International Orthopaedics (2018) 42:2663–2674
https://doi.org/10.1007/s00264-018-3883-1

REVIEW ARTICLE

Vertical shear pelvic injury: evaluation, management, and fixation strategies

Laura Blum[1] · Mark E. Hake[1] · Ryan Charles[1] · Todd Conlan[1] · David Rojas[2] · Murphy Trey Martin[2] · Cyril Mauffrey[2]

Received: 16 February 2018 / Accepted: 8 March 2018 / Published online: 26 March 2018

Abstract
Vertical shear pelvic ring fractures are rare and account for less than 1% of all fractures. Unlike severely displaced antero-posterior compression and lateral compression pelvic fractures, patients' mortality is lower. Nevertheless, patients must be managed acutely using well-defined ATLS protocols and institution-specific protocols for haemodynamically unstable pelvic ring fractures. The definitive treatment of vertical shear pelvic fractures is however more controversial with a paucity of literature to recommend the ideal reduction and fixation strategy. While the majority of injuries can be reduced and fixed in a closed manner, orthopaedic traumatologists should be familiar with the contraindications to those techniques as well as options such as tension band plating and lumbo pelvic fixation. Our paper reviews the acute management, associated injuries and definitive reduction and fixation strategies of vertical shear pelvic fractures. In addition, we propose a treatment algorithm for the selection of the most appropriate fixation technique.

Keywords Vertical shear · Pelvic fracture · Pelvic ring injuries · Unstable pelvis · Combined mechanism · Young and Burgess · Tile C pelvic fractures · Unstable pelvic fractures

Introduction

Pelvic ring fractures (PRF) account for less than 1% of all fractures [1]. Vertical shear (VS) pelvic fractures are a subset of PRF and are defined as unstable injuries resulting from a complete disruption of both the anterior and posterior ring (bone, soft tissues, or both) [2–4]. Current literature on VS injuries is limited to case series and retrospective cohort studies. As such, the incidence of VS fractures is not well defined and ranges from 5.6 to 20.5% of PRF [2, 3]. To occur, VS injuries require high-energy axial loading through a unilateral extremity. They are commonly sustained during motor vehicle accidents and falls from height [3]. While there is significant morbidity and mortality associated with PRF, isolated and appropriately classified, vertical shear injuries demonstrate a low mortality [3].

Anatomic and radiologic studies [4, 5] describe the anterior injury as being through the pubic symphysis, through a combined fracture of the superior and inferior rami, or through a fracture of the acetabulum. Posteriorly, variants include a fracture through the sacrum, ilium, or SI joint [4] with disruption of the sacroiliac complex with disruption of the sacrospinous, sacrotuberous, and posterior pelvic ligaments, which are intimately associated with the internal iliac vessels and lumbosacral plexus.

The instability and severity of these injuries makes stabilization and definitive treatment a complex problem. Damage control measures may be indicated if and when the patient's haemodynamic status warrants urgent temporary external fixation. Once the patient is resuscitated, planning and execution of definitive reduction and fixation requires expertise in 3D pelvic anatomy, available reduction techniques, and fixation strategies. In this article, we aim to review the initial evaluation of patients presenting with a vertical shear pelvic ring fracture, discuss options and indications for differing approaches for definitive fixation, and finally provide our surgical recommendation, specifically with regard to the technique of reduction and fixation of vertical shear pelvic fractures.

✉ Cyril Mauffrey
cyril.mauffrey@dhha.org

[1] Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, MI, USA

[2] Department of Orthopaedics, Denver Health Medical Center, University of Colorado, School of Medicine, 777 Bannock Street, Denver, CO 80204, USA

Classification and radiographic analysis

Optimal treatment of VS injuries relies on accurate understanding of the injury. There are multiple classification systems for PRF including Tile and Young-Burgess classification schemes [3–6]. Based on the Tile classification, VS fractures are categorized as Type C, which are rotationally and vertically unstable. Type C fractures are sub-classified into C1 (unilateral), C2 (bilateral, where one side is Type C) and C3 (bilateral, both sides are Type C) [6]. The Young-Burgess classification includes Vertical Shear as a distinct pelvic fracture pattern [3]. These systems demonstrate clinical importance as they correlate with mortality when injuries are sub-classified into stable and unstable categories [7]. Lastly, the OTA/AO classification is frequently referenced, and incorporates the Young-Burgess classification system [8]. This classification sorts vertical shear pelvic ring injuries into category 61C, unstable ring injuries [8].

Regardless of which method is utilized, classification of VS injuries is based on standard anteroposterior (AP) pelvis and inlet and outlet radiographs [4]. AP pelvic radiographs are an initial part of ATLS evaluation and a large amount of information can be inferred from these images (Fig. 1) including asymmetry, rotation and displacement of each hemipelvis. As such, it is in our opinion that, whenever possible, radiographs should be obtained prior to any reduction manoeuvre with sheets, pelvic binder, or external fixation device in order to aid in planning for definitive fixation. In fact, X-rays or CT scans taken at a later stage may mask the real nature of the injury and lead to unpleasant surprises in the operating room [9].

