Chapter 18
Soft Tissue Wounds and Fasciotomies

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Deployment Experience:

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BLUF Box (Bottom Line Up Front)

1. Do it in the operating room. Big wounds benefit when you have good lighting, equipment, supplies and anesthesia, and the operating room has these things.
2. Trust your instincts and your and physical exam.
3. Closely examine every wound and the surrounding tissue.
4. Bleeding, contamination control, diagnosis and reconstruction are the priorities of trauma surgery.
5. Prompt removal of devitalized tissue and debris is imperative to prevent local and systemic problems later.
6. There will be more dirt, debris, and foreign bodies in these wounds than you've ever seen, and it may take several OR sessions to get them clean.
7. Leave all wounds OPEN initially. If someone else closed it – OPEN IT!
8. Pulsatile pressure lavage systems are convenient but they can hurt soft tissue and may promote rebound bacterial growth. Use simple irrigation.
9. Vacuum therapy and frequent irrigation and debridement is good.
10. Complete full fasciotomies can save limbs and lives. Not a place for mini-fasciotomies.
11. Closing wounds primarily is better than skin grafting and taking patients to the operating room frequently will help achieve that goal.

The surgeon is not yet born who does not think that he is the one who can close in war a gunshot wound primarily.

Philip Mitchiner, 1939

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M. Martin and A. Beekley (eds.), *Front Line Surgery: A Practical Approach,*
DOI 10.1007/978-1-4419-6079-5_18,

When you imagine "war surgery", you probably conjure up visions of crashing into the chest or abdomen just in time to save a live. Although very dramatic, this will be relatively uncommon in your combat surgical practice. This chapter is dedicated to what will be your most common operative case in combat – operative management of soft tissue wounds. Thanks to modern body armor and vehicles, many of the previously fatal injury mechanisms are now producing less fatal, but still significant, soft tissue injuries. These injuries are devastating and we rarely see these extensive soft tissue injuries during our training in the US. The garden variety civilian stab wounds, slash wounds, and hand gun injuries are incredibly minor compared to the wounds produced by things like a 50 caliber machine gun, an AK47 round, or more commonly an explosive device. We simply just don't see these wounds routinely in the US civilian trauma centers and thus don't have a developed comfort level with the management and pitfalls. The high velocity stuff is just simply unreal and requires a different set of rules and strategies to optimize your patient's outcome. No amount of reading can completely prepare you for some of these injuries. The goal of this chapter is to shorten the learning curve and have you mentally prepared before you are faced with one.

There are four steps in trauma surgery:

1. Hemorrhage control
2. Contamination control
3. Diagnosis
4. Reconstruction

Whether you are doing a laparotomy or treating soft tissue injuries, the steps and priorities are not any different. Take bleeding wounds and big wounds to the operating room immediately. As a general rule of thumb, being in the operating room with wounds is easier on the patient, the hospital staff, and you. You get the best results by doing a good job and the place to do the best job is in the operating room.

In addition to the operative debridement and management of extensive soft tissue wounds, the need for fasciotomy is also a common reality of modern combat casualty care. While the technique utilized for performing these decompressions is similar to that utilized in civilian practice, the indications and specific concerns differ. Additionally, the austere environment of the deployed setting has afforded us a valuable experience with novel approaches to the subsequent closure of these wounds – experience that we hope to impart to you in this chapter.

Large Soft Tissue Wounds

The most important aspect of initial treatment of any soft tissue wound is to stick to your ABC's. These wounds are frequently overwhelming in appearance and you will find that people have a tendency to focus on the wound and not the patient. Avoid the temptation to focus on what may be the most impressive wound of your life and miss other life threatening issues. Prioritize as you would any trauma patient. If you have ample help and someone else can assess the airway and breathing, then you can address bleeding simultaneously. If you are running the

team, then while someone else is trying to control the hemorrhage, you can ensure airway and breathing. You will save many more lives in combat medical care by controlling hemorrhage from a large soft tissue wound than you will by performing an emergent airway.

Once more pressing casualty issues have been addressed and emergent injuries excluded, attention should then be directed at the soft tissue wound. Bleeding from the wound is the first step. Direct pressure is the preferred method in civilian trauma, but in combat trauma it is frequently inadequate and also requires a pair of hands that you usually need for other tasks. A well placed and secured tourniquet is the preferred method for extremity hemorrhage control on the battlefield and in the combat hospital. If the patient arrives without one, put one on in the Emergency Room. For wounds distal to the elbow or knee, the tourniquet can be removed either in the operating room or in the resuscitation area. If there is uncontrollable arterial bleeding, pressure dressing can be applied and the tourniquet should be retightened or reinforced with a second proximal tourniquet (Fig. 18.1). For many of the wounds seen in war time, the wounds are not suitable for tourniquets as they are very proximal (Fig. 18.2). While it might seem tempting to simply irrigate these wounds in the Emergency Department or resuscitation area, we would advise you to avoid this temptation for all but the very smallest of wounds that do not need to be explored.

