Mechanisms of soft-tissue injury
3.1 Blunt trauma

3.1.1 Introduction

Blunt—usually direct—trauma may result in soft-tissue injury, which initially is often underestimated because it presents with a less dramatic clinical appearance than penetrating trauma. The extent of the injury may increase as pathophysiological processes continue for days after injury (chapter 10.3.3). Understanding the susceptibility of skin, muscle, nerves, and vascular structures to blunt or crushing occurrences enables the surgeon to thoroughly assess the condition of the injured area in order to formulate a treatment plan. This chapter describes such mechanisms, with emphasis on direct impact and crush injuries. As with any other type of injury, there is a substantial range of severity, from simple contusion to closed lacerations to devastating crush injuries. While closed injuries may not carry the same risk of infection as their penetrating or open crushing counterparts, they may have equally poor outcomes due to vascular injury or massive muscle necrosis.

3.1.2 Direct trauma

The most frequent cause of blunt trauma leading to significant soft-tissue damage is a direct blow, most often covering a larger area of impact than seen in penetrating injuries and with variable disruption of the integument. If the injury results from a more focal point of impact, disruption of the skin occurs, with possible concomitant vascular or neurologic injury. In a larger impact area, the energy is dissipated. Thus, open injuries are less frequent. However, this impact can still cause significant damage.

In a validated rat model, Crisco et al [1] found that the degree of damage incurred depended upon both the mass and velocity of the impacting object as well as the radius of curvature or dimensions of this object. They discovered a predictable time course of pathology, which follows initial injury. Immediately after impact, the gross appearance of the damaged muscle demonstrated marked hemorrhage and edema near the surface, which extended radially from the point of impact (Fig 3.1-1). Microscopically, this area showed intracellular formation of vacuoles within intact myofibrils and clear myofibril disruption of varying extent. There was no immediate change in quantities of collagen, and no early markers of fibroblast migration.

There appear to be three distinct zones of injury (Fig 3.1-2): the central or gap zone, directly beneath the point of impact; the regenerative zone, where edema develops over the initial few days, and the uninjured, surviving zone. These zones depend upon the amount of energy imparted to the soft tissue as well as its relationship to the surrounding hard tissues. A relationship also exists between muscle mass and the possibility for muscle displacement. Studies have demonstrated that a muscle, which is contracted at the time of injury, sustains less severe damage than muscle in a relaxed state. In the latter case, the zone of direct injury tends to be

---

**Fig 3.1-1** Intramuscular contusion. Note that the muscle fibers are more or less intact despite hemorrhage and edema extending radially from the point of impact.

**Fig 3.1-2** Three zones of injury in muscle.
1 Central gap zone.
2 Intermediate regenerative zone.
3 Peripheral zone of intact muscle.
4 Uninjured nerves.
5 Transected nerve.
displaced and deeper. The degree of damage initially present may clinically be difficult to determine. In severe injury, clear disruption can lead to hematoma, whereas lesser damage will rather create intramuscular hemorrhage.

A blunt impact creates damage that is highly dependent upon the material properties of the recipient tissue. When a considerable soft-tissue envelope is present, the impact creates shearing forces within adipose tissue, the underlying muscle, and neurovascular structures, which will dissipate some of the energy. However, when the soft-tissue envelope is minimal, skin and bone will typically be the first to fail. In case skin and bone remain intact even though the imparted energy is severe, a closed, complete laceration may occur. This is marked by failure and retraction of the muscle mass away from the zone of injury (chapter 10.3), resulting in an obvious defect. If linear structures are present, these are subjected to similar shear forces. Nerve tissue has very little tolerance in regard to stretching and prolonged compression.

