Standard Review Article

Pelvic ring injuries: recent advances in diagnosis and treatment

Victor A. de Ridder, MD, PhD, MBA, FRCS[a,*], Paul S. Whiting, MD[b], Zsolt J. Balogh, MD, PhD, FRACS, FACS[c], Hassan R. Mir, MD, MBA[d], Blake J. Schultz, MD[e], Milton "Chip" Routt, MD[e]

Summary: Pelvic ring injuries typically occur from high-energy trauma and are often associated with multisystem injuries. Prompt diagnosis of pelvic ring injuries is essential, and timely initial management is critical in the early resuscitation of polytraumatized patients. Definitive management of pelvic ring injuries continues to be a topic of much debate in the trauma community. Recent studies continue to inform our understanding of static and dynamic pelvic ring stability. Furthermore, literature investigating radiographic and clinical outcomes after nonoperative and operative management will help guide trauma surgeons select the most appropriate treatment of patients with these injuries.

Keywords: pelvis, acetabulum, pelvic ring

1. Introduction

This article represents a summary of the pelvic ring symposium presented during the International Trauma Care Forum at the 2021 OTA/AO Annual Meeting. Entitled "Pelvic Ring Injuries: Recent Advances in Diagnosis and Treatment," this article covers 3 topics relevant to the diagnosis and treatment of pelvic ring injuries. First, strategies for initial management will be discussed with an emphasis on hemorrhage control. This will be followed by a discussion of pelvic ring stability, including a review of current literature exploring the topics of static and dynamic stability. Finally, we will discuss how to select appropriate approaches and fixation strategies for definitive management of various pelvic ring injury patterns.

2. High-Energy Injuries: Stopping the Bleeding

2.1. Introduction

Pelvic ring injury (PRI)-associated mortality is dominated by acute exsanguination, postinjury multiple organ failure, and venous thromboembolism. These seemingly diverse pathologies are all closely related to major blood loss.[1] The link is obvious for acute exsanguination, but it is less well-known that the severity of traumatic shock, characterized by metabolic acidosis and transfusion requirements, is a strong independent predictor of multiple organ failure and fatal venous thromboembolism. In developed trauma systems, the potentially preventable mortality rate is very low, but it is frequently due to PRI-associated bleeding. Without an organized institutional approach, the mortality of hemodynamically unstable pelvic ring injuries is more than 30%.[2] However, protocol-driven management can minimize the mortality rates to less than 10% in this challenging group of polytrauma patients. These facts highlight the importance of a focused, expeditious approach to hemorrhage control in PRIs.[3]

Historically, owing to delayed surgical closure of the pelvic ring and an approach to fluid resuscitation of the hemodynamically unstable patient that was based on a goal of normalizing blood pressure, venous and cancellous bone capillary bleeding was a major problem. Currently, with the consistent application of prehospital pelvic binders that reduce pelvic volume and blood- and clotting factor-based resuscitation strategies that target hemostasis rather than achieving normal blood pressure, venous and bony capillary bleeding does not lead to exsanguination in closed PRIs. A recent observational study concluded that all hemodynamically unstable patients with pelvic ring injuries have arterial bleeding from the tributaries of the iliac arteries, as identified on contrast-enhanced computerized tomography, on digital subtraction angiography, or during surgery.[4] The incidence of closed PRI-associated arterial bleeding is approximately 1–2 cases per 100,000 population per year.[5] These injuries are frequently associated with polytrauma, where other potentially life-threatening injuries and other sources of bleeding need to be considered. When polytrauma patients are hemodynamically compromised and have a PRI, in 60% of the cases the pelvis is the main source of blood loss. Oftentimes, these patients are not hypotensive below 90 mm Hg systolic blood pressure, but they almost always demonstrate significant metabolic acidosis (defined as a base deficit worse than −5 mMol/L) and require blood transfusion. Up to 35% of these patients have associated abdominal injuries, but less than 10% have simultaneous life-

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[a] Trauma and Pediatric Trauma, University of Utrecht, The Netherlands, [b] Department of Orthopedics and Rehabilitation, University of Wisconsin Hospital and Clinics, Madison, WI, [c] Department of Traumatology, John Hunter Hospital and University of Newcastle, Newcastle, New South Wales, Australia, [d] Director of Orthopedic Trauma Research, Florida Orthopedic Institute, Tampa FL; and, [e] University of Texas Health Science Center at Houston, Houston TX.

