Multiple Trauma Part V: Specific trauma abdomen, pelvis and extremities

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Intended Learning Outcomes

Multiple Trauma Part V: Specific trauma abdomen, pelvis and extremities

1. Explain the epidemiology, classification and presentation of patients with abdominal trauma
2. Describe the diagnostic interventions and management of patients with abdominal trauma
3. Differentiate the fracture patterns of pelvic ring unstable injuries
4. Describe the diagnostic and management priorities in pelvic ring fractures
5. Describe principles of planning surgical intervention in pelvic injury/trauma
6. List the possible complication of pelvic trauma and their management
7. Explain the epidemiology, classification and presentation of patients with extremity trauma
8. Describe the diagnostic interventions and management of patients with extremity trauma
9. Outline the multidisciplinary process of decision making for limb amputation
10. Outline advantages and drawbacks of different immobilization measures

eModule Information

Relevant Competencies from CoBaTrICE

Multiple Trauma Part V: Specific trauma abdomen, pelvis and extremities

- **1.1** Adopts a structured and timely approach to the recognition, assessment and stabilisation of the acutely ill patient with disordered physiology
- **1.4** Triages and prioritises patients appropriately, including timely admission to ICU
- **1.5** Assesses and provides initial management of the trauma patient
- **2.2** Undertakes timely and appropriate investigations
- **2.3c** Performs and interprets ultrasonographic assessment of the abdomen to assess intraperitoneal free fluid
- **2.8** Liaises with radiologists to organise and interpret clinical imaging
- **2.9** Monitors and responds to trends in physiological variables
- **3.3** Recognises and manages the patient with circulatory failure
- **4.3** Administers blood and blood products safely
- **4.4** Uses fluids and vasoactive / inotropic drugs to support the circulation
- **6.5** Manages the pre- and post-operative care of the trauma patient under supervision

Abreviations

AAOS: American Academy of Orthopaedic Surgeons
ABI: ankle brachial index
ACS: acute compartment syndrome
AKI: acute kidney injury
AIS: abbreviated injury scale
ARDS: acute respiratory distress syndrome
CPK: creatine phosphokinase
CPP: cerebral perfusion pressure
CT: computed tomography
DCO: damage control orthopaedics
DELAYED-SDOS: delayed safe definitive orthopaedic surgery
EARLY-SDOS: early safe definitive orthopaedic surgery
ETC: early total care
FES: fat embolism syndrome
GCS: Glasgow coma score
ICP: intracranial pressure
IPC: intermittent pneumatic compression
LSI: limb salvage index
MESI score: musculoskeletal score for severity of injury
MESS: mangled extremity scoring system
MRI: magnetic resonance imaging
MTC (score): Montpellier trauma centre (score)

NFTI: need for trauma intervention
NIRS: near infrared spectroscopy
NISSA: nerve injury, ischemia, soft tissue injury, skeletal injury, shock and age of patient score
OIS: organ injury scale
PRISM: prompt individualized safe management
PSI: predictive salvage index
PTr: prothrombin time ratio
ROC: receiver operating characteristic
RRT: renal replacement therapy
SBP: systolic blood pressure
TTS (score): thoracic trauma severity (score)
VTE: venous thromboembolism

1. Abdominal trauma

Severe abdominal injuries in adults account for approximately 15-20% of all trauma cases and are associated with high mortality rates of around 20% (MacKenzie et al. 2006). In Europe, abdominal injuries are predominantly blunt traumas, while penetrating traumas are an increasingly common pathology. In both civilian and military settings, the most frequent cause of death in patients who die early after severe trauma is hemorrhage (>80% of cases). It is important to note that death is considered preventable in one out of two cases, and the site of injury considered to be the cause of death is the abdomen in 53% of cases (Kreis DJ et al. 1986). Rapid and appropriate medical & surgical care, organized prior to the patient's arrival, can reduce mortality.

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1. 1. Epidemiology and Mechanisms of Abdominal Trauma

Morbidity and mortality from abdominal injuries are strongly influenced by the presence of hemorrhagic shock. Mortality associated with hemorrhagic shock ranges from 15% to 30% (Ashley et al. 2024; MacKenzie et al. 2006). Morbidity is determined by the extent of the injuries, the association with organ failures, and secondary complications such as peritonitis or pancreatic leaks.

1. 1. 1. Types Abdominal Trauma

Two types of abdominal trauma are distinguished:

- **Non-penetrating trauma (NPT):** These account for the majority of cases in continental Europe, with 80 to 90% of cases (Gauss et al. 2019). However, their proportion is 60 to 70% in Great Britain and the United States (Fairfax, Hsee and Civil. 2015; Jaffe. 2023; Gauss et al. 2024). NPT results from a considerable transfer of energy, often observed in mechanisms such as shearing (vehicle accidents), deceleration (vehicle accidents, falls from great heights), or compression (vehicle accidents). The kinetic energy released causes the destruction of parenchymal and vascular structures, causing acute or delayed hemorrhages, lacerations or shearing of the parenchyma, or even disinsertion of the mesentery which can lead to peritonitis (due to leakage of digestive or biliary fluid) or inflammation (pancreas) at a later stage. It is important to note that this energy transfer is accompanied in 30 to 40% of cases by serious injuries in other regions of the body (Bouzat et al. 2020).

- **Penetrating trauma (PT):** Their incidence appears to be increasing in Europe (Bieler et al. 2021; Descamps et al. 2022). PT can be of accidental or voluntary origin (suicide attempt) or the result of an, assault. The effects of a knife differ from those of a firearm as on the one hand the energy transferred to the body is different and firearms can also cause injury through the creation of a bullet cavitation and fragments.

1. 1. 2. Clinical examination

The priority of the clinical examination is to identify signs of organ failure (neurological, respiratory) and circulatory insufficiency (skin color, capillary refill time, pulse, and measurement of blood pressure). Any circulatory insufficiency should suggest, among other things, an abdominal injury with hemorrhage.
Some signs suggest an abdominal injury: pain on palpation, spontaneous abdominal pain, rebound tenderness, abdominal distension, hematuria, guarding, seatbelt sign (abdominal wall ecchymosis). However, the predictive performance of these clinical signs to identify abdominal trauma, particularly in the prehospital setting, is low and the absence of pain does not exclude an injury, which is subsequently objectified in 10% of cases (Bouzat et al. 2020). Consequently, the clinical examination is insufficient to rule out or consider an abdominal injury, and suspicion requires in most cases its elimination by CT scan of the entire body.

1. 1. 3. Ultrasound - Focused Assessment with Sonography for Trauma (FAST)

Ultrasound or FAST (Focused Assessment with Sonography for Trauma) is the essential tool for the initial evaluation of a severely injured trauma patient and is integrated into a global approach (Al-Shaqsi and Stringer 2010; Netherton et al. 2019). The main objective is to rule out intra-abdominal effusion in three compartments: Morison pouch (recessus hepatorenalis),Kolle pouch(recessus splenorenalis) and Douglas pouch (recessus rectovesicalis). Extended FAST (eFAST) also allows exploration of the thorax for effusion and pleural sliding, pericardial effusion and overall function and level of distension of the inferior vena cava. A meta-analysis shows the ability of the FAST to diagnose a thoraco-abdominal injury and to detect an intra-abdominal effusion with a very strong specificity (Bøtker et al. 2018). However, the FAST may be negative in case of low abundance effusion (<500ml) and does not allow structural diagnosis or localization of the source of the fluid or a retroperitoneal effusion. Its diagnostic performance is attenuated in the prehospital setting and in severely ill patients (Rowell et al. 2019). A positive FAST should suggest an intra-abdominal hemorrhagic target until proven otherwise. In case of associated circulatory insufficiency, a FAST in favor of abdominal effusion strongly guides the overall strategy (see Figure1) (Planquart et al. 2022). An initially negative FAST should be repeated in the presence of a patient whose condition deteriorates, reflecting the dynamics of the bleeding.

1. 1. 4. CT scan

In the case of severe trauma, the CT scan should always include the whole body and, in the abdominal region, sequences injected at the arterial and portal times. The whole-body CT scan or Body CT scan plays a strategic role in the management of abdominal trauma and is the gold standard for establishing a complete injury assessment (Bouzat et al. 2020). The CT scan is very effective in identifying hemorrhagic lesions and allows a strategy to be established, including in penetrating trauma, particularly ballistic. The CT scan have lower performance for hollow organ injuries. The detection of mesenteric infiltration, a substrate for shearing lesions, is delicate and the performance of the CT scan does not allow the diagnostic strategy to be based solely on the Body CT scan; surgical exploration is sometimes necessary, particularly to rule out lesions of the hollow organs and the mesentery (Holmes, McGahan and Wisner. 2012; Abdel-Aziz and Dunham. 2019). The overall risk-benefit is clearly in favor for performing an injected Body CT scan, both regarding exposure to contrast products and the level of irradiation. However, the time and transportation of the patient required to perform the CT scan may justify the decision to perform first damage control surgery for patients in very unstable condition.

1. 1. 5. Other examinations

Other examinations have a less prominent place in determining the initial strategy. Regarding the initial biological assessment, abdominal trauma has no specificities. A panel of usual tests including arterial blood gas analysis with lactate measure, blood count, creatine levels, conventional hemostasis test or viscoelastic tests in case of shock are essential. The measurement of lipids or transaminases allows to describe a kinetics in the hours and days following admission in case of parenchymal lesion.

1. 1. 6. Algorithm for management of abdominal trauma

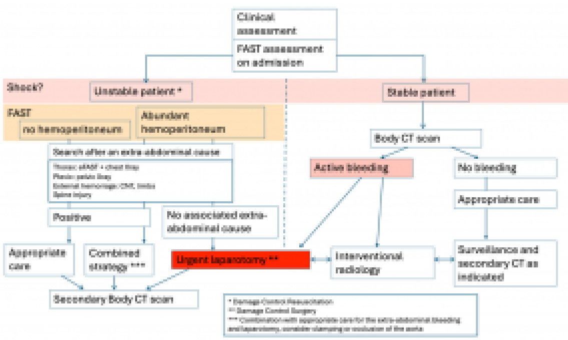

Figure 1: Algorithm for management of abdominal trauma.

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1. 2. Strategy of care

1. 2. 1. Stratification of actions

The presence of circulatory failure with suspicion of hemorrhagic shock determines the overall approach. In case of suspected hemorrhagic shock with an identified or highly suspected abdominal bleeding, it is sometimes needed to directly send the patient to the operating room for a Damage control surgery. The assessment of the patient's hemodynamic stability is based on multiple parameters and the response to initial resuscitation. A reference threshold is a systolic blood pressure below 90 mmHg (James et al. 2022). A systolic pressure below 100 mmHg constitutes a warning threshold, as does any tachycardia above 110 beats per minute or an elevated respiratory rate > 25/minute or shock index > 0.9 (ration of the heart rate to systolic blood pressure). These signs should alert for established or developing shock. Point-of-care Lactate, base excess, hemoglobin measurements are very useful (Régnier et al. 2012; Figueiredo et al. 2018). Initial resuscitation and the response of the patient to it should then guide the further management. When the initial resuscitation establishes a clinical condition allowing a whole-body CT scan to be performed, this option offers the advantage of obtaining a complete injury assessment and allows for a more targeted bleeding control. A non-surgical option involving embolization by interventional radiology is sometimes possible. This offers a less invasive alternative to surgery, although it sometimes takes longer time and further deterioration in the meantime can be a risk. The overall initial strategy is summarized in Figure 1, initial algorithm for the management of abdominal trauma.

