment pressure that exceeds the arterial inflow, with resultant ischemia and necrosis. Failure to identify and treat compartment syndromes in a timely fashion leads to preventable morbidity and mortality, and is a common source of litigation. The diagnosis of compartment syndrome is largely clinical, but measurement of compartment pressures may be useful in patients with equivocal findings or altered level of consciousness. The below- knee lower extremity is most commonly affected, followed much less frequently, by the forearm, thigh, buttock, foot and hand

Pathophysiology/Epidemiology:

Compartment syndrome has been found wherever a compartment is present: hand, forearm, upper arm, abdomen, buttock and the entire lower extremity. The pathophysiology of compartment syndrome is relatively straightforward. Groups of muscles and their associated nerves and vessels are surrounded by thick fascial layers that define the various compartments of the extremities. These compartments are of relatively fixed volume, as the fascial layers are unable to expand. Compartment syndrome occurs either when compartment size is restricted or compartment volume is increased. This can occur because of fractures, vascular injuries, electrical burns, blast injuries, crush injuries, too tight casts of splints, or tissue trauma after fracture reduction.

As the pressure within the compartment (from blood, fluid, or external pressure) increases, the tissue perfusion decreases and cellular metabolism is impaired, leading to cellular death. If this pressure is not relieved in a timely fashion, irreversible damage will occur. The usually quoted time is 4 to 6 hours, but it may be as little as an hour for a patient in shock. Polytrauma patients with hypotension can sustain irreversible injury at lower compartment pressures than normotensive patients, and a very high index of suspicion should be maintained in this group.

The leg (calf) is the area that is most commonly affected, accounting for 68% in a large civilian series (Branco), followed by the forearm (14%), and the thigh (9%). In a review of 294 combat-injured soldiers undergoing 494 fasciotomies, Ritenour et al reported the calf as the most common site (51%) followed by the forearm (22%), thigh (8%), upper arm (7%), hand (6%), and the foot (5%).

Certain injury patterns have been associated with higher likelihood of needing fasciotomy. Branco et al found that incidence of fasciotomy varied widely by mechanism of injury (0.9 % after motor vehicle collision to 8.6% after a gunshot wound). Additionally, the need for fasciotomy was related to the type of injury, ranging from 2.2% for patients with closed fractures to 41.8% in patients with combined venous and arterial injuries. The study by Branco identified ten risk factors associated with the need for fasciotomy after extremity trauma: young males, with penetrating or multi-system trauma, requiring blood transfusion, with open fractures, elbow or knee dislocations, or vascular injury (arterial, venous, or combined) are at the highest risk of requiring a fasciotomy after extremity trauma.

Diagnosis:

The diagnosis of compartment syndrome is a clinical diagnosis. The classically described five "Ps" – pain, pallor, paresthesia, paralysis, and pulselessness – are pathognomonic of compartment syndrome. However, *these are usually late signs. Extensive and irreversible injuries may have taken place by the time they are manifested.* The most important symptom of compartment syndrome is *pain greater than expected due to the injury alone.* Remember that the loss of pulse is a late finding, and the presence of pulses does not rule-out compartment syndrome! *The presence of open wounds does* not *exclude compartment syndrome*. In fact, the worst open fractures are actually more likely to have compartment syndrome.

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In actual practice, tissue pressure (compartment pressure) measurements have a limited role in making the diagnosis. However, in polytrauma patients with associated head injury, drug and alcohol intoxication, intubation, spinal injuries, use of paralyzing drugs, extremes of age, unconsciousness, or low diastolic pressures, measuring compartment pressures may be of use in determining the need for fasciotomy. The pressure threshold for making the diagnosis of compartment syndrome is controversial, though most prevalent in the literature is 30 mm Hg . Many surgeons use the "Delta-P" system. The compartment pressure is subtracted from the patient's diastolic blood pressure to obtain the Delta-P. Muscle is at risk when the compartment pressure is within 10-30 mmHg of the diastolic pressure. If the Delta-P is less than 30, the surgeon should be concerned that a compartment syndrome may be present. Other factors to consider when considering fasciotomy are length of time of transport to definitive care and ability to do serial examination.

Compartment syndrome is, first and foremost, a clinical diagnosis. A patient manifesting signs and symptoms of compartment syndrome should be operated on expeditiously. In patients with polytrauma, compartment syndrome should be a diagnosis of exclusion and one should have a low threshold for performing fasciotomy- especially in patients with vascular trauma. The safest approach is to err on the side of early and aggressive intervention. In other words, if you are thinking about doing a fasciotomy, it should be done. The reliance on clinical examination with a low threshold for fascial release may result in unwarranted fasciotomies, but it avoids the grave consequences of a missed diagnosis.

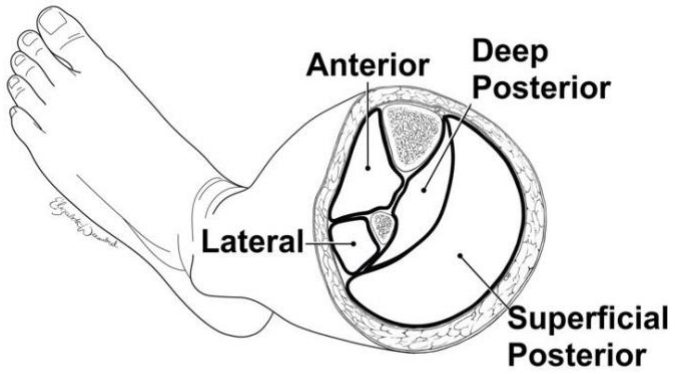
Treatment of Compartment Syndrome:

The definitive treatment of compartment syndrome is *early and aggressive fasciotomy.* In patients with vascular injury who require fasciotomy in conjunction with a vascular repair, it makes great sense to perform the fasciotomy *before* doing the repair. The rationale for this is that the ischemic compartment is likely to already be tight and thus will create inflow resistance to your vascular repair, making it susceptible to early thrombosis.

The remainder of this chapter will detail the relevant anatomy, landmarks, step by step surgical techniques, and pitfalls associated with fasciotomy of the extremities most commonly affected by compartment syndrome.

Lower Leg Fasciotomy:

The lower leg (calf) is the most common site for compartment syndrome requiring fasciotomy. The leg has four major tissue compartments bounded by investing muscle fascia:



Cross-sectional anatomy of the mid-portion of the left lower leg, depicting the four compartments that must be released when performing a lower leg fasciotomy.