Vascular injury has been described in conjunction with blunt trauma [2]. The degree of trauma inflicted in order to cause vascular injury is often severe enough to also cause associated limb loss, hemorrhage, and even life-threatening injury to the trunk, or a systemic inflammatory response. In these situations, careful clinical assessment, including peripheral neurovascular examination as well as an ankle-brachial index test, are mandatory. The nature of such an arterial injury is rather an avulsion (intimal tear) than a true crush and, therefore, loss of pulses is not consistently complete. Diagnosis requires awareness and detailed assessment. An ankle-brachial index (ABI) less than 0.9 has been found to be 100% correlated with occult lower-extremity vascular injury in healthy subjects [3].

### 3.1.3 Crush injury

Crush injury occurs when force is applied over an extended period of time to an immobilized portion of the body. Localized ischemia may occur as vessels are occluded by the external pressure. Crush injury of muscles is often associated with systemic effects of the ischemia, and may result in severe electrolyte imbalance, and myoglobinuria. The systemic effects have been described extensively, and are directly related to the severity and duration of tissue damage. They are manifested as an ischemic phase followed by reperfusion of the damaged area once the pressure is relieved (ischemia reperfusion injury) (Fig 3.1-3). Products of cellular death are then circulated, causing direct toxicity to end organs such as the brain, the lungs or the kidneys. Less frequently, a physical disruption of linear structures, such as vessels and nerves, is observed, precluding tissue reperfusion.

Crushing often exceeds the elasticity of the skin, causing it to burst (Fig 3.1-4). Tissues most sensitive to sustained pressure, such as vessels and nerves, fail early. Therefore, neu-
3.2 Penetrating trauma

3.2.1 Introduction

Penetrating injuries comprise a wide spectrum of soft-tissue injuries, from low-energy stab wounds to the systemic devastation of war-related blast injuries. Their severity is closely related to the affected structures and location, the degree of energy dissipation, and the behavior of the penetrating object within the tissue as well as the propensity for contamination. These determinants are critical for the amount of damage, lethality or long-term morbidity. While clinical treatment and evaluation of these injuries will be described subsequently, it is imperative to first understand the mechanisms leading to these injuries, and the associated pathology. This knowledge of the injury needs to include the degree to which these events impact the victim systemically as well as the associated injuries that are typically seen in such contexts. This section will discuss such aspects, beginning with a basic overview of ballistic injuries, respectively the study of the impact of a projectile on the human body.

3.2.2 Ballistic injury

In order to fully understand the effect of ballistic trauma, one must know the meaning of several terms rarely used in clinical practice except in the field of penetrating injury. Ballistics encompasses three discrete aspects of the trajectory of a projectile during its flight. Internal ballistics relates to the behavior of a bullet within its firing tube or at the instant of explosion. External ballistics describes the flight path from tube to the object of impact, and terminal ballistics refers to the events upon impact. Terminal ballistics...
correlates to wound ballistics whenever it relates to living tissue upon impact. As the projectile passes through tissue, the area directly damaged is called the permanent cavity. The term temporary cavity has been used to describe the tissues that are stretched in response to a cavity being formed as the bullet becomes unstable and tumbles. Terminal or wound ballistics will be the focus of this section.

The ultimate damage that a projectile inflicts upon its target is directly related to the quantity of kinetic energy it transfers to that target, which is a function of the composition, configuration, and stability of the projectile at impact as well as the characteristics and location of the organs hit by the projectile. Kinetic energy follows the equation \( KE = \frac{1}{2} mv^2 \), where \( m \) = the mass of the projectile and \( v \) = the velocity of the projectile [5]. Projectile mass can vary greatly from extremely small blast fragments to the 3.5 g round of the M16 military rifle to an artillery round weighing several kilograms. Throughout the history of studying ballistic injuries much emphasis has been placed upon velocity. In fact, while velocity is extremely important in laboratory settings, its significance to the study of human wounding patterns is much more ambiguous. In real life, velocity at the time of impact, is difficult to assess and depends upon the shape and composition of the projectile, the distance it has travelled as well as friction or drag from the surrounding air or material traversed. While arbitrarily defined, the most universally agreed upon terms for this subject define high muzzle velocity to be greater than 609.6 m/s (ie, 2000 ft/s). This velocity has previously been accepted as the point at which cavitation occurs within soft tissue. These factors are important in order to understand the behavior of a projectile immediately prior to impact. The most important consideration with respect to the damage caused by a projectile is the amount of kinetic energy imparted to the tissue rather than the velocity of the missile alone. This kinetic energy may not always be completely expended within the target. When a projectile has completely passed through a body, resulting in a perforated wound, it still retains part of its kinetic energy.

