(ii) Acute management of pelvic ring fractures

Marius Keel\textsuperscript{a},*, Otmar Trentz\textsuperscript{b}

\textsuperscript{a}Division of Trauma Surgery, University Hospital Zurich, Zurich, Switzerland
\textsuperscript{b}Division of Trauma Surgery, University Hospital Zurich, Raemistrasse 100, CH-8091 Zurich, Switzerland

Summary During the primary survey, patients with pelvic ring fractures undergo decision making for day 1 surgery including life-saving surgery, damage control surgery and early total care or delayed definitive surgery dependent on haemodynamic status, physiologic criteria (hypothermia, coagulopathy, acidosis), scoring of injury severity and personal or operative resources. The staged sequential procedures of 'pelvic damage control' include damage control surgery with control of haemorrhage and contamination, decompression of abdominal and pelvic compartment syndromes, debridement of soft tissue injuries as well as temporary or definitive osteosynthesis, followed by resuscitation in the intensive care unit, 'second-look' operations, scheduled definitive surgery and secondary reconstructive surgery. External fixation of the posterior pelvic ring by pelvic C-clamp and pelvic packing represent the work horses for haemorrhage control of severe pelvic ring injuries in haemodynamically unstable patients, whereas angiographic embolisation is an option for haemodynamically stable patients or persistent bleeding after or during damage control surgery.

Introduction Severe pelvic ring fractures are often associated with severe bleeding and major intraabdominal injuries.\textsuperscript{1,2} Therefore, the acute management of pelvic ring injuries is complex and demands an algorithm for deciding which patient should be operated immediately and which operative strategies should be chosen.\textsuperscript{2,3} Day 1 surgery of patients with severe pelvic ring fractures includes life-saving surgery, damage control surgery and early total care. The decision for one of these strategies or for delayed definitive surgery is made dependent on haemodynamic status, physiologic criteria (hypothermia, coagulopathy, acidosis), scoring of injury severity and personal or operative resources.\textsuperscript{4} The term 'damage control' was popularised by Rotondo in 1993 for the successful treatment of penetrating abdominal injuries.\textsuperscript{5} This strategy has become the gold standard of care for abdominal trauma of severely injured patients and was defined as rapid abbreviated laparotomy to stop haemorrhage and peritoneal soiling and staged sequential repair after ongoing resuscitation and recovery from the lethal triad of hypothermia,
Acidosis and coagulopathy. Based on the damage control concept for abdominal injuries, the application of the same principles to the management of multiply injured patients with associated fractures of the long bones and pelvic ring fractures was named ‘damage control orthopaedics’ (DCO). The philosophy of ‘pelvic damage control’ is to abbreviate surgical interventions by deferring repair of anatomical lesions before the development of irreversible physiologic endpoints according to the classical staged laparotomy. This operative concept reduces the mortality rate and the incidence of posttraumatic complications in patients with severe pelvic ring fractures. The aim of this review article is to summarise the principles and steps of the acute management of severely injured patients with pelvic ring fractures.

Initial management and decision making for day 1 surgery

According to the Advanced Trauma Life Support (ATLS) principles, severely injured patients with pelvic ring fractures undergo the primary survey of airway (A), breathing (B), circulation (C), neurologic status (D; disability) and core temperature (E; environment) (Fig. 1). Pelvic stability is tested by manual compression in anterior–posterior and lateral–medial directions.

Patients with severe trauma who are unconscious (Glasgow Coma Scale (GCS) < 9 points) or in shock benefit from immediate endotracheal intubation and oxygenation. Simultaneous with airway management, a quick assessment of the patient will determine the degree of shock present. A patient with a systolic blood pressure < 90 mmHg, a thready pulse and flat neck veins is assumed to have hypovolaemic shock. If the patient’s primary problem in shock is blood loss, the intention is to stop the bleeding and replace the volume deficit. Obvious blood loss such as external bleedings and occult blood loss e.g. into the abdomen or retroperitoneum should be immediately detected clinically or by basic imaging which includes chest, pelvis and lateral cervical spine radiographs. In addition, focused assessment for sonographic examination of the trauma patient (FAST) has become a standard procedure in the primary survey. Free abdominal fluid is a strong indicator for intraperitoneal lesions in addition to profuse retroperitoneal bleedings in patients with severe pelvic injuries.