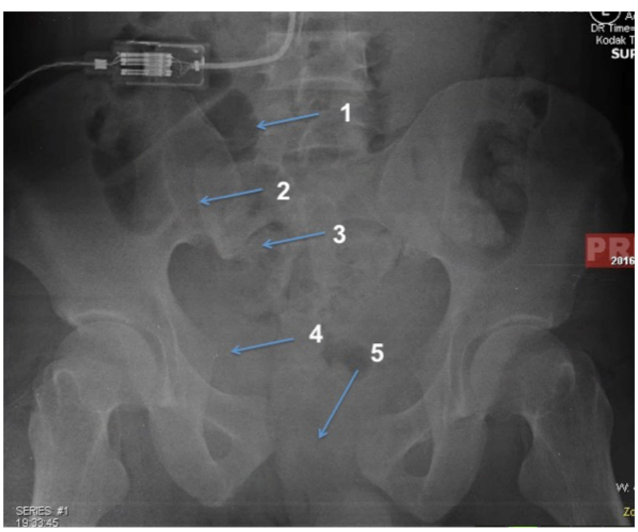

Fig. 1 Injury AP pelvis radiograph demonstrating findings concerning for a combined mechanism pelvic injury including evidence of superior displacement of the right hemipelvis indicated by (1) transverse process fracture of L5, (2) SI joint diastasis, (3) transforaminal sacral fracture, internal rotation of the right hemipelvis indicated by (4) prominent ischial spine, and (5) diastasis of the pubic symphysis. The above figure was published in Tips & Tricks in Orthopedic Trauma Surgery, Chapter "pelvic fractures" by Mauffrey et al. and used with permission from TreeLife Media (A Kothari Medical)

It is important to keep in mind that the imaging we view is a static image of a dynamic process. This means that the injury and deformity may have been more severe at the time of impact. Subtle radiological signs such as fracture of an L5 transverse process may at times be consistent with proximal migration of the affected hemipelvis and should raise concern for potential pelvic instability [10]. Inlet views are ideal for visualizing anterior or posterior translation as well as internal or external rotation. Outlet views identify vertical translation, as well as flexion and extension and location of sacral fractures. It is theorized by some that vertical instability is suggested by greater than 5 mm displacement of posterior SI complex or the presence of a posterior sacral fracture gap [11].

Cross-sectional imaging with CT serves to add information and can help characterize the injury in addition to being critically important for pre-operative planning of definitive reduction and fixation. Posterior lesions are best seen on computed tomography (CT) [12] including foramina involvement and displacement in multiple planes. Gapping of a complete posterior fracture may infer vertical instability.

Mechanism and associated injuries

Pennal described a superiorly directed force as the mechanism of injury resulting in a VS fracture [4]. A 12-month population study by Balogh et al. showed that Tile Type C fractures were more commonly associated with high-energy mechanisms including motorbike and car accidents, pedestrians hit by a car, and falls from greater than 1 m in height [1].

Burgess et al. associated VS fractures with closed head injuries, pneumothorax, bowel injury, and retroperitoneal haematoma [3]. Further investigations have associated VS injuries with urological, soft tissue, and lumbosacral plexus injury. Posterior urethral injuries occur more commonly with vertically directed forces and can lead to urethral stricture, incontinence, and impotence [13–15]. Vertically unstable open pelvic fractures are frequently associated with posterior soft-tissue injury to the buttock or perineum [13]. Lumbosacral injuries are common if the posterior ring fracture involves the sacrum, specifically the L5 nerve root, which may manifest as a foot drop [16].

Morel-Lavallée lesions are associated with VS pelvic fractures and can increase morbidity by predisposing to infection [17]. One study found Morel-Lavallée lesions occurred at a rate of 39.4% based on CT diagnosis. This is significantly higher when compared to lateral compression (LC) and anterior-posterior compression (APC) injuries, in which such soft tissue lesions occurred in 11.6 and 11.7%, respectively [17].

Associated vascular injuries occur at rates that are controversial. Unstable pelvic fractures which included LC, APC, and VS fractures accounted for a higher percentage of transfusion requirements and mortality compared to stable fracture patterns [18]. However, studies that distinguish specific fracture patterns demonstrated that VS fractures have lower incidence of pelvic vascular injury when compared to APC and LC injuries [19]. VS injuries had 40% incidence of associated pelvic vascular injury, whereas APC and LC injuries had respective incidence of 52 and 60% [19]. This may be attributed to a shortening of the vascular tree during the vertical shear mechanism, compared to the stretching that occurs with APC injury [3, 19, 20]. It is, however, essential to be aware that high energy pelvic fractures are often the result of a combination of force vectors resulting in degrees and directions of displacement that may be surprising. Therefore, when treating a patient with a presumed vertical shear injury, the clinician should maintain high index of suspicion for associated vascular injury.

Mortality risk for PRF is stratified by age, early physiologic derangement, presence of other injuries (head or trunk), injury severity scores, and haematologic instability [21, 22]. For VS patterns, small series have reported mortality rates as low as 0% [3, 23].

Initial management

The immediate goals of treatment include Advanced Trauma Life Support (ATLS) and adequate resuscitation of the patient followed by temporary stabilization of the pelvic ring to reduce the pelvic volume and facilitate haemostasis [18, 19].

In order to achieve haemodynamic stability in patients with unstable pelvic ring injuries, angioembolization (AE) and preperitoneal pelvic packing (PPP) are two modalities that are frequently employed, either independently or as adjuncts to each other. Success rates of AE range from 59 to 100% [24]. However, vascular injury is frequently not identified on angiography [25, 26], given 85% of bleeding in pelvic fractures has been shown to come from a venous or bony source, rather than arterial [27]. Furthermore, angiography may not be readily available, thus inhibiting timely resuscitation. Studies have shown time to angiography to be significantly longer than time to PPP [28–30], reported in some studies to take up to three times longer [30]. Additionally, Schwartz, et al. demonstrated that time to IR is significantly increased on nights and weekends compared to daytime [31]. Conversely, PPP can be accomplished in less than 30 minutes [25] and studies have shown reduced mortality rates in patients in which PPP is employed [29–32]. This may be due to the fact that PPP directly addresses the primary source of bleeding, most commonly venous and bony haemorrhage.