Upon impact with a human target, a projectile, whether it is a high-velocity bullet, a low-velocity shotgun pellet, arrow, or even a knife blade, will begin to transfer motion or kinetic energy to the target. The degree of damage is ultimately proportional to this transfer of energy, but is very much affected by additional forces acting upon the projectile. It becomes important to understand the behavior of the projectile within the tissue in order to understand the factors determining energy transfer. A nonspherical projectile with forward momentum meets a countering force acting to decelerate it—this is called friction or drag—which acts upon the leading surface. If the long axis of a nonspherical projectile is aligned with the direction of flight, this simply slows the projectile. However, if the bullet deviates from its track, the deceleration force turns into momentum and begins to tilt it out of the original direction of flight. This is defined as yaw. As yaw increases, the surface of the projectile imparting energy to the target is larger. This is known as the base-immersion phenomenon. A common mis-

Fig 3.2-1  Idealized flight pattern of a rifle projectile. Yaw diminishes over distance traveled until the projectile enters another medium such as flesh. In a high-energy situation, the bullet becomes unstable and its yaw may increase up to the point when the bullet reverses by 180° and continuous moving end first, known as the base-immersion effect. When this occurs, there is an associated tremendous dissipation of energy into that part of the injured tissue.

1 Skin surface.
2 Deep tissues.
3 Permanent cavity.

Fig 3.2-2  Idealized pathomorphology of a soft-tissue gunshot wound in skeletal muscle. Surface view. The wound consists of three zones:
1 Central zone of permanent cavity.
2 Intermediate zone of extravasation.
3 Peripheral zone of concussion.
conception is that yaw plays a significant role during flight prior to impact. If a projectile is spinning, such as occurs with the spiral grooves of a modern rifle, then yaw can be counteracted by gyroscopic forces that tend to minimize this deviation. For a variable distance after leaving the rifle tube, a bullet may have significant yaw, but this tends to decrease up to the time of impact. At impact, however, yaw can become more pronounced due to the marked difference in tissue density compared to air, and the bullet thus becomes unstable. In many situations the bullet completely rotates into a base-forward attitude within the second medium. Projectile studies in ballistic gelatin have demonstrated a consistent reversal at a penetration depth that is characteristic for each projectile [6]. The clinical significance of this effect lies in the explosive transfer of energy at the point when the bullet flips. This point can substantially be affected by previous impact with external objects—tree limbs, windows, clothing—or internally by contact with bone, fascial planes or tissues of different densities such as muscle and lung tissue. In such situations, the bullet may either impact with an enlarged surface and be deformed or else fragment into smaller missiles, each causing its own wound track. Occasionally, fragmentation of a primary projectile or impact with movable objects can propel multiple secondary projectiles. The path of destruction that the bullet leaves behind after it has passed is called the permanent cavity, and is divided into three zones (Fig 3.2-2): the central zone of permanent cavity, the intermediate zone of extravasation, and the peripheral zone of concussion [7].

The concept of cavitation pertains to a stretching of the soft tissue as the projectile travels through it. While cavitation, or stretching of soft tissues, has been demonstrated at all velocities, the marked expansion of this cavity consistently develops at velocities of over 609.6 m/s (ie, 2000 ft/s). This effect does not create the irreversible destruction that is seen from direct trauma within the permanent cavity, but certain tissues such as brain, nerves, and bone are less tolerant than more elastic tissues such as lung and liver. The cavity is very transient, but does create a vacuum, and it is this vacuum that can impel foreign debris and contamination into the cavity. Ballistic gelatin is a homogeneous material and readily demonstrates the phenomenon of cavitation (Fig 3.2-3, 3.2-4). Cavitation is markedly reduced in living tissue due to the anisotropic properties of fascia and connective tissues. Therefore, cavitation does not have as profound an effect as previously theorized. It may still be implicated in the stretch injuries seen in nerve and vascular tissues in close proximity to the permanent cavity.