It is important to understand the anatomical arrangement of these compartments as well as some key structures within each compartment in order to perform a proper four-compartment fasciotomy. It is not necessary to remember the names of all the muscles in each compartment, but it is useful to remember the following:

- The anterior compartment contains the anterior tibial artery and vein and the common peroneal nerve (recently renamed the common fibular nerve);
- The lateral compartment contains the superficial peroneal nerve (recently renamed the superior fibular nerve), which must not be injured;
- The superficial posterior compartment contains the soleus and gastrocnemius muscles;
- the deep posterior compartment contains the posterior tibial and peroneal vessels and the tibial nerve.

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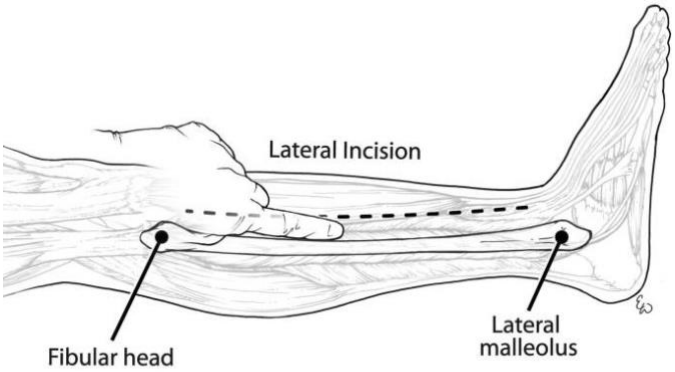
When dealing with a traumatically injured extremity, there is absolutely no role for getting fancy. The use of a single incision for four-compartment fasciotomy of the lower extremity is mentioned only to condemn it. Attempts to make cosmetic incisions should also be condemned and the mantra should be "bigger is better." Compartment syndrome of the lower extremity dictates **two incision four-compartment fasciotomy** with *generous* skin incisions.

There are several key features that will enable a successful two incision four-compartment fasciotomy. One of the key steps is proper placement of the incisions. As extremities needing fasciotomy are often grossly swollen or deformed, marking the key landmarks will aid in placement of the incisions. It is useful to mark the patella and the tibial tuberosity as well as the tibial spine which serves as a reliable midpoint between the incisions. The lateral malleolus and fibular head are the landmarks used to identify the course of the fibula on the lateral portion of the leg. The lateral incision is marked just anterior (~1 fingerbreadth) to the line of the fibula, or "***A FINGER IN FRONT OF THE FIBULA***." It is important to stay anterior to the fibula as this minimizes the chance of damaging the superficial peroneal (superior fibular) nerve and helps to correctly identify the intermuscular septum between the anterior and lateral compartments.

The medial incision is made one thumb-breadth below the palpable medial edge of the tibia, or ***A THUMB BELOW THE TIBIA***. The extent of the skin incision should be to a point approximately three fingerbreadths below the tibial tuberosity and above the malleolus on either side. It is very important to mark the incisions on both sides prior to opening them, as the landmarks of the swollen extremity will become rapidly distorted once the incisions are made.



Placement of the lateral incision, as shown on the right leg: the fibular head and lateral malleolus are used as reference points to mark the edge of the fibula. The lateral incision (dotted line) is marked one finger-breadth in front of this ("A FINGER IN FRONT OF THE FIBULA").

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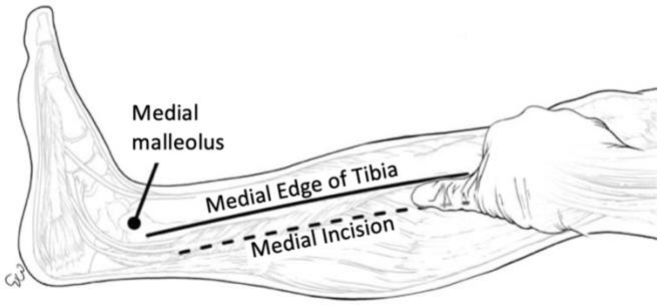
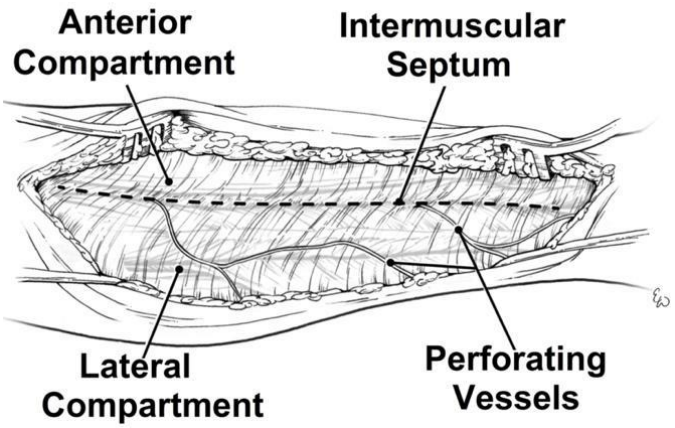


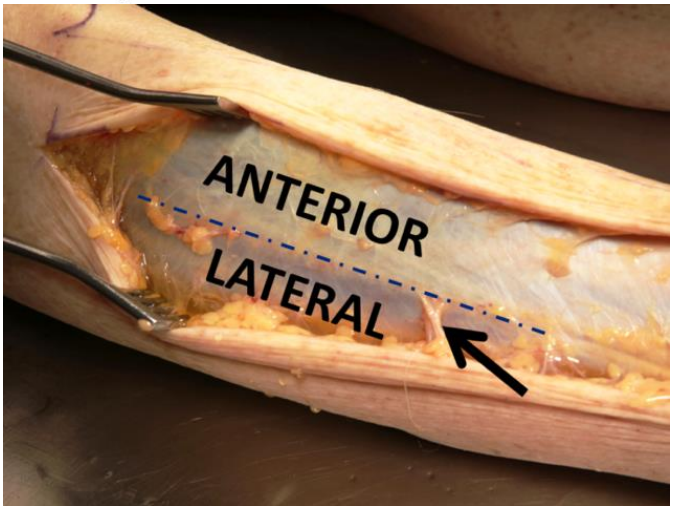
Placement of the medial incision, shown on the Right leg: a dotted line is marked one thumb breadth below the palpable medial edge of the tibia (solid line). A THUMB BEHIND THE TIBIA.

