## 4.1 Polytrauma: pathophysiology, priorities, and management

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Definition</td>
<td>337</td>
</tr>
<tr>
<td>2. Importance of fractures</td>
<td>337</td>
</tr>
<tr>
<td>3. Pathophysiological background</td>
<td>337</td>
</tr>
<tr>
<td>4. Timing and priorities of surgery</td>
<td>338</td>
</tr>
<tr>
<td>5. General aims and scopes of fracture management in polytrauma</td>
<td>340</td>
</tr>
<tr>
<td>6. Pros and cons of different fixation methods</td>
<td>342</td>
</tr>
<tr>
<td>7. Fracture management under specific conditions</td>
<td>342</td>
</tr>
<tr>
<td>7.1 Massive hemorrhage due to crushed or disrupted pelvis</td>
<td>342</td>
</tr>
<tr>
<td>7.2 Early fracture fixation in patients with severe brain injury</td>
<td>343</td>
</tr>
<tr>
<td>7.3 Early fixation of femoral shaft fractures in severe polytrauma or polytrauma patients with chest injury</td>
<td>344</td>
</tr>
<tr>
<td>7.4 Limb salvage versus amputation</td>
<td>345</td>
</tr>
<tr>
<td>8. Summary</td>
<td>345</td>
</tr>
<tr>
<td>9. Bibliography</td>
<td>346</td>
</tr>
</tbody>
</table>
4.1 Polytrauma: pathophysiology, priorities, and management

1 Definition

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

2 Importance of fractures

Fractures frequently occur in polytrauma patients. These fractures can be considered as wounds of 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 abolishes the option to select the nursing position most suitable for intensive care of brain and chest injuries.

3 Pathophysiological background

The wound around a fracture is an inflammatory focus, consisting of dead tissue in an ischemic or marginally perfused, hypoxic zone. This focus behaves like an endocrine organ, releasing mediators and cytokines locally to tissue macrophages, as well as into the circulation causing systemic reactions.

By releasing these substances a cascade of local and systemic defense mechanisms are activated and immunocompetent cells are attracted to control, debride, and repair the tissue defects.

Stress and pain are potent stimuli [1] for neuroendocrine, neuroimmunological, and metabolic responses (Fig 4.1-1). If, in addition, 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

![Fig 4.1-1 Afferent input in trauma and resulting reflex responses.](image-url)
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 (MOF) [3–5].

### 4 Timing and priorities of surgery

The primary objective during initial care of polytraumatized patients is survival with normal cognitive functions. The first priority is resuscitation to ensure adequate perfusion and oxygenation of all vital organs (Fig 4.1-2). This can usually be accomplished by conservative means such as intubation, ventilation, and volume replacement according to the 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).

**Fig 4.1-2** Algorithm for initial assessment, life support, and day-1 surgery.
If there is poor response to resuscitation or ongoing physiological frailty in the patient, definitive surgery should be avoided and the concept of damage control applied. The rationale behind this concept is saving 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;
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 circumstances:
1. **reactively**: “bail-out” surgery, which means aborted termination of procedures in a patient at imminent risk of death;
2. **preemptively**: calculated early decision to accomplish definitive repair in staged sequential procedures due to a high risk of physiological deterioration.

Damage-control procedures such as control of hemorrhage and source control by irrigation, packing, external fixation of long bones and pelvic ring, provisional closure of wounds or abdominal cavity are followed by stabilization of the physiological systems in the intensive care unit. After physiological restoration in the ICU, staged definitive surgery can take place under much better and safer conditions. Concerning fracture repair, there is a “window of opportunity” between day 5 and 10 posttrauma. Damage-control surgery is indicated in about 1/3 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 start according to the general principles of fracture care.

Within the scope of this algorithm fracture fixation must have high priority:
- Limb-threatening and disabling injuries (including open fractures) require at least damage control: debridement, 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 need 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 days 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 ARDS, of fat embolism and pneumonia, of MODS, sepsis, and of 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 end points of resuscitation [14] have been accomplished (Tab 4.1-1; 4.1-2).

Between the fifth and tenth day posttrauma there exists an immunological window of opportunity 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 in relative safety.

This period of immunosuppression lasts for about 2 weeks, so that secondary reconstructive procedures can be planned for the third week posttrauma.

<table>
<thead>
<tr>
<th>End points of resuscitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable hemodynamics</td>
</tr>
<tr>
<td>No hypoxemia, no hypercapnia</td>
</tr>
<tr>
<td>Lactate &lt; 2 mmol/l</td>
</tr>
<tr>
<td>Normal coagulation</td>
</tr>
<tr>
<td>Normothermia</td>
</tr>
<tr>
<td>Urinary output &lt; 1 ml/kg/hour</td>
</tr>
<tr>
<td>No need for vasoactive or inotropic stimulation</td>
</tr>
</tbody>
</table>

Tab 4.1-1 Parameters and criteria which indicate a successful resuscitation.

<table>
<thead>
<tr>
<th>Physiological status</th>
<th>Surgical intervention</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response to resuscitation</td>
<td>None</td>
<td>Life-saving surgery</td>
</tr>
<tr>
<td></td>
<td>Partial</td>
<td>Damage control</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>Early total care</td>
</tr>
<tr>
<td>Hyperinflammation</td>
<td>“Second look” only!</td>
<td>Day 2–3</td>
</tr>
<tr>
<td>“Window of opportunity”</td>
<td>Definitive surgery</td>
<td>Day 5–10</td>
</tr>
<tr>
<td>Immunosuppression</td>
<td>No surgery</td>
<td>Day 12–21</td>
</tr>
<tr>
<td>Recovery</td>
<td>Secondary reconstructive surgery</td>
<td>Week 3 +</td>
</tr>
</tbody>
</table>

Tab 4.1-2 Priorities and timing of surgery depending on the physiological status.