The notion that a projectile is sterile and wound contamination will not occur has been disproven [8]. In fact, in cavitation situations, the vacuum associated with the temporary cavity has been demonstrated to draw external material and even bacteria into that cavity. Sometimes this vacuum effect is also referred to as blowback.
3.2.3 Pathophysiology

Perhaps the most important feature of penetrating ballistic wounds that needs to be understood is the mechanism by which a projectile disrupts the injured tissue. Tissue damage occurs by one or more of the following mechanisms [9]:

- **cutting**, due to direct contact
- **stretching**, due to transverse or shear waves created by the transfer of kinetic energy (cavitation)
- **compression**, due to longitudinal or shock waves in front of the projectile, and
- **heating**, due to the transfer of energy in the form of friction.

Much of the early work on wound ballistics was done in ballistic gelatin. This material is isotropic—i.e., it behaves similarly in all directions and velocities and, therefore, fails to accurately model the human body. Skin, fat, fascial planes, and muscle layers can have a profound effect on the course of a projectile. It has been demonstrated that a round object requires ~ 76.2 m/s (i.e., 250 ft/s) to penetrate human skin [10]. Notably, a sharp object such as a knife blade or arrow tip requires much less velocity and will penetrate skin with less local tissue damage. As demonstrated in the section regarding ballistics, the amount of kinetic energy at the time of impact and its subsequent transfer to the recipient tissue is of utmost importance. Additional factors include the stability of the projectile within the tissue; its size and construction; the tissue through which it travels within the body; the elasticity and density of the tissues traversed; the mechanism of tissue disruption; and finally the number of fragments involved [11].

Wounding studies on the effects of wounds caused in certain tissues have demonstrated that density of the tissue is less important than its effective elasticity. When a projectile enters muscle directly, the permanent cavity is linear but will be affected by fascial investments, proximity to bony attachments, and thickness. A projectile traversing the mid portion of a muscle will do less damage than a similar round at the point of a muscle insertion. Once a bullet becomes unstable, it will rotate and this creates more devastation than a linear permanent track. Similarly, impact with bone will often cause secondary fragmentation and multiple permanent tracks. Although less common, some projectiles may fragment even in soft tissues. Nerves and vessels are often spared direct transection, but the tension associated with cavitation can cause avulsion (tear of arterial intima), stretching (neurapraxia), or intraneurial disruption (axonotmesis) [12]. These longitudinal structures are more frequently injured if bound tightly within tissue planes or in more distal injuries, where the smaller terminal branches are less elastic. Smaller-diameter structures are more at risk of direct injury and capillary damage rather than major vessels and largely contribute to the central zone of extravasation. There is an additional effect on the tissues that develops over time:

![Fig 3.2-5a–b](image)

High-energy projectile which penetrated above the knee. Note the severe damage caused by bone fragments created when the bullet struck bone. Exit wounds are not always larger, depending on the bullet trajectory within the target tissue.

- a Medial view: entry point.
- b Lateral view: exit point.
immediately following the injury, the permanent track is visibly damaged, hemorrhagic, and physically disrupted, ie, the zone of extravasation redundancy. Within 24 hours the surrounding tissue shows signs of contusion, an apparent spread of the ischemia, severe inflammation and edema formation, and residual contamination. The microscopic examination of this intermediate zone of contusion appears similar to that of blunt injury. Finally, hollow organs are more sensitive to the pressure wave that accompanies the temporary cavity. Tissues of higher elasticity rebound from pressure while those associated with noncompressible fluid, such as intestines, bladder, or heart are subject to rupture. Therefore, these tissues can collapse or vessels attached to them are sheared off.