* Corresponding author. Address: Victor A. de Ridder, MD, PhD, MBA, FRCS, Nieuwe Uitleg 7C, 2514 BP Den Haag, Netherlands. E-mail: vicrid@mac.com

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threatening bleeding in the peritoneal cavity, which is of higher priority than the PRI-associated hemorrhage.[5]

A complete discussion of the initial management of the hemodynamically unstable patient with a pelvic ring injury is beyond the scope of this article, but in short, it assumes that hemostatic resuscitation with early clotting factor replacement, identification of other sources of bleeding, focused assessment with sonography for trauma (FAST), chest and pelvic radiographs, and point-of-care blood testing within 10 minutes of arrival.[6] PRI-associated arterial bleeding can be predicted with high accuracy if the patient has a pelvic fracture, negative FAST, no obvious other sources of bleeding, and significant metabolic acidosis and if the treating clinicians consider the initiation of transfusion.[4]

Several methods and adjuncts are available for hemorrhage control in PRI patients, which will be detailed below. Many of these methods are used simultaneously or in an overlapping fashion with considerable interinstitutional variability in preference and sequencing. Pelvic binders are a component of prehospital care, but if not present on arrival, they should be applied in the emergency department. Their main role is similar to limb splinting; they provide the necessary tissue stability for clot formation by close apposition of the corresponding anatomical structures. For application, it is important to keep the medial malleoli at the same level, to bring the knees together with internally rotated hips, and to tighten the binder at the level of the greater trochanters. In principle, the femora are used as levers to reduce the pelvic ring and the binder is tightened to maintain reduction of the pelvis. Although the reduction of most PRIs radiographically improves with binder application, lateral compression (LC) injuries can demonstrate worsening displacement, but no specific harm has been documented with this practice.[7] Binders can be kept on until hemorrhage control is achieved. Prolonged use of pelvic binders may lead to skin breakdown, and in cases where prolonged binder use is needed, and frequent skin checks should be performed.

2.2. Embolization

Angioembolization (AE) is the gold standard for controlling pelvic arterial bleeding. This intervention is minimally invasive, targeted, definitive, and highly effective. Institutions need to develop performance indicators to have AE available as fast as operative hemorrhage control could happen during emergency trauma laparotomy.[8] Ideally, AE should take place in a hybrid operating room, which eliminates the decision about the specific procedural location (ie, operating room or angiography suite) to which the patient should be transported.[9] Selective embolization is preferred if time allows, and valuable time can be saved by temporary balloon control for parts of the internal iliac vasculature until selective embolization can be achieved.

2.3. Pelvic Packing

Preperitoneal pelvic packing (PPPP) has been practiced in Europe for decades and has recently gained popularity in North America.[10] This technique was developed to address catastrophic venous bleeding and was popularized before modern hemostatic resuscitation efforts were established. PPPP can be effective temporarily against arterial bleeding, but the packing pressure must exceed 100 mm Hg, and this can be detrimental to perfusion of intrapelvic organs and muscles. Pelvic packing is fast, but the rates of infection and other complications are high. Furthermore, this technique requires a minimum degree of skeletal stability, which provides a foundation to pack against. Up to 30% of PPPP patients also require AE after the index procedure, which highlights the importance of controlling arterial bleeding. Although time to PPPP is reportedly shorter than AE, the combined time to PPPP + AE should be reported as representative of the time to definitive hemorrhage control. Recent systematic reviews and meta-analyses revealed that PPPP and AE studies cannot be compared because of nonstandardized reporting and differences in chronology and study populations.[11] Recent reports from institutions previously favoring PPPP revealed the diminished role of this hemorrhage control modality since the introduction of hemostatic resuscitation.[12]