Other institutions are introducing resuscitative endovascular balloon occlusion of the aorta (REBOA) as a treatment of haemorrhagic shock in patients with pelvic fracture, which has been shown to increase mean SBP by 55 mmHg following occlusion [33]. While early findings regarding use of REBOA are encouraging, large studies are currently lacking, and therefore the potential risks and benefits of its use are still being elucidated [34].

While, VS fractures are associated with lower transfusion requirements than APC [7] and LC fractures, stabilization and reduction of intrapelvic volume can be achieved with the use of a sheet, pelvic binder, or external fixation when indicated [27, 35]. The literature pertinent to the use of pelvic binders or sheets for VS fractures remains controversial. While some authors suggest that those adjuncts may worsen the deformity [18], others place vertical shear fractures in the same category as APC III injuries and as such, patients are placed in pelvic sheets early in the resuscitation process [18]. Once again, common sense would suggest that in the acute phase and while in the emergency room, the untrained eye may find it challenging to discern a pure vertical shear injury from a combined mechanism pelvic fracture and it may be wise to recommend early sheet placement independent of the fracture type [27].

Additionally, immobilization can be further augmented with complete bed rest with supracondylar femoral traction [3]. Furthermore, C-clamps may be used to confer additional stability [25, 35]; however, use of C-clamps in the acute setting is controversial and not utilized at our institution. When required, a well-positioned supra acetabular external fixator can serve the purpose of temporary stabilization and reduction of pelvic volume for haemodynamic purposes without the neurovascular injury risks of C clamp placement.

Skeletal traction may be employed to help reduce the vertical displacement of the affected hemipelvis when displacement is > 1 cm [36]. However, when traction is ineffective at maintaining adequate reduction for VS fractures, provisional fixation may be indicated. For unstable PRF, investigations have shown that anterior external fixation has become increasingly utilized as a part of resuscitation rather than reconstruction [34]. In PRF, anterior fixation is thought to contribute to haemostasis by maintaining a reduced pelvic volume allowing tamponade [37]. However, its role in VS patterns is not well defined as there is concern that external fixation can cause further internal rotation of the affected hemipelvis leading to further displacement of posterior ring if the posterior pelvis is not fixed simultaneously [37]. This is likely due to the large distance between the posterior ring and the external fixator frame anteriorly, which allows for large bending moments and resultant distracting forces when the pins are loaded [38]. For these reasons, external fixation should be viewed as temporary fixation option given its inability to provide sufficient stability to the posterior aspect of the pelvic ring in vertically and rotationally unstable pelvic ring injuries [39].

Definitive fixation

Stability of the pelvic ring relies predominantly on achieving stability through the posterior weight bearing sacroiliac joint and its associated strong interosseous ligaments [39]. Definitive fixation must therefore include fixation of the posterior pelvic ring in order to achieve adequate stability. Posterior fixation is frequently supplemented with fixation of the anterior ring [38, 40, 41]. Several surgical strategies are well established in the literature but to date, the selection remains dealer's choice since there is a lack of prospective evaluation on the topic. It is essential to emphasize that despite guidance from the literature in terms of fixation options and clear pros and cons for each strategy, the holy grail of 'steps and technique of reduction' remains an art more than a science. We will elaborate further on our preferred reduction strategy in the tips and tricks section later in the paper.

Sacroiliac and trans-sacral trans-illiac screws

Sacroiliac (SI) screw constructs may be employed for SI joint dislocations as well as sacral fractures. For this construct, one or more screws are inserted from the lateral iliac cortex into the upper sacral segment, sometimes inserted so that they extend only into the ipsilateral upper sacral segment (iliosacral), and other times traversing the entire sacrum, exiting through the contralateral iliac cortex (trans-sacral trans-illiac (TSTI). TSTI screws have the advantage of improved bony purchase; especially in patients with osteoporosis, as the sacral alae have poor bone density, even in healthy subjects. Increased strength achieved by obtaining screw purchase in bilateral iliac cortices improves the resistance to vertical shear forces transmitted through the fracture site due to the fact that longer screws are able to distribute displacement forces along their entire length [40–42].

SI screws can be placed percutaneously if adequate closed reduction is achieved; otherwise they can be placed using an open approach and reduction. The open posterior approach has been associated with high rates of wound complications [43–45]. Suzuki et al. published infection rates as high as 10% with posterior approach [46].

However, Stover et al. reported an infection rate of 3.4% with the posterior approach, citing proper patient selection and technique as the keys to avoiding high rates of wound complications reported in other studies [44]. Conversely, percutaneous approach risks damage to L5 and S1 nerve roots, especially in instances of inadequate fluoroscopic imaging. Additionally, it is associated with higher rates of malunion**,** and the procedure requires a certain level of expertise, which may necessitate patient transfer to a different facility to meet those needs [43]. Despite the potential benefits of screw placement through a percutaneous approach, if closed reduction is not achieved, an open approach is recommended in order to obtain adequate reduction through direct reduction techniques. Furthermore, in these instances percutaneous screw placement may not be possible due to the compromised availability of screw space and increased risk of damage to surrounding neurovascular structures caused by residual displacement [47].

