5 Polytrauma: Pathophysiology, Priorities, and Management

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5.1 Definition

Polytrauma is a syndrome of multiple injuries exceeding a defined severity (Injury Severity Score [ISS] ≥ 17) with sequential systemic reactions that can lead to dysfunction or failure of remote organs and vital systems, which have not themselves been directly injured.

5.2 Importance of Fractures

Fractures frequently occur in polytrauma patients. These fractures can be considered as wounds of the bone and soft tissue, giving rise to physiologic stress, pain, and hemorrhage. They can be contaminated if open wounds are present and cause compartment syndrome with ischemia-reperfusion injury. The instability of the skeleton renders the patient immobile and denies the option to select the nursing position most suitable for intensive care of brain and chest injuries.

5.3 Pathophysiological Background

Wounds (i.e., around fractures) are inflammatory foci, consisting of dead tissue in an ischemic or marginally perfused hypoxic zone. Such foci behave like endocrine organs, locally releasing mediators and cytokines to tissue macrophages as well as into the circulatory system causing systemic reactions. In severely injured patients, the lung is one of the first major immunological contact and response organs (Fig. 5.1). By releasing these substances, a cascade of local and systemic defense mechanisms is activated and immunocompetent cells are directed to control, débride, and repair the tissue defects.

Stress and pain are potent stimuli [1] for neuroendocrine, neuroimmunological, and metabolic responses. In addition, if hemorrhage, contamination, and ischemia-reperfusion injury complicate fractures, or if these are caused by associated injuries, systemic reactions to trauma produce a systemic inflammatory response syndrome (SIRS) [2]. SIRS is associated with a general capillary leak syndrome and high-energy consumption demanding a hyperdynamic hemodynamic state (flow phase) and an increased availability of oxygen. This flow phase generates an intense metabolic load with significant muscle wasting, nitrogen loss, and accelerated protein breakdown. This hypermetabolic state is accompanied by an increase in core body temperature and by thermal dysregulation.

If adequate and timely resuscitation is neither permitted (by the severity of trauma) nor provided (by the quality of care), the high-energy consumption will lead to "burn out". This process moves from depletion of immunocompetent cells and acute-phase proteins to critical immunosuppression and sepsis, then onward via increased cell damage, to a multiple organ dysfunction syndrome (MODS), and ultimately lethal multiple organ failure [3–5].

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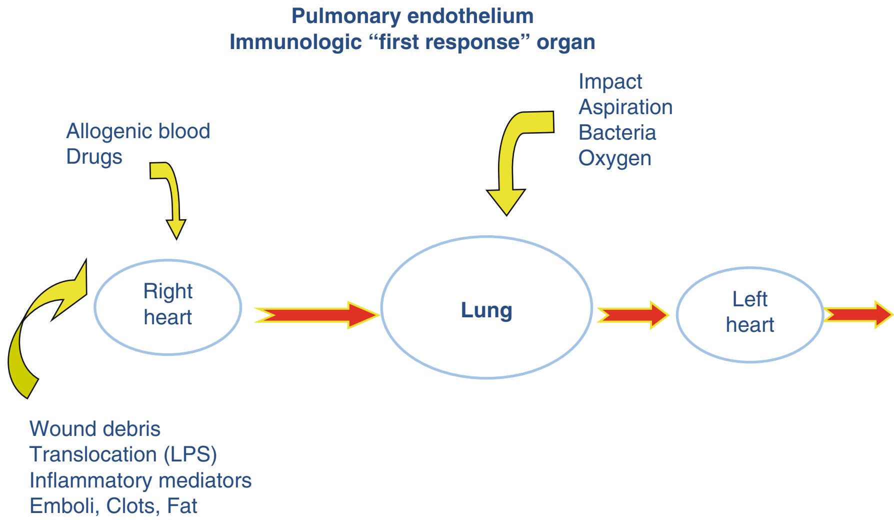

Fig. 5.1 Traumatic and interventional antigenic load on the pulmonary endothelium and alveolar epithelium in severe trauma conditions