As soon as possible blood work is obtained that includes arterial blood gas analysis, haematocrit, prothrombin time, partial thromboplastin time and arterial blood gas analysis.

Figure 1 Algorithm of the acute management and treatment of patients with pelvic ring fractures. See text for details and explanations.
haemoglobin, lactate level, base deficit, pH, blood type and cross-match, and a screening battery of other laboratory tests including coagulation parameters. The fluid used to resuscitate and the further workup will depend on the patient’s response to initial fluid load (2 l prewarmed crystalloids), the laboratory and further clinical analyses.11

The ‘responder’ may require no more than crystalloids to replace the volume deficit and progress to the secondary survey, which focuses on a complete physical head to toe examination that directs further diagnostic studies (extended imaging) such as CT scan trauma protocol and extremity radiographs (Fig. 1).4 The ‘transient responder’ may need typed and cross-matched blood. The application of platelets, fresh frozen plasma (FFP) or fibrinogen is well established in patients with unstable pelvic fractures, whereas the treatment of coagulopathy with recombinant activated factor VII (rFVIIa) is undergoing trials. Patients with a ‘transient response’ to resuscitation with a hypotension (<90 mmHg) in excess of 70 min or a transfusion rate of 10–15 units of packed red blood cells should be transferred to the operating room without delay and undergone damage control procedures.4

Furthermore, attempts have been made for ‘responders’ to define physiologic criteria for the initiation of damage control based on hypothermia (<34 °C), coagulopathy (prothrombin time >19 s or partial thromboplastin time >60 s; platelet count <90,000) and acidosis (pH <7.2 or lactate serum level >5 mmol/l), called the lethal triad.7,9 Then the failure to normalise an abnormal serum lactate level by 48 h after trauma has been correlated with mortalities ranging from 86% to 100%.4 Further cited indications especially for DCO concern type and severity of injury: injury severity score (ISS) >35 points; severe head injury, the abbreviated injury scale (AIS) >2 points; multiple injuries with an ISS >20 points and additional thoracic trauma AIS >2 points; multiple injuries with abdominal/pelvic trauma and haemorrhagic shock; severe soft tissue injuries, radiographic evidence of bilateral pulmonary contusion as well as type of surgery (presumed operation time >60 min and expecting major blood loss).9 These first-hit (trauma load) and second-hit (interventional load) phenomena predispose these patients ‘at risk’ or ‘borderline’ for the development of severe systemic inflammation (host defense response) after surgery with a high incidence of local infections, sepsis, multiple-organ dysfunctions and high mortality rate.4,6 They justify the decision for damage control of pelvic ring injuries instead of early total care or delayed definitive surgery (Fig. 1).

Fluid replacement in patients with severe haemorrhagic shock and no response to the initial fluid replacement ‘in extremis’ is controversially discussed.4 It is suggested that immediate massive volume replacement before surgical control of bleeding might disrupt a blood clot that had obliterated a bleeding vessel. Therefore patients with unstable pelvic ring fractures and persistent severe haemorrhagic shock should undergo lifesaving procedures. In addition, the patient ‘in extremis’ may need type O blood and clotting factors.