Fractures may have an important impact on the severity of systemic traumatic reactions due to
- 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 debrided after some delay or if debridement is not radical enough, bacterial nutrients will develop in the wound. A second or even third debridement is therefore mandatory.
- dead, ischemic tissue with a marginally perfused hypoxic zone: In unstable, displaced fractures, especially...
after high-energy impact, a radical soft-tissue debridement 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 without or with vascular injuries are prone to ischemia-reperfusion injury with microvascular damage due to oxygen radicals (Fig 4.1-3). Blunt tissue contusions may activate xanthine oxidase; ischemia will produce the substrate xanthine/hypoxanthine, and reperfusion will add the 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 CNS, stimulate a neuroendocrine, neuroimmunological, and metabolic reflex arc (Fig 4.1-3).

- **interference with intensive care**: Unstable fractures prevent effective patient postures (upright chest), and pain-free handling in intensive care.

![Fig 4.1-3](image-url) Mechanism of ischemia-reperfusion injury: dangerous triad of providing activated enzyme, substrate, and cosubstrate.
The general aims and scopes for fracture management are:
- control of hemorrhage;
- control of sources of contamination, removal of dead tissue, prevention of ischemia-reperfusion injury;
- pain relief;
- facilitation of intensive care.

These concepts can be realized by hemostasis, debridement, 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.

**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 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. Furthermore, it is important to realize that simple fracture types (transverse and short oblique) in a young patient with a narrow medullary canal and a well developed muscle envelope, are much 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. There is presently no evidence that intramedullary nailing without reaming is less dangerous than intramedullary nailing after reaming.

Plating requires a major surgical approach and is usually technically more demanding. On the other hand, it permits simultaneous debridement and fasciotomies.

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

To summarize: Every fixation method has its biological advantages and disadvantages. Rigid protocols should therefore be avoided when timing and choice of implant are considered.

**7 Fracture management under specific conditions**

**7.1 Massive hemorrhage due to 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-Lavalle syndrome). Besides aggressive fluid replacement these patients require immediate reduction and fixation of the pelvic ring by an external fixator or a pelvic compression clamp (C-clamp) (chapter 6.4). If the hemodynamic response is good, the diagnostic work-up can be completed and pelvic reconstruction can be done as staged surgery.

However, if the patient remains unstable, emergency laparotomy is mandatory to stop the bleeding. In these circumstances 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 junction. 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.

### Table 4.1-3

<table>
<thead>
<tr>
<th>Hypotension Type</th>
<th>n</th>
<th>Death or vegetative state (GOS 1–2) [%]</th>
<th>Favorable outcome (GOS 4–5) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No hypotension</td>
<td>307</td>
<td>17</td>
<td>64</td>
</tr>
<tr>
<td>Early hypotension (from injury through resuscitation)</td>
<td>248</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td>Late hypotension (in the ICU)</td>
<td>117</td>
<td>66</td>
<td>20</td>
</tr>
<tr>
<td>Early and late hypotension</td>
<td>39</td>
<td>77</td>
<td>15</td>
</tr>
</tbody>
</table>

**Traumatic Coma Database:**

Influence of systemic hypotension on the outcome after severe traumatic brain injury [21]

In traumatic brain injury (TBI) it is of paramount importance to prevent secondary brain damage [20, 21] due to hypotension (Tab 4.1-3) 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 (GCS) < 9 after craniotomy need ICP (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, as 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.

7.3 Early fixation of femoral shaft fractures in severe polytrauma or polytrauma patients with chest injury

Several studies have well documented the advantages of early fixation of long-bone fractures—especially 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 type A and B fractures. This leads to a significant release of mediators as well as to the passage of configured emboli to the lung. The latter can be demonstrated by transesophageal echocardiography [15]. While these side effects of nailing can be disregarded in patients with isolated fractures, they are likely to cause rapid pulmonary deterioration in the multiply injured when the procedure is started [6, 25, 26].

Other stabilization procedures, such as plating or application of an external fixator, can also initiate mediator release, but to a much lesser extent. In order to protect pulmonary function, one should refrain from using the biomechanically better method (intramedullary nailing). A more biological technique (external fixation) is less distressing to already compromised endogenous defense systems and the pulmonary endothelium.

- Primary intramedullary nailing of the femur (especially in type 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 done with external fixators only [6].

Plating may be a good alternative when ISS values are between these limits, especially if the soft-tissue conditions require debridement, 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 has occasionally to 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 indicates 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.
4.1 Polytrauma: pathophysiology, priorities, and management

Solid nails should therefore predominantly be used for open fractures (no dead space) and are especially recommended 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 the tenth day after trauma (Tab 4.1-3).

This concept of staged surgery in a subset of patients in critical condition appears to be generally accepted by most authors in Central Europe. In contrast, a variety of investigations from North America continue to argue that all femoral shaft fractures should be submitted to primary nailing regardless of the patient’s clinical status [12, 27, 28]. These retrospective studies, however, have a variety of 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.

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]. In polytrauma, 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 debridement, revascularization, fasciotomies, and fracture fixation, followed by repeated debridements and early soft-tissue reconstruction during a “window of opportunity”.

When the decision is to amputate, this should be performed at a level of healthy tissue with a “guillotine” technique, combined with primary open wound management.

8 Summary

Polytrauma must be considered as a systemic surgical problem. Successful management requires
1. a sound understanding of pathophysiology;
2. complete patient resuscitation;
3. correct triage and timing;
4. trauma algorithms.

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

The primary objective is survival of the patient. Early fixation of major fractures—performed under the correct parameters—has proven to be an important tool to obtain this primary objective.
4 General topics

9 Bibliography


4.1 Polytrauma: pathophysiology, priorities, and management

