Soft-tissue complications comprise a spectrum of entities ranging from the simple postoperative wound dehiscence to the complex, mangled lower extremities seen with high-energy trauma. Therefore, it is important for every orthopaedic surgeon to have a basic knowledge and working algorithm for managing compromised soft-tissues. With an increase in the utilization of operative treatment for the care of orthopaedic injuries, one can expect to see an increasing number of postoperative wound complications. Complications are often unavoidable and are secondary to the nature of the injury or the status of the host. However, a proportion of these complications can be avoided by strict adherence to certain principles and the meticulous management of soft-tissue handling.

Anatomy

The soft-tissues are comprised of skin, subcutaneous fat, fascia, musculotendinous units, ligaments, periosteum, and neurovascular structures. The epidermis and dermis comprise 5% to 20% and 80% to 95% of the skin, respectively, and together function as the primary barrier to infection. As with all living tissues, blood supply is of the utmost importance, and its preservation is the key determining factor of whether a complication will occur.

Ian Taylor, utilizing radiographic studies, cadaver dissection, and ink injection techniques, mapped out the arterial network that supplies the soft-tissues. As a result of his work and those of others who preceded him, some basic anatomical concepts are known. The first is that the blood supply travels within or adjacent to the connective tissue framework. Vessels course from fixed loci to mobile areas. He noted that the body consists of a three-dimensional jigsaw, made up of units of tissue supplied by named source arteries. Furthermore, he discovered that the territory supplied by the source artery in the deep tissues corresponded with the overlying integument. The term “angiosome” was coined to denote the composite blocks of tissue supplied by the main source arteries that span between the skin and bone. Another important observation he noted was that the depth of the arterial axis, which supplies direct vessels to the skin, varies in different regions of the body. For example, in loose skinned areas of the body, the arterial axis is located at the level of the subdermal plexus. Where the skin is affixed to the deep fascia, the arterial axis is located on the surface of this fascia. This concept is fundamental in skin flap design and confirms the rationale for including the outer layer of the deep fascia with flaps that are raised in the extremities.

Assessment and Classification of Wounds

The initial management of a soft-tissue injury starts with a comprehensive history and physical. What was the mechanism of injury and when did it occur? What is the vascular status of the extremity? Is there skin, muscle, or bone loss? Is there gross contamination or a compartment syndrome present? What patient factors are present...
which may have an impact on healing? Has the patient received appropriate antibiotic and tetanus prophylaxis? No single assessment is adequate and a continual evaluation of the injured limb is essential. Remember, tissue that is alive today may be dead tomorrow.

Not all wounds are similar. Some are the result of crush injuries and others are caused by lacerations. Abrasions and avulsions impart shear forces to the tissues and may be superficial or deep. There are chronic wounds that are often the result of improper surgical technique and soft-tissue handling (Fig. 1). The mechanism of injury has important implications regarding treatment and prognosis. For example, crush injuries are among the most difficult injuries to treat. They are often the result of high-energy trauma, involve large surface areas, and the viability and vascularity of the soft tissues are always in question. Crush injuries require radical and often multiple debridements to ensure a clean, viable soft-tissue bed. Closed avulsion injuries may separate the integument from the underlying fascia. This degloving injury may necrose the skin and subcutaneous tissues and is commonly seen in older individuals.

Tscherne and the AO group have devised classification schemes for soft tissue injuries with a distinction made for closed and open fractures. Tscherne ranks injuries from Type 0 (minimal soft tissue damage with simple fracture patterns) to Type III (extensive skin contusion and crush, compartment syndrome, severe or comminuted fracture configuration). The AO classification scheme, designed in 1990, incorporates five grades of injury and three types of tissue (skin, musculotendinous units, and neurovascular structures). The Gustilo and Anderson classification system for open wounds takes into account the size of the wound, energy of injury, need for soft tissue coverage, and whether there is a vascular injury requiring repair for viability of the limb.