The rule of thumb is that wounds are highly contaminated. Dirt and debris will always be present. Metallic fragments from the explosive device itself or surrounding objects may be present, particularly when the victim was in a vehicle that gets blown up. You may often find bone fragments in the wound but no bony fractures – these are fragments from bystanders or from the attacker in suicide-bombing type incidents (aka “bioshrapnel”). Decaying tissues and human or animal feces have also been found in explosive devices employed by insurgents to enhance wound infection rates. Everything imaginable can be found in the wounds (Fig. 18.3). In the least, the projectiles and fragmentation components of modern war wounds represent substantial risk for severe infection. Devitalized tissue, if not adequately debrided, will only fuel these infections and contribute to adverse outcome.

General guidance for initial operative intervention consists of three main components: irrigation, debridement and leaving wounds open. Antibiotics should be given right away as empiric therapy. The choice of antibiotic should cover gram-negative bacteria (particularly acinetobacter) as they are much more prominent than in civilian trauma practice. We advise wide coverage for gram-positive and gram-negative organisms in your peri-operative choice. Next you should then focus on irrigation. While high-pressure pulsatile lavage (HPPL) systems are commonly utilized in civilian practice, it is the current recommendation by the Joint Trauma Theater System clinical practice guidelines (JTTS CPGs) that the employ of these devices be avoided. While these devices make the irrigation process easier, there is concern that the use of HPPL is associated with additional trauma to the tissues, creating an environment with a greater abundance of devitalized tissue and setting the stage for more aggressive bacterial re-growth. Several studies have shown higher wound infection and complication rates with pulse lavage compared to standard irrigation. Antibiotic resistant acinetobacter has also been associated with the HPPL. These devices are also relatively expensive and may not be available at

Fig. 18.1 Wounds where tourniquets were applied. Panel (**a**) – bilateral tournaquets applied at groin, both legs amputated. Panel (**b**) – tourniquet not applied due to lack of active blood loss. Panel (**c**) – cloth tourniquet applied above wound

all medical treatment facilities in the area of conflict. For these reasons, the use of bulb suction or gravity-fed systems should be utilized to provide for high volume irrigation of all wounds in a more gentle fashion. Normal saline, sterile water and potable tap water all have similar usefulness, efficacy and safety for this purpose. How much irrigation to utilize depends on the size of the wound. As bacterial loads in the wound will drop dramatically with increasing volumes of 1, 3, 6 and 9 L of irrigation, we advise (as does the current JTTS CPG on the topic) that the following

Fig. 18.2 Wounds that tourniquet cannot be effectively applied. Panel (**a**) – wound created by rocket propelled grenade. Panel (**b**) – improvised explosive device

be utilized as a rule of thumb: 1–3 L for small volume wounds, 4–8 L for moderate wounds, and 9 or more liters for large volume wounds or wounds with evidence of heavy contamination. If the HPPL system is used, it can be made more gentle by putting your fingers over the injecting end and to let the fluid fall into the wound. This turns the HPPL into a high flow low pressure system.

After effective irrigation of the wound has removed all loose debris, you should turn your attention to debridement. Remove all remaining foreign material that is readily visualized or palpated through the wound – do not routinely extend wounds to "chase" a fragment that you might have seen on radiography – it will only create new potential spaces for infection and you may injure another structure in the process. While the degree of debridement will require you as the operating surgeon