The Lateral Incision of the Lower Leg:

The lateral incision is made **ONE FINGER IN FRONT OF THE FIBULA** and should in general extend from three fingerbreadths below the head of the fibula down to three fingerbreadths above the lateral malleolus. The exact length of the skin incision will depend on the clinical setting. Care must be taken to make sure that it is long enough so that the skin does not serve as a constricting band. The skin and subcutaneous tissue are incised to expose the fascia encasing the lateral and anterior compartments. Care should be taken to avoid the lesser saphenous vein and peroneal (fibular) nerve when making these skin incisions.

Once the skin flap is raised, the intermuscular septum is identified. This is the structure that divides the anterior and lateral compartments. In the swollen or injured extremity, it may be difficult to find the intermuscular septum. In this setting the septum can be identified by following the perforating vessels down to it, as seen below:

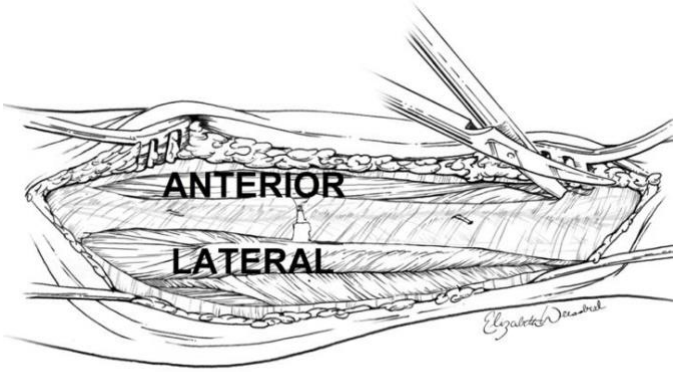


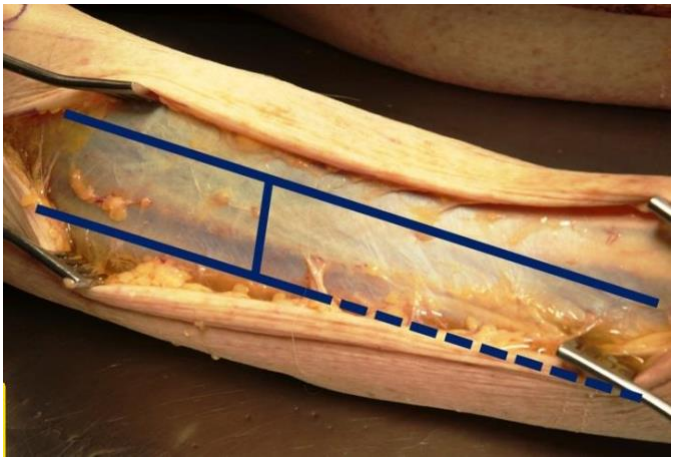


The lateral incision on a right lower extremity demonstrates the intermuscular septum (dotted line), which separates the anterior and lateral compartments of the lower leg. Note one of the perforating vessels (arrow) which enters and helps to identify the septum.

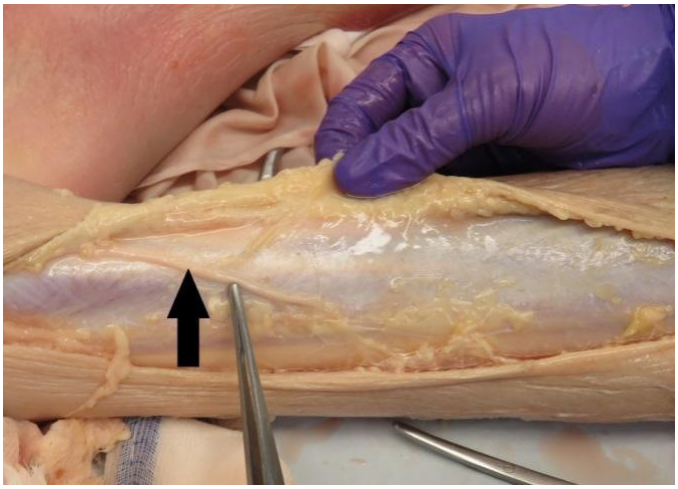
Classically the fascia of the lateral lower leg is opened using an "H"-shaped incision. The cross piece of the "H" is made using a scalpel which will expose both compartments and the septum. The legs of the "H" are made with curved scissors at least one cm away from the septum using just the tips which are **turned away** from the septum to avoid injury to the peroneal (fibular) nerves. The superficial peroneal (superior fibular) nerve originates around the head of the fibula and descends to the foot within the lateral compartment becoming superficial two thirds to three fourths of the way down the leg and

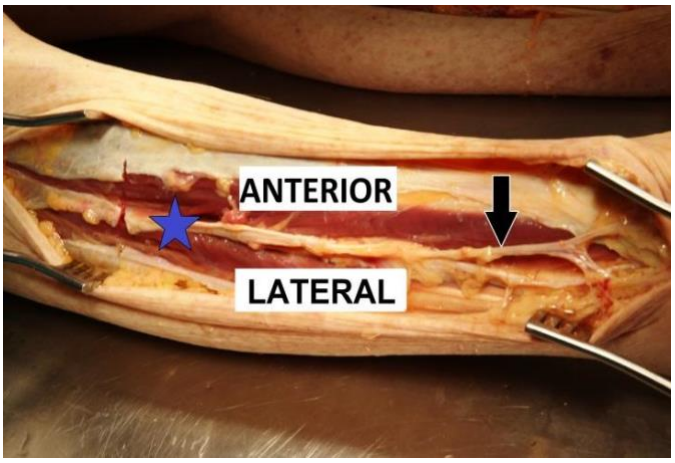
then crossing over to the anterior compartment. Care must be taken to avoid injury to this nerve as the fascial incisions approach the ankle. The fascia should be opened by pushing the partially opened scissor tips in both directions on either side of, and at least one cm away from, the septum, opening the fascia from the head of the fibula down to the lateral malleolus. Inspection of the septum and identification of the common peroneal (fibular) nerve and/or the anterior tibial vessels confirms entry into the anterior compartment. The skin incision should be closely inspected and extended as needed to ensure that the ends do not serve as a point of constriction.