1. 2. 2. Surgery

An exploratory xyphopubic laparotomy allows direct inspection of organs and structures, control of bleeding and control of contamination. Any delay in surgery in case of active bleeding increases mortality (estimated 1% per 3 minutes) (Clarke et al. 2002). Intraoperatively, it is essential to define whether the procedure will be definitive or abbreviated (with several stages, see damage control). In this context, it is imperative to keep in mind that patients with abdominal trauma rarely have isolated injuries. To define the overall strategy, associated injuries such as pelvic, thoracic or head injuries, as well as the patient's frailty, must be integrated. In multiple severe injuries, establishing the optimal sequence represents a challenge but the control of bleeding must be the priority.

1. 2. 3. Non-operative management

A strategy without surgery, known as non-operative management (NOM), supported by robust studies becomes possible when the patient is hemodynamically stable and without major injuries (see organs section) (Arvieux et al. 2020). A NOM strategy can be combined with interventional radiology techniques. A NOM strategy avoids the complications associated with surgery () and often allows the organ to be preserved. NOM requires transfer to a specialized unit with surveillance and the ability to intervene quickly if necessary. The duration of surveillance is not formalized; a minimum of three to five days and a control CT scan in this window seems consensual (Bouzat et al. 2020). In all cases, a follow-up is required as exposed in the ERATIC guidelines (Hardcastle et al. 2025).

1. 2. 4. Penetrating trauma

An essential principle is to consider any penetrating trauma of the abdomen as a penetrating trauma of the trunk (Biffl and Leppaniemi. 2015). The location of the entry wound, and its size do not predict the injured structures. An entry wound at the abdominal level can be associated with injuries of thoracic, pelvic, retroperitoneal and inguinal structures and vice versa, including for knife injuries. A single bullet can injure multiple organs by ricochet and/or cavitation and/or fragmentation. A patient with hemorrhagic shock from penetrating abdomen/trunk trauma should be directed without delay to an operating room with a ready medical-surgical team. Surgical control of bleeding determines the prognosis. A CT scan exploration is necessary after hemostasis surgery and hemodynamic stabilization. The observation of a single penetrating injury of the trunk should systematically invite a careful search for other penetrating injuries on the entire trunk, including the back.

1. 2. 5. Damage control surgery and resuscitation

The principle of Damage Control (DC) is based on a step-by-step approach. The first step is based on treatment limited to life-threatening problems (bleeding, organ perforation, long bone fracture) by rapid, non-definitive surgery for hemostasis, (fecal) decontamination and external fixation of fractures. Attempting definitive and rprolonged reconstruction surgery increases inflammation and the risk of subsequent organ failures. The risk increases even more, when the wrong surgical strategy is combined with a wrong resuscitation strategy, example given, is a too large amount of cristalloids which increases the risk of coagulopathy, ARDS and abdominal compartment syndrome (Cole et al. 2021). Therefore damage control sugery needs to be completed by damage control resuscitation.

Patients who benefit from a DC strategy present with persistent circulatory shock despite aggressive resuscitation (blood products, norepinephrine) and other factors contributing to what is called the lethal diamond: metabolic acidosis (pH<7.2), hypothermia (temperature<34°C), hypocalcemia and coagulopathy (Holcomb et al. 2007).

Briefly DC Resuscitation is based on limiting volume expansion by crystalloid, administration of tranexamic acid 1g as a bolus, followed by another 1g, treatment of hypocalcemia, administration of blood products (or whole blood) early, i.e. red blood cell concentrates, fresh plasma and platelets in a 1:1:1 to 2:1:1 ratio (Holcomb et al. 2015), administration of fibrinogen concentrate if evidence of hypofibrinogenemia (conventional laboratory < 1.5g/dl or viscoelastic test), maintaining a systolic pressure between 80 to 90 mmHg or greater than 110mmHg if head injury with GCS < 9, until bleeding control is obtained. For a detailed description, the reader is invited to refer to the European recommendations (Rossaint et al. 2023).

Regarding DC Surgery, it is imperative to limit the duration of surgery to 60 minutes). The objectives consist exclusively of ensuring hemostasis and fecal devision; definitive repairs will be carried out in a second step (Lamb et al. 2014). DC so-called abbreviated surgery techniques consist, for example, of removing an organ (e.g. the spleen), packing (e.g. liver), targeted hemostasis (e.g. ligature), fecal decontamination (resection and closure of a loop of the digestive tube without anastomosis). In case of bleeding from pelvic origin, pelvic packing may be associated. As far as possible, it is preferable in this phase not to surgically open the retroperitoneum, as pressure adds to hemostasis and by opening the retroperitoneal cavity, counterpressure gets lost.

In experienced trauma centers, the resuscitative endovascular balloon occlusion of the aorta (REBOA) is an option. Studies show that it can be as effective as resuscitative thoracotomy for subdiaphragmatic lesions in stabilizing the patient while DC is performed although current trials lack of clear benefit. Its place remains to be determined.

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1. 3. Organs’ specificities

All trauma lesions of the abdominal organs are categorized according to the American Association of Surgery of Trauma (AAST) classification in several grades.

1. 3. 1. Liver

Liver injuries are common in abdominal trauma. The patient's hemodynamic status dictates the management and not the degree of injury. In case of instability and active bleeding, surgery as a first-line treatment before Body CT scan with DC techniques is necessary. Outside of this context, three attitudes and their combination are possible: abstention and surveillance (NOM), interventional radiology techniques (embolization, drainage), surgery.

For non-penetrating trauma with hemorrhage, surgical techniques (packing, hepatorrhaphy, non-anatomical resection) are most often deployed (Melloul, Denys and Demartines. 2015; Rotondo et al. 1993). The mortality of patients with shock are considerable at 31% (Melloul, Denys and Demartines. 2015). Complications consist of biliary leaks (10 to 20%), hepatocellular insufficiency (rare), abscesses (frequent) and respiratory complications. Among operated patients, 12 to 28% require secondary arterial embolization for persistent bleeding. Postembolization necrosis is frequent, about 30 to 40% of cases. In patients without hemodynamic instability, a NOM strategy provides satisfactory results in 92% of cases; 1-5% of cases require secondary arterial embolization (Melloul, Denys and Demartines. 2015). Biliary complications in a NOM approach are found in 4%, including 2-5% with a need for surgery. Mortality at 90 days of the NOM approach was 5%. Arterial embolization was effective in 93% of cases with between 10 and 30% observation of surgery for abdominal compartment syndrome, secondary hemorrhage or biliary leaks; the overall mortality related to liver trauma after embolization was 10%.

1. 3. 2. Spleen

In the same way to the liver, the attitude for splenic trauma is decided with the patient's hemodynamic status. The attitudes include surgery (splenectomy), embolization and abstention with surveillance. In case of instability despite resuscitation, surgery is necessary. For hemodynamically stable patients, an interventional attitude with embolization or even abstention and surveillance are possible. The risk factors of a NOM strategy failure are: age > 55 years, high overall injury burden and associated lesions (Injury Severity Score), need for transfusion, treatment with anticoagulants, cirrhosis (Podda et al. 2022). However, significant hemoperitoneum or vascular malformation (fistula, pseudoaneurysm) are not predictive of NOM strategy failure (Requarth, D'Agostino RB and Miller. 2011). In case of hemodynamic stability, with high-grade splenic lesions, embolization can be combined with a NOM attitude to avoid a poor evolution (vascular malformation or secondary leakage). In the absence of hemodynamic instability or associated lesions (diaphragm lesion, penetrating wound, hollow organ lesion), the majority of splenic lesions can be managed with a NOM attitude. Preemptive embolization is considered in case of extravasation of contrast product or high-grade lesions (AAST >4, Table 1) and reduces the failure rate (Sabe et al. 2009).

A NOM strategy requires surveillance in a suitable structure, for 3 to 5 days at least for AAST lesions > Grade 2 with the capacity to intervene quickly (Bouzat et al. 2020). Secondary ruptures are described up to day 14. A NOM strategy without or with embolization generates fewer infectious complications than splenectomy (4% versus 32%). The specific complications of embolization are cysts, recurrent bleeding, abscesses and splenic infarction.

The immunocompetence of the spleen after embolization is unknown; antibiotic prophylaxis and vaccination are not recommended (Freeman et al. 2022). After surgical splenectomy, antibiotic prophylaxis for 2 years with penicillin and vaccination for encapsulated germs (Streptococcus pneumoniae, Neisseria meningitidis, Haemophilus influenzae) ideally from day 14, is required.

1. 3. 3. Pancreas and extrahepatic biliary tract

Lesions of the duodenopancreatic block are a diagnostic and therapeutic challenge because of their retroperitoneal location and their low incidence (Moren et al. 2023). In 40% of patients with these linjuries, the first reading of the Body CT scan does not indicate the injury and requires a high clinical suspicion, enzyme measurements (amylase, lipase) and repeated CT-scan imaging. Management depends on the injured part (right or left) and involvement of the main pancreatic duct. Low-grade lesions (grade I & II) correspond to contusions and lacerations; their management is most often non-interventional with a low complication rate (<15%). Grades III to V often require intervention, either radiological or surgical, particularly if the head or main pancreatic duct is involved to prevent frequent complications associated with high mortality (fistulas, abscesses, infections, cysts, hemorrhage, perforation, etc.). The diagnosis of biliary tract lesions is often delayed by specialized imaging (e.g. Magnetic resonance cholangiography (MRC) enhanced with hepatobiliary contrast agent or cholangiography). Management combines surveillance, interventional radiology and rarely surgery (Moren et al. 2023). The morbidity and mortality rate are high, and hospital stays are often prolonged.

1. 3. 4. Hollow organs

Closed abdominal trauma rarely affects the intestines, with a prevalence of 1%. Their management requires rapid diagnosis to avoid infectious (peritonitis) or ischemic complications. The diagnosis is challenging; suggestive signs are, for example, the seatbelt sign, peritonism (be careful if patient has altered consciousness), enhancement of the wall or lack of contrast uptake of the digestive tract on Body CT scan, effusion, pneumoperitoneum. The performance of the CT scan remains limited with many false positives and negatives. In case of hemodynamic instability or diagnostic doubt, surgical exploration (e.g. laparoscopy) is necessary (Bouzat et al. 2020). Severe lesions may require resection-anastomosis, and sometimes repair in several stages. In case of NOM, close monitoring with repetitive imaging is essential.

1. 3. 5. Kidney and urinary tract

Genitourinary trauma concern 10 to 20% of abdominal trauma. They are rarely in the forefront in the acute phase. The diagnostic is made by the CT scan. The majority of kidney and urinary tract lesions are eligible for a NOM strategy, the expansion of a reproperitoneal bleeding is limited by the retroperitoneum, which tamponades the bleeding by counter-pressure. The deployment of arterial embolization techniques has increased the effectiveness of the NOM strategy (Erlich and Kitrey. 2018). The surgical intervention remains reserved for rare cases with hemorrhage through the retroperitoneum with hemodynamic instability. An intraperitoneal bladder lesion requires delayed surgical repair; an extraperitoneal bladder lesion remains manageable by catheterization and spontaneous healing in 97%. Urine extravasation does not contraindicate a NOM strategy; the excretory tract can be stented by ureteral endoprosthesis, particularly for grades >4 with sometimes delayed surgery.