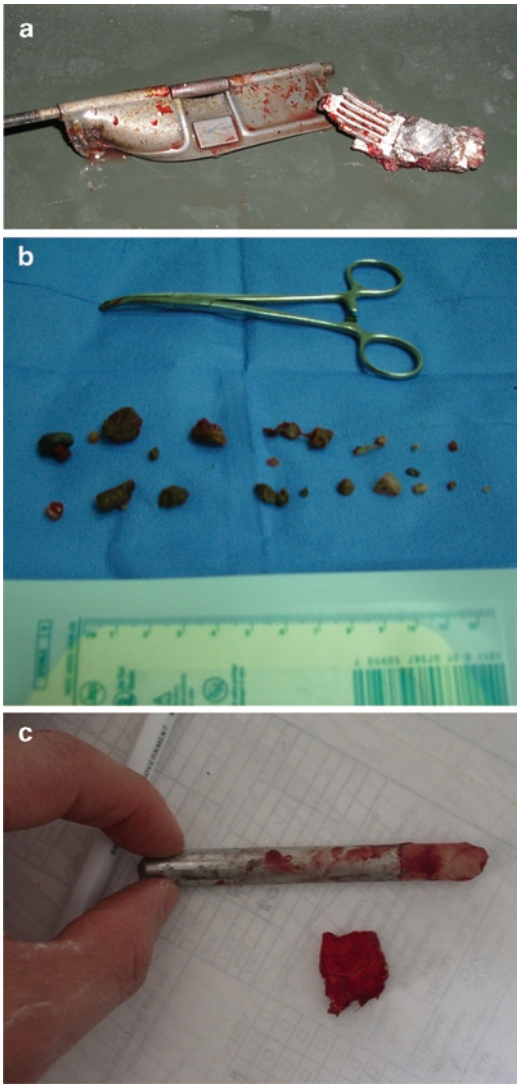

Fig. 18.3 Foreign objects found in wounds. Panel (**a**) – cover of an M-4 rifle. Panel (**b**) – dirt and rocks in wounds. Panel (**c**) – unknown object found in tissue after improvised explosive device

to utilize your own judgment, take care to ensure that all devitalized tissue is removed while at the same time attempting to preserve as much soft tissue as possible for reconstruction at a higher echelon of care or later operations. For muscle, purple or black tissue that does not move with the electrocautery should be removed, but when in doubt you can leave it for the next time the wound is debrided if the wound is left open. There is a widely propagated surgical fallacy about the need for massive wide debridement of high-velocity missile wounds. This

is based on erroneous assumptions and distortions regarding the size and extent of injury related to the sonic wave and temporary cavity created, with some authors advocating debridement of a cavity 30 times the size of the projectile. Do not do this; you will only create significant morbidity and cosmetic defects. This has been refuted by both ballistics data and combat surgical experience.

Once irrigation and debridement have been completed, you will be left with the decision of what to do with the now hopefully cleaner and healthier looking wound. Avoid the temptation of closure at the initial operation – there remains the strong possibility that the damage to the tissues has not fully declared itself and that additional debridement will be required at subsequent operation. Dynamic wound vacuum therapy has been revolutionary in the treatment of wounds and if available it has been found to be extremely useful. You have to be very careful however that the wound hemostasis is complete as a vessel that reopens can bleed tremendously with the negative suction. For contaminated soft tissue defects, vacuum therapy is ideal. The utilization of vacuum-assisted closure provides for control and clearance of effluent and promotes early wound healing. Additionally, the use of vacuum therapy and other dynamic approaches limits the degree of wound contraction and increases the likelihood of subsequent delayed primary closure of some wounds. For wounds that will not prove amenable to delayed primary closure, vacuum therapy will promote the development of an early granulation bed that may prove amenable to graft coverage in the reconstructive setting. One additional tip is that stretching of the skin and subcutaneous tissue with sutures over the wound vac helps later closure without skin grafting. **Your planning for closure should start at the first operation**.

Now that you have completed the initial operation, the patient may be transported to the ICU or ward of your facility for continued resuscitation and postoperative care. The question you must then ask is: "When do I take the patient back for subsequent intervention for this wound?" In general for open wounds they should be taken back to the operating room approximately 24 h later. Subsequent irrigation and debridement can be done at larger intervals such as 48–72 h, but if the interval is longer the surprises and disappointments are not worth it. Depending on the length of stay of the patient at your facility and the condition of the wound, some patients may prove amenable to delayed primary wound closure or grafting after just a few operations. You must be mindful, however, that the infection rates in the austere environment of forward care are higher than stateside facilities. For the majority of severe wounds, particularly those involving amputation sites, the wounds should not be closed in theater for casualties that will be evacuating to a higher echelon of care. For those patients that do not fit into this category, utilize sound judgment to balance appropriately aggressive closure with an appreciation of these infectious risks.

You will also need to coordinate carefully with casualty evacuation personnel to determine the optimal timing of subsequent procedures. Remember that your patient may be in the evacuation chain for 48 h or more until they arrive at a facility and can be returned to the operating room. The way to ensure optimal wound care for medical evacuees is to have a policy that all wounds that require multiple operative sessions are taken to the OR for a final washout and debridement within 8–12 h of transfer.

The dressing should also be clearly marked with the date and time of the most recent procedure as you cannot count on medical records to follow the patient.

Small Multiple Wounds

With war wounds, judgment is critical. Judgment comes from experience, and experience comes from mistakes. Fortunately you can learn from the mistakes of others rather than repeating these same mistakes on your own. Remember that the mechanism is very important. High velocity rounds are very different than hand gun injuries. For high velocity rounds the entry and exit are usually obvious, most commonly with a small entrance wound and a large cavity at the exit site. However, some high velocity wounds can be seemingly innocuous at the entry and exit sites but have devastating damage to the underlying tissues in-between. This should be suspected and ALL of these wounds should be operatively explored.