2.4. Resuscitative Reduction Strategies

The role of external fixation and C-clamp application in acute lifesaving hemorrhage control has been recently re-evaluated and emphasized less and less. The pelvic binder provides enough stability until AE of the arterial bleeders can be accomplished. After that, internal fixation is preferred at the earliest feasible and safe time frame. External fixation can be applied to the pelvis (depending on the fracture pattern) if the patient is taken to the operating room for other reasons and definitive surgery will be beyond 24–48 hours or if the PRI will be best managed by this modality definitively. C-clamp is a powerful device for posterior pelvic ring stabilization, but malpositioning and migration of the pins is a real concern.[13] Pelvic C-clamp application also compromises the aseptic insertion of percutaneous definitive internal fixation and prevents rolling the patient side to side during critical care nursing.

Early (<48 hours) definitive internal fixation of PRIs has recently been proven to be an effective and safe approach to minimize postinjury complications and accelerate recovery. Many PRIs are amenable for minimally invasive acute (<6 hours) definitive internal fixation even in the state of traumatic shock with simultaneous hemostatic resuscitation and rewarming.[14] If the fracture pattern requires large open approaches or prone positioning, it should be postponed until the coagulopathy is controlled and resuscitative efforts are completed. This can usually be achieved around the 24–36-hour mark at the latest.

2.5. Alternative Techniques

Resuscitative endovascular balloon occlusion of the aorta is an approach to manage life-threatening pelvic bleeding, which has received recent enthusiasm.[15] The current case reports and retrospective series are unable to show convincingly the superiority of this technique over rapid AE, but the utility of early insertion of a low-profile "on-demand" balloon catheter just above the aortic bifurcation (the access for which can be also used for AE or selective balloon tamponade) is certainly promising. Theoretically, partial occlusion of the caudal aorta also can limit hemorrhage, facilitate clot formation, and lessen the chances of severe reperfusion injury. Obviously, in the extreme situations in which resuscitative endovascular balloon occlusion of the aorta is used, there are also frequent complications at the site of the vascular access and distally on the lower extremity, which may require vascular repair, fasciotomy, or even amputation.

2.6. Summary and Recommended Strategy

There is considerable variability in the presentation and management priorities of the PRI patients with hemodynamic instability, but in an ideal scenario, a patient should arrive with a properly placed pelvic binder with blood and clotting factor-based resuscitation en route. On arrival to the emergency department, the patient should undergo rapid assessment for other sources of bleeding in the resuscitation bay. If pelvic arterial bleeding is suspected, the patient should be brought to a hybrid procedure suite expeditiously, with ongoing resuscitation. There, AE, pelvic external fixation, or minimally invasive definitive internal fixation can be accomplished. These interventions would allow the patient to sit up and recover within hours after the initial injury.

3. Which Pelvic Ring Injuries are Unstable?

3.1. Introduction

All currently used pelvic ring injury classification systems rely on static imaging, be it plain radiographs or computerized tomography (Fig. 1).[16–19] The increased use of prehospital and emergency department binders has improved outcomes,[20] but pelvic binders can mask the true extent of displacement at the time of injury.[21,22] In a cadaveric study, Gardner et al[23] showed that anteroposterior compression (APC) injuries recoil by up to 48% and LC fractures recoil by up to 80%.

Current indications for the surgical stabilization of pelvic ring injuries include pain and instability. Stabilization of sacral fractures provides early pain relief, although it is unclear whether this is to a clinically relevant level in heterogeneous studies.[24] Olson defined pelvic stability as that which could withstand the physiologic forces incurred with protected weight-bearing and/or bed-to-chair mobilization, without abnormal deformation of the pelvis, until bony union or soft-tissue healing could occur.[25] Pelvic instability in C-type fractures is readily appreciated. However, there is little consensus regarding the definition of pelvic ring stability in B-type fractures.