1. 3. 6. Vascular lesions

Vascular injuries concern 5-15% of abdominal trauma and are associated with other serious lesions and high mortality, sometimes up to 60%. The predominant mechanism is compression of vascular structures against a fixed external or internal structure (e.g. bone or belt) or shearing (frequent for mesenteric lesions) leading to dissection or rupture. The CT scan with contrast injection is the preferred diagnostic modality. The grade and severity determine the management. Endovascular techniques are increasingly frequently deployed (Chandhok and Civil. 2017). In case of intimal lesion (flap, media preservation), management consists of surveillance and antiplatelet aggregation. The evidence of a pseudoaneurysm (intima and media lesion with preserved adventitia) or leak (rupture) or thrombi can be addressed with endovascular management (stent, embolization), or sometimes surgery. If hemorrhage and shock are observed, vascular surgery without delay is necessary. Disinsertion or rupture injuries are most often treated with surgery if established ischemia is observed, more rarely with endovascular techniques.

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2. Pelvic ring injury

High energy fractures of the pelvis are a challenging problem both in the immediate post-injury phase and later when definitive fixation is undertaken. It is one of the few post-traumatic fractures that is acutely life threatening since either retroperitoneal hemorrhage or major arterial vessel injury can rapidly cause the patient to bleed to death. No single management algorithm can be applied because of associated injuries and the wide variety of trauma systems that have evolved around the world. Pelvic ring fractures must already be recognized as a source of bleeding in the prehospital setting or at latest in the resus room. Management of unstable pelvic fractures concentrates on hemodynamic status: pelvic binders, angiographic embolization, pelvic packing, early fracture reduction and blood transfusion with regard to controlling haemorrhage. Only thereafter can definitive treatment be instituted to prevent deformity and reduce complications. This should be undertaken by specialist surgeons in a hospital resourced, equipped and staffed to manage the whole spectrum of major trauma and factors that influence delayed mortality, adverse functional outcome and complications.

2. 1. The concept of stability: anatomical considerations and classifications

2. 1. 1. Anatomical considerations

An intact pelvis provides protection for its visceral content and traversing neurovascular structures. It is the site of load transfer between the axial skeleton and the lower extremities. The main ligamentous and muscle attachments are finely balanced to allow load transfer to take place when standing, sitting and during locomotion. The bony pelvis is turned into a basin by the pelvic floor – a complex network of ligaments, tendons and muscles that is pierced by the urethra, anus and vagina. When the pelvic floor is torn, huge amounts of blood can escape into the thighs and retroperitoneal space. It is useful to think of the pelvis as the cross-roads of the lower body. It is where forces, innervation, blood supply and perhaps surgical specialties all come together. It is not possible to treat injuries to the bony and ligamentous pelvis successfully without suspecting, identifying and managing associated soft tissue, visceral, and neurovascular injuries.

2. 1. 2. Classifications

The first classifications of pelvic fractures were initially based on anatomical descriptions of the injuries. Pennal and Sutherland proposed the first mechanistic classification of pelvic fractures. They distinguished different categories of fractures by the injury mechanism involved: anteroposterior compression, lateral compression, vertical shear. They thus laid the essential foundations of the classifications developed to date. The Young and Burgess classification (Figure 2) which is derived from the initial anteroposterior (AP) radiograph is predominantly based on the mechanism of injury and severity of the fracture. This classification aims to define the relationship of the mechanism of force delivery and magnitude and direction of the impact forces on the pattern of associated organ injuries which occurs in conjunction with a particular form of pelvic fracture. Fractures are divided into four categories based on the mechanism of injury, two of which are subdivided according to the severity of injury.

- Anterior posterior compression. These fractures are secondary to a direct or indirect force in an AP direction leading to diastasis of the symphysis pubis, with or without obvious diastasis of the sacroiliac joint or fracture of the iliac bone.
- Lateral compression. A lateral compression force, which causes rotation of the pelvis inwards, leads to fractures in the sacroiliac region and pubic rami.
- Vertical shear. An axial shear force causes disruption of the iliac or sacroiliac junction, combined with cephalic dis- placement of the fracture component from the main pelvis.
- Combined mechanism. A combination of two of the above vectors leads to a characteristic pattern of pelvic fracture.

The Tile classification (Figure 3) is more complex by introducing the notion of treatment which is directly influenced by the degree and direction of instability. It describes how each injury may be placed on a stability scale and how accurate clinical and radiological assessment may determine the degree of stability and any pelvic injury. However, all of the above-mentioned classifications sometimes remain difficult to put into practice. In particular, the link between the mechanism and the anatomical lesion is sometimes impossible to specify. Similarly, the emergency assessment of the stability of the lesion remains poorly defined, relying on radiological criteria that are often incompletely validated. Tile, in association with the reflections of a working group of the AO (Association for Osteosynthesis) proposed an alphanumeric classification in order to try to harmonize therapeutic conduct and prognostic assessment. It is currently the most widely used and will be our reference classification. It allows us to describe and detail the elementary lesions and the mechanisms involved, by detailing three main categories and the subdivisions.

- Stable A injuries with osteo-ligamentous integrity of the posterior pelvic ring and intact pelvic floor; the pelvis can withstand physiological loads without dislocation (Figure 4A).
- Rotationally unstable B injuries with partially preserved stability of the posterior pelvic ring (Figure 4B).
- Translationally unstable C injuries with disruption of all posterior osteo-ligamentous structures and also of the pelvic floor. The direction of dislocation (vertical, posterior, distraction, additional rotation) plays a subordinate role. The pelvic ring is thus interrupted anteriorly and posteriorly, and the affected half of the pelvis is unstable (Figure 4C).

Another limitation of these classifications is the absence of consideration about spino-pelvic dissociation in some combined pelvic ring injuries and lumbo-sacral fractures or some isolated bilateral sacral fractures (Figure 4D).

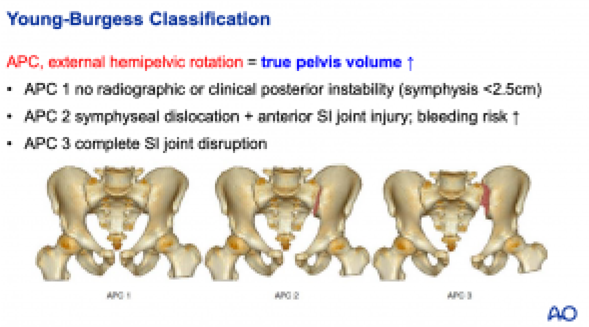

Figure 2A: Young and Burgess classification. From AO Trauma Pelvic Course.

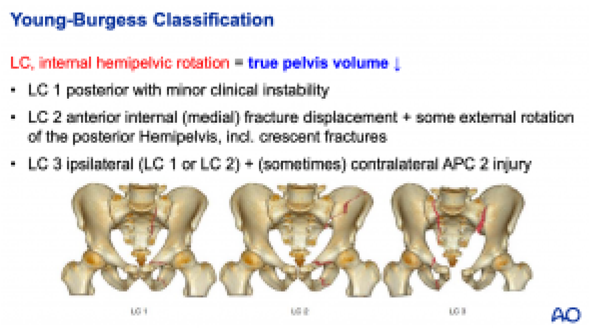

Figure 2B: Young and Burgess classification. From AO Trauma Pelvic Course.

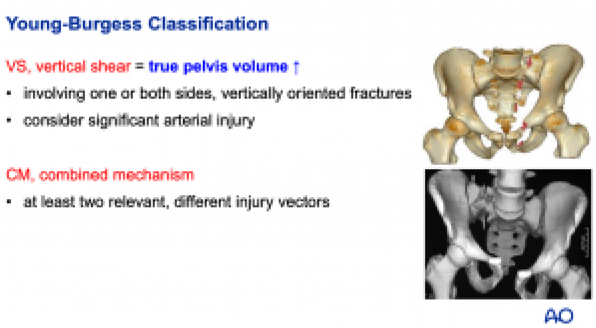

Figure 2C: Young and Burgess classification. From AO Trauma Pelvic Course.

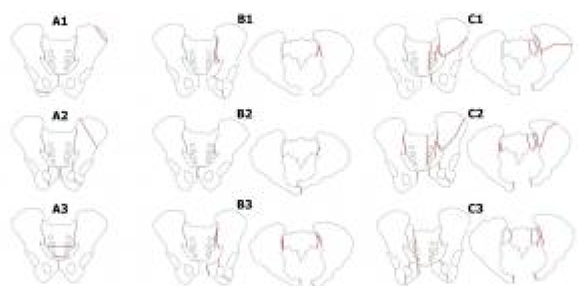

Figure 3A: Tile Classification. From AO Trauma Pelvic Course from Puchwein P, Hallmann B, Eibinger N. Bleeding management in pelvic trauma: state of the art. Curr Opin Anaesthesiol. 2025 Jun 1;38(3):323-330.

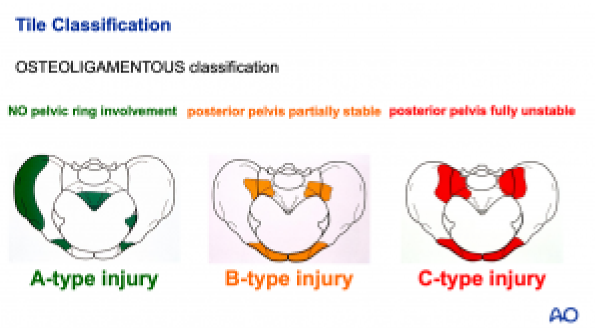

Figure 3B: Tile Classification. From AO Trauma Pelvic Course from Puchwein P, Hallmann B, Eibinger N. Bleeding management in pelvic trauma: state of the art. Curr Opin Anaesthesiol. 2025 Jun 1;38(3):323-330.

Figure 4A: AP view of left Iliac wing fracture as an exemple of stable A injuries with osteo-ligamentous integrity of the posterior pelvic ring and intact pelvic floor; the pelvis can withstand physiological loads without dislocation. Images Pr. Boudissa.

Figure 4B: AP view of an open book fracture as an exemple of rotationally unstable B injuries with partially preserved stability of the posterior pelvic ring. Images Pr. Boudissa.

Figure 4C: AP views of two translationally unstable C injuries with disruption of all posterior osteo-ligamentous structures and also of the pelvic floor. The pelvic ring is thus interrupted anteriorly and posteriorly, and the affected half of the pelvis is unstable. Images Pr. Boudissa.

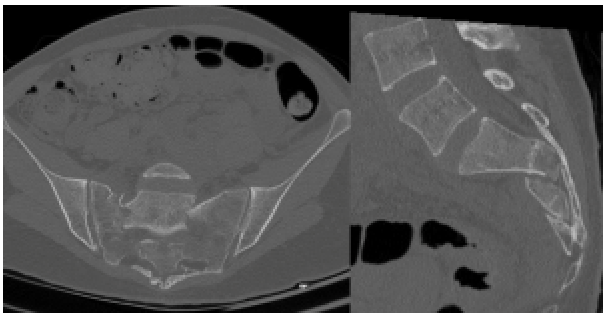

Figure 4D: Sagital CT reconstruction of bilateral sacral fracture with transverse component responsible for a spino-pelvic dissociation. Images Pr. Tonetti.