Although many of these injuries will require the soldier to be evacuated from the area, select ones may be managed locally and the soldier returned to duty. The wound depicted in Fig. 18.4 resulted from a close range high velocity round and

Fig. 18.4 Close range high velocity injury to left upper arm. Panel (**a**) – entry site. Panel (**b**) – exit site. Panel (**c**) – closed entry site in 2 weeks. Panel (**d**) – exit site after irrigation and debridment and closure in 2 weeks. Wound closed over penrose and drain pulled out over 10 days

when explored, the muscle damage was impressive and the muscles were dead. This wound was debrided and closed over a penrose drain. Over the next week the drain was advanced out, the wound fully closed and the patient started on physical therapy on the 4th week of injury. By the 6th week the patient resumed full duty. This casualty did not have to be transferred out of theater, and the casualty was able to return to duty to return back with his troops. The patient could have been sent home with a purple heart but he was treated in theater at a level II surgical facility. He remained out of action and on limited duty for 6 weeks but he was able to contribute to his unit and the logistics of evacuating him out and getting a replacement was avoided.

While the big wounds are memorable, the routine far forward was multiple small wounds. These are especially challenging and deceiving. Small fragmentation injuries to the face and neck, arms, legs and hands are extremely common. For civilians and local military, torso injuries from fragmentation are much more frequent due to the lack of body armor. These "peppering" injuries are difficult to assess and seemingly innocuous wounds can hide devastating injuries. As an example, two patients were treated at our facility after a suicide bombing. The first patient has fragment injuries to his entire body, totaling over 100 small wounds. He was found to have no significant injuries and returned to duty in several days. Another casualty was seen and although he was in extremis, he had no obvious external injuries. A chest X-ray showed a massive hemothorax and a small pellet in his right chest. On closer inspection he had a tiny innocuous almost invisible puncture wound in his left chest mid axillary line at the nipple level. The pellet went through his heart and mediastinum. Every patient in an explosive-related incident should get a detailed external inspection and an imaging evaluation for internal injuries, even if their wounds appear small and superficial.

Fasciotomies

Fasciotomy is among the most commonly performed procedures in present theaters of conflict. Subsequently the wounds resulting from decompressions of the extremities will be among the most common you will be expected to manage. You will find that blast injuries account for a considerable number of indications for fasciotomy. The effects of associated fragmentation, crush mechanisms, associated lower extremity fractures, vascular injuries and even blast wave effects themselves may contribute to the development of compartment syndrome of the extremities. The modern advent of early casualty evacuation by air also introduces an environment in which the signs and symptoms of compartment syndrome are difficult to detect. These conditions frequently mandate the more liberal utilization of prophylactic fasciotomy than in civilian practice.

In our civilian practices, we rarely perform prophylactic fasciotomies. We have the luxury of being able to reliably perform continued and repeat examinations, and intervene immediately if needed. You (and your patient) will not have this luxury

in combat. For a general rule of thumb, if you suspect a compartment syndrome is present or has a reasonable chance of developing, perform a fasciotomy. Increasing pain remains the most reliable indicator of the need for this intervention, but an exam is not always possible or reliable in patients who are intubated, comatose, or is being transferred rapidly across several echelons of care. If you have performed an extremity vascular ligation or repair, routine fasciotomy should be your default. Burn patients also represent a special scenario. For patients with deep circumferential burns of the extremities, the performance of an escharotomy will in most cases avoid the need for subsequent fasciotomy.

Whenever fasciotomy is undertaken, avoid the temptation to perform lesser procedures. Full decompression of the affected compartments is paramount for success. Mini-fasciotomies look cute, but will earn you the disdain of your colleagues at the next echelon who will inevitably have to extend the fasciotomy to adequately decompress the compartments – and likely have to debride the resultant dead muscle within the compartment. Compartment syndromes can occur in all of the extremities in combat trauma, and you will need to know how to adequately decompress the compartments at each of these locations.

Upper Extremity Fasciotomy

Compartment syndrome of the upper arm is less common than the forearm, but should the upper arm require decompression you can accomplish this through a lateral skin incision from the deltoid insertion to the lateral epicondyle. The upper arm has two compartments, and you should be able to visualize the septum dividing the anterior and posterior compartments through this incision. Make certain to decompress both compartments, while taking care to spare the larger cutaneous nerves and, in particular, the radial nerve which passes through the intermuscular septum from the posterior to anterior compartments just below the fascia.