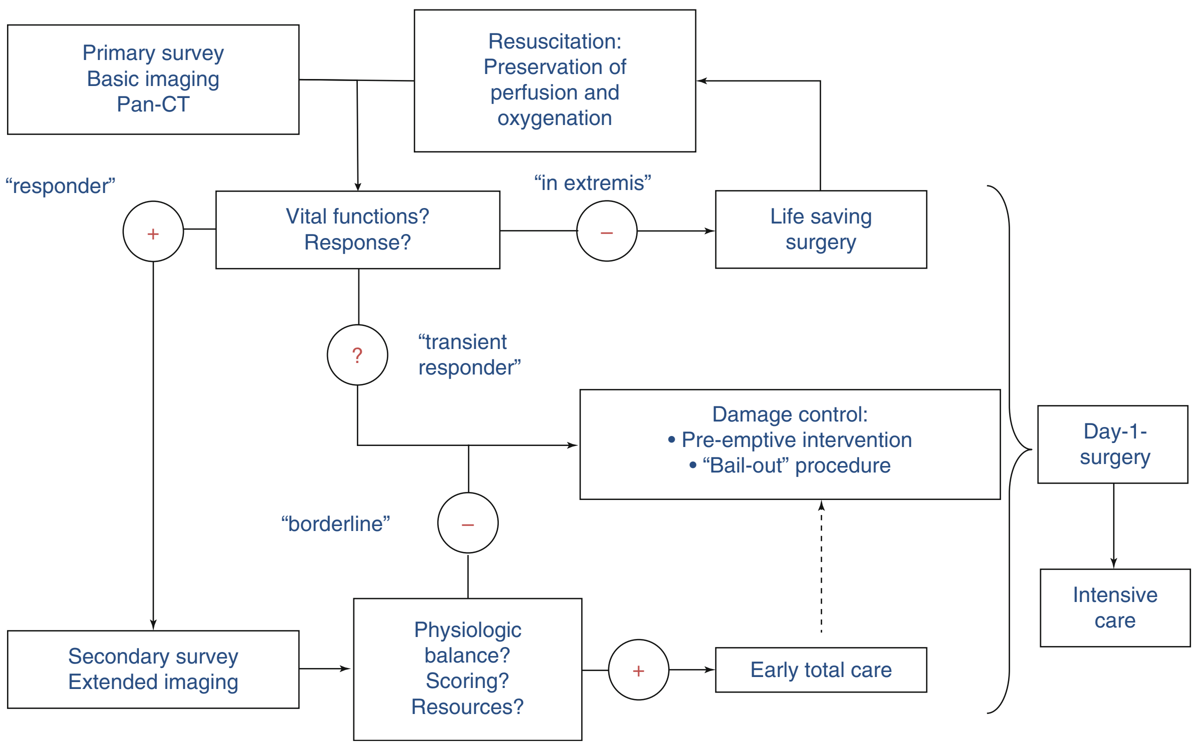

Fig. 5.2 Algorithm for resuscitation, assessment, and acute surgery in polytrauma

5.4 Timing and Priorities of Surgery (Fig. 5.2)

The primary objective during initial care of polytraumatized patients is survival with normal cognitive function. The first priority is resuscitation to ensure adequate perfusion and oxygenation of all vital organs. This can usually be accomplished by conservative means such as intubation, ventilation, and volume replacement according to the Advanced Trauma Life Support (ATLS®) protocol. If the response to such measures is not successful, *immediate life-saving surgery* is necessary:

- Decompression of body cavities (tension pneumothorax, cardiac tamponade, epidural hematoma);
- Control of exsanguinating hemorrhage (massive hemothorax or hemoperitoneum, crushed pelvis; whole limb amputation, mangled extremity).

If there is poor response to resuscitation or ongoing physiological weakness in the patient, definitive surgery should be avoided and the concept of *damage control* applied. The rationale behind this concept is saving the life by deferring repair of anatomical lesions and focusing on restoring physiology [6–9].

Briefly stated, there are two different conditions for selecting *damage-control surgery*:

1. *Physiological criteria*: hypothermia, coagulopathy, and acidosis; patient "in extremis".
2. *Complex pattern of severe injuries*: expecting major blood loss and prolonged reconstructive procedures in an unstable patient.

Damage control can be utilized in two ways:

1. *Reactively*: "bail-out" surgery, which means aborted termination of procedures in a patient at imminent risk of death;
2. *Pre-emptively*: calculated early decision to accomplish definitive repair in staged sequential procedures because of a high risk of physiological deterioration.