It is important to recognize and reverse both patient and surgeon factors that can have a deleterious effect on wound healing. Patient factors include diabetes, peripheral vascular disease, malnutrition, chronic steroid use, and smoking. Other risk factors include the timing and duration of surgery, the presence of dead space and/or foreign bodies, and injudicious use of self-retaining retractors. Many soft tissue infections have been avoided by provisional stabilization of lower extremity perarticular fractures using spanning external fixation prior to operative fixation to allow soft tissue swelling to subside.

Equally important is the ability to recognize wounds at risk for infection and to identify and treat complications early when they do occur. Wounds at risk consist of avulsed skin flaps, wounds located over the pretibial surface and Achilles tendon; and flaps that are contused, ecchymotic, or blanched. Koval and colleagues looked at the effects of placing incisions through blisters. They found that clear blisters are at no increased risk for wound complications, as opposed to hemorrhagic blisters, which represent a complete separation of the dermis from the epidermis (Fig. 2). Early wound complications include drainage, hematomas, cellulitis, and wound dehiscence.

**Suturing Techniques**

Lack of tension and perfect coaptation of skin edges providing maximal eversion are central components of good wound healing. The most common error made when approximating a wound is closing the skin under too much tension. This leads to tissue ischemia and potential necrosis. Always allow room for swelling, and remove any sutures that cause blanching of the wound edges. Other basic concepts include avoiding too much suture material, which can incite an inflammatory response (sutures should be placed about 1 to 2 cm apart); placing the needle at 90 degrees to the skin and following the curvature of the needle; and grasping only the dermis with the forceps. The buried suture, if placed correctly, reduces dead space, decreases tension along the wound edge, and provides wound eversion. It should not be placed too close to the epidermis (i.e., avoid skin dimpling) or else it may “spit.” Horizontally placed, buried dermal sutures can incorporate more tissue without comprising skin vascularity. Retention sutures may reduce vascular compromise along the wound edge by allowing the use of finer suture material to approximate the wound.

Specific suturing techniques include the vertical mattress suture, the running continuous suture, the running subcuticular suture, the corner stitch, and the Donnati stitch. The vertical mattress suture improves eversion and coaptation of the wound. It also decreases dead space and provides increased tensile strength across the wound. These can be alternated with simple sutures. The running continuous suture is fast and easy and evenly distributes tension along the wound edge. The running subcuticular suture takes time to perform and does not evert the wound edges; however, it avoids the problem of skin irritation and suture marks. The corner stitch, or modified horizontal mattress, is excellent for wounds at corners, Z-plasty flaps, and intersections of multiple wounds. It produces good skin coaptation without compromising the vascularity of the tip of the far skin. The Donnati stitch has been used in wounds with vulnerable skin flaps. With this stitch, only a dermal bite is taken on the side of the wound with the at-risk skin flap, the needle not exiting through the epidermis. The opposite side has a vertical mattress configuration.

**Debridement**

A thorough, radical debridement is the single most important factor in both avoiding and adequately treating a wound infection. It should proceed in a systematic, organized fashion and include all layers from the skin to
bone to ensure a healthy, viable wound bed. Even in closed wounds, such as an avulsion-type degloving injury, debridement may be necessary. With modern methods of soft-tissue coverage, the fear of leaving vital structures exposed secondary to an aggressive debridement should no longer be a concern.

In the acute, post-traumatic extremity, debridement begins with extension of the traumatic wound to adequately evaluate all tissues within the zone of injury. A preliminary irrigation may help to flush clots and visualize the tissues better. Debridement should be done sharply, thus avoiding further trauma to remaining tissues. Muscle is the major pabulum for infection and all nonviable muscle must be excised. The determination of muscle viability may be assessed using the four C’s: color, consistency, capacity to bleed, and contractility. All free segments of bone devoid of soft tissue attachments should be removed, even if they provide structural support to the fracture. All tissues of questionable viability may be re-evaluated at a subsequent debridement, usually within 24 to 48 hours.