3.2.4 Weapon-specific effects

In general, the effectiveness of any specific weapon relies on its capacity to dissipate kinetic energy to the recipient tissue. When a low-velocity projectile penetrates tissue, it carries only a small amount of total kinetic energy to dissipate. While cavitation can occur with any projectile, the explosive effects are not often observed with low-energy rounds. Conversely, if a high-velocity round perforates, or passes completely through a soft-tissue target without disrupting or fragmenting bone, it imparts relatively little of its total kinetic energy (Fig 3.2-5a–b). Clear examples of the variability that can occur with the same type of projectile depending on its imparted energy are shotgun wounds. A shotgun can fire a large combination of pellet sizes and powder loads to propel the pellets, and is very dependent upon range to be effective. Specifically, the smaller caliber pellets seen in birdshot have very little mass individually, yet comprise a large amount of total energy. As these pellets are each subject to individual deceleration, their range is relatively short (Fig 3.2-6). The larger caliber pellets, such as buckshot or a single slug can mimic a similar caliber rifle bullet. In fact, the caliber of buckshot is very similar to a 22-caliber rifle round. The shotgun pellets, however, are subject to scatter, and within a few meters their energy begins to dissipate. Ordog et al described three grades of severity in relation to the distance of the target from the shotgun [13]. Type I wound patterns occur at distances > 6.4 m with individual pellets able to cause significant injury, but in general only create widely scattered skin perforations and multiple low-energy injuries. Type II wounds occur from 2.74–6.4 m and consist of multiple parallel tracks of destruction with a high degree of vascular injury of up to 35%. Type III wounds, inflicted at a distance < 2.74 m, are associated with total destruction in a straight path, regardless of shot size or powder load. These can often be recognized by a wound diameter of less than 15.24 cm. Type II and III injuries are associated with major fracture in up to 48%, and peripheral nerve injury up to 58% of patients (Fig 3.2-7). Nonetheless, shotgun wounds carry a disproportionately

Fig 3.2-6 Shotgun wounds at extremely close range will have an appearance similar to a solid, high-energy round as the pellets have no time or distance to scatter. After a few meters, however, the pellets spread and create multiple penetrating wounds, frequently with complete energy dissipation, as in this shotgun blast to the shoulder.

Fig 3.2-7 AP x-ray of a femoral fracture caused by a high-energy rifle shot. The round had first passed through a wooden door.
high rate of morbidity and even mortality in spite of this variability of projectile size and velocity.

On the other end of the spectrum, penetrating wounds caused by knife stabs impart a relatively low amount of kinetic energy, and consequently do not create the widespread local tissue damage seen with bullets or pellets. The damage of a knife-stab wound is most often directed via direct cutting, leading to the very limited permanent cavity of penetration. Injury to specific structures depends on the path of the knife, and unlike ballistic projectiles, this path typically follows a straight trajectory, independent of tissue elasticity or tissue planes. There is little stretching, compression, or heat injury with stab wounds [11]. Similarly, contamination is directly limited to that introduced by the utensil causing the skin penetration, and there is little to no contusion zone.

Much has been written regarding differences between handguns and high-energy weapons such as those used in military action. The basic principles described above apply to the entire spectrum of damage that can be seen. Handgun injuries must be assessed for associated neurovascular injury within the region injured, while nearly every rifle injury will cause extensive damage.

3.2.5 Blast injury

The final aspect of penetrating soft-tissue injury pertains to effects related to explosive blasts. Throughout the world, explosive blasts rank extremely high, both in regard to morbidity and mortality. In recent conflicts, injuries to the musculoskeletal system account for 54–70% of injuries and as high as 78% of these were related to explosions. Injury of the human occurs when the rapid expansion of gas surrounding the point of explosion propagates a supersonic shock wave in all directions from the blast. The spectrum of injuries related to blasts is categorized relative to the mechanism.