2. 2. Clinical examination and imaging

2. 2. 1. Clinical examination

The patient's pelvis must be examined clinically. The examination includes an external search for bruises or hematomas, checking the pelvic stability and inspecting the orifices with vaginal and rectal examination. The primary diagnosis includes a test of pelvic stability and a clinical examination of the soft tissue around the pelvic girdle and the perineum. Occult soft tissue injuries (rectal or vaginal tears, blood leaking from the urethral meatus as an indirect sign of a urethral or bladder rupture) must also be recognized, as otherwise serious septic complications can result.

If both pelvic wings can be moved towards each other, there is rotational instability. This is checked by bilateral manual external compression of the pelvic ring at the level of the pelvic wings. Bilateral compression of the pelvic wings in a ventro-dorsal direction is used to check for an external rotation injury. If one half of the pelvis can be moved distally by longitudinal traction on the leg, there is vertical instability. If during the clinical examination one half of the pelvis is very mobile and can be moved independently of the main skeleton, vertical instability is almost certain. In any case a radiological diagnosis must be established unless life-threatening injuries to other parts of the body are to be treated with higher priority.

2. 2. 2. Imaging

For radiological fracture diagnosis, a plain X-ray image should first be taken in AP and, if necessary, in special projections. A computer tomography can be performed instead of the plain X-ray, but should primarily serve to supplement the plain X-ray and thus to further classify the injury. If intrapelvic bleeding cannot be ruled out, the CT diagnosis should be carried out with contrast medium.
The plain AP radiograph is essential and will demonstrate most injuries (Figure 5). Instability is suggested by displacement of the posterior sacroiliac complex by a fracture, dislocation or both. Another radiological abnormality suggestive of instability is an avulsion fracture of the transverse processes of the lower lumbar vertebrae. While rami fractures and diastasis of the pubic symphysis are more easily seen on a radiograph than posterior displacement, it is the latter which is more crucial in the initial stages. The widespread use of pelvic binders by pre-hospital care providers can make the initial radiograph appear normal. A new plain AP radiograph should be performed after pelvic binders removal.

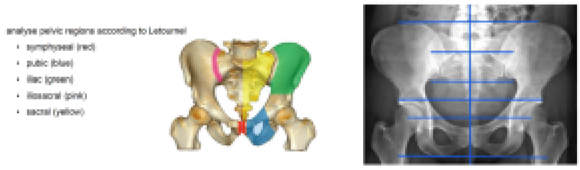

Figure 5: Example of checklist to analyse AP pelvic X rays. Blue lines correspond to symmetrical bony landmarks (translational instability). From AO Trauma Pelvic Courses.

Signs of pelvic instability include, for example, an expansion of the symphysis or the SI joints. A displacement of the pelvic blades in a horizontal or vertical direction should also be interpreted as instability. It should always be remembered that the dislocation was often more drastic at the time of the accident than at the time of diagnosis. For example, a fracture of the transverse process of the 5th lumbar vertebra should also be considered a sign of instability if there is also an injury to the pelvis, but no displacement of the pelvic blade can be seen in the diagnostic imaging. The orientation of the pelvic instability is important for classification. If there is only rotational instability of the pelvis across the vertical axis of the posterior pelvic ring, this is a group B injury. If, on the other hand, there is translational instability in the vertical or horizontal direction, this is a group C injury. An unstable pelvic fracture can be assumed if a gap of more than 3 cm can be felt in the area of the symphysis during the clinical examination. Instability should be assumed if the iliac blades move in an anterior-posterior or medio-lateral direction when compressed. If the iliac blades are visibly misaligned, possibly with visible fragments, instability can also be assumed.

If the patient's general condition allows him to be transported to the X-ray department, a CT scan of the pelvis is performed. This is essential for further diagnostics and for determining the treatment mode.

Increasingly, spiral CT devices are used to perform a whole-body CT scan in the early phase after hospital admission. The data obtained in this way serves as a comprehensive and orientational examination during the initial treatment of seriously injured patients. Two- and three-dimensional reconstructions of the CT images are also not a priority. However, they are very helpful for planning the definitive surgery and determining the osteosynthesis procedure for the anterior and posterior pelvic rings (Figure 6). In a haemodynamically unstable patient, ultrasound is used to identify accompanying intraabdominal bleeding. If the patient is haemodynamically stable enough, contrast enhanced CT scan can be used to identify active arterial bleeding and angiography with embolization may be indicated (Figure 7).

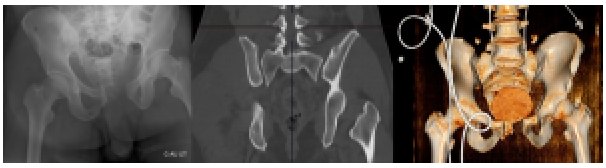

Figure 6: Example of translationally unstable C injuries with disruption of all posterior osteo-ligamentous structures and also of the pelvic floor. AP pelvic X ray, frontal CT reconstruction and 3D reconstruction. Images Pr. Boudissa.

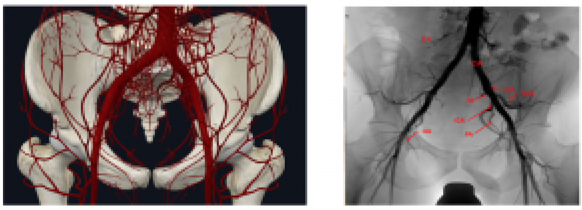

Figure 7: 3D model of arterial vascularization in pelvic area and real angiography. Images Pr. Boudissa.

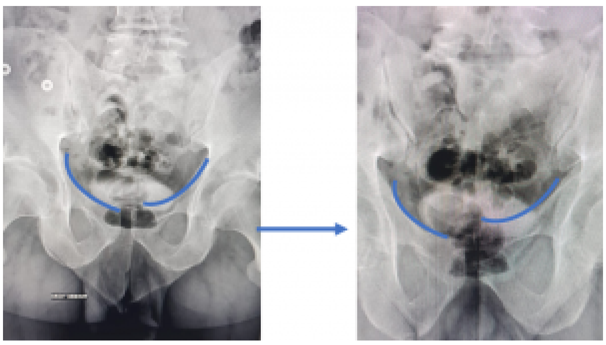

Figure 8: Vertical instability revealed by examination under anaesthesia. Images Pr. Boudissa.

2. 3. Complex pelvic fractures

The term complex pelvic fracture applies to all bony injuries to the pelvis with a simultaneous injury to holo-visceral organs of the pelvis or injuries to nerves and vessels or the urinary tract. It is also helpful to distinguish between open and closed pelvic injuries. A pelvic injury is described as open in the following situations:

- primary open pelvic fractures: by definition, a direct connection between the broken bone and the skin or mucous membrane of the vagina or anorectum,
- closed pelvic fracture with inserted tamponades to stop bleeding,
- closed pelvic lesion with documented contamination of the retroperitoneum due to an intra-abdominal injury.

In contrast, pelvic fractures with only a lesion of the bladder or urethra are not to be described as open but as complex.

Instability, particularly of the posterior pelvic ring, is accompanied by a strong tendency to bleed from the presacral venous plexus. Evidence of pelvic instability should lead to increased attention to the circulatory situation. Instability is classified as internal rotation or external rotation instability depending on how easily the pelvic blade can be opened - inwards or outwards. In the case of translational instability, this can be present in the horizontal plane as craniocaudal instability or in the sagittal direction as anterior-posterior instability. In addition to the increased risk of bleeding, the instability can lead to further complications such as thrombosis and secondary nerve, vascular and organ injuries. The latter injuries can also already be present at a primary stage and must be excluded as part of the primary diagnosis of unstable pelvic injuries. Pelvic instability must be treated surgically at an early stage. Depending on the patient's condition, this may initially be an emergency measure or a definitive one, which is often somewhat more time-consuming.

2. 4. Initial management of unstable pelvic ring injuries: the “damage control”

Pelvic ring injuries are known to cause a retroperitoneal haematoma, which may be life-threatening. In a personal series of 2064 cases at the French Alps Trauma Centre, we identified 135 unstable lesions (6.5%) with 28% out of these were the cause of haemorrhagic shock upon arrival. Different algorithms have been proposed for the management of unstable pelvic fractures (Figure 9).

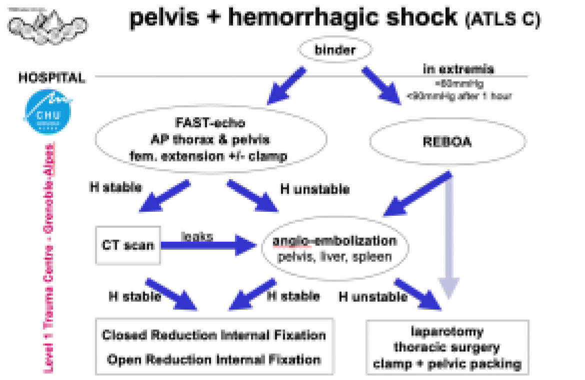

Figure 9: Algorithm for management of a haemodynamically unstable patient with a pelvic ring injury in Grenoble Alpes Trauma Centre.

There are numerous causes of bleeding: venous, osseous and arterial. Management should begin at the scene of the accident. re-hospital management should there- fore include compression of the retroperitoneal space by pulling together the two coxal bones by compression at the hight of the femoral trochanter A belt (Figure 2) or a sheet wrap using the Seattle technique (Figure 10) prevents expansion of the retroperitoneal haematoma, and the loss of several precious hemoglobin grams. The clinical symptoms which should alert the surgeon and the intensive care specialist are pulse acceleration, which occurs after a loss of 750 mL of blood, then an increase in diastolic pressure and anxiety after 1500 mL of blood loss. Other predictors of major haemorrhage in patients with a fracture of the pelvis are: an emergency department hematocrit value of ≤ 30%; pulse rate of 130 beats/min; a displaced fracture of the obturator ring; and a wide pubic symphyseal diastasis. Hemostasis and filling maneuvers should be begun in the presence of these symptoms. There are some anatomo-pathological lesions that provide a prognosis for bleeding. In a retrospective analysis of 171 patient whom were admitted to one of the shock rooms of Grenoble University Hospital, France, between January 2004 and December 2008 with treatment according to the institutional algorithm of the Alps Trauma Center and Emergency North Alpine Network Trauma System (TRENAU), the primary identification and classification of osteo-ligamentous lesions allowed to anticipate the importance of bleeding and to adapt the management of patients accordingly, in order to quickly organise angiography with embolization.

No definitive treatment of osteo-ligamentous lesions should be proposed during the acute phase. This is orthopaedic ‘‘damage control’’.

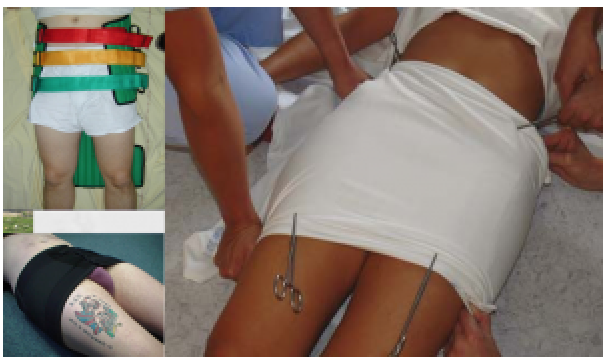

Figure 10: Example of pelvic binder (belt) or sheet wrap using the Seattle technique to close the

pelvic ring. Images Pr. Tonetti.