Debridement of a chronic wound must include excising all scar tissue in its entirety down to normal tissue planes. If vital structures are entrapped within the scar, dissection should begin in healthy tissue and proceed toward the scar, thus enabling one to separate out the vital structures. A hall burr is used to debride bone until punctate bleeding, (the “paprika sign” as popularized by Cierny6) is evident.

“The Reconstructive Ladder”

The term “reconstructive ladder” was coined by Levin7 to serve as an algorithm when treating soft tissue defects. As one climbs higher rungs on the ladder, the complexity of the soft tissue procedures increases. Starting at the bottom, we begin with primary closure and progress to delayed primary closure and end with healing by secondary intention. The next rung on the ladder is the split-thickness skin graft, which is used to successfully close many extremity wounds. More complex wounds that will not support skin grafts require vascularized tissues to achieve wound closure. These may be local or free flaps. The most complex wounds may require the use of multiple rungs on the reconstructive ladder.
Soft Tissue Coverage

Grafts, by definition, obtain their blood supply from the donor bed to which they are applied. This is in contrast to flaps that bring with them their own vascular supply. Most extremity wounds with full-thickness skin loss may be closed using a skin graft, which is why every orthopaedist should be familiar with the application of skin grafts. Skin grafts may include all [full-thickness skin grafts (FTSG)] or part [split-thickness skin grafts (STSG)] of the dermis.

Since grafts obtain their vascular supply from the wound bed, avascular tissues will not accept a skin graft, and will require more complex soft tissue coverage. Examples of poor recipient tissues include exposed bone and tendons, neurovascular structures, and necrotic tissue. Most grafts used for reconstructive purposes are STSGs. They are more likely to “take” and can cover a larger surface area than FTSGs. In general, FTSGs are used for defects of the hands and face.

The harvesting and application of a skin graft is a two-step process that requires strict immobilization in the first few days. During the first 48 hours, the graft survives by imbibition of wound bed exudate. Afterwards, new blood vessels begin to grow from the wound bed up into the graft (a process known as inosculation). By the fifth to seventh day, a skin graft is usually adhered and vascularized.

The harvesting and application of a skin graft is a simple technique yet requires careful attention to detail. First, one must adequately prepare the recipient site. A curette is useful to remove nonviable material and to create a healthy, bleeding bed. Although hemostasis is imperative, avoid overuse of the Bovie as this can leave the bed charred. After debridement, applying a saline-soaked gauze with or without the addition of a topical hemostatic agent, such as thrombin, will provide hemostasis to the recipient bed while the graft is harvested.

Necessary equipment to perform a STSG includes a dermatome, mesher, mineral oil, sutures or staples, and appropriate dressings. The dermatome can be adjusted to determine the thickness (usually between 0.012 and 0.017 of an inch) and width of the graft. Mineral oil is applied to the donor site to ease gliding of the dermatome. The dermatome is advanced firmly at an angle of 45 degrees to the skin. Punctate bleeding should be noted from the dermis as the dermatome is advanced. If subcutaneous fat is seen, harvesting is stopped, the graft is replaced, and the thickness of the graft is readjusted.

The decision to mesh a graft is made for two reasons; first, to permit postoperative drainage to prevent hematoma formation; and second, because meshing increases the size of the graft, thus enabling it to cover a larger surface area. The graft may be affixed to the recipient bed using sutures or staples. Care must be taken to carefully contour the graft to any depressions throughout the recipient bed. The final step is application of a suitable dressing, with the goal of providing a moist, clean environment. A nonadherent dressing (Xeroform or Adaptic) is first placed on the graft. This may then be covered with gauze moistened with a glycérin-based (Bunnell’s) solution or bacitracin, followed by a soft, dry dressing. Again, care is taken to conform the dressing to the peaks and valleys of the wound bed. If it is not possible to wrap the area with gauze, a bolster-type dressing may be applied.