The forearm has three compartments, the mobile wad proximally, the volar (flexor) and the dorsal (extensor) compartments. Most commonly, effective decompression can be accomplished through a single incision (Fig. 18.5) that begins on the palmar surface between the thenar and hypothenar musculature of the palm and extends transversely across the wrist to arch from the ulnar side of the arm at the wrist to the volar side along the full distance of the forearm. At the elbow, just radial to the medial epicondyle, the incision is curved across the elbow flexion crease. At the wrist, the carpal tunnel is also likely to require release, as is the fibrous band overlying the brachial artery and median nerve at the elbow. This incision allows for soft tissue coverage of the neurovascular structures at the wrist and elbows, and prevents soft-tissue contractures from developing at the flexion creases. In 99% of cases this will also adequately decompress the swollen hand, but if a hand fasciotomy is required then this incision can be extended distally along the thenar eminence.

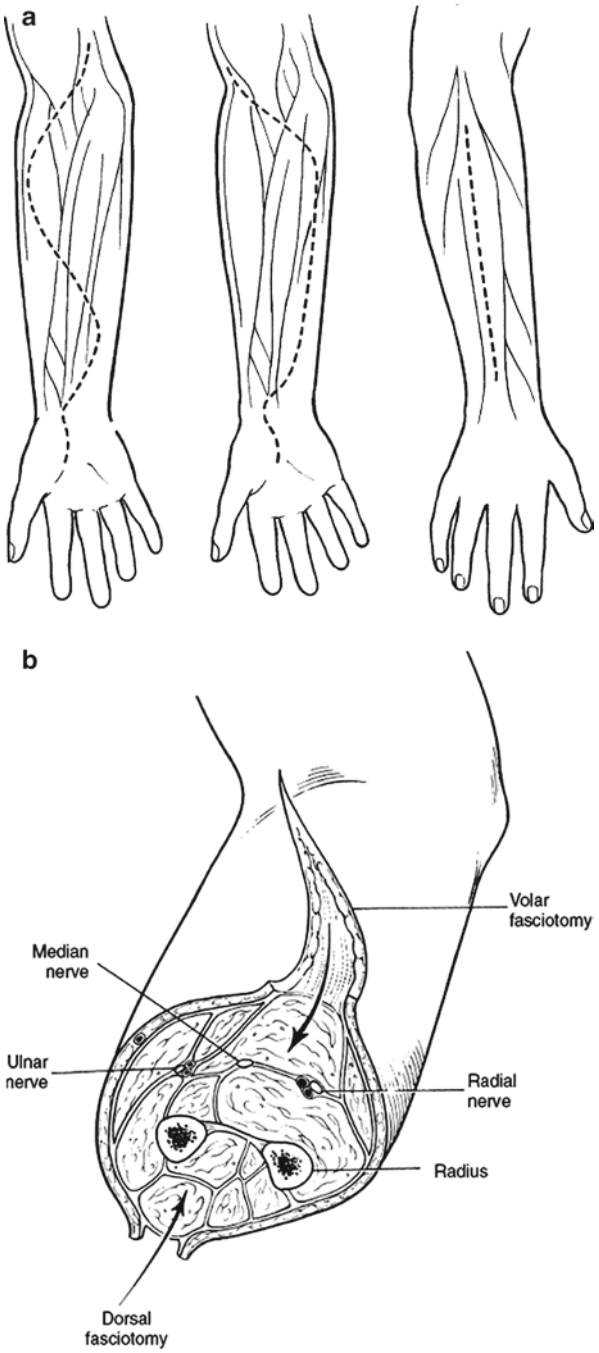

Fig. 18.5 (**a**) Options for forearm fasciotomy incisions. (**b**) Release of the dorsal and volar compartments. (Reproduced with permission from Velmahos G and Toutouzas K. Surg Clin North Am 2002;82:125–141.)

Lower Extremity Fasciotomy

The thigh has three compartments: anterior (quadriceps), medial (adductors) and posterior (hamstrings). The incision for decompression of the thigh extends along the lateral leg from the greater trochanter to the lateral condyle of the femur. After dissection down to the fascia, you must incise the iliotibial band and reflect the vastus lateralis off the intermuscular septum to release the anterior compartment. Then incise the intermuscular septum the length of the incision to release the posterior compartment. Be careful at this point to avoid making the releasing fascial incision too close to the femur, as there are a series of perforating arteries passing through the septum at this location that run posterior to anterior near the bone. Release the medial adductor compartment through a separate incision anteromedially from the groin to just above the knee.