While stabilization of the posterior pelvic ring is of primary importance in achieving stability of VS pelvic ring fractures, anterior pelvic plating has been shown to significantly augment stability of the construct and prevent malunion [48]. Keating et al. reported a decreased rate of malunion with internal fixation of the anterior pelvic ring for VS injuries [42]. Furthermore, quality of reduction has been associated with improved post-operative outcomes and therefore many advocate for fixation of the anterior pelvic ring to assist with reduction and to help neutralize any displacement forces [8, 39, 41, 47, 49]. A 6 or 7-hole pelvic reconstruction plate is typically employed for anterior pelvic ring fixation. Nonlocked plating is adequate for symphyseal plating as Moed et al. demonstrated no advantage when locked plating is utilized for these injuries [50].

Several biomechanical studies have been performed to evaluate the effect of thread length and different construct configurations for SI screw fixation. Many advocate for the use of fully threaded screws as studies have shown that fully threaded screws are significantly stronger than partially threaded [40]. However, partially threaded lag screws may be beneficial for reduction of fracture gapping during placement of the first screw, especially in instances when screws are placed percutaneously, relying on closed reduction techniques rather than direct, open reduction. It is important to note that over-compression of the sacral nerve root in transforaminal sacral fractures is a theoretical risk due to significant comminution, and care must be taken to avoid this scenario [16, 42].

Other biomechanical studies have evaluated the strength imparted by placing two SI screws rather than one. Many advocate for two TSTI screws in the S1 or the S1 and S2 sacral segments [40, 51]. Van Zwienen et al. evaluated the stiffness of SI screw constructs and demonstrated significantly improved load to failure values and improved rotational stiffness in constructs in which there were two SI screws compared to one [52]. There was no difference in strength between constructs with two screws in the S1 segment and constructs with one screw in the S1 segment and one in the S2 segment. Conversely, Sagi et al. did not demonstrate any additional benefit to a second SI screw [41].

Tension band plating

Transiliac posterior tension band plating is performed by plating the dorsal surface of the sacrum with fixation in the iliac

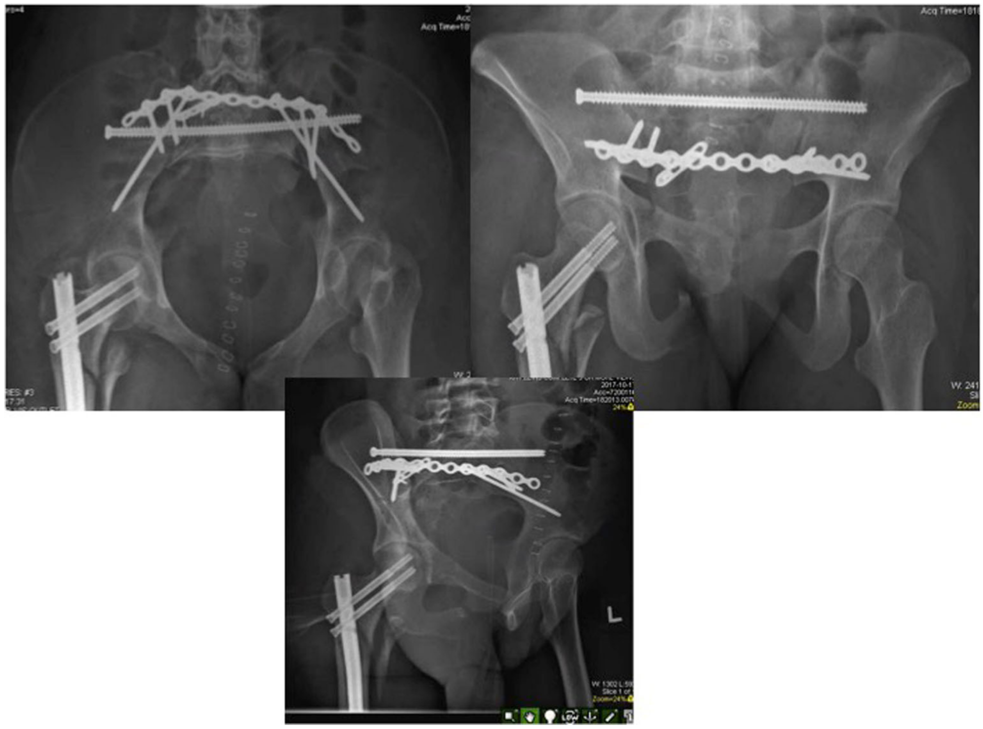

Fig. 2 Inlet, outlet and obturator oblique radiographs of a vertical shear pelvic fracture treated with tension band plating and trans-sacral trans-iliac screw fixation