The fascia of the right lateral lower leg (foot is to the right of the photo) is opened in a classic "H"-shaped fashion for the length of the compartments with scissors turned away from the septum to avoid damage to underlying structures.





The superficial peroneal (superior fibular) nerve (arrows) runs in the lateral compartment from the knee and crosses over the septum (star) into the anterior compartment 2/3 to 3/4 of the way down the leg towards the ankle. This must be carefully avoided by keeping the scissor tips pointed away from the septum and looking for the nerve as the fasciotomy is extended to the lateral malleolus. The left lateral lower leg (foot to the left) is seen on the top and the right lateral lower leg (foot to the right) is seen on the bottom.

Pitfalls of the Lower Leg Lateral Incision:

The anterior compartment is the most commonly missed compartment when performing a fasciotomy of the lower extremity. The most common reason the anterior compartment is missed is due to the incision being made too far posteriorly, either over or behind the fibula. If the incision is made too far posteriorly, the intermuscular septum between the lateral and superficial posterior compartments is mistaken for the septum between the anterior and lateral compartments and the anterior compartment is not opened, as shown below:

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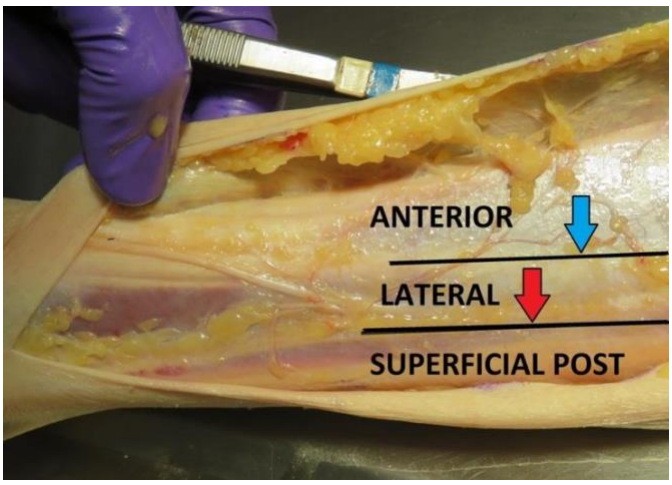
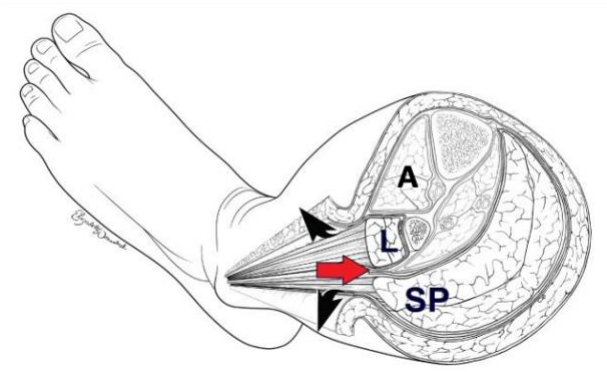
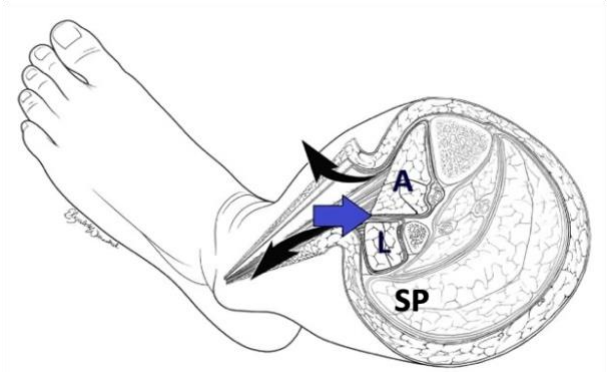


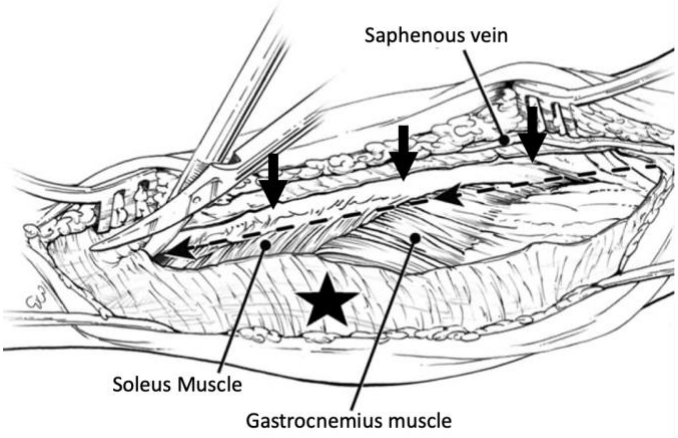
As seen here on the lateral Left leg, there is an intermuscular septum (Red arrow) between the lateral and superficial posterior (post) compartments which can be mistaken for the septum between the anterior and lateral compartments (Blue arrow) if the incision is made too far posteriorly.

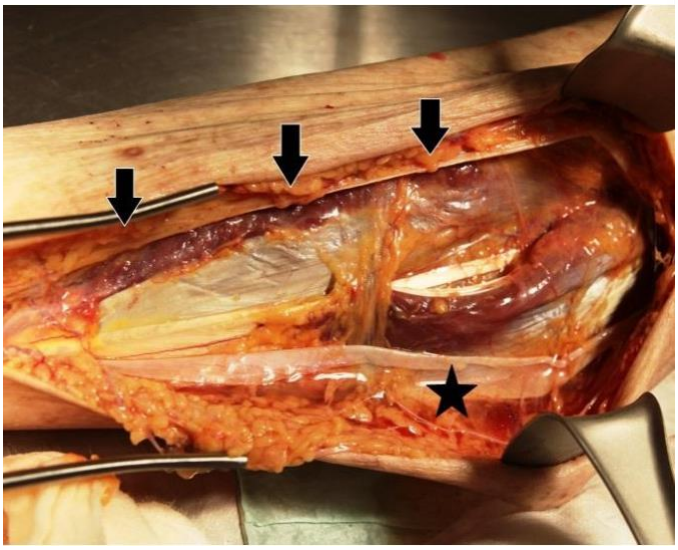




As seen here on the left leg, if the lateral incision is made too far posteriorly the intermuscular septum (Red arrow) between the lateral (L) and superficial posterior (SP) compartments can be mistaken for the septum between the anterior (A) and lateral (L) compartments. In this situation, the anterior compartment would not be decompressed. The proper incision, shown by the Blue arrow, is made when the incision is made "ONE FINGER IN FRONT OF THE FIBULA"

The medial incision is made one fingerbreadth below the palpable medial edge of the tibia (**ONE THUMB BEHIND THE TIBIA**). When making this incision, it is important to identify and preserve the greater saphenous vein, and ligate any perforators to it. After making an incision through the skin and subcutaneous tissues, the fascia overlying the superficial posterior compartment is exposed. This compartment contains the soleus and gastrocnemius muscle. Opening this fascia, from the tibial tuberosity to the medial malleolus, effectively decompresses the superficial posterior compartment.