3.2. Anteroposterior Compression Injuries

APC pelvic injuries are classified from 1 to 3, with each designation representing increasing instability. Tile described these patterns through cadaveric video studies. Symphysis disruption >2.5 cm indicated disruption of the pelvic floor and anterior sacroiliac ligaments.[26] Doro et al confirmed the threshold of 2.5 cm in male specimens but reported a 1.8-cm threshold in female specimens. They reported that anterior sacroiliac disruption is unlikely with <1.8 cm of diastasis and likely with >4.5 cm.[27] Gary et al[28] performed MRI imaging and found that, contrary to the Young-Burgess classification system, patients with APC-2 injuries had damage to the sacrospinous ligament in only 50% of cases.

It is important to be able to differentiate which APC-1 injuries are in fact occult APC-2 injuries and which APC-2 injuries have attenuated posterior sacroiliac ligaments and multiplanar instability. Sagi et al described a 15-view examination under anesthetic (EUA) for diagnosing occult pelvic ring injury. The EUA consists of static resting films, internal and external rotation stress films, and push-pull maneuvers of both lower extremities. These are each performed in the AP, inlet, and outlet projections. They found that 50% of injuries presumed to be APC-1 injuries had >2.5 cm of horizontal rotation and underwent fixation and 40% of APC-2 injuries were found to have multiplanar instability (>2.5 cm horizontal and >1 cm vertical) and underwent supplemental posterior pelvic fixation.[29] These findings may explain why posterior fixation of APC-2 pelvic ring injuries decreases rates of anterior plate failure and malunion.[30] Avilucea et al found a 40% failure rate of anterior-only fixation versus only 5% in those fixed posteriorly also. Suzuki et al[31] performed stress examinations on presumed APC-1 injuries and found that 27% were in fact occult APC-2 injuries.

EUA helps to dynamically assess APC injuries and guide treatment. The author's protocol is to stress all APC injuries. Stability is defined as <2.5 cm of horizontal displacement and <1 cm of vertical displacement under stress. If stable on EUA, these injuries are treated nonoperatively and allowed to weight-bear as tolerated (WBAT). Whiting et al[32] showed that a negative stress examination under anesthesia reliably predicts pelvic ring union without displacement with immediate WBAT. If unstable on EUA, they receive both anterior and posterior fixations, with protected weight-bearing on the posteriorly injured side for 12 weeks.

3.3. Lateral Compression Injuries

Lateral compression injuries are classified from 1 to 3 with each designation representing increasing instability. The LC-1 fracture

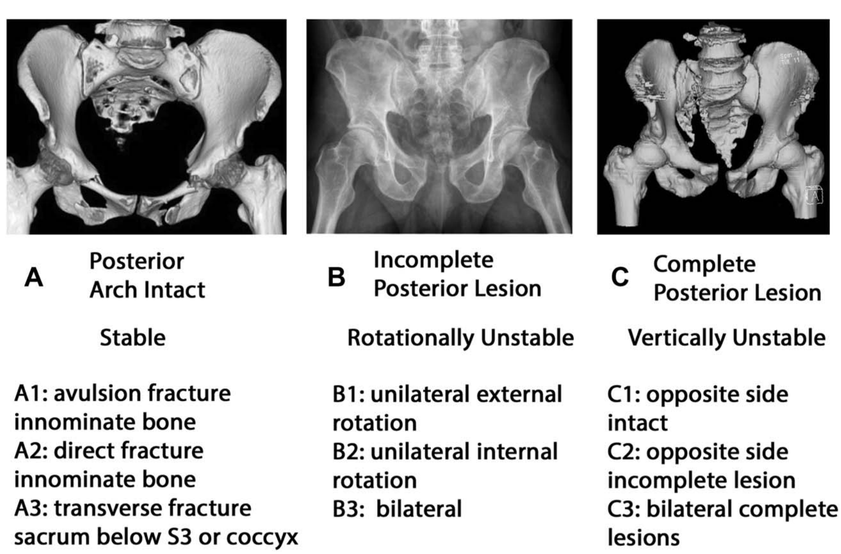

Figure 1. Tile—AO/OTA pelvic fracture classification.