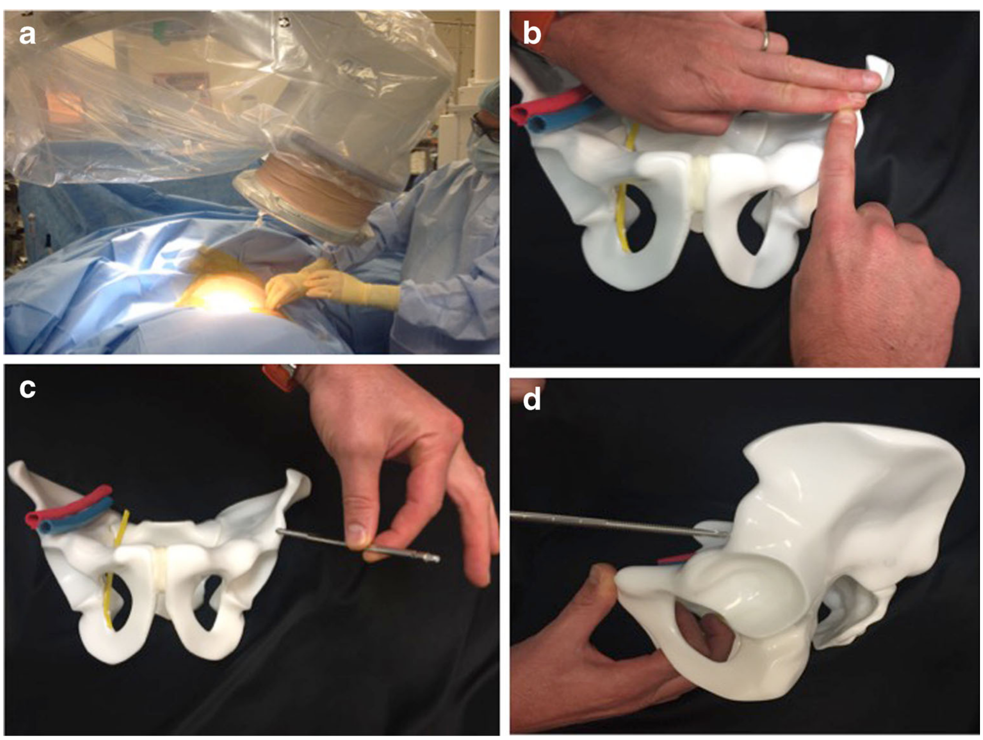

Fig. 3 Technique for obtaining correct starting point and trajectory for supra-acetabular external fixator pins. Obturator outlet view (**a**) is utilized to obtain correct starting point located but this during this maneuver the surgeon's hands can be in the way of the X-ray. We modify this technique by doing a stab incision located approximately 2 cm distal and 1 cm medial to the ASIS and using a tonsil to dissect down to the anterior inferior iliac spine (AIIS). Our pin is then inserted a few mm on the prominence before X-ray (obturator outlet) is taken (**b**). Correct trajectory typically requires the pin be directed approximately 40 degrees medial (**c**) and 40 degrees caudal (depending on the degree of displacement and mal-alignment) (**d**). The above figure was published in Tips & Tricks in Orthopedic Trauma Surgery, Chapter "pelvic fractures" by Mauffrey et al. and used with permission from TreeLife Media (A Kothari Medical)

spines [53]. Advocates of this fixation method argue that TSTI screw fixation risks iatrogenic damage to neurovascular structures, especially in cases with comminuted Denis zone II and III sacral fractures, with rates reported as high as 7.7% [54]. Posterior plating theoretically reduces this risk as it can maintain adequate reduction without compressing the comminuted fragments [55], and therefore may be indicated as an alternative means to posterior fixation for patients with sacral dysmorphism lacking adequate bony corridors for safe placement of iliosacral screws in the upper segment, or in cases of significant sacral comminution [53, 55]. Disadvantages to this mode of fixation include extensive surgical dissection and higher rates of wound complication as well as prominent hardware (Fig. 2) [53].

Lumbosacral fixation

Lumbosacral fixation is any construct that connects the spine to the pelvis. It is referred to as triangular osteosynthesis