Wounds with full-thickness defects will often require the importation of vascularized tissue to achieve wound closure. Flaps may be classified according to their method of transfer, their composition, and their blood supply. The most commonly used flaps in orthopaedic surgery are the rotational flaps (fasciocutaneous, gracilis, and soleus) and free microvascular flaps (latissimus dorsi and rectus flaps). The flap selected will depend upon the size and location of the defect, the quality and availability of suitable local tissues, and other comorbid conditions present in the patient.

Muscle flaps are considered the gold standard for coverage of osteomyelitis and acute traumatic defects. They are superior to fasciocutaneous tissues when it comes to revascularizing bone, obliterating dead space, controlling sub-flap levels of bacteria, and improving antibiotic delivery to the injured site.

Commonly used rotational flaps include the gastrocnemius flap for proximal-third defects of the lower extremity and soleus flaps for middle-third defects. Free flaps are used for defects of the distal third of the tibia.

Treatment Considerations in Open Tibia Fractures

Treatment of high-energy open tibia fractures is challenging due to the degree of soft tissue and bone loss that are associated with these injuries. Many of these fractures have high rates of nonunion and infection, with accompanying morbidity and loss of function.

After assessing for limb viability, the priority of treatment is antibiotics and tetanus prophylaxis, splinting, debridement, stabilization, temporary wound closure, definitive wound closure, and functional rehabilitation. The following discussion will focus on temporary and definitive wound closure.

The usual protocol of packing a wound with saline-soaked gauze and wrapping with a Kerlix may actually have deleterious effects. A wound will desiccate within a few hours with this type of dressing, adding to the amount of non-viable, necrotic material already present. In addition, this dressing is not effective as a barrier for bacterial contamination, provides poor dead space management, and will usually be soaked through and foul smelling the next day.

For wounds with minimal soft tissue loss, where a delayed primary closure or skin graft is used, an emollient-type dressing can be applied. This may consist of
a layer of Neosporin covered with a semi-permeable dressing. Distasio and associates\(^\text{10}\) reported on the use of multiple, relaxing skin incisions, “pie-crusting,” to help in achieving closure of traumatic wounds. They had no cases of wound dehiscence, skin slough, or infection in 22 patients. This technique involves placing numerous, small (5 mm to 10 mm) incisions through the dermis arranged in 1-cm wide rows parallel to the primary wound or incision.

Vacuum-assisted closure (VAC) dressings have recently gained popularity in the treatment of both acute and chronic wounds with soft tissue defects. The technique removes chronic edema, leading to increased localized blood flow, and the applied forces result in the enhanced formation of granulation tissue.\(^\text{11}\)

For more complex wounds, the antibiotic bead pouch technique\(^\text{12,13}\) has been shown to be effective in lowering the infection rates in open tibia fractures and can be utilized for dealing with dead space management. This method of temporizing coverage increases bacteriocidal levels of antibiotics at the wound site and provides a moist, aerobic wound environment that resists bacterial contamination. All wounds should be re-debrided every 24 to 72 hours in the operating room prior to definitive soft-tissue coverage.

Although no absolute time frame is known, a wound can be safely closed once all necrotic tissue has been removed and a healthy wound bed has been obtained. Many authors have stressed the importance of achieving soft-tissue coverage in a timely fashion.\(^\text{14-16}\) This decreases the number of associated procedures, lowers the complication rate, and shortens the time to union. If one chooses to use local tissue for coverage, it is imperative that the tissue be outside of the zone of injury. If not, the effect of transposing the damaged tissues may be the impetus for ischemia and necrosis. Many complications can occur with flap closure, and most will require an additional trip to the operating room. These include a sub-flap abscess, flap necrosis, and ischemic flaps.

**Summary**

Meticulous handling of the tissues, reversal of known patient risk factors, and attention to detail can avoid many soft-tissue complications. Prompt management or consultation of a soft-tissue expert may reduce the morbidity and need for extensive reconstructive procedures.

**References**