The lower leg (calf) has four compartments that must be adequately decompressed (Fig. 18.6). This is most completely and safely done through the use of two liberal incisions (Fig. 18.7). Make your lateral incision along a line centered between the fibula and the anterior tibial crest from a few centimeters below the knee to the ankle. Once the fascia is identified, make a small incision transversely in the fascia to adequately identify the intermuscular septum. Identification of this septum is the key move for decompression of the anterior and lateral compartments – and failure to do so will result in a missed decompression of one of these compartments (most commonly the anterior). Once the septum has been identified, divide the fascia on either side of the septum the full length of the skin incision. Take care at the superior extent of this incision, as the superficial peroneal nerve will be immediately under the fascia and is easily transected. The second incision is made medially, at least 2 cm medial to the medial-posterior palpable edge of the tibia. At this location, make certain to identify the greater saphenous vein and retract it anteriorly en route to the fascia. Incise the fascia the full length of the skin incision longitudinally to decompress the superficial posterior compartment. Retracting the muscles of this compartment posteriorly will allow access the fascia overlying the tibialis posterior and the deep posterior compartment. Be careful here in extending the fascial incision of this compartment proximally, as the deep posterior compartment contains a number of neurovascular structures that warrant respect.

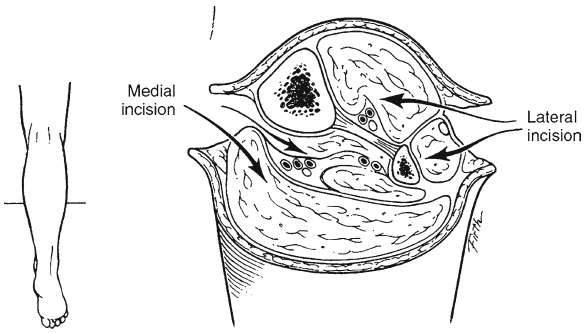

Fig. 18.6 Four compartments of the leg approached through medial and lateral incisions. (Reproduced with permission from Velmahos G and Toutouzas K. Surg Clin North Am 2002;82:125–141.)

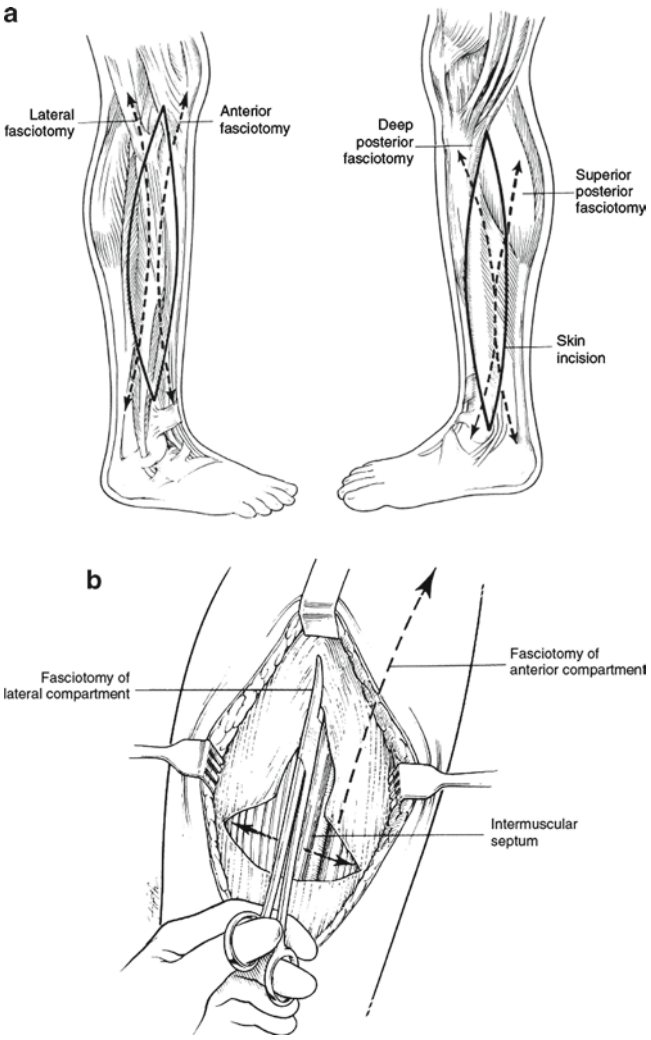

Fig. 18.7 (**a**) Diagram of skin incisions (*solid line*) and fascial incisions (*dotted line*) for a standard four-compartment leg fasciotomy. (**b**) A transverse fascial incision can help clearly define the anterior and lateral compartments to ensure they are both released properly. (Reproduced with permission from Velmahos G and Toutouzas K. Surg Clin North Am 2002;82:125–141.)