Primary blast injury results from the direct effect of the overpressure shock wave on the body, and occurs in very close proximity to the actual explosion. This affects hollow organs such as the lungs and digestive system. These injuries are thought to be related to the intense overpressure, and are rarely survived. In victims who do survive, scattered and rapidly confluent pulmonary hemorrhagic contusions occur, and can lead to progressive respiratory failure. In nearly all victims, a pneumothorax or hemothorax is encountered, but these victims usually do not survive unless they are immediately rescued and receive treatment. Abdominal injury associated with primary blast affects gas-filled organs primarily, with colon rupture, bowel perforation, mesenteric shear injuries, and resultant hemorrhage. Tympanic membrane rupture is nearly universal and can be seen in all levels of blast injury. Soft-tissue injury is typically devastating, and, with this most severe subset, traumatic amputation is associated with very high rate of mortality.

Secondary blast injury results from flying debris that hits the body [14]. Within the scope of this chapter most penetrating injuries are due to secondary blast. Due to the initial propulsion, fragments can have extremely high initial velocities of as much as 1800 m/s (ie, 5,905 ft/s). All penetrating injuries from secondary debris should be considered high-energy wounds, associated with significant contamination and destruction.

Tertiary blast injury is most often a severe, blunt injury when the body itself is propelled into a stationary object. In these scenarios, the victim becomes the projectile and the injury is typically blunt trauma or impalement.

Quaternary blast injury finally comprises miscellaneous injuries such as burns, inhalation, crush, or radiation injuries, which may also be related to the explosion (Fig 3.2-8) [15].
All these injury patterns are directly affected by the environment as well: enclosed spaces tend to compound effects from additional pressure waves, flying or collapsing material as well as the ability to evacuate the victims in time. Associated injuries such as skull fractures, burns, and penetrating abdominal injuries are common, and require immediate assessment. Penetrating material damages soft tissues either by cutting, tearing, crushing, or burning. This also applies to the pathophysiology of blasts. The projectiles from explosions can be anything from the weapon casing to household items to organic material. While bullets will often follow a predictable trajectory, the fragments from a blast, which are of extremely variable size and often irregular shape, will not. These missiles are aerodynamically unstable, and may even have extremely high velocity or mass at very close proximity to the explosion, but rapidly lose velocity [16]. Similar to shotgun injuries, the injury to soft tissue is directly related to the amount of kinetic energy imparted to the tissue. The variable, irregular and often jagged nature of the projectiles can compound the injury by accentuating the tearing or crushing of tissue. Additionally, these fragments more often injure longitudinal structures, which may resist stretching but are vulnerable to direct laceration. Due to the devastating effects of these mechanisms, the occurrence of compartment syndrome and crush injury is common due to massive tissue damage, prolonged extrication or delays due to mass casualty situations.

3.3 Shear injury

3.3.1 Introduction

Shear injury occurs when horizontal forces, especially friction, act between an adherent, immobile surface and the more elastic surface of the body. The skin, a durable protective cover, is the largest organ in the body. Moreover, in respect to evaluating injuries caused by shear or the application of a horizontal force to the soft tissues, a basic knowledge of this organ is important. Between the outer epidermis and the deeper dermis lies a strong basement membrane, beneath which small blood and lymphatic vessels run. The epidermis is resistant to shear, while the dermis is quite elastic. Deep within the subcutaneous layer, deposits of fat exist in varying amounts, depending on the region of the body and the individual body habitus. This underlying fat is resistant to impact, but less so to shear forces transmitted through the skin and all other tissue layers. The individual effect of shear force on these tissues depends on their adherence to the deeper skeletal structures. Regions with little adherence may tolerate shear at the superficial layers, yet lose their integrity within deeper layers. This section will first address the deepest layers affected by shear and conclude with the most superficial.