was historically believed to be stable vertically, and <1.5 cm of shortening was deemed acceptable. It has been challenging for surgeons to predict which nonoperatively managed LC fractures will result in symptomatic malunion based on static imaging. Bruce et al[33] showed that the presence of a complete sacral fracture with ramus fractures was a strong predictor of future displacement.

In the retrospective review by Soles et al, 118 patients with <10 mm of sacral displacement were treated nonoperatively with only one "failure."[34] Vallier et al[35] reviewed 333 unilateral sacral fractures treated at 16 different trauma centers. Most patients who were treated operatively had >5 mm of sacral displacement, and Zone 2 fractures were more commonly fixed. A key finding from these studies is that many radiographically similar fractures received both operative and nonoperative managements based on the treating surgeon's preference on static images. This is further evidence for the potential value of dynamic assessment of pelvic stability to aid in treatment decisions. Centers not using dynamic assessment seem to have inconsistent indications for the necessity and type of pelvic fixation. Adding dynamic assessment to the repertoire can help guide treatment strategies.[36]

Sagi et al applied the 15-view EUA to LC fractures. LC-1 fractures with <1 cm of overlap were deemed to be stable. 1–2 cm of overlap received anterior fixation only, and >2 cm of overlap received anterior and posterior fixation. Thirty-five percent of LC-1 fractures were found to be unstable on EUA. 63% of LC-2 fractures were found to be unstable. Whiting et al[32] found that a negative stress examination reliably (negative predictive value of 100%) predicts pelvic union without displacement with immediate weight-bearing. A 2014 survey of 111 OTA/AO members found only a fair agreement rate (K = 0.39) in decisions to operate on static images of LC-1 pelvic fractures.[37] Another survey in 2020 by Carney et al[38] included EUA findings, and 80% of surgeons now agreed on what constituted a stable or unstable injury pattern requiring fixation.

The counter arguments to EUA include that the thresholds were set by a single expert surgeon, that the forces applied between surgeons vary, and that there is currently no evidence that fixation of fractures deemed to be unstable on EUA is associated with improved patient outcomes.[39] Other potential disadvantages of EUA include the requirement of sedation, operating room and surgeon utilization, and radiographic exposure. A proposed solution is the use of lateral decubitus stress radiographs without sedation.[40] Parry et al reported a 100% correlation with EUA and good patient tolerance. However, lateral radiographic images are of poor quality, and there are no reports on late displacement for those treated nonoperatively. Dekeyser et al reported that supine stress radiographs in the ED can predict successful nonoperative treatment and correlate with EUA. Although this avoids a trip to the OR, it adds another variable with inexperienced junior residents performing and interpreting the examination.[41]

3.4. Surgical Indications

The author's current protocol is to treat incomplete sacral fractures nonoperatively and allow the patients to WBAT. If they fail to mobilize because of pain, then they are taken for EUA with likely fixation. Patients with a complete sacral fracture undergo EUA and, if unstable, are fixed (stable are nonoperative and WBAT) by the sequential EUA protocol as described by Avilucea et al (Fig. 2).[42] In cases with bilateral anterior ring injuries, at least one side is stabilized if unstable on EUA. The patient is then allowed to mobilize with foot flat weight-bearing for 12 weeks on the side with a posterior injury.