How to Manage the Fasciotomy Wound

There are several dynamic ways to address the fasciotomy wound. Vacuum therapy is well tolerated and facilitates control of effluent as the tissues continue to swell. The problem with this approach is that since the dressing changes do not have to be done frequently, there is sometimes a tendency to not take the patient back often. Delay in treating the wounds frequently will result in the skin retracting and making primary

closure difficult. This will then ultimately result in split thickness skin graft. While this is acceptable, delayed closure of the skin will prevent subjecting the patient to taking skin off to cover a wound and is cosmetically preferable. There are many methods and devices available to assist in pulling the skin and subcutaneous tissue together. The main problem is that most approaches only pull on the skin edges. For example a favored technique is to use a "roman lace" technique where vessel loops are stapled or sewn at the edge of the skin and then some tension is applied to the open wound. The problem is that this is rarely strong enough to pull the wound closed. If too much tension is applied then the sutures or staples fall out.

Pulley Suture: Trick of the Trade

A trick of the trade which is highly effective in closing any type of wound is what we call the "pulley stitch" (Fig. 18.8). Care has to be taken as this suture is so effective that it can create a compartment syndrome from the skin. This technique is cheap as it only uses a heavy monofilament suture and can even be pre-placed loosely at the original operation so that it can be pulled at the bedside. This suture has been used successfully to close fascia, or any tissue. The principle of the suture is that you use one continuous suture to pull an area of tissue evenly as the sliding suture will distribute the tension equally, as opposed to the vertical mattress where all the tension is on the outer suture and the tissue in between is bunched up. The inner suture only reapproximates the skin edges. The pulley suture will pull tissue far away from the wound while pulling tissue in the middle and at the skin edges as well.

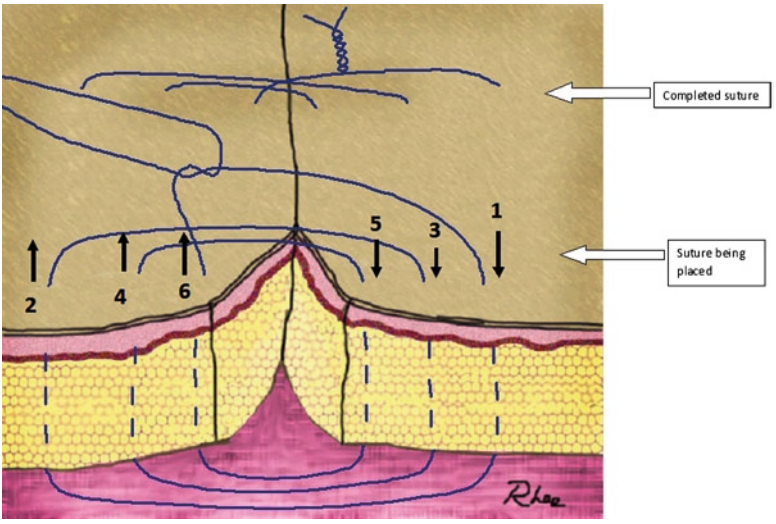

Fig. 18.8 Pulley Suture technique. Large suture is place continuously, 1 FAR – 2 FAR – 3 MIDDLE – 4 MIDDLE – 5 NEAR – 6 NEAR

The wound can be closed over a small penrose drain if needed. After the several pulley sutures have been placed, other simple or running sutures can be placed between or across the pulley suture (Fig. 18.9), or staples can be used. Once the skin has stretched in a day or so, sutures under tension can be cut and the sutures that were not under tension will take over the burden of the tension. This technique has prevented the need of many reconstructive surgeries including skin grafting (Fig. 18.10). To create a pulley suture, start with a simple interrupted suture taking about 2 cm bites of the skin and subcutaneous tissue. The second pass should mirror the first, except now take the bites about 1 cm from the skin edge, in the same line as your first pass. The third pass is again in the same direction, but taking only skin edge to skin edge (2–3 mm). Steady gentle upward traction on the suture ends will now create