**Life-saving surgery**

The left anterolateral ‘crash’ thoracotomy (emergency room thoracotomy (ERT)) or sternotomy with thoracic aortic cross-clamping and open cardiopulmonary resuscitation as a life-saving intervention represents a controversial indication for patients with unstable pelvic ring injuries and severe haemorrhagic shock who arrive in trauma centres after a short scene/transport time with witnessed and/or objectively measured vital parameters (patients ‘in extremis’) (Fig. 1).2,4 In addition, this access allows cannulation of the right atrium with a catheter for massive resuscitation. However, ERT or sternotomy should be performed selectively due to its very low survival rate in patients sustaining cardiopulmonary arrest secondary to blunt trauma (1.5%). Furthermore, for patients with pelvic ring injuries and exsanguinating abdominal or retroperitoneal haemorrhage without response to fluids ‘crash’ laparotomy can be life saving. To control haemorrhage, blood and clot are removed digitally and by suction. Thereafter, lateral retraction of the abdominal wall is performed to enable four-quadrant packing. The abdominal aorta is controlled digitally at the aortic hiatus or by placement of an aortic infradiaphragmatic cross-clamp. After successful resuscitation, life-saving procedures for patients ‘in extremis’ with unstable pelvic ring injuries should be completed with closed reduction and stabilisation of the posterior pelvic ring by the pelvic C-clamp.3

**Damage control surgery**

If patients ‘in extremis’ survive life-saving procedures or after decision making for damage control as ‘preemptive intervention’ on the basis of clinical and laboratory findings, patients with severe pelvic fractures should undergo damage control surgery
immediately. The concept of 'pelvic damage control' includes stepwise control of haemorrhage and contamination, decompression of abdominal or pelvic compartment syndromes, débridement of soft tissue injuries and finally the temporary or definitive pelvic ring osteosynthesis.

Figure 2 (a) Plain film of the pelvis of a haemodynamically unstable young lady after a rollover injury showing a vertical shear injury with a transfemoral sacral fracture on the left side and bilateral rami fractures combined with an open anterior hip dislocation on the right side. (b) Preoperative state of anteriorly dislocated femoral head. (c) Intraoperative status after closed reduction of posterior pelvic ring and placement of pelvic C-clamp, laparotomy with pelvic packing, reduction and débridement of open hip dislocation, placement of supraacetabular pins for anterior external fixator and installation of catheters for the measurement of bladder pressure to monitor the intraabdominal pressure. (d) Postoperative plain film of the pelvis with the placed pelvic C-clamp, supraacetabular external fixator and pelvic packing. (e) Plain film of the pelvis after posterior local plating of sacral fracture and lumbo-iliac distraction osteosynthesis at the end of the first week after injury. (f) Plain film of the pelvic 1 year after injury with formation of ectopic ossification.
Control of haemorrhage

Pelvic C-clamp and external fixator
The immediate recognition of haemorrhagic shock and effective control of the bleeding play a pivotal role for the survival and posttraumatic course of patients with severe pelvic ring injuries. However, the treatment of exsanguinating haemorrhage after pelvic ring fractures is controversial.2–4,10,13,14 Though acute closed reduction and external stabilisation of the disrupted pelvis is well accepted, which technique and device used still give rise to debate. According to prehospital experience, the use of a pelvic binder or belt is established in different trauma centres as temporary external stabilisers.1,13 The pelvic C-clamp as a posterior device for vertical shear injuries (C-type fractures) is mechanically superior to these non-invasive external fixation systems or anterior external fixator (Fig. 2).2,3,15 However, the application of the C-clamp can be complicated by vascular injuries, nerve injuries through overcompression in sacral fractures, perforation of pelvic organs, displacement of the unstable hemipelvis into the true pelvis, loss of reduction, loosening of the pins, and pin tract infections. To avoid the displacement of the hemipelvis, an additional anterior supraacetabular external fixator should be applied in very unstable fractures (Fig. 2). In addition, the pelvic C-clamp is not applicable in fractures of the iliac bone and most trans-iliac fracture dislocations.15