The medial incision as seen on the right lower leg, ankle is to the left in this picture. The incision is placed such that the saphenous vein can be identified and preserved. Here, the superficial posterior compartment is opened first. The fascia (star) is opened to expose the soleus and gastrocnemius muscles in the superficial posterior compartment below the edge of the tibia (arrows.)

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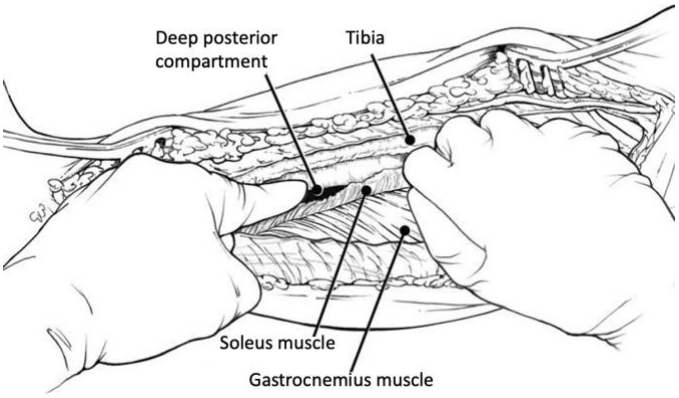
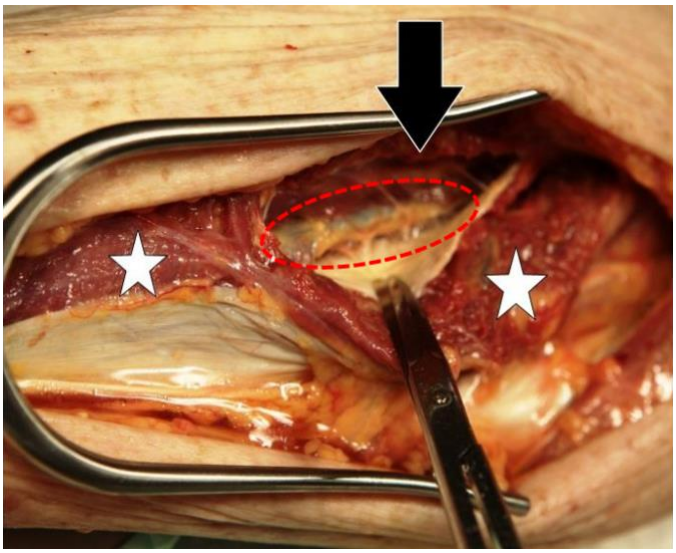
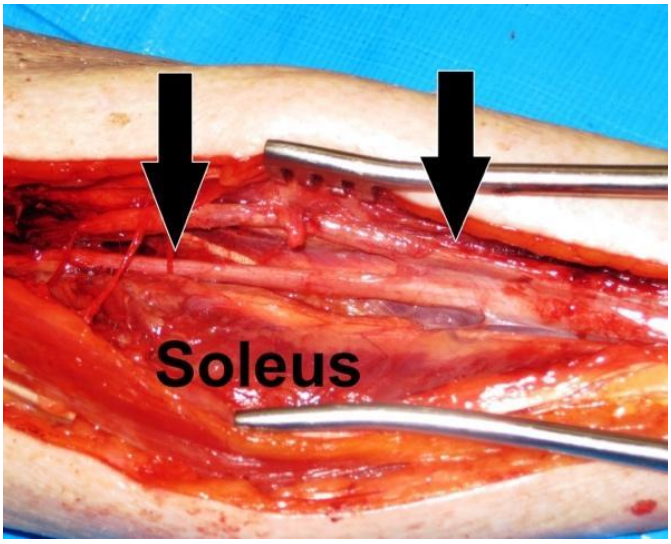
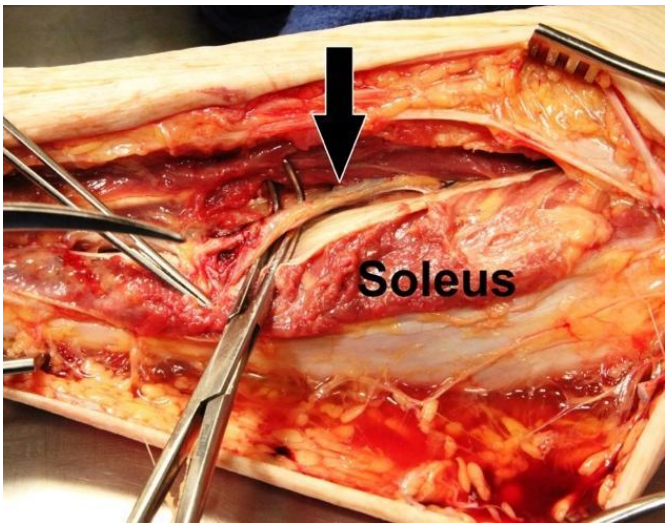
The key to entering the deep posterior compartment is the soleus muscle. The soleus muscle attaches to the medial edge of the tibia. Dissecting these fibers (referred to by some as the soleus bridge) completely free from and exposing the underside of the tibia ensures entry into the deep posterior compartment. Identification of the posterior tibial neurovascular bundle confirms that the compartment has been entered. The muscle in each compartment should be assessed for viability. Viable muscle is pink, contracts when stimulated with diathermy, and bleeds when cut. Dead muscle should be debrided back to healthy viable tissue. The skin incision is left open and either covered with gauze or a vacuum-assisted wound closure device. Vacuum wound closure after fasciotomy has been shown in recent studies to speed up and improve the chances of definitive closure of these wounds.