2. 4. 1. Binders and pelvic clamps

The use of a compression belt for more than 6 hours is difficult due to compression of the greater trochanters and the risk of bedsores. This should be replaced by transcondylar traction to reduce elevation of the hemi-pelvis and place a pelvic clamp using the Ganz technique (Figure 11). This is only effective if the iliac wing is intact. It is effective in sacro-iliac disruptions and sacral fractures. It also allows access to the abdomen and the groin (arteriography). These external reduction maneuvers should be performed in a shock control unit and should not interfere with rapid multidisciplinary management with CT scan, angiography or surgery. This compression maneuver and stabilization of the posterior bone lesion is nevertheless the pre-requisite before performing interventional endovascular therapies, or when performing preperitoneal pelvic packing (PPP) The indication for clamping is not an osteoarticular injury but hemodynamic instability. The clamp stops intra-focal bleeding and lowers the volume of the pelvic compartment where the haematoma is, and acts as couterpressure for pelvic packing.

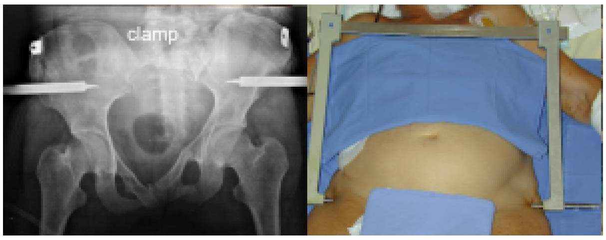

Figure 11: Example of pelvic C-clam AP pelvic X ray and clamp positioning.

2. 4. 2. Angiography

During angiography the terminal branches of the internal iliac artery are explored: ilio-lumbar artery, lateral sacral artery, superior gluteal artery, internal pudendal artery. Embolization is performed with material that is resorbable after 6-12hours (Figure 12). This may involve leaving a catheter in place to perform additional embolization in case of re-permeabilization of embolized vessels or hemostatic disturbances. In a retrospective analysis of 171 patient whom were admitted to one of the shock rooms of Grenoble University Hospital, France, between January 2004 and December 2008 with treatment according to the institutional algorithm of the Alps Trauma Center and Emergency North Alpine Network Trauma System (TRENAU), there were significantly many more Tile C unstable fractures treated by embolization. Anterior lesions with pubic symphysis disruption were significantly more likely to lead to active bleeding treated by selective embolization. Posterior pelvic ring lesions with iliac wing fracture and transforaminal sacral fractures were also more frequently associated with bleeding treated by embolization.

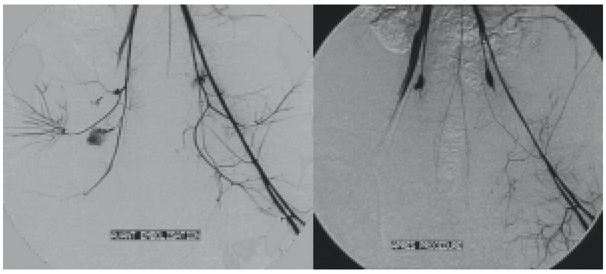

Figure 12: Example of embolization procedure showing arterial blushes before (left) and after (right) coiling.

2. 4. 3. Packing

In many hospitals, angiographic embolization may be more time-consuming or delayed and surgical haemostasis may be available more rapidly. Pelvic packing requires surgical facilities and expertise and aims to directly tamponade sources of bleeding within the pelvis. Packs can be placed in the preperitoneal and retroperitoneal spaces (Figure 13). The method is invasive and the packs must be subsequently removed, usually at least 48 hours after insertion. Packing may be combined with concurrent external fixation. It may be necessary to combine surgical haemostasis and angiographic methods.

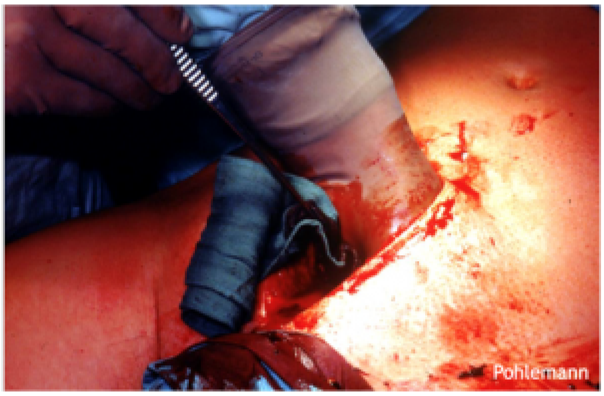

Figure 13: Example of packing. Laparotomy sponges are used to create a tamponade of the veinous bleeding in the retroperitoneal space. Images Pr Pohlemann.

2. 4. 4. REBOA

In cases of extreme shock (“in extremis”), an endovascular balloon occlusion of the aortamay be performed by femoral route immediately above the aortic bifurcation (ZONE III) to minimise the bleeding. REBOA should in no case delay transter to the operating room or angiography for definitive hemorrhage control; REBOA is only a bridging strategy.

2. 4. 5. External fixation

If the patient cannot receive definitive treatment after 5 days, the clamp should be replaced by an external fixator, which is associated with fewer cutaneous complications. However the vertical stability of this device is not sufficient and transcondylar traction should be maintained until definitive treatment with internal fixation can be performed.

2. 4. 6. Open fractures of the pelvic ring

The life-threatening risk of pelvic ring fractures is doubled in case of an open fracture. These may include Morel-Lavallee lesion with cutaneous necrosis, an anorectal or an inguinal lesion. Faringer’s stages of severity can be used in these cases (Figure 14). A high colostomy at the transverse colon can divert fecal matter, simplify care and obtain perineal healing in Faringer’s zone 1. A high colostomy allows ilio-inguinal access to the pelvic ring, in case anterior fixation is needed later on. Morel Lavallée degloving lesions with cutaneous necrosis are frequent in Faringer peritrochanteric zone 3. Debridement and continuous draining is sometimes necessary. Lavage should be repeated regularly. Healing by continuous aspiration is useful in the acute phase (VAC therapy). Mortality associated with pelvic and perineal trauma (PPT) has fallen from 25% to 10% in the last decade thanks to progress accomplished in medical, surgical and interventional radiology domains.

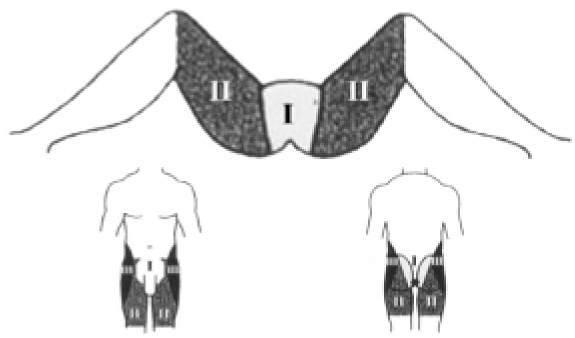

Figure 14: Fahringer severity classification from Faringer PD, Mullins RJ, Feliciano PD, Duwelius PJ, Trunkey DD. Selective fecal diversion in complex open pelvic fractures from blunt trauma. Arch Surg 1994;129:958—63.

2. 4. 7. Management of urogenital injuries

The examination should look for meatal bleeding, urinary retention or dysuria. Investigation of the urethra by contrast enhancement can be performed with a urogenital catheter, with a 600cc syringe with a conic tip (gavage syringe) filled with contrast medium. If there is filling without any leaks gentle catheterization can be performed. Catheterization can be performed immediately if there are no suspicious clinical signs. A large diameter catheter is preferable. Catheterization is performed without guide. If there is any blockage this maneuver should be stopped. In that case a supra-pubic catheter is recommended. Injury to the urethra is not suggested by any specific anterior pelvic arch injury. On the other hand, a highly displaced fracture on the ilio-pubic ramus can easily cause injury to the bladder if it is full. Management differs depending on whether there is a lesion of the intraperitoneal bladder, which should be rapidly sutured, or a subperitoneal lesion, which should be drained. Repair of the urethra is usually performed later, once peri-urethral injuries have healed (2 months).

2. 4. 8. Indications for early definitive treatment of osteo-ligamentous injury

Multiple trauma patients present with a systemic inflammatory response syndrome (SIRS), which begins after the first day and ends after approximately 4 days. After 10 days the Compensatory Anti-inflammatory Response Syndrome (CARS) develops, reducing the patient's immune defenses against surgery. Thus the patient should undergo surgery either before the first day or between the 4th and 10th days. The decision on further managemenden should be based on physiologic stability of the patient, or their response to initial management,based on a temperature of above 34ºC, an absence of acidosis with a PH of above 7.2 (normal lactate) and the absence of coagulopathy with fibrinogenemia above 1g/L. These stable patients may benefit from early definitive osteo-ligamentous treatment (‘‘early total care'') immediately following admission into a reference center.

2. 5. Complications and prognosis

2. 5. 1. Post-operative course and thromboembolic risk

A 90º seated position solicits the posterior arch of the pelvic ring and should be avoided for at least 45 days. We prefer the seated in bed position at 45º, for 45 days.
Once the incision has healed the patient can be moved during hydrotherapy. One hundred percent full weight bearing on both legs is not allowed until 3 months after surgery. Unilateral weight bearing does not protect the pelvic arch because it creates asymmetric loads, which tend to deform the pelvic ring.
Recommended times until weight bearing are approximate and depend upon the patient's physical condition and the number of screws and their types (trans-sacral or not). They can be reduced when the patient is young and increased in older patients, smokers or patients with co- morbidities.
Pelvic injuries considerably increases the thromboembolic risk; some centers perform regular doppler control of the lower extremities, e.g. before surgery (see Venous thromboembolism).

2. 5. 2. Surgical complications

Iatrogenic neurological complications due to an extra- osseous sacro-iliac screw trajectory are severe. The position of the screw must be changed. They result in sequelae such as drop foot and neuropathies with long-term functional deficits. When compression screw fixation was performed in a sacral fracture, the clinical examination may reveal a postoperative deficit. In this case the path of the nerve roots should be confirmed on CT scan and a mobile fragment should be looked for. The screw should be changed for a fully threaded screw and neurolysis of the lumbosacral trunk or the root of S1 is performed depending on the deficit. Infectious complications of the posterior incision require debriding-lavage and intravenous antibiotics. Secondary displacements may occur due to defective fixation, and are usually anterior. Revision surgery is usually necessary to reinforce the system. A sacro-iliac screw may be too short or may not be screwed far enough into the body of S1. The anterior clamp is then a temporary, non-surgical solution to reinforce stability in a weak patient.

2. 5. 3. Urogenital Complications

Genital dysfunction is underestimated if it is not specifically look for. This may include retrograde ejaculation, impotence, and painful intercourse due to vaginal dryness. They are the consequence of anterior vascular lesions and lesions to the neuro-vegetative system. The pre-sacral pudendal plexus may be involved. The approach is pragmatic with the use of Sildenafil (Viagra) in men as a therapeutic test. If medical treatment fails a penile implant is indicated. Urethral stricture may develop in men, which is usually due to catheter trauma. Repeat dilations are performed in this case.