3.5. Summary

The challenges of assessing instability start with the fact that pelvic injuries are dynamic, yet the vast majority our decision making is still based on static imaging. Dynamic assessment can

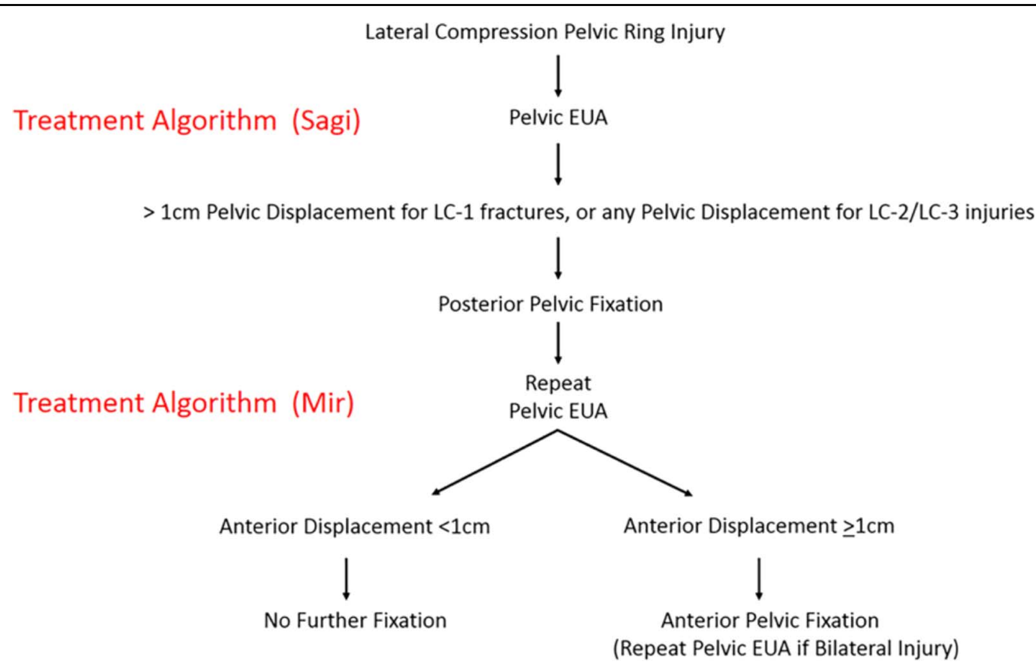

Figure 2. Pelvic examination under anesthesia. Reproduced with permission from Avilucea FR, Archdeacon MT, Collinge CA, Sciadini M, Sagi HC, Mir HR. Fixation strategy using sequential intraoperative examination under anesthesia for unstable lateral compression pelvic ring injuries reliably predicts union with minimal displacement. J Bone Joint Surg Am. 2018; 100(17):1503–1508. https://doi.org/10.2106/JBJS.17.01650.

help guide the need for fixation, and sequential EUA can help guide fixation strategies. More aggressive surgical treatment can clearly lead to reduced malunion and early pain. We are also still judging treatment success largely by radiographs. More studies are needed to determine the effect of alignment and malunion on functional outcomes.

4. Unstable Injuries: Selecting the Right Approach and Fixation

4.1. Introduction

When treating unstable pelvic ring injuries, closed reduction techniques are usually attempted first, and when adequate reduction is not achieved, then open exposures are necessary. The optimal surgical exposure allows the surgeon to see, clean, manipulate, reduce, clamp/wire, and stabilize the fracture or dislocation. In addition to fracture characteristics and location, patient-specific factors such as related soft-tissue and other primary system injuries, resuscitation status, prior abdominal surgery, history of hernia, and coordination of care with other medical teams play a role in the final decision for the approach and fixation strategy. Pelvic ring injuries usually have multiple areas of instability. It is important to focus on all the focal instabilities to maximize fixation strength. This review discusses common fracture locations and specific approach and fixation options (Fig. 3).