On the right medial lower leg the soleus muscle (stars) is dissected off of the inferior border of the tibia (arrow) allowing entry into the deep posterior compartment. Seeing the neurovascular bundle (Red circle) confirms entry into the deep posterior compartment.



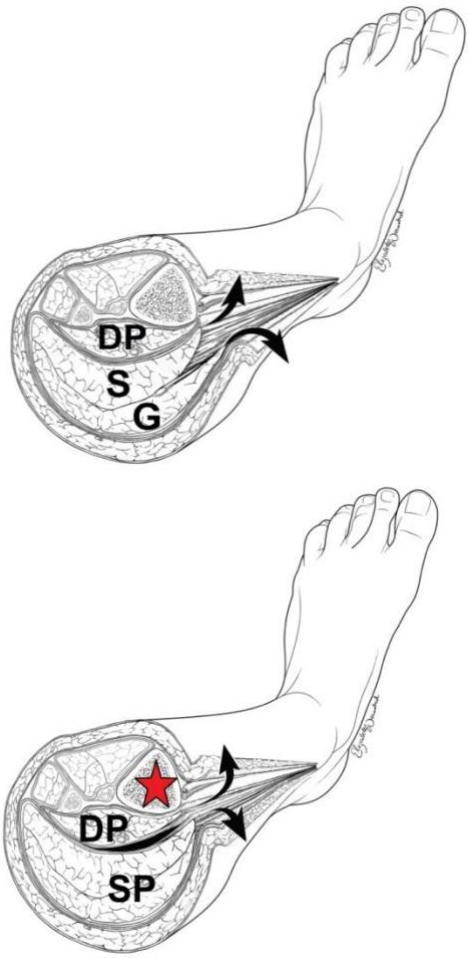


Identification of the posterior tibial neurovascular structures (arrows) confirms entry into the deep posterior compartment after taking the soleus muscle down from the tibia. Top: the medial left leg, ankle is to the right of the photo. Bottom: the medial right leg, ankle is to the left of the photo.

Pitfalls of the Medial Incision:

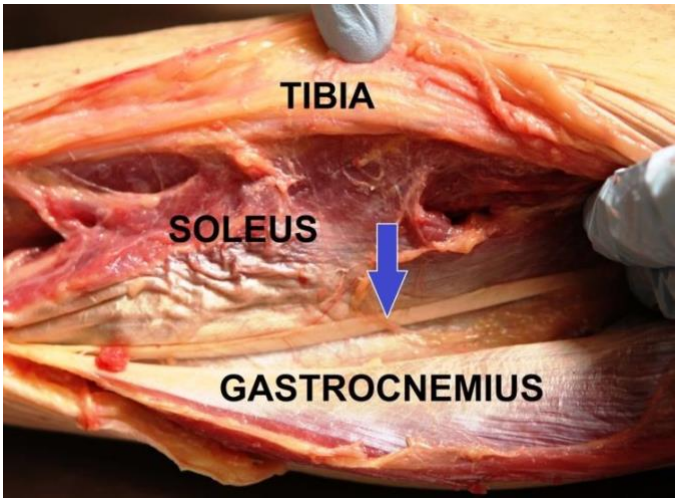
The deep posterior compartment is the second most commonly missed compartment when performing a fasciotomy of the lower extremity. The most common reason the deep posterior compartment is missed is due a dissection plane made between the gastrocnemius and soleus muscles

and believing that opening the fascia over the soleus muscle equates to having opened the deep posterior compartment.



As seen here in the medial left leg, if the dissection plane is made between the soleus (S) and gastrocnemius (G) muscles, the deep posterior (DP) compartment is unopened. The soleus fibers must be detached from the underside of the tibia (star) to separate the superficial posterior (SP) from the deep posterior compartment such that it can be opened.

In the injured extremity, a prominent plantaris tendon (also known as the "intern's nerve") may be mistaken for the posterior tibial neurovascular bundle leading one to erroneously believe that the posterior compartment has been entered and decompressed.



In this photo of the medial right leg, the ankle is to the left of the photo. The plantaris tendon (arrow) is found in the plane between the soleus and gastrocnemius muscles and may be mistaken for the posterior tibial neurovascular bundle. Note that the soleus muscle has not yet been detached from the tibia (as shown in the photos above), therefore the deep posterior compartment has not yet been decompressed.

Inadequate length of either the fascial or skin incision can result in failure to reduce compartment pressures to acceptable levels.

Inadvertent injury to the saphenous vein can cause significant bleeding. The saphenous system should be always preserved if possible, but especially in the case of vascular trauma. Note that entry into the deep posterior compartment, as described here, allows access to the neurovascular bundle of the lower leg. This is the preferred exposure for repair of the popliteal and tibial vessels in trauma situations. In this case, fascial decompression is part of the operation, which is appropriate. This approach is discussed elsewhere in this Manual.

Compartment Syndrome of the Thigh:

Compartment syndrome is uncommon in the thigh because of the large volume that the thigh requires to cause an increase in interstitial pressure. In addition, the compartments of the thigh blend anatomically with the hip allowing for extravasation of blood or fluid outside the compartment. Major risk factors for thigh compartment syndrome include: severe femoral fractures, vascular injury, severe blunt trauma/crush or blast injury to the thigh,

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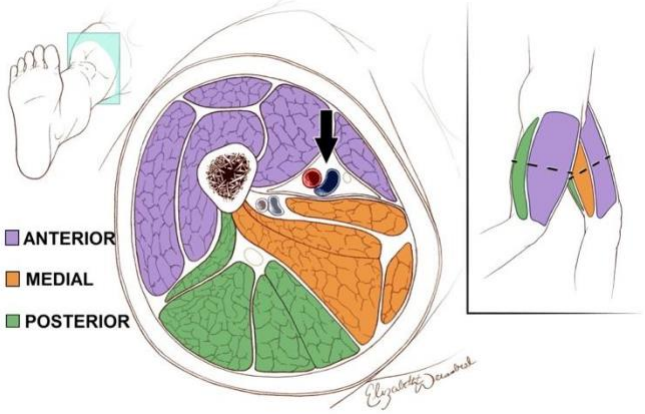
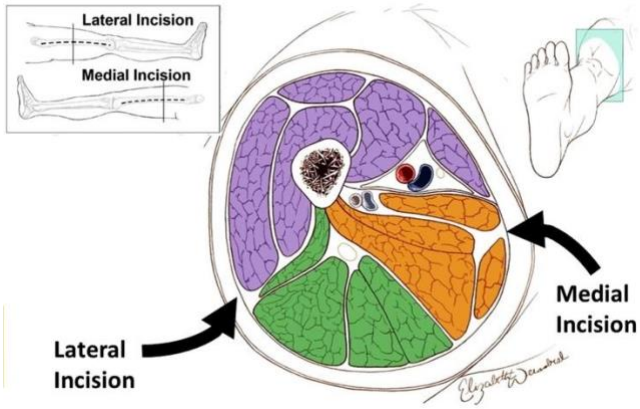
iliofemoral deep vein thrombosis, and external compression of the thigh. The thigh contains three compartments: anterior, posterior and medial. The anterior (not the medial) compartment contains the femoral artery and vein and is the most likely to develop compartment syndrome.