Pelvic packing
The reduction and stabilisation of the posterior pelvic ring mostly does not result in complete spontaneous haemostasis ‘self-tamponade’ of retroperitoneal bleeding by decreasing pelvic volume and fracture haemorrhage.3,10 Then severe pelvic ring injuries lead to damage of the constraining ligaments of the pelvic ring, the pelvic floor and the iliopectineal fascia. Moreover, the retroperitoneal space is not separated cranially by constraining compartments. Thus, the retroperitoneal haematoma can drain into the abdomen or into the chest along the psoas muscle (called chimney effect) with a circulatory decompensation and a fatal outcome. Therefore, in patients with persistent haemorrhagic shock after external stabilisation of the pelvic ring, laparotomy and pelvic packing are recommended to control retroperitoneal presacral and the paravesical venous bleeding.2,3,10 The rare arterial haemorrhage (10–20%) in an unstable pelvic fracture can also be successfully treated by pelvic packing. Furthermore, the high incidence of associated intraperitoneal lesions (31%) in patients with severe pelvic fractures emphasizes the rationale for laparotomy and pelvic packing (Fig. 3).1

Direct surgical haemostasis
Severe pelvic fractures have often associated intraabdominal solid organ injuries such as liver (10%) or spleen (6%) and rarely bleeding from large-bore vessels.1 After initial four-quadrant packing and pelvic packing for severe pelvic injuries, temporary infradiaphragmatic aortic occlusion or balloon catheter tamponade may be necessary for completion of haemorrhage control. Intraabdominal or pelvic vascular injuries can be managed by simple lateral repair whereas end-to-end anastomosis or graft interposition is time consuming. As a damage control procedure the internal iliac artery can be ligated. However, ligation of the aorta, vena cava, common or external iliac artery or veins often precipitates significant ischaemia with a high mortality and should be reserved only for desperate situations. An alternative to ligation may be the rapid placement of temporary arterial or venous shunts to preserve the leg.16

Blood loss through vascular injuries in open fractures or traumatic haemipelvectomy should be stopped by manual compression followed by tamponade, clamping and ligation (Fig. 4). Techniques to control liver bleeding during damage control include perihepatic packing after Pringle manoeuvre, direct ligation of bleeding vessels, hepatorrhaphy, cauterisation, topical haemostatic agents, partial resection or hepatic artery

Figure 3 (a) Plain film of the pelvis of a haemodynamically unstable boy after a rollover injury with a sacroiliac dislocation on the right side, a sacroiliac fracture dislocation on the left side, symphysis dislocation and rami fractures of the left side and associated injuries of the external iliac artery, rectum, bladder and ureter as well as a Morel-Lavalle lesion. (b) Postoperative plain film of the pelvis after anterior iliosacral and symphysis cerclages and pelvic packing. (c) Intraoperative status of the open abdomen with a zipper after laparotomy with packing, colostomy, and repair of left ureter, iliac vascular repair and fasciotomy of the leg. (d) Open abdomen with abdominal V.A.C.® and colostomy after second look. (e) Second look with débridement of the Morel-Lavalle lesion and status after decompressive fasciotomy of the leg. (f) Plain film of the pelvis after disarticulation of the left hip because of ischemia-reperfusion damage with muscle and skin necrosis of the left leg. (g) Plain film of the pelvis after surgical hemipelvectomy 8 weeks after injury. (h) Situs 9 months after injury with healed abdominal wall and colostomy.
Splenic injuries require mostly an immediate splenectomy, whereas splenorrhaphy or partial resection should be reserved for haemodynamically stable patients. In the presence of diffuse retroperitoneal bleeding renal injury should be excluded by exploration. Severe renal injury in the exsanguinating patient is best dealt with by nephrectomy if a contralateral kidney is palpable, alternatively retroperitoneal packing is carried out primarily.

Transcatheter arterial embolisation
Transcatheter arterial embolisation to control haemorrhage in patients with severe pelvic ring fractures is recommended in some trauma centres. However, several dangerous complications and a mortality up to 50% are reported. In addition, the technique is time consuming and simultaneous treatment of associated injuries is inhibited. Data from different studies describing patients undergoing pelvic packing, respectively,
and embolisation are not comparable. Studies with patients who underwent crash or emergency laparotomy and pelvic packing always represent patients 'in extremis' or 'transient responders', whereas patients with embolisation are haemodynamically more stable.\textsuperscript{2,3,10,13,14,17} However, angiographic arterial embolisation can be helpful in patients with ongoing haemorrhage after damage control laparotomy and pelvic packing or repacking at the first 'second-look' operation or in those patients who can be haemodynamically stabilised with volume replacement. This technique is not only practicable in angiographic interventional facilities but also intraoperatively e.g. to embolise selectively the superior gluteal artery in patients with severe pelvic ring fractures (Fig. 5).