4.2. Pubic Symphysis and Ramus Injuries

Pubic symphysis and ramus injuries can be exposed through either a Pfannenstiel incision or a low midline vertical approach.[43] Although these superficial incisions are perpendicular to each other, the deep dissection interval is the same. With anterior approaches to the pelvic ring, the patient's prior surgical and hernia history is particularly important. A malleable retractor protects the bladder as the caudal insertions of the rectus abdominus muscle are elevated subperiosteally exposing the cranial anterior pubic bone bilaterally. It is important to repair this attachment during closure. The peripheral dissection is extended bilaterally as necessary along the pelvic brim as far as the SI joint. During preoperative planning, communication corona mortis vessels can be identified on the computed tomography scans usually located approximately 6 cm lateral to the pubic symphysis.[44]

4.3. Pubic Symphysis

For most symphyseal disruptions, reduction is achieved using a tenaculum clamp on the anterior parasymphyseal bone.[45] The clamp is positioned remote from the planned plate location. Oblique clamp applications will reduce a variety of rotational or vertical deformities. A single, flexible 3.5-mm nonlocking pelvic reconstruction plate provides stable fixation for most anterior ring injuries along with posterior ring injury fixation. The plate length is commonly 6 to 10 holes and is precontoured to optimize bone fit and screw trajectories. The plate can also be used to assist in the reduction of residual symphyseal widening by inserting the 2 central screws initially, aimed away from the midline, and sequentially tightening them.[46] Double plating symphyseal injuries showed biomechanical advantages, but has not proven clinically superior, especially as the sole anterior fixation solution without concomitant posterior ring injury fixation.[47]

4.4. Pubic Ramus

Medium-sized tenaculum reduction clamps are used for displaced noncomminuted ramus fractures. Drill holes on either side of the fracture are used to improve the clamp tines stability. Ramus fractures are fixed with an independent ramus plate or a plate extending from the pubic symphysis if there is concomitant symphyseal injury. Superior pubic ramus medullary screws are another fixation option.[48]

Superior pubic medullary ramus screws are inserted either antegrade or retrograde. For retrograde insertions, the patient's soft tissues and genital anatomy must allow safe access to the appropriate start site and desired screw trajectory.[48,49] One or more screws can be used depending on the shape and size of the osseous fixation pathway and selected screw diameter.[50,51]

4.5. Ilium Fractures

Fractures of the ilium involving the pelvic ring causing instability are less common, occurring in approximately 10% of unstable

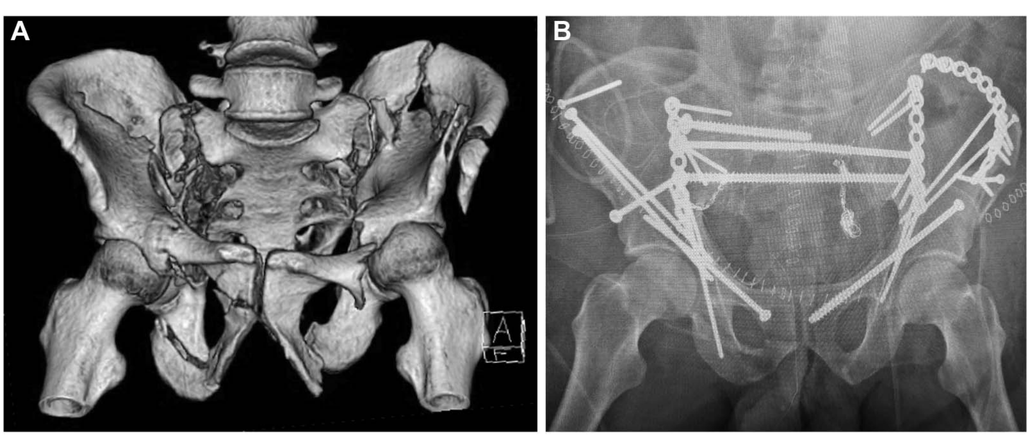

Figure 3. A, Preoperative 3D reconstruction of a complex unstable pelvic ring injury involving bilateral superior and inferior rami, iliac wing, sacroiliac, and sacrum fractures. B, Postoperative AP radiograph showing definitive fixation. Bilateral ramus fractures are fixed with a retrograde partially threaded screw on the right and an antegrade partially threaded screw on the left. Both ilium fractures are fixed with a combination of screws and plates for the iliac wing and plates for the pelvic brims. The bilateral SI joint injuries and sacral fractures are fixed with oblique sacroiliac screws at the upper sacral segment and a transverse, transsacral-transiliac screw at the second sacral segment.