2. 5. 4. Neurological complications

Initial neurological lesions can be present in half of these cases with a full or partial recovery in the majority of cases. They result in neuropathic pain in L4-L5 (lumbosacral trunk) and S1. Sacro-iliac pain must be distinguished from incomplete reduction. During the acute phase, neurolysis of the lumbosacral trunk by ilio-inguinal approach is only proposed to relieve compression of a bone fragment. Usually there is no visible compression and treatment is symptomatic with anti- epileptic drugs. The prognosis of these lesions is poor when they involve deficits that are secondary to sacro-iliac disruption causing nerve root avulsions. During sacral trauma the lumbosacral plexus branches are injured. The prognosis is better in these cases with spontaneous recovery. A spinal stimulation implant may be a solution for debilitating nerve root avulsion.

In Chapter References

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3. Extremity injury

In this chapter, we will only deal with extremity injuries whose abbreviated injury scale (AIS) is equal or superior to three. Pelvic injuries will not be addressed as they were discussed earlier in the module. The grading used for open fractures will be Gustilo classification (Gustilo, Mendoza and Williams. 1984). Extremity injury is frequent in trauma patients, either isolated or associated with visceral injuries. Their intrinsic severity and their propensity for aggravating other trauma-related injuries contribute to vital and functional outcomes and must be addressed in Trauma centres with adequate level (Pottecher et al. 2021). Need for trauma intervention (NFTI) outperforms conventional triage criteria and should also be used in severe extremity injury (Chin et al. 2023; Ageron et al. 2025).

Early prehospital concerns deal with bleeding control, adequate triage and analgesia. Direct manual compression, haemostatic dressing and tourniquet are complementary tools to deal with extremity bleeding (Charlton et al. 2021). Tourniquets previously had poor reputation and accused of inducing limb loss. Recent military reports and experience from terror attacks worldwide now confirms that their use is safe, efficient and associated with limited vascular and nervous injury when applied judiciously (Beaucreux et al. 2018; Ko et al. 2024).

Missed vascular injuries are associated with significant morbidity and should be thoroughly investigated. Hard signs of vascular injury (expanding hematoma, thrill, ischemic limb) are easily recognized but soft signs (externalised bleeding of arterial origin during collection or transport, open or blunt trauma in the vicinity of a main vascular axis, non-pulsatile haematoma next to an arterial path, neurological deficit) may be overlooked if not specifically sought (Feliciano et al. 2011; Feliciano et al. 2013). The ankle-brachial index (ABI) completes physical examination and may rule out vascular injury when a normal ABI value (> 0.9) is associated with absence of both hard and soft signs (deSouza et al. 2017). CT angiography is the best imaging modality for revealing or ruling out vascular injury (Seamon et al. 2009; Kobayashi et al. 2020). In situations with a high level of suspicion (e.g. dislocation of the knee), performance of the CT should be anticipated to include the suspected limb within the explored area.

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3. 1. Surgical prioritisation

3. 1. 1. Principles of surgical prioritisation in multiple trauma patients

Prioritisation of surgical and haemostatic interventions in severe trauma patients should consider both physiological derangements, potential ongoing bleeding and potential drawbacks of non-definitive interventions. The threshold considered for "early" surgery is usually set at 24h (Pfeifer et al. 2024).

The grading of initial severity, performed after first measures of resuscitations, should facilitate the destination of the trauma patient after first assessment in the trauma bay.

Variables considered for prioritisation vary from recommendation to recommendation and from one trauma team to the other, but the following are usually addressed are summarized in table 1 (Pottecher et al. 2021).

Table 1: Surgical prioritization according to clinical and biologic variables

Status / Variable	**Stable clinical status**	**Intermediate clinical status**	**Unstable clinic status**
Haemodynamic condition & transfusion requirements	**Stable circulatory status** • No vasopressor drug (norepinephrine) or < 2 mg/h • No blood transfusion • Lactate < 2.5 mmol/L	**Moderate circulatory shock** • Vasopressor drug (norepinephrine) 2 – 4 mg/h • Transfusion 1–4 units of packed red blood cells • Lactate: 2.5 – 4 mmol/L	**Severe circulatory shock** • Vasopressor c (norepinephrin > 4 mg/h • Transfusion ≥ units of pac red blood cells • Lactate > mmol/L
Haemostasis	**Mild coagulopathy** • PTr < 1.2 • Fibrinogen ≥ 1.5 g/L • Platelets ≥ 100 000 /mm^3	**Moderate coagulopathy** • PTr 1.2–1.5 • Fibrinogen 1 – 1.5 g/L • Platelets 50 – 100 000/mm^3	**Severe coagulopa** • PTr > 1.5 • Fibrinogen < 1 • Platelets < 50 /mm^3
Central temperature	**Mild hypothermia** • > 35°C	**Moderate hypothermia** • 32 - 35°C	**Severe hypotherm** • 32°C

Respiratory function	**Stable respiratory function** • PaO_2/FiO_2 >300	**Moderate ARDS or hypoxemia** • PaO_2/FiO_2 150 – 300	**Severe ARDS or hypoxemia** • PaO_2/FiO_2 < 1
Muscle involvement	No rhabdomyolysis	**Severe rhabdomyolysis** (myoglobin ≥ 10 000 UI/L)	**Massive rhabdomyolysis** (myoglobin ≥ 20 00 UI/L)

Associated injuries	**Mild associated injuries** • ISS <25 • Mild traumatic brain injury (GCS 13-15) • No extra-spine AIS ≥ 4	**Intermediate risk associated injuries** • ISS > 25 or an injury AIS =4 • Moderate traumatic brain injury (GCS 9-12) • Thoracic Trauma Severity (TTS) score 8–11 • Pulmonary contusion ≥ 2 lobes • Aortic injury OIS 2 • Abdominal injury OIS ≥3 or moderate haemoperitoneum • Moderate retroperitoneal hematoma (MTC score ≥ 6) • Transitory or subclinical limb ischemia	**High risk associat injuries** • ISS > 40 or injury AIS ≥ 5 • Severe Traum Brain injury (G < 9) • Thoracic Trau Severity (T score ≥12 • Pulmonary contusion ≥ lobes • Massive air l coming from l laceration • OIS grade ≥ aortic in before surgery • OIS grade ≥ abdominal in and/or requirin haemostatic procedure • Massive retroperitoneal hematoma (M score ≥ 10) • Bilateral diaphyseal complex fem fractures • Multiple diaphyseal complex fractu • Critical l ischemia

Requirements for associated emergent surgeries	Low-risk surgery	**Intermediate or high-risk surgery** • Laparotomy • Spine surgery in prone position • Multi-site orthopaedic surgery • Preventive embolization • Vascular stenting	**Major high-risk surgery** • Decompressiv craniectomy • Resuscitative thoracotomy lung resection • Resuscitative laparotomy • Pelvic clamp • Pelvic packing • Angioemboliza for pelvic or s organ bleedin
Therapeutic proposal	**Low-risk patient** • Early safe definitive orthopaedic surgery	**Intermediate-risk patient** • Initial resuscitation, temporary stabilization and Prompt individualised safe management (PRISM)	**High-risk patient** • Damage-Contr Orthopaedics (mid-term stabilization) followed by s delayed defini orthopaedic surgery

Abbreviations:
AIS: abbreviated injury scale
GCS: Glasgow coma score
ISS: injury severity score
MTC (score): Montpellier trauma centre (score)
OIS: organ injury scale
PTr: prothrombin time ratio
TTS (score): thoracic trauma severity (score)

3. 1. 1. 1. Surgical Prioritisation

Surgical decision-making should follow the hierarchical framework first life, then limb, then function. Extra-skeletal injuries must be assessed before committing to orthopaedic intervention, and a multidisciplinary approach is advocated in every case.

3. 1. 1. 2. Extra-skeletal considerations

In traumatic brain injury, orthopaedic surgery should be deferred until ICP is below 20 mmHg and CPP is above 60–70 mmHg. Once haemodynamics, respiratory and metabolic parameters are optimised, extensive orthopaedic procedures may proceed provided haemorrhagic lesions are stable and haemostasis is restored. Sometimes orthopedic surgery should be performed in a window with stable organ function before a new complication arises, for example ARDS in thoracic trauma.

In chest trauma, liberal chest drain placement is recommended before lengthy procedures, particularly in patients with bilateral lung contusions, bilateral pneumo- or haemothoraces.

In abdominal trauma, early fracture fixation is safe as long as haemodynamic stability is maintained, even in the presence of an open abdomen or negative pressure dressing.
Spinal injuries should be stabilised within 24 hours regardless of neurological deficit, to enable early physiotherapy and reduce pulmonary complications.
In combined vascular and orthopaedic injuries, restoration of distal perfusion — by temporary intravascular shunt or definitive repair — takes priority over fracture fixation.

With regard to orthopedic injuries, three strategies have been described:

- **Early Total Care (ETC):** definitive fixation within 24h (e.g. intramedullary nailing)
- **Early Safe Definitive Surgery (EARLY-SDOS):** definitive fixation within 48h
- **PRISM:** Damage Control Orthopaedics (DCO — external fixation or traction) followed by Delayed Safe Definitive Surgery (DELAYED-SDOS) after 48h

Prioritization should assess the surgical load, prioritize life (major limb fracture haemorrhage) over limb and focus on the prevention of severe disability followed by the risk of limb loss. In patients with multiple fractures and stable or stabilized physiology, prioritization should consider the location and complexity of fractures, the anticipated blood loss and duration of the surgical procedure, team expertise and resource availability. In every case, a holistic approach and multidisciplinary assessment is advocated to consider patient eligibility to operating room; it should consider the anatomic injury distribution and a holistic pathophysiologic approach (Halvachizadeh et al. 2024).

3. 1. 2. Immobilization measures

When damage control surgery is considered the best initial option, immobilization of fracture sites is prominent to avoid pain, disability and early systemic complications (fat emboli syndrome and acute respiratory distress syndrome (ARDS) for instance). Immobilization of long bone fractures can be obtained using external fixation or skeletal traction. Their preferential use depends on teams' preferences and patients' clinical pathways. When the patient is already in the operating room for another procedure, external fixation appears preferable. In the event of non-surgical treatment within the first 24 hours, skeletal traction does not induce more multi-organ failure or

ARDS compared to external fixation (Scannell et al. 2010). However, external fixation facilitates nursing in the ICU, transportation to radiological ward or operating room and may avoid pressure ulcers associated with long term use of skeletal traction. In the case of long-lasting skeletal traction, pulmonary complications may become prominent (Maury et al. 2021). Indeed, fat embolism or respiratory complications may occur with skeletal traction, because the latter device does not prevent mobilization of the fracture site, it does not maintain consistent limb alignment and imposes a strict dorsal position. Therefore, external fixation may be preferred when definitive fracture fixation is not anticipated in the following days.

3. 1. 3. Complications of extremity injuries

3. 1. 3. 1. Vascular injury

Missed vascular injuries — most commonly involving the popliteal artery — risk rhabdomyolysis, functional loss and limb loss. Assessment combines clinical examination with Doppler-derived ankle-brachial index (ABI).

Hard signs (pulsatile or expanding haematoma, significant external bleeding, limb ischaemia, audible thrill) confirm arterial involvement and mandate immediate surgical exploration or CT angiography.