Damage control procedures such as control of hemorrhage, source control, irrigation, packing, external fixation of long bones and pelvic ring, and provisional closure of wounds or abdominal cavity are followed by stabilization of the physiological systems in the intensive care unit (ICU). After physiological restoration in the ICU, *staged definitive surgery* can take place under improved and safer conditions. With regard to fracture repair, there is a "window of opportunity" between day 5 and 10 post-trauma. Damage control surgery is indicated in about one third of polytrauma patients.

- *If there is a positive response to resuscitation and the patient remains stable during the "secondary survey", then "early total care" can begin according to the general principles of fracture care.*

Fracture fixation must have a high priority within the scope of this algorithm:

- Limb-threatening and disabling injuries (including open fractures) require at least damage control: débridement, fasciotomies, reduction, stabilization, and revascularization [10].
- Long bone fractures (especially femoral shaft fractures), unstable pelvic injuries, highly unstable large joints, and spinal injuries require at least provisional reduction and fixation. Definitive fixation may have to wait. A better option would be temporary stabilization by means of an external fixator followed by scheduled, definitive osteosynthesis (intramedullary nailing) during a window of opportunity between day 5 and 10 [10].

There is evidence, from clinical experience as well as in the literature, that early fracture fixation in polytrauma is beneficial in terms of mortality and morbidity [11–13].

The arguments and experience in favor of early fixation of femoral fractures and unstable pelvic-ring injuries are:

- Reduction of the incidence of acute respiratory distress syndrome (ARDS), fat embolism and pneumonia, MODS, sepsis, and thromboembolic complications;
- Facilitation of nursing and intensive care: Upright chest position, early mobilization, use of less analgesia.

Definitive osteosynthesis as day 1 surgery is advisable only when all the endpoints of resuscitation [14] have been accomplished.

Between the fifth and tenth day post-trauma an immunological window of opportunity exists, when the phase of hyperinflammation is followed by a period of immunosuppression and when new cell recruitment and de novo synthesis of acute-phase proteins are taking place.

- *During the "window of opportunity", scheduled definitive surgery of long bone fractures (shaft and articular) can be performed relatively safely.*

This period of immunosuppression lasts for about 2–3 weeks; therefore, secondary reconstructive procedures can be planned for the third or fourth week post-trauma (Fig. 5.3).

Physiology	Surgery	Time
Response to resuscitation:	– Life saving surgery ? "Damage control" + Delayed primary surgery	Day 1
Hyper-inflammation	"Second looks", only!	Days 2–3
"Window of opportunity"	Scheduled definitive surgery	Days 5–10
Immunosuppression	Emergencies, only !	
Recovery	Secondary reconstructive surgeries	Weeks 3–4

Fig. 5.3 Roadmap for timing of surgeries according to the physiological status of the patient

5.5 General Aims and Scopes of Fracture Management in Polytrauma

Fractures can have an important impact on the severity of systemic traumatic reactions as a result of

- *Hemorrhage*: Prolonged states of shock as well as exsanguinating hemorrhage are frequently associated with open or highly unstable pelvic ring injuries or femoral shaft fractures.
- *Contamination*: Open fractures must always be considered as contaminated. If a wound can only be débrided after some delay or if débridement is not radical enough, bacterial nutrients will develop in the wound. A second or even third débridement is therefore mandatory.
- *Dead, ischemic tissue with a marginally perfused hypoxic zone*: In unstable, displaced fractures, particularly after high-energy impact, a radical soft-tissue débridement is necessary as soon as possible in order to control the source of the inflammatory reaction.
- *Ischemia-reperfusion injury*: Prolonged hypovolemic shock and compartment syndromes related to fractures with or without vascular injuries are prone to ischemia-reperfusion injury with microvascular damage because of oxygen radicals. Blunt tissue contusions may activate xanthine oxidase; ischemia will produce the substrate xanthine/hypoxanthine, and reperfusion will add co-substrate oxygen. A dangerous triad is thus established.
- *Stress and pain*: Unstable fractures cause pain and stress, which via afferent input [1] to the central nervous system, stimulate a neuroendocrine, neuroimmunological, and metabolic reflex arc.
- *Interference with intensive care*: Unstable fractures prevent effective patient postures (upright chest) and pain-free handling in intensive care.