pelvic ring injuries.[52] Most of them course from the iliac crest through the greater sciatic notch, risking injury to the superior gluteal vessels and nerves. The lateral surgical interval of an ilioinguinal approach is used for most iliac fracture open reduction and internal fixation. This interval is easily expanded by developing the lateral half of the middle window, thereby easing retraction of the iliopsoas and significantly increasing the exposure. This is particularly helpful for fractures involving the anterior inferior iliac spine. Posterior iliac crescent fractures can be closedly reduced or directly exposed with a posterior vertical paramedian approach.[53,54]

Iliac fracture fragments are reduced using tenaculum or other clamps.[46] The most common fixation of ilium fractures involves screws between the cortical tables at the iliac crest site and a malleable plate applied at the pelvic brim. Biomechanically, screws and plates are equally as effective for unstable iliac fracture fixation as long as the crest and brim fracture sites are both stabilized.[55] Most iliac crescent fractures can be treated with closed reduction and percutaneous iliosacral screw fixation. Larger crescent fractures can be stabilized with percutaneous screw fixation in the pelvic brim corridor.

4.6. Posterior Pelvic Ring Injuries

Most sacroiliac joint (SI) injuries and sacral fractures can be indirectly reduced with closed or minimally invasive techniques. Circumferential pelvic antishock sheets are useful for acutely reducing the pelvic volume and compressing displaced SI injuries.[56] Working portals cut through the sheet, allowing percutaneous screw insertions, external fixator pin placements, and vascular access.[57] Skeletal traction offsets cranial hemipelvic displacement, and external fixators are used to correct rotational deformity using both gluteal pillar and anterior inferior iliac spine fixation pins depending on the vector of correction needed.[58]

4.7. Sacroiliac Joint

When the attempted indirect reduction is insufficient, the SI joint is usually exposed directly through the lateral window of an ilioinguinal approach. To facilitate a clamp vector perpendicular to the SI joint and away from the planned implant application, a small incision is made along the lateral iliac crest and the lateral clamp tine is placed subperiosteally along the outer table of the posterior ilium. The medial tine is positioned on the sacral ala under direct visualization to ensure it is lateral to the L5 nerve root.[46] Clamps attached with bone screws can also be used. A posterior vertical paramedian approach can also be used.

After reduction through an anterior approach, anterior plates can provide provisional or definitive fixation. Percutaneous cannulated screws are often used for definitive fixation. Critical evaluation of the preoperative imaging for fracture deformity and sacral morphology, specifically dysmorphism, is important for planning safe screw fixation.[52,58–62] Oblique or transverse screws are placed across the upper sacral segment depending on the available osseous fixation pathway and desired compressive trajectory of the screw.[59,61,63] Compression of the SI joint can be obtained with partially threaded screws, but this should be avoided if there is sacral comminution or preoperative neurologic deficits to avoid overcompression of the nerve pathways. Screws at multiple levels increase the strength of the construct and are recommended if osseous fixation pathways are available.[64]

4.8. Sacrum

For direct reductions of sacral fractures, a dorsal approach provides the best exposure. If there is a concomitant spinopelvic injury that needs fixation, a dorsal midline incision is used.[65,66] If only one side of the sacrum needs to be exposed, a posterior vertical paramedian incision is best.

Reduction is achieved with a tenaculum clamp. A variety of implants have been described for sacral fracture fixation, including the most common iliosacral screws.

4.9. Summary

Unstable pelvic ring injuries are preferentially treated with closed reduction techniques and percutaneous fixation, but when needed, the appropriate open approach is chosen based on fracture characteristics, preferred fixation strategies, and patient-specific factors. The surgeon must remember that accurate reduction and stable fixation for each instability site improve the overall results.

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