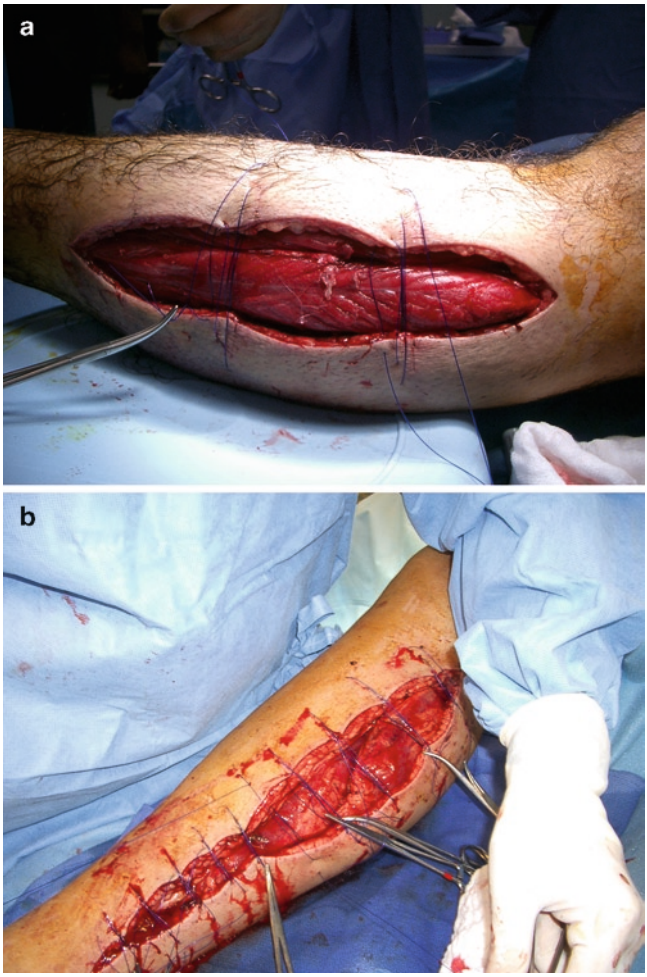

Fig. 18.9 Panel (**a**) – pulley sutures being placed with 2-0 prolene. Panel (**b**) – multiple pulley sutures in place ready to tie

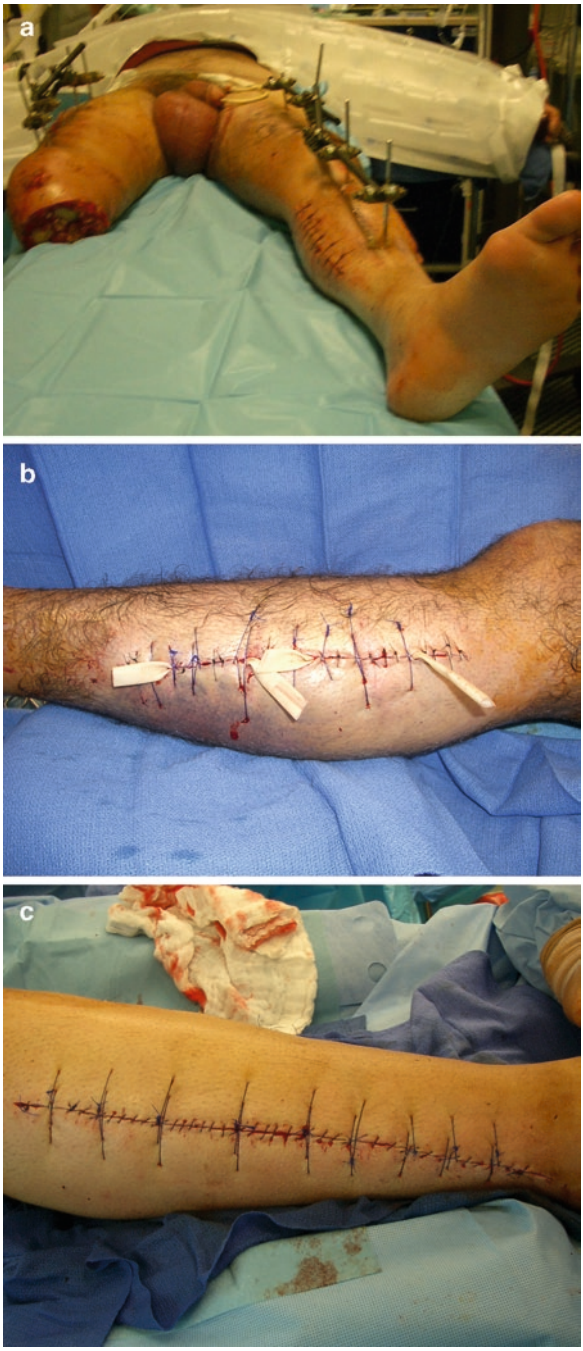

Fig. 18.10 Examples of definitive combat wound closures. Panel (**a**) – fasciotomy wound closed. Panel (**b**) – closed over penrose. Panel (**c**) – skin edges closed across the pulley sutures

significant and distributed force to bring the wound together and allow for easy knot tying under no tension. As opposed to the vertical mattress suture which is "far – far – near – near", the pulley suture is: "Far – far – middle – middle – near – near".

Final Thoughts

Soft tissue wounds experienced in modern warfare are considerable challenges that you will frequently encounter. Be aggressive about irrigation and debridement – it will serve you well in avoiding the local and systemic effects of what can develop into devastating infection. But do not be aggressive about closing these wounds at the initial operation! This is one of those lessons that seem to be learned the hard way by newly deployed surgeons, over and over again. Remember that your decision making and technique can set the stage for a successful outcome or a devastating complication, even when dealing with the "simple" soft-tissue wound.