The general aims and scope of fracture management are:

- Control of hemorrhage;
- Control of sources of contamination, removal of dead tissue, prevention of ischemia-reperfusion injury;
- Pain relief;
- Facilitating intensive care.

These concepts can be realized by hemostasis, débridement, fasciotomy, fracture fixation, and tension-free wound coverage.

For stabilization of long bones, external and internal fixation as well as plates and nails are options depending on the circumstances.

5.6 Pros and Cons of Different Fixation Methods

Intramedullary nailing is, from the biomechanical point of view, the method of choice for shaft fractures of the femur and tibia. However, femoral nailing, reamed as well as unreamed, bears the risk of pulmonary embolization [15].

The main reason for this is the manipulation of the content of the medullary canal by opening, insertion of guide-wire, reaming, and placement of a nail. This increases the intramedullary pressure so that emboli of bone marrow content, fibrin clots, and debris are introduced into the pulmonary circulation. Embolization also causes activation of coagulation and other cascade systems.

The immense clearing capacity of the pulmonary endothelium may already be compromised by a lung contusion, a massive transfusion of allogenic blood, a spill over of cytokines and mediators from large wounds with dead tissues, or an incomplete resuscitation from shock. In this situation, the additional insult arising from iatrogenic embolization can crucially damage pulmonary function (Fig. 5.1). Furthermore, it is important to realize that simple fracture types (transverse and short oblique) in a young patient with a narrow medullary canal and well-developed muscle envelope are more prone to be followed by pulmonary embolization after intramedullary nailing than complex fractures with extensive fragmentation of the femoral shaft, or fractures in elderly individuals with poorer muscles and a wide medullary canal. Currently, there is no evidence that intramedullary nailing without reaming is less dangerous than intra-medullary nailing after reaming.

Plating requires a major surgical approach and is usually technically more demanding. However, it permits simultaneous débridement and fasciotomies.

External fixation minimizes additional surgical trauma. As a fixing and time-saving procedure, it prevents compartment syndrome. The drawbacks are insufficient stability for definitive treatment, pin-track infections, and limitation of plastic soft-tissue procedures.

In summary, every fixation method has its biological advantages and disadvantages. Rigid protocols should therefore be avoided when timing and choice of implant are considered.

5.7 Fracture Management Under Specific Conditions

5.7.1 Massive Hemorrhage as a Result of a Crushed or Disrupted Pelvis [16, 17]

Open or closed crush or disruption of the pelvic ring (“open book”, “vertical shear” injuries) can produce exsanguinating hemorrhage into the retroperitoneum, the peritoneal cavity, or to an open or closed (semi-) circular degloving injury (Morel-Lavallee syndrome). In addition to aggressive fluid replacement, these patients require immediate reduction and fixation of the pelvic ring by an external fixator or a pelvic compression clamp. If the hemodynamic response is good, the diagnostic work-up can be completed and pelvic reconstruction can be performed as staged surgery.

However, if the patient remains unstable, emergency laparotomy is mandatory to stop the bleeding. In such circumstance the pelvic ring must be stabilized by pelvic binders, external or internal fixation, followed by surgical hemostasis, tight pelvic packing, and provisional closure of the abdomen. Angiographic embolization may be of assistance at this juncture. The possibility of abdominal compartment syndrome must be kept in mind [18, 19]. After recovery in the ICU, one or two “second-look” procedures are mandatory, followed by definitive stabilization of the pelvis and closure of the abdominal wall (Fig. 5.4a–c).

5.7.2 Early Fracture Fixation in Patients with Severe Brain Injury

In traumatic brain injury (TBI), it is of paramount importance to prevent secondary brain damage [20, 21] resulting from hypotension and hypoxemia, and to maintain optimal cerebral perfusion. Epidural or acute subdural hematomas require urgent surgical evacuation and hemostasis. Patients with TBI and Glasgow Coma Scale <9 after craniotomy require intracranial pressure monitoring immediately after life-saving surgery [22]. Given a good response to resuscitation (stable hemodynamics and adequate oxygenation), early fracture fixation has a positive effect [23] in brain-injured patients because it facilitates nursing care, reduces painful stimuli (afferent input), and decreases the need for sedation and analgesia.

Concerns that early fixation of major fractures in TBI patients may–under the circumstances just described–increase mortality rate are not evidence based [23].