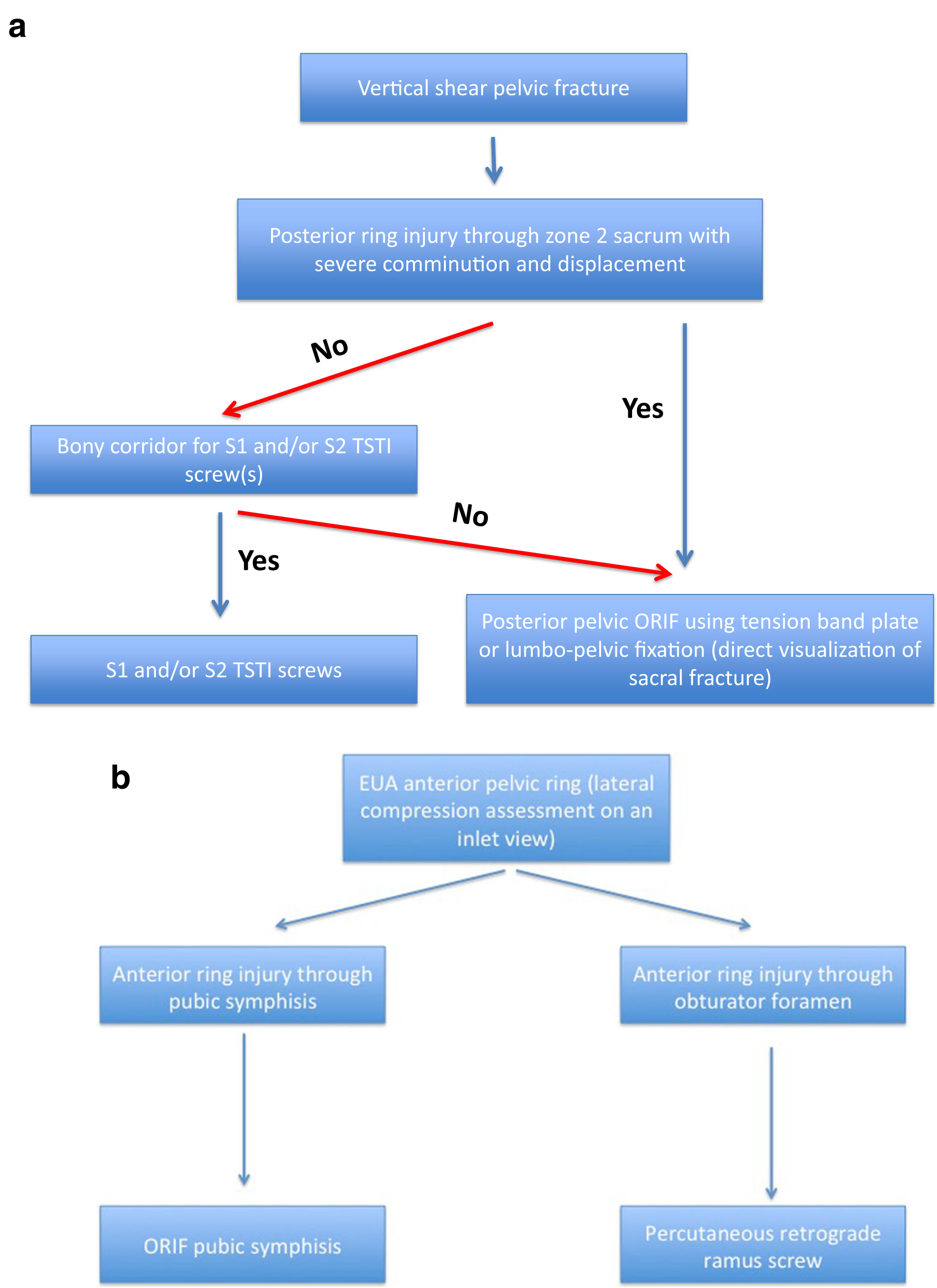

Fig. 4 **a** Our preferred treatment algorithm for the selection of fixation strategy based on fracture type, degree of comminution and displacement and patients' anatomy/size of bony corridors. **b** Selection of fixation strategy for the anterior pelvic ring component. TSTI (Trans Sacral Trans Iliac Screw); EUA (Examination Under Anesthesia)

(TOS) when a sacroiliac screw is added to the construct [40]. These fixation constructs utilize the spine as a strut to help prevent vertical displacement of the unstable hemipelvis. By combining sacroiliac screws with lumbosacral fixation, TOS achieves multiplanar stability and allows for full weight bearing in the early post-operative period. However, some argue that the ability to begin early weight bearing is irrelevant as these patients are typically multiply injured with associated neurological injuries and for these reasons are unable to begin weight bearing in the early post-operative period despite adequate fixation with TOS [46].

Biomechanical testing has shown that unstable sacral fractures have more stability with TOS when compared to SI screw fixation alone, and maintains reduction until healing in 95% of patients [56, 57]. TOS is recommended for transforaminal sacral fractures where adequate fixation and reduction cannot be achieved with SI screws alone. Complications include iatrogenic nerve injury secondary to fracture manipulation and malreduction and high rates of secondary surgery for symptomatic hardware [57]. As was discussed with sacroiliac screws, improved stability can be attained with concomitant anterior pelvic symphyseal plating [39].

Outcomes

Outcomes following fixation of VS pelvic ring fractures appear to be largely related to reduction of the fracture [40, 48, 57]. It has been reported that any displacement greater than 10 mm was a poor prognostic indicator [14, 58]. Reports show a clear improvement in long-term outcomes for patients with less than 5 mm of residual displacement [58]. However, severe post-operative SI joint pain is reported in as much as 11% of patients with VS injuries even when a satisfactory reduction is achieved [43]. It should be emphasized that pure SI joint dislocations appear to have worse outcomes, particularly higher