Soft signs (non-pulsatile haematoma adjacent to a vascular axis, trauma in proximity to a major vessel, neurological deficit from nerve compression, suspected arterial bleeding during transport) identify injury in 3–25% of cases and should prompt ABI measurement.

The ABI is calculated as the ratio of ankle to brachial systolic pressure in the supine patient, using Doppler at 45°. The lowest value across the pedal and posterior tibial arteries is used. An ABI below 0.9 carries a sensitivity of 87% and specificity of 97% for vascular injury. Conversely, a normal ABI in the absence of both hard and soft signs virtually excludes significant arterial injury (negative likelihood ratio 0.01), avoiding the need for further imaging. ABI is particularly valuable in knee dislocations and Schatzker type IV–VI tibial plateau fractures.

3. 1. 4. Venous thromboembolism

Prevalence of venous thromboembolism (VTE) remains high in severe trauma patients and may reach 30% despite early and protocolized mechanic and pharmacological prevention (Hamada et al. 2017). In the prospective study performed by Hamada et al., independent risk factors for VTE were central venous catheter (OR 4.39, 95%CI (1.1-29)), medullar injury (OR 5.59, 95%CI (1.7-12.9)), initial systolic arterial pressure < 80 mmHg (OR 3.64, 95%CI (1.3-10.8)), and pelvic fracture (OR 3.04, 95%CI (1.2-7.9)). Some limb fractures (femur, proximal tibia) are at higher risk than others (tibia, ankle, foot, Achilles tendon rupture and immobilisation in a cast). Risk assessment scores are numerous (Risk Assessment Profile for thromboembolism (RAPT), DVT risk assessment score (DRAS), and the Trauma Embolic Scoring System (TESS)), based on fracture location and patients' risks and usually display areas under the ROC curve around 0.7 (Chen, Sun and Kong. 2023). Clinical diagnosis performance is poor, and definitive diagnosis relies on combined Doppler venous ultrasound. Early initiation of mechanical thromboprophylaxis with intermittent pneumatic compression (IPC) while the patient is immobile and has a bleeding risk is recommended (Grade 1C) but not always feasible in limb trauma patients (Rossaint et al. 2023). There is concern that, in trauma brain injured patients, early pharmacologic thromboprophylaxis using low molecular weight heparin may be associated with brain lesions progression and neurologic worsening. After respecting a 72h delay between trauma and pharmacologic prophylaxis, recent meta-analysis suggests that this regimen is safe, even in brain-injured patients (Dengler et al. 2024). In a large US cohort of 12879 trauma patients with AIS head 3, 4 or 5, initiation of pharmacologic prophylaxis before 48 hours was associated with lower mortality and VTE incidence but higher rates of nonfatal neurosurgical intervention (Johnson et al. 2024) . Systematic use of inferior cava filters is not recommended but may be used in case of absolute contraindication for both pharmacological prophylaxis and IPC (Court-Brown et al. 1998).

3. 1. 4. 1. Infection

Infection is of particular concern in open wound limb fractures since it may trigger osteomyelitis and consolidation impairment. While the incidence of fracture-related infection is 1% is closed fracture, it may reach 25% in open fractures (Chang et al. 2019). Proper fracture healing depends on the quality and vascular supply of surrounding soft tissue. Open fractures are primarily characterized by external contamination and disserve a meticulous classification. Fracture-related infections depend on both local conditions and patient’s comorbidities. Hence, a holistic patient approach is compulsory to provide adequate medical and surgical care. The recommended classification for open fracture is currently the one developed by Gustilo and Anderson (from type I to type IIIC)1 which incorporates the extent of bony and soft tissue injury as well as the contamination of the wound. The risk of fracture-related infection is low in grade I but can reach 50% in Grade IIIC. The principles of surgical treatment include wound debridement, copious irrigation, fracture stabilization and intravenous antimicrobial therapy. It is commonly accepted that such treatment should be initiated as soon as possible and no later than 24h after trauma.

Assessment of tissue vitality will allow excision of necrotic tissues and edges of the wound. In case of extensive tissue injury or mangled extremity, many scores (the Mangled Extremity Scoring System -MESS, the Nerve Injury, Ischemia, Soft tissue injury, Skeletal Injury, Shock and Age of patient score- NISSSA, the Predictive Salvage Index -PSI, or the Limb Salvage Index -LSI) were developed to assist clinicians in the eventual decision of amputation. However, no single score appears adequate and sufficient for proper classification (see below). After debridement, the fracture should be stabilized (usually with external fixation) and peripheral perfusion assessed (either with Doppler ultrasonography or plethysmography). The risk of compartment syndrome mandates close clinical monitoring and assessment of intracompartimental pressure. Negative pressure wound therapy is frequently used for temporary wound closure as it reduces bacterial load, promotes vascularization facilitates oedema reduction and granulation tissue formation. The rate of fracture-related infection is related to the timing of antimicrobial therapy and wound closure. Antimicrobial therapy differs from antibiotic prophylaxis as it aims at covering contaminated wound fracture. It should cover soil Gram-positive and Gram-negative pathogens including anaerobes and should ideally be provided within 3 hours after trauma. Aminopenicillin plus betalactamase inhibitors are usually recommended, sometimes associated with aminoglycosids in case of massive contamination29. In the absence of documented infection, antibiotic therapy should be interrupted after 72h. In case of allergy to betalactamins, clindamycin (900mg) and gentamycin (6-7 mg/kg) should be given. Tetanus immunization status should be checked and, if negative, tetanus prophylaxis using human immunoglobulins and/or vaccination should be provided.

3. 1. 4. 2. Amputation

Decision for amputation has sometimes to be made in case of mangled or devascularized extremity. Many scores were developed to assist clinicians in deciding to procced for amputation, essentially lower limb. The Mangled Extremity Severity Score (MESS) (Johansen et al. 1990) integrates ischemia, shock, bone and soft tissue damage, and patient characteristics. The Narakawa Index (Nerve injury, ischemia, soft tissue, skeletal injury, shock, age of patient score, NISSSA score) constitutes an alteration of MESS but also encompasses nerve injury element (McNamara, Heckman and Corley. 1994). The Musculoskeletal Score for Severity of Injury (MESI score) estimates the risk of limb amputation by assessing extent of injury, presence of neurovascular damage, type of fracture, patient characteristics, and the period from the occurrence of trauma to the definitive treatment. A MESS above 7 was classically considered a threshold for limb amputation but subsequent studies revealed it lacked both sensitivity (Menakuru et al. 2005) and specificity (Brown et al. 2009). The duration of limb ischaemia appears key in the success of limb preservation and prolonged warm ischaemia (> 6h) significantly decreases its success rate. Taken as a whole, the different scores developed in recent years cannot be used as the sole criterion by which amputation is decided, and, in case of successful limb salvage, these scores are not predictive of effective functional recovery (Schirò et al. 2015). Signs of neurovascular deficit and compartment syndrome (see further) should be investigated as soon as vital distress is cured and stabilization (hemodynamic, respiratory, neurologic) is obtained.

While complex limb trauma and mangled extremity are often associated with significant bleeding and haemorrhagic shock, it should be kept in mind that, compared to other haemostatic methods, prehospital tourniquet use in such situations is associated with improved survival (Teixeira et al. 2018) and similar amputation rate (Kauvar, Miller and Walters 2018). As assessment and management of such injuries is particularly challenging for the clinician in charge, a multidisciplinary approach should be requested, ideally involving orthopaedic, vascular and plastic surgeons to take therapeutic decisions. CT angiography of the affected limb, when possible, may provide useful information related to soft tissue insults, bone injury and vascularization. It may either be included in the initial whole-body CT (but proper limb angiography may compete with necessary opacification of other vital organs) or performed afterwards if clinical stability of the patient permits. Patient history, clinical status and preferences should be sought as well. As mangled extremity injury requires high energy trauma, the patient usually suffers vital organ injuries which complicate prioritization and impede informed consent for either amputation or limb reconstruction. As preservation of life constitutes the priority, clinicians should also consider the huge physical, societal and psychological burdens associated with limb amputation. Conversely, late amputation after attempt of limb salvage is associated with a very high incidence of complications and revision surgeries which may negatively impact psychologic well-being of the patient. Thus, patients should take active part in final decision whenever possible as long as their level of consciousness allows. Advance directives seldom consider severe limb trauma and provide little help in decision making in unconscious patients. Relatives or family members may then inform healthcare workers about patient's preferences. Whenever possible, below-knee amputations are preferable in active young patients as, in such circumstances, functional outcomes are comparable with those of limb conservation.

The MESS score was also tested in upper limb trauma but poorly predicts salvageability and therefore should not be used to make decisions (Yoneda et al. 2024).

3. 1. 4. 3. Compartment syndrome

Risk factors for compartment syndrome after trauma are fracture (especially tibia (where its prevalence may exceed 5%) (Ulmer. 2002) and forearm fractures), crush injury, young age (under 35) and male sex. Its pathophysiology includes an ischaemic phase when intracompartmental pressure increases, obviating microcirculatory perfusion, muscle and nerve oxygenation and promoting shutdown of sarcolemmal active ion transport. When perfusion is eventually reestablished, reperfusion injury induces membrane lipid peroxidation, increased membrane permeability, release of intracellular compounds in the systemic circulation and intense inflammatory reaction. Timely diagnosis of acute compartment syndrome (ACS) is critical since fasciotomy is limb saving and missed ACS may lead to muscle necrosis, definitive nerve and vascular injury and, eventually, limb amputation. Typical physical signs for ACS are summarised in Figure 15 and include: 1) a severe pain which appears out of proportion with limb trauma (especially after fracture fixation), 2) pain with passive stretch, 3) tenseness, 4) paraesthesia and 5) paresis. Pallor and pulsesness are "too late signs" which appear when irreversible damage is done, and their absence should neither be reassuring nor rule out ACS (Ulmer. 2002). Weakness of the extensor hallucis longus may be a a sign of missed ACS. Measurement of intracompartmental pressure relies on different devices, may be intermittent or continuous (recommended) and is considered pathologic either when its value exceeds 30 mmHg or when muscle perfusion pressure (obtained by subtracting intracompartmental pressure from diastolic blood pressure) decreases under 30 mmHg. Measurement of intracompartmental pressure is particularly relevant in obtunded patients or those under continuous sedation. Some single use, continuous electromechanical biosensors were recently developed and appear promising although they should be tested clinically before widespread adoption (Merle et al. 2020). Owing to the paucity of reliable diagnostic measures, the American Academy of Orthopaedic Surgeons (AAOS) has developed an evidence-based clinical practice guideline to assist caregivers in the diagnosis ACS (AAOS 2018). In such situations, the AAOS considers that biomarkers (myoglobinuria and serum troponin) are of little value. Near Infrared spectroscopy (NIRS) may prove useful in hospitalized patients but its predictive diagnostic value still needs formal confirmation (Walters et al. 2019). The positive predictive values of physical examination and intracompartmental pressure measurements are poor but their combination reaches a diagnostic accuracy of 68% (Lorange et al. 2023). When fasciotomy is performed early, less than 24h after crush injury, amputation rate is greatly reduced (Demir et al. 2023). Fasciotomy should be unique or multiple and long enough to relieve excessive pressure in all four compartments of the leg in lower limb ACS. Operative fixation (external or internal) should be performed for initial stabilization of long bone fractures with concomitant acute compartment syndrome requiring fasciotomy (AAOS 2018). Negative pressure wound therapy may decrease time to wound closure and need for skin grafting. Neuraxial anaesthesia and/or plexic/troncular locoregional analgesia may hinder early clinical diagnosis of ACS in leg fracture. In such situations, experts recommend low concentration local anaesthetics without adjuncts, single injection together with repeated clinical and intracompartmental pressure measurements (Nathanson et al. 2021). Safe alternatives to neuraxial and peripheral nerve blocks (intra-articular analgesia, sensory blocks, fascial plane blocks and low-concentration continuous peripheral nerve blocks) may prove effective without pitfalls associated with dense blocks (Hilber et al. 2024).