This cross-section of the mid right thigh shows the three compartments of the thigh: anterior (Purple), medial (Orange), and posterior (Green). Note that the femoral artery and vein (arrow) are found in the anterior compartment.

If compartment syndrome of the thigh exists, a lateral incision is made first as this enables decompression of both the anterior and posterior compartments. Often, the lateral incision is all that is needed, though on occasion with a severely swollen extremity a medial incision will be needed as well. The lateral incision of the thigh extends from the intertrochanteric line to the lateral epicondyle of the femur to expose the iliotibial band or fascia lata which is opened the length of the incision. The vastus lateralis muscle is reflected superiorly and medially to expose the lateral intermuscular septum (between the anterior and posterior compartments) which is incised the length of the incision. Commonly after the anterior and posterior compartments are decompressed the pressure in the medial compartment is measured and if elevated, this compartment is also decompressed through a medial incision.



The two incisions required to decompress the compartments of the thigh are depicted with the anterior (Purple) and posterior (Green) compartments opened via the lateral incision and if indicated the medial (Orange) compartment opened through the medial incision.

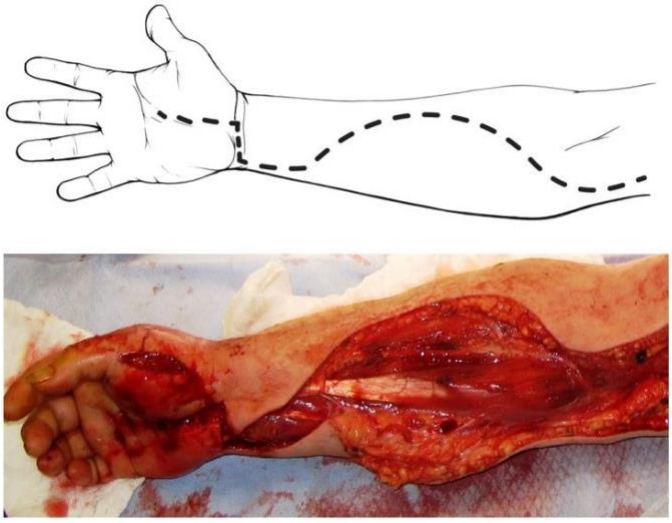
If needed, the medial compartment can be opened through a medial incision placed along the course of the saphenous vein. This is followed by rotation of the sartorius muscle, and incision of the medial intermuscular septum between the medial and anterior compartments.

Compartment Syndrome of the Forearm and Hand:

Compartment syndromes of the hand and forearm are much less common than in the lower extremity, but it is vital that they are recognized and treated when they occur. Compartment syndrome of the upper arm is very unusual, but may follow supracondylar fracture of the humerus. Compartment syndrome of the forearm may be associated with fractures, crush or blast injury, burns or vascular injury. Compartment syndrome of the hand can occur from trauma but is more commonly associated with infiltration of intravenous fluids. As there are no sensory nerves in the hand compartments, physical findings do not include sensory abnormalities, and the pressure threshold for release is much less than in the legs (15–20 mmHg).

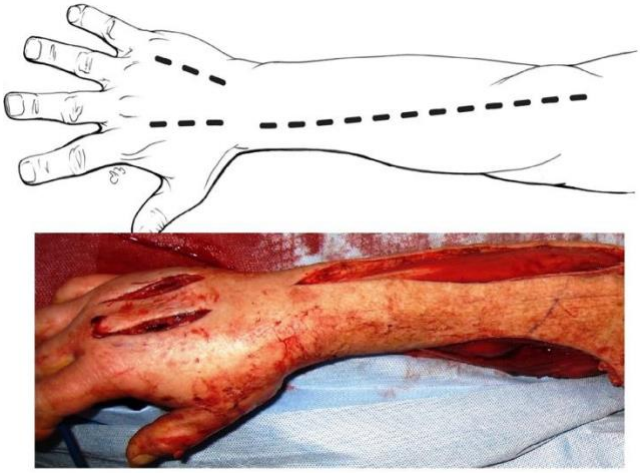
The forearm is classically described as having three compartments: Volar (Anterior); Mobile Wad (Brachioradialis / Radial head area); and Dorsal (Posterior). Some anatomy texts and practitioners subdivide the volar into superficial and deep compartments. The literature contains

descriptions of multiple volar incisions. The most commonly used and described volar fasciotomy incision of the forearm is a curvilinear incision (to release the anterior and mobile wad compartments) which is extended to the hand to release the carpal tunnel. The incision crosses the antecubital fossa in a curvilinear fashion to the radial aspect of the upper forearm and then is carried toward the ulnar aspect down to the wrist and then across the wrist in a transverse fashion and onto the palm to release the carpal tunnel. This volar incision allows for decompression of the volar (anterior) and mobile wad compartments as well as the carpal tunnel. This incision is preferred because of potentially better cosmetic results, and maintenance of an adequate skin blood supply between it and the dorsal incision at the wrist.



The volar incision as seen on the right arm enabling decompression of the anterior (volar) and mobile wad compartments.

The dorsal (posterior) compartment of the forearm is released through a linear dorsal incision, with two additional incisions on the dorsum of the hand to release the hand. To ensure that the compartments of the forearm are completely decompressed it is important to do a complete epimysiotomy (opening the fascia overlying the muscle) of each of the muscles, exposing the muscle bellies in the entire length of the forearm. Each muscle has its own separate fascial compartment which must be decompressed separately; simply opening up the forearm is not sufficient treatment.