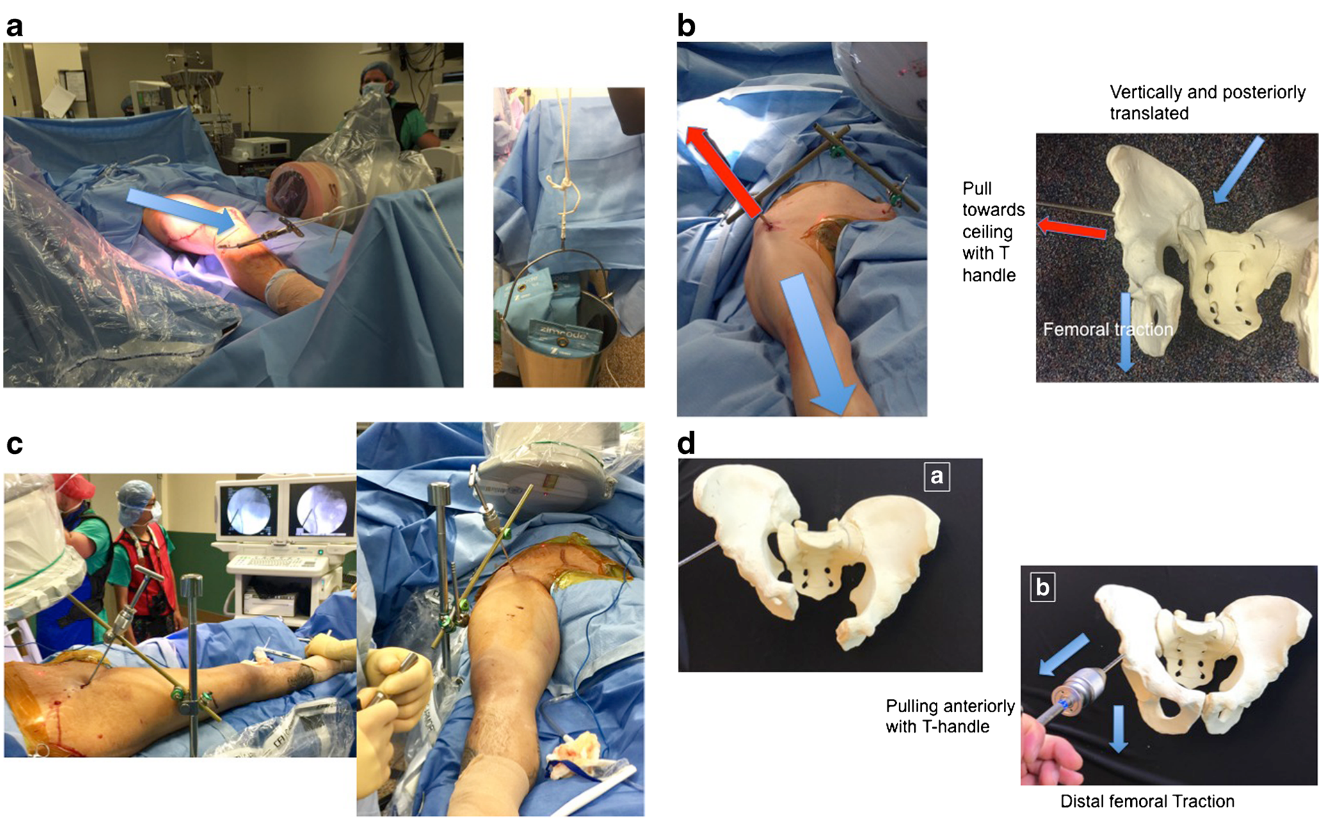

Fig. 5 **a** Use of distal femoral or proximal tibia traction with the leg prepared and draped attached to a sterile rope and a bucket hanging over the flat top radiolucent table. The bucket can be filled with sand bags (up to around 40 pounds) to help correct the proximal migration of the ipsilateral hemipelvis. **b** Supra-acetabular pin placement and vector of pull (towards the ceiling on a supine patient) to help correct posterior displacement and translation of the hemipelvis. The bone model identifies the 2 combined vectors of pull both distally to correct vertical displacement and anteriorly on a supine patient to correct the posterior translation. **c** By using a sterile side bar bolted to the table, the Schantz pin is used to reduce the fracture and then secured to the side post using an external fixator bar allowing the patients' own body weight to maintain reduction of the posteriorly translated hemipelvis. **d** Bony model demonstrating a displaced right hemipelvis reduced using the above technique with a supra acetabular external fixator pin and axial longitudinal distal femoral traction. The above figure was published in Tips & Tricks in Orthopedic Trauma Surgery, Chapter "pelvic fractures" by Mauffrey et al. and used with permission from TreeLife Media (A Kothari Medical)

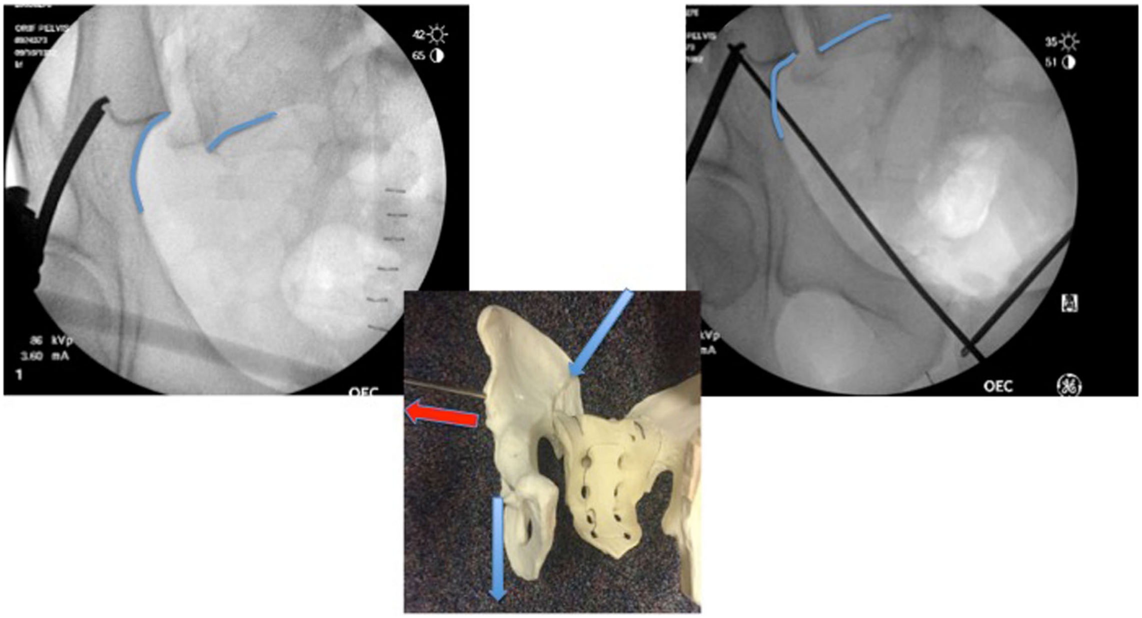

Fig. 6 Intra-operative fluoroscopic images demonstrating initial vertical and posterior displacement of the sacroiliac joint (**a**) followed by reduction of the sacroiliac joint following reduction with axial longitudinal traction via distal femoral traction pin and pull through supra-acetabular pins towards the ceiling (**b**). The above figure was published in Tips & Tricks in Orthopedic Trauma Surgery, Chapter "pelvic fractures" by Mauffrey et al. and used with permission from TreeLife Media (A Kothari Medical)