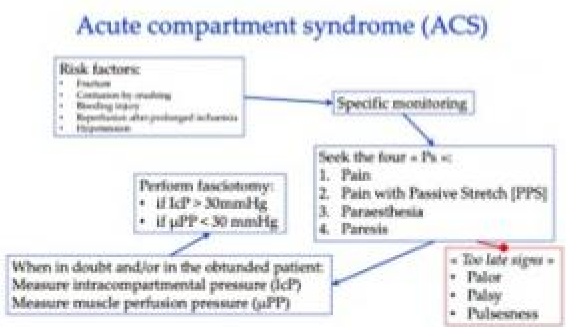

Figure 15: Acute compartment syndrome.

3. 1. 4. 4. Rhabdomyolysis and acute kidney injury

Rhabdomyolysis arises when muscle breakdown releases intracellular electrolytes, myoglobin, content of sarcoplasmic reticulum and other damage-associated molecular patterns into the systemic circulation. Systemic complications associated with rhabdomyolysis are myocardic depression and acute kidney injury (AKI). The latter is multifactorial and may imply renal vasoconstriction, production of reactive oxygen species and polymerisation of myoglobin with Tamm-Horsfall proteins in an acidic environment triggering tubular obstruction. In a retrospective registry study performed on 8592 patients, severe rhabdomyolysis (CK > 5000 IU/L) was associated with a 4% increase in 30-day mortality in trauma patients with concurrent haemorrhagic shock, along with increased multiorgan failure and septic shock (Martinez et al. 2024). Apart from AKI (15 to 50% of patients), rhabdomyolysis patients may suffer hepatic dysfunction (25%), cardiac dysfunction, compartment syndrome and disseminated intravascular coagulation.

Trauma patients at higher risk of rhabdomyolysis are those with a large burden of injury (ISS > 16), large muscle involvement, including limb or torso crush trauma, mangled extremity, compartment syndrome, body mass index > 30kg/m^2 or vascular trauma inducing limb ischemia (Kodadek et al. 2022). As clinical signs of significant rhabdomyolysis (muscle weakness, tenderness, swelling, tea-coloured urines) are non-specific definitive diagnosis relies on biochemical assays. In these circumstances, many creatinine kinase thresholds were suggested (CK level > 5 folds the upper limit of normal or >1000 IU/L) but their association with subsequent AKI is loose. Severe rhabdomyolysis is usually defined by a peak CK level above 5000 IU/L. Myoglobin is a smaller molecule (17 kDa) with a quicker response (non-dependent on lymphatic transport and released faster in the bloodstream), a shorter half-life and a significant involvement in rhabdomyolysis-induced AKI (Bosch, Poch and Grau. 2009). In a monocenter retrospective study, Tarazona et al. described that admission myoglobin in trauma patients (with a best cutoff value of 1217 µg/L) was a better predictor of any stage AKI and stage 2 and 3 AKI (sensitivity 74%, specificity 77%) than admission CK (Tarazona et al. 2021). A scoring system was also developed by McMahon et al., considering demographic and biologic variables, to identify rhabdomyolysis patients at risk of renal replacement therapy (RRT) or death (McMahon, Zeng and Waikar. 2013). But this score is not specific for trauma-induced rhabdomyolysis. Once rhabdomyolysis is identified, prevention of AKI requires generous fluid expansion (400mL/h initially) aiming at a urine output between 1 and 3 mL/kg/h and a urine pH > 6.5 to prevent myoglobin polymerization with Tamm-Horsfall proteins. The type of fluid (either balanced solution e.g. lactated Ringer, 0.9% NaCl or 0.45% NaCl) is left to the clinician choice since potassium containing solutions may increase the risk of hyperkalaemia while 0.9% may induce hyperchloremic acidaemia. Bicarbonate and mannitol do not seem to provide supplemental benefit compared to vigorous fluid resuscitation (Somagutta et al. 2020). Loop diuretics are not recommended. The rate of fluid administration should be personalized balancing risks between insufficient resuscitation and fluid overload. Hemodynamic monitoring may be of clinical value. Hyperkalaemia and hyperphosphatemia are frequent in trauma-induced rhabdomyolysis and result from the release of intracellular stores. Hypocalcaemia results from the deposit of calcium in injured muscle cells. It may aggravate the arrhythmic effects of hyperkalaemia and, in this situation, be corrected. Otherwise, hypocalcaemia should not be corrected as it prompts the deposit of calcium-phosphate aggregates in injured muscles. When the patient remains anuric despite generous fluid resuscitation deemed adequate, renal replacement therapy should be considered, continuous or intermittent techniques deemed equally efficient. For now, there is no indication for prophylactic RRT to prevent AKI in rhabdomyolysis patients. Blood purification with a cytokine absorber may slightly decrease myoglobin blood concentrations in patients without ongoing rhabdomyolysis but was not demonstrated to decrease kidney insult or RRT duration. Some experts recommend that extracorporeal myoglobin removal by hemoadsorption may be considered in patients with myoglobin levels of > 10,000 ng/ml but the level of evidence is very low (Forni et al. 2024) and a 12-hourly adsorber exchange interval should be anticipated to cope with rapidly declining myoglobin elimination performance (Weidhase et al. 2025).

3. 1. 4. 5. Fat embolism syndrome and acute lung injury

Fat embolism syndrome (FES) is a rare event, typically described after long bone and/or pelvic fractures and intramedullary surgical procedures. Its pathophysiology involves circulation of fat droplets in the bloodstream (fat embolism) reaching distant organs and inducing serious injuries (FES). However, the exact succession of events remains partly unveiled and may imply both a mechanic (vascular obstruction by lipid droplets) and a biologic process (inflammation triggered by the release of fatty acids). Most fat embolisms remain asymptomatic: autopsy studies reveal up to 80% of fat embolism after femur fracture, intraoperative echocardiographic studies show evidence of circulating fat droplets during medullary reaming for long bone fixation while clinical FES is described in less than 5% of patients with lower limb or pelvic fractures (Kwon and Coimbra. 2024). Risk factors for FES include patient factors (male sex, age < 40), trauma factors (high energy trauma, closed fractures which increase intramedullary pressure and risks for fat embolism) and treatment factors (intramedullary reaming and delay in fracture fixation). Trauma-induced endotheliopathy may also increase the risks of fat adherence to activated endothelial surface. Manifestations typically involve concomitant respiratory failure (90%, hypoxaemia and dyspnoea, increased alveolo-arterial oxygen gradient) cutaneous manifestations (30%, skin petechial rash on non-dependent aspect of the axillae, anterior chest, neck, face, oral mucosa, and conjunctivae), altered mental status (60%, from abnormal anxiety, paroxysmal sympathetic hyperactivity syndrome to coma) and ocular abnormalities (visual field defects, exudates or conjunctival oedema). Hemodynamic compromise may also be present and linked with impaired right ventricular afterload, triggered by mechanical obstruction and hypoxic pulmonary vasoconstriction. Proposed diagnostic criteria were based on small sample sizes and lack both validation and specificity (Kwon and Coimbra. 2024). Anaemia and thrombocythemia are also frequently encountered but do not contribute to build up definitive diagnosis. Free fat globules or fat globules captured by macrophages may be found in bronchoalveolar lavage specimens. Imaging (both lung CT ground glass opacities and interlobular thickening in both lungs, “crazy paving” pattern (Figure 16) and brain magnetic resonance imaging (MRI) “starfield pattern” on diffusion-weighed imaging) sometimes reveal unspecific features (Luff and Hewson. 2021).

Prevention remains key and mainly involve adequate hemodynamic resuscitation, rapid fracture stabilization and avoidance of fractured bone mobilization. Indeed, early fixation of fractures may provide a 70% reduction of FES incidence (Robinson. 2001). Intramedullary nailing increase FES occurrence compared to external or plate fixation. Therapeutic treatment mainly remains symptomatic to cope with respiratory failure.

Figure 16: Acute fat embolism

3. 1. 4. 6. Pain

After limb trauma, prevalence of pain is high both in the prehospital setting and emergency department. In those situations, inhaled methoxyflurane may provide superior pain relief compared to standard of care (intravenous morphine 0,1mg/kg for severe pain 11-point numeric rating scale, (NRS) equal or superior to 7, ketoprofen or paracetamol for moderate pain NRS 4 to 6) in limb trauma patients and a shorter time to onset of pain relief (Mercadante et al. 2019). Intranasal ketamine may also provide effective and rapid pain relief (Nasr Isfahani, Shokoohi and Golshani. 2022). Yet, traditional intravenous analgesic medications may fail to provide effective pain alleviation. They may also mask pain from other trauma sites, delaying effective diagnosis and treatment of remote trauma injuries. High pain scores following musculoskeletal injuries were identified as a risk factor for the development of chronic pain (Edgley et al. 2019; Alkassabi et al. 2022). Effective pain relief after limb trauma is of paramount importance to avoid the development of complex regional pain syndrome whose main features (severe pain and sensory, autonomic, motor, and trophic abnormalities) may have dramatic somatic and psychologic consequences (Ferraro et al. 2024). Peripheral, ultrasound-guided nerve blocks provide significant advantages over intravenous analgesics in patients admitted to the trauma centre with severe limb trauma. They can be performed with the patient lying in the supine position avoiding uncomfortable or painful patient mobilization (Huaguo et al. 2024). In elderly patients with hip fracture, iliac fascia block provides efficient pain relief and reduce both opioid-related side effects (including delirium) and hospital length of stay (Gola et al. 2021). A recent registry reports that pain relief is efficient in more than two thirds of patients after ultrasonography-guided nerve blocks performed in the emergency department and that the complication rate is very low (10 of 2735 blocks; 0,4%) (Liu, Tovar Hirashima and Yadav. 2025; Goldsmith et al. 2024). Risks associated with masking acute compartment syndrome when providing pain relief for leg fracture with nerve blocks were previously addressed. Health care professionals should be aware of the significance of the occurrence of breakthrough pain, provide locoregional anaesthesia with low concentration drugs and monitor compartment pressures in high-risk patients. In more complex multiple trauma, optimal use of regional analgesia should be incorporated into a multi-modal analgesic therapeutic strategy in which with ketamine and clonidine may also play a role. In such situations involving large tissue attrition, the neuropathic component of persisting pain (including phantom limb pain) should not be ignored but aggressively treated with anti-neuropathic medications (pregabalin and amitriptyline introduced as soon as possible). A multidisciplinary approach should be envisioned considering the psychologic burden of major trauma aftermath (Beard and Wood. 2015).

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