Figure 5 (a) Plain film of the pelvis of a haemodynamically unstable patient after a fall from a great height with an open iliac wing fracture. (b) Intraoperative status after packing and débridement of the open fracture. (c) Intraoperative angiography and transcatheter embolisation of the active bleeding of superior gluteal artery. (d) Plain film of the pelvis 8 months after injury and several second-look operations with aggressive débridement showing extended ectopic ossification.

Control of contamination

Severe pelvic fractures are also accompanied by hollow viscus injuries, small bowel in 9% and colon or rectum in 4%.\textsuperscript{1} These injuries must be controlled with clamps, staples, suturing, or resection without anastomosis.\textsuperscript{4,7,8} Very seldom injuries of the pancreas in patients with pelvic fractures (0.4%) should be primarily managed by drains and packing.\textsuperscript{1,4,7,8} Urethra and bladder injuries of patients with severe pelvic fractures are common (15%) and are managed temporarily with suprapubic catheter drainage and/or repair.\textsuperscript{1,4,7,8} After control of haemorrhage, contamination and definitive packing a decision for rapid skin closure (Fig. 2) or primary installation of a zipper (Fig. 3) must be made according to the physiologic parameters.
Decompression of compartment syndromes

The disruption of the retroperitoneal muscle compartments after severe pelvic ring injuries can lead to uncontrolled haemorrhage especially from on-going coagulopathy with the risk of abdominal compartment syndrome (ACS) or pelvic compartment syndrome. In addition, following crystalloid resuscitation and prolonged laparotomy progressive and sustained oedema and distension of the bowel in combination with the insertion of abdominal packs increases the volume and may lead to an increase in the intraabdominal pressure (IAP) following the closure of the abdominal fascia. The indication for abdominal decompression in situations without primary laparotomy or after closure of the damage control laparotomy depends on the renal, respiratory and cardiac dysfunctions to raised IAP, measured by the bladder pressure (Fig. 2). The development of oliguria/anuria, high airway pressures, inadequate oxygenation or a bladder pressure of $>$25 mmHg are indications for decompression of the abdomen. As prevention of ACS the abdomen should be not closed after life saving or damage control laparotomies. The abdomen can be closed temporarily with a zipper (Fig. 3). Following stabilisation of coagulation the vacuum-assisted closure (V.A.C.) technique (Fig. 3) is recommended because it facilitates the subsequent definitive abdominal wall closure (Fig. 3).

The risk for pelvic compartment syndromes such as iliopsoas, gluteus maximus or gluteus medius are very low after pelvic ring injuries because of the trauma-induced decompression of the fascia through the dislocated iliac wing fractures. However, severe contusions, haematoma or distended skin on the lateral side or the buttock area after closed pelvic ring fractures are suspicious for the development of a pelvic compartment syndrome. If in doubt, surgical decompression of these muscle compartments is mandatory to prevent muscle necrosis with crush syndrome, skin necrosis and secondary infections (Fig. 3). In addition, pre-emptive decompression of the muscle compartments of the leg should be done in patients with pelvic ring fractures and associated iliac or femoral vascular injuries (Fig. 3). The incision should be chosen according to the approaches for the acute or definitive osteosynthesis. The soft tissue defects can be closed temporarily by textile tamponades or synthetic skin substitute (Epigard) and in patients with a compensated coagulation system by V.A.C. dressings. Secondary wound closure or skin grafting should be done after second-look operations and the certainty that the extremity will survive. However, extended muscle necrosis especially after vascular injuries is complicated by crush syndrome and septic posttraumatic courses with multiple-organ failure. Disarticulation in the hip or surgical hemipelvectomy can represent the final life-saving solution (limb for life!) (Fig. 3). The decision for these mutilating procedures should be made during the second-look operations to avoid exacerbating the posttraumatic course.