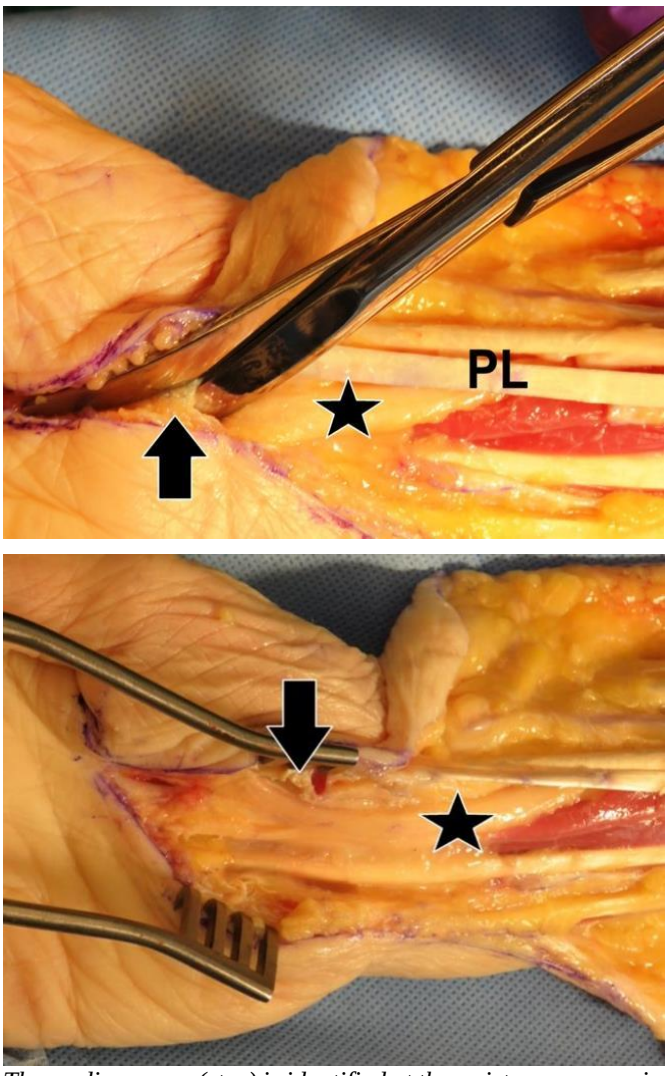


The dorsal incision as seen on the right arm with additional incisions on the hand enabling decompression of the dorsal compartment of the forearm and the intraosseous compartments of the hand.

In most cases of suspected compartment syndrome of the forearm, the carpal tunnel should be opened completely at the wrist. This is accomplished by identifying the median nerve at the wrist crease and using scissors passed on either side of the transverse carpal ligament above the median nerve and divided. The transverse carpal ligament is generally wider than one might expect (> 2 cm) and there is a haptic and audible "crunch" that accompanies its division. If one "cuts until the crunch is gone", the carpal tunnel is fully opened. If compartment syndrome of the hand is suspected it is best to involve a hand specialist early, as often additional incisions will be required to decompress the thenar and hypothenar compartments.

Compartment Syndromes and Fasciotomies of the Extremities

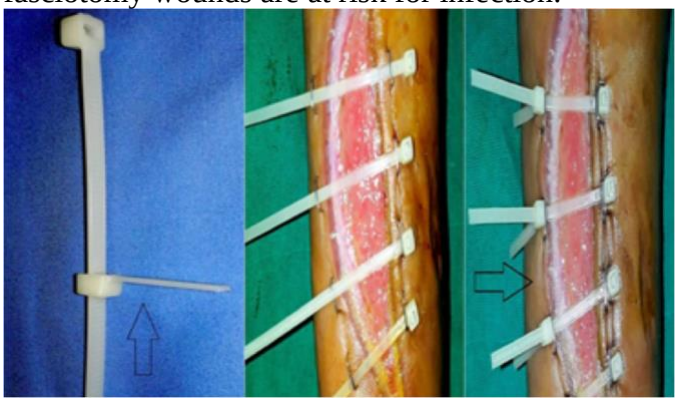
Mark W. Bowyer



The median nerve (star) is identified at the wrist crease running under the palmaris longus (PL) tendon. Scissors are placed above and below the transverse carpal ligament (arrow) which is divided to completely open the carpal tunnel.

Aftercare and Complications:

If necrotic muscle is present, it should be debrided at the time of original fasciotomy. As described above, these procedures will create large wounds that must be covered. The open wounds should be covered with non-adherent dressing or moist gauze. Wound closure can be accomplished with the assistance of traction such as the "shoelace technique" or vacuum- assisted devices. The wounds should be re-evaluated 24–48 h after the initial fasciotomy with further debridement as indicated. After the acute process subsides, delayed primary closure or split-thickness skin grafting may be performed. Often, after swelling has gone down one of the two calf wounds can be closed primarily, leaving the other one open to be grafted. Until definitive wound closure, patients with open fasciotomy wounds are at risk for infection.



A system for closing wounds slowly over time using nylon ratcheting ties. Other practitioners have simply looped the ties through punctures in the skin edges and tightened them serially. Source: Ahmad I et al, https://www.doi.org/10.36106/ijsr

Incomplete or delayed fasciotomies can lead to permanent nerve damage, loss of limb, multi-system organ failure, rhabdomyolysis and death. Early recognition and aggressive fasciotomy will help to minimize these adverse outcomes.

Conclusions:

Compartment syndrome must be suspected in all polytrauma patients with extremity injury. Patients in the intensive care unit are also at risk to develop compartment syndrome from a variety of non-traumatic conditions – principally: sepsis, massive resuscitation, and reperfusion. It is essential that all clinicians caring for these patients have an intimate knowledge of the pathophysiology, etiology, and evaluation of compartment syndrome. Additionally, all surgeons need to have a comprehensive knowledge of the relevant anatomy, and the techniques for performing a proper fasciotomy. A high index of suspicion must be maintained (especially in patients with altered levels of consciousness), and early and aggressive fasciotomy will minimize the morbidity and mortality associated with failure to adequately treat compartment syndromes.

Compartment Syndromes and Fasciotomies of the Extremities

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