3.3.2 Closed degloving injury

The skin as a whole is relatively elastic, while the layer of microvasculature between the subcutaneous tissue and dermis can be affected by avulsive forces. In locations such as the lower lumbar region, the greater trochanter and the proximal thigh, and less commonly, the knee or the shoulder, the epidermal layer is relatively thick, and can withstand friction better than the deeper structures. A Morel-Lavallée lesion originally described an injury pattern commonly associated with detachment of the skin and subcutaneous layers from deeper fascia in pelvic fractures [17]. This type of injury often forms a wide-spread, blood-filled space has formed on the muscle fascia as a result of shearing of skin and subcutaneous tissue against the underlying muscle fascia. Occasionally, a bulge forms and fluctuation may be present.

1 Epidermis and dermis.
2 Subcutis.
3 Muscle fascia.
4 Muscle.
5 Extensive hematoma.
Mechanisms of soft-tissue injury

of lesion is caused by compression and shear stress at the transition zones of subcutaneous tissue and muscle fascia or the periosteum of bone as seen in run-over accidents. It leads to shearing of skin and subcutaneous tissue from the underlying muscle, respectively bone, followed by the development of a blood-filled hollow space and fat liquefaction at predestined regions of the body (Fig 3.3-1). If the skin remains intact this closed degloving injury can persist for weeks or even months, and carries a risk of infection generally thought to be caused by hematogenous seeding. Up to 46% of closed degloving lesions may have culture positive aspirates prior to incision and debridement. The clinical appearance usually is a fluctuant mass with mobile skin, and bruising, but may also present as a solid tumor that could be confused with neoplasm. Once opened, these cases carry similar prognoses as full-thickness burns with severe infection and skin necrosis (Fig 3.3-2) [18].

3.3.3 Open degloving injury

In most areas of the body, shear forces cause disruption of the skin. Unlike the Morel-Lavallée lesion, these injuries are due to a higher level of energy. As a consequence of the energetic impact, these injuries are frequently associated with injuries to the deeper tissues, including fractures, disruption of muscle attachments, tearing of nerves and avulsion of vessels. Due to their more impressive nature, they are diagnosed much earlier (Fig 3.3-3) [19].

3.3.4 Fracture blisters

When the shearing forces to the skin arise from within, usually due to extensive edema, the lesion seems to occur superficially. Such superficial shearing injuries are called fracture blisters (chapter 12.1) and can appear as clear or blood-filled blisters. Clear blisters lie completely within the epidermis, but the hemorrhagic type often extends deeper into the dermis, compromising the crossing microcirculation (Fig 3.3-4). Giordano and Koval found that 7 of 53 patients with blood-filled fracture blisters developed complications after surgery, which were either caused by or located in the vicinity of these blisters, but no complications occurred with clear blisters [20]. Additional prospective evidence for standardized management of fracture blisters noted an incidence of 7.2% of blisters in all lower-extremity fractures, with 47% blood-filled, 43% clear, and 10% a combination of both. This study also validated a treatment protocol for unroofing the blister surface and applying silver sulfadiazine until the swelling of the skin permitted surgery and the blister appeared reepithelialized, on average after 7.7 days [21].

Fig 3.3-2 Morel-Lavallée lesion (degloving injury) managed with open debridement. There is a large cavity over the greater trochanter in a patient with an acetabular fracture. A small open wound reaches into this lesion. The cavity extends almost to the knee and across the mid line posteriorly.

Fig 3.3-3 Open degloving injury of the foot, which occurred when the patient was run over by a car tire.
Finally, the most superficial type of shear injury is that of abrasion, where there is no chance for the skin to retain its elastic properties against the immobile surface. Here skin is literally torn off in layers, depending on the duration of the force applied and the thickness of the skin affected. Depending on the depth, shearing of microvessels within the superficial dermal layer occurs as well as subsequent contamination. With the superficial protective skin layer absent, the underlying structures are also at risk as the rate of exposure accelerates and progressively deeper layers are destroyed by continuing shear.

Fig 3.3-4  Fracture blisters in a patient with a high-energy injury and a closed calcaneal fracture.

References and further reading