Débridement of soft tissue injuries

Extended soft tissue injuries of the pelvis were described by Morel–Lavallé. These pelvic décollements result from crush and shearing mechanisms and are characterised by a degloving of the subcutaneous fat from the pelvic fascia (Fig. 3). An aggressive débridement with resection of avital soft tissue reduces local septic complications. In the same manner open pelvic fractures should be managed with an complete resection of necrotic tissues and extended irrigation to minimise the risk of infections (Fig. 5). In situations with diffuse persistent bleeding after débridement, textile tamponades can be placed temporarily (Fig. 5), otherwise V.A.C. can be applied.

Temporary or definitive pelvic ring osteosynthesis

The damage control concept for pelvic ring injuries does not exclusively include pelvic C-clamp or external fixators for the stabilisation of the pelvic ring. For iliac fractures or transiliac fracture dislocations as well as symphyses disruptions, primary open reduction, mostly through the transabdominal approach, and internal fixation of the iliac wing, iliosacral joint or the symphysis with plates or screws and cerclages (Fig. 3) represent a perfect method as abutment for pelvic packing to control the haemorrhage. In addition, internal fixation has shown a superior stability in comparison with external fixation in several biomechanical studies. However, open reduction and internal fixation is time-consuming and imprecise reduction of the iliosacral joint or the symphysis can render the definitive reduction and osteosynthesis of associated posterior pelvic ring injuries, especially sacral fractures and acetabular fractures, more difficult.
The concept of damage control can be described as staged sequential procedures. Following the abbreviated damage control surgery the patient is moved to the intensive care unit (ICU), where ongoing core rewarming, correction of coagulopathy, fluid resuscitation and optimisation of haemodynamic status with correction of the acidosis and reexamination of the patient ‘tertiary survey’ to diagnose missed injuries are carried out. Endpoints include a core temperature $\geq 35^\circ$C, normalisation of the prothrombin time, and a systemic lactate level $\leq 2.5$ mmol/L within 12 h. Additionally, an array of supportive therapies or diagnostic tools (measurement of bladder pressure) are established to avoid secondary hits such as septic complications, ischaemia-reperfusion injuries, ACS and organ damage. When normal physiology has been restored, ‘second-look’ operations with removal of pelvic or abdominal packing, reconstruction of the digestive tract, colostomy formation can be undertaken usually within 24–72 h after trauma (Fig. 1). Recurrent or persistent bleeding (more than 10 units of packed red blood cells in the early postoperative period) will necessitate immediate repacking or angiographic embolisation.

Concerning definitive pelvic or other fracture fixations there is a ‘window of opportunity’ between days 4 and 10 after trauma (scheduled definitive surgery). Secondary reconstructive surgery after severe pelvic injuries includes abdominal wall reconstruction, anastomosis after colostomy or secondary hip prosthesis and is recommended after recovering from the status of immunosuppression, respectively, from the catabolic metabolism ($\geq 4$ weeks) (Fig. 1).

**Early total care or delayed definitive surgery**

During early total care of pelvic ring fractures such as plating of the symphysis in cases with isolated symphysis dislocation, intraoperative problems can arise or unexpected associated injuries are found. In addition, inability to achieve haemostasis due to coagulopathy, inaccessible major venous injury, time-consuming procedures in a patient with suboptimal response to resuscitation, reassessment of intraabdominal contents and inability to reapproximate abdominal fascia due to visceral oedema are reasons for turning to the damage control concept as a ‘bail-out’ procedure. Furthermore, ancillary issues indicating benefits of damage control or of delayed definitive surgery in haemodynamically stable patients (Fig. 6) with pelvic ring fractures are limited resources, limited experience of the surgical team in complex injuries, or a fatigued and overwhelmed surgical team (Fig. 1). However, selecting damage control too carelessly may mean an unnecessarily premature termination of surgery in patients who would otherwise have recovered from a single definitive procedure.
References