- *Time-consuming fracture reconstructions should be postponed to the fifth to tenth day during the window of opportunity following initial damage control with external fixation.*

5.7.3 Early Fixation of Femoral Shaft Fractures in Severe Polytrauma Patients or Polytrauma Patients with Chest Injury

Several studies have documented the advantages of early fixation of long bone fractures, particularly of the femoral shaft in polytrauma. These advantages include:

- Facilitation of nursing care;
- Early mobilization with improved pulmonary function;
- Shorter time on the ventilator;
- Reduced morbidity and mortality [6, 11–13, 24].

Locked intramedullary nailing has become the standard method in closed and open femoral shaft fractures. However, there is abundant experimental and clinical evidence of a considerable increase in intramedullary pressure during the nailing procedure, especially in simple types A and B fractures. This leads to a significant release of mediators as well as to the passing of emboli to the lung. The latter can be demonstrated by transesophageal echocardiography [15]. While the side effects of nailing can be disregarded in patients with isolated fractures, they are likely to cause rapid pulmonary deterioration in the multiply injured patient when the procedure begins [6, 25, 26].

Other stabilization procedures such as plating or application of an external fixator can also initiate mediator release, though to a lesser extent. In order to protect pulmonary function, intramedullary nailing (the biomechanically better method) should not be done. The application of an external fixator is less

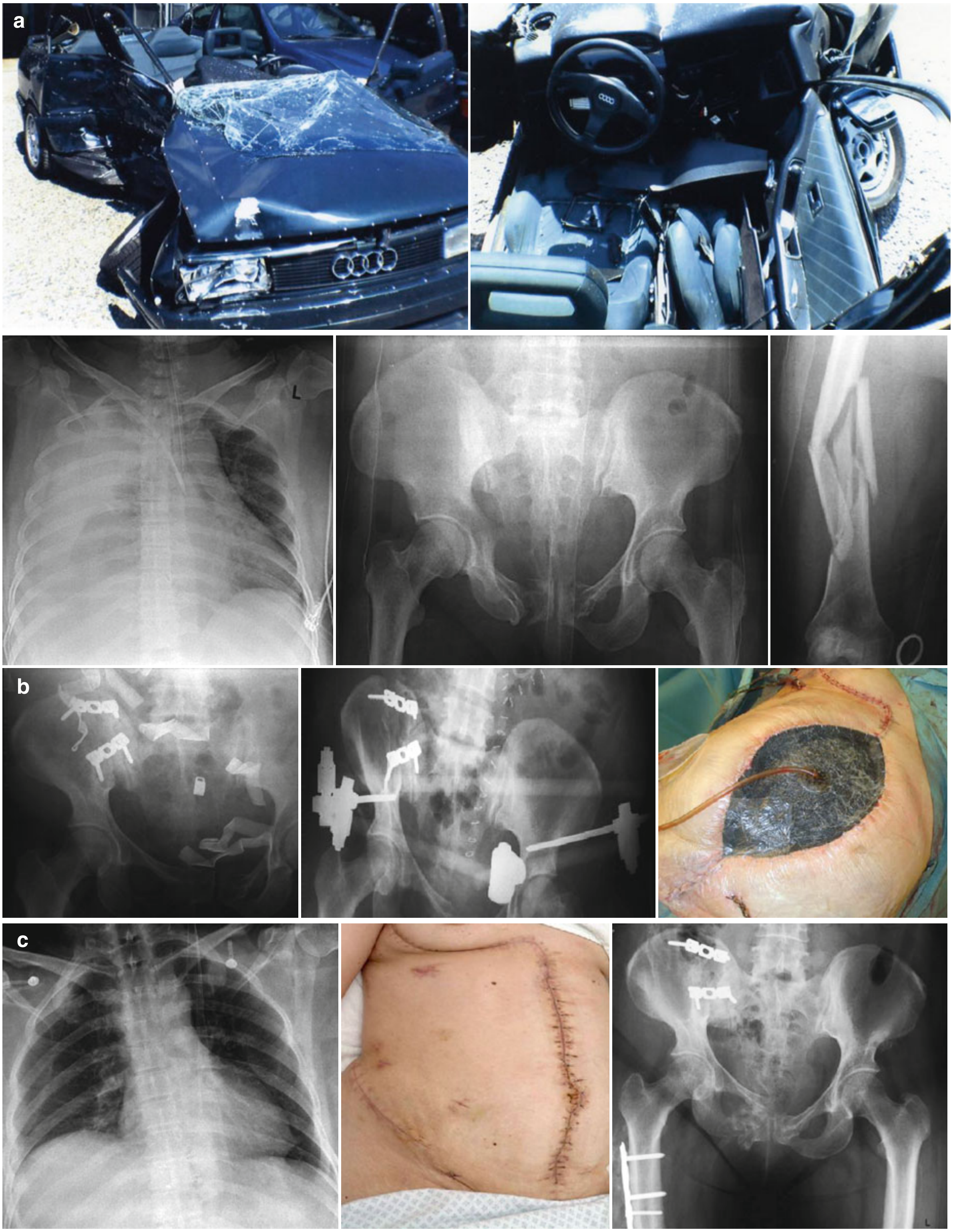

Fig. 5.4 (**a**) A 45 year old female crushed in the right front seat during an automobile accident with severe right side impact. Injuries included thoraco-abdominal trauma, pelvic fracture, bladder injury, femoral shaft fracture, and severe shock. (**b**) Damage control: bleeding and source control, fixation of posterior pelvic ring, packing abdomen and pelvis, abdomen left open, external fixation of femur. Second look: Removal of packs, anterior external fixator pelvis, vacuseal abdomen. Day 6: definitive plate fixation femur, repeat vacuseal abdomen. (**c**) Status after definitive wound healing

distressing to already compromised endogenous defense systems and the pulmonary endothelium.

- *Primary intramedullary nailing of the femur* (*especially in types A and B fractures*) *can only be recommended for polytraumatized patients without significant chest injury* (*ISS <25*). *If the ISS exceeds 40 points*, *primary stabilization is still essential*, *but should be performed only with external fixators* [6].

Plating can be a good alternative when ISS values are between these limits, particularly if the soft-tissue conditions require débridement, fasciotomy, and active control of hemorrhage. Seriously compromised soft tissues may respond to additional distraction with a further reduction of perfusion, enhancing the possibility of a compartment syndrome. In such situations, a temporary shortening of a limb must occasionally be accepted.

In complex type C fractures with extensive comminution, the range of indications for nailing can be extended because no substantial pressure increase can occur. As clinical and experimental data indicate that the application of solid nails with smaller diameters and without reaming may also cause relevant pulmonary impairment, their use has no significant advantage over reamed nails.

Solid nails should therefore predominantly be used for open fractures (no dead space) and are recommended particularly if a scheduled definitive change from external to internal fixation is intended. Any switch to a biomechanically better procedure should be performed early, ideally between the fifth and tenth day after trauma.

This concept of staged surgery in a subset of patients in critical conditions appears to be generally accepted by most authors in Central Europe. In contrast, a number of investigators from North America continue to argue that all femoral shaft fractures should have primary nailing performed regardless of the patient's clinical status [12, 27, 28]. These retrospective studies, however, have several inconsistencies regarding patient selection and comparability of study groups. However, a prospective randomized trial recently performed suggests that most polytraumatized patients with femur fractures with or without chest injury can be safely treated with intramedullary fixation [29]. A low rate of ARDS was demonstrated in all groups.

5.7.4 Limb Salvage Versus Amputation

The development of microsurgical techniques for free vascularized tissue transfer has increased the chances of saving mangled extremities or nearly amputated limbs [30]. For polytrauma patients, however, such salvage procedures are rarely indicated because they increase the systemic inflammatory load. The mangled extremity severity score can assist in decision making [31]. There are only rare indications for heroic salvage attempts. These require a multi-stage concept with initial débridement, revascularization, fasciotomies, and fracture fixation, followed by repeated débridements and early soft-tissue reconstruction during a “window of opportunity”.

When the decision is to amputate, the amputation should be performed at a level of healthy tissue combined with primary open wound management.

5.8 Summary

Polytrauma must be considered as a systemic surgical problem.

Successful management requires

1. A firm understanding of pathophysiology;
2. Complete patient resuscitation;
3. Correct triage and timing;
4. Trauma algorithms.

Algorithms optimize the physiological state of patients prior to life-saving surgery and provide procedures that are safe, simple and quick, and well executed.

The primary objective is survival of the patient. Early fixation of major fractures – performed under the correct parameters – has proved to be an important tool in achieving this primary objective.

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