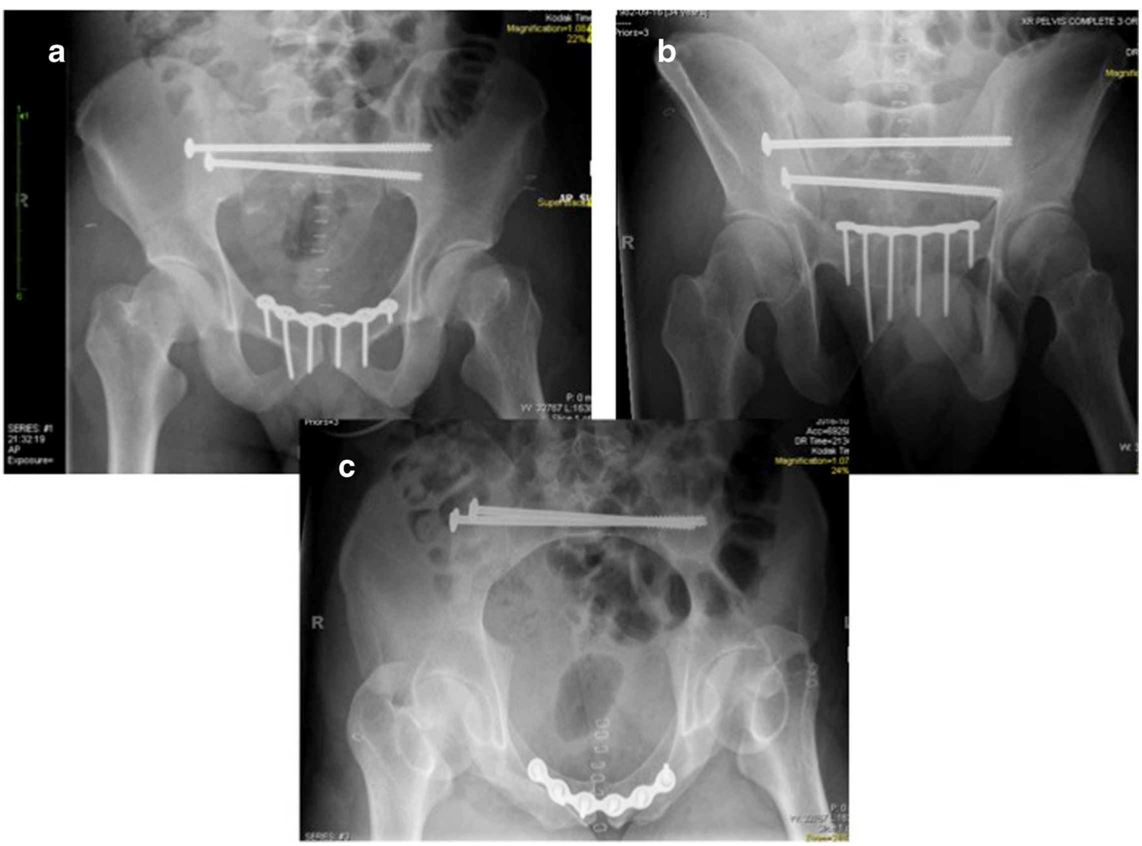

Fig. 7 Post-operative AP (**a**), outlet (**b**) and inlet (**c**) radiographs showing final reduction and fixation construct. Two trans-sacral, trans-illiac screws were placed, as well as an anterior 6-hole plate. The above figure was published in Tips & Tricks in Orthopedic Trauma Surgery, Chapter "pelvic fractures" by Mauffrey et al. and used with permission from TreeLife Media (A Kothari Medical)

rates of chronic pain, when compared to SI joint fracture-dislocations [58].

Neurologic injury is also associated with poor outcomes following VS pelvic ring injuries [14, 58], and occurs at higher rates in transforaminal sacral fractures. While many patients recover with time, permanent injury can certainly impair functional outcomes for patients even when an anatomic reduction is achieved. Early reduction of the pelvic ring appears to improve chances of neurologic recovery. This is thought to be secondary to mechanical factors such as stretching or compression of the nerves that is alleviated with reduction of the pelvic ring [16]. New onset sexual and urinary dysfunction have been linked to VS pelvic ring injuries, with reported rates as high as 53 and 57% respectively and have been associated with development of major depression by 1 year following surgery [15]. Additionally, sexual dysfunction and urinary tract infection have been shown to be independent risk factors for decreased quality of life post-operatively [51].

Author's preferred method of management

Provisional fixation

For temporary stabilization and hemodynamic stability purposes, we view a well-positioned anterior pelvic external fixator as a powerful and safe tool [27] providing sufficient temporary mechanical stability and a solid base upon which to perform pre-peritoneal pelvic packing (if required). Our groups' experience with the implementation of powerful and aggressive resuscitative and stabilization algorithm was recently shown to reduce mortality rates significantly in patients presenting with severe pelvic ring injuries [59]. When provisional fixation with external fixation is indicated, we prefer stabilization with supra-acetabular pins rather than iliac crest pins (Fig. 3). The supra-acetabular position can accommodate larger diameter pins achieving better pin-bone interface and improved construct stiffness, which makes them stronger reduction aids when compared to iliac crest pins [60, 61]. Furthermore, because of their location, the pins tend to be better tolerated by patients [60]. While supra-acetabular pins have a biomechanical advantage compared to iliac crest pins, placement is technically more difficult and therefore iliac crest pins may be more appropriate for external fixator pin placement in non-expert hands [60, 61].

Pre-operative planning

The safe zone for passing SI and trans-sacral screws is determined using CT scans, as well as planning for screw length and starting point. Axial views are utilized to assess anterior-posterior diameter of bony corridors and sagittal views are used to estimate inlet and outlet angles for intra-operative fluoroscopy as well as determining an accurate starting point. Axial cuts are then used to measure the planned screw length at the identified level for each screw location. If this measurement is off by more than 5 mm intra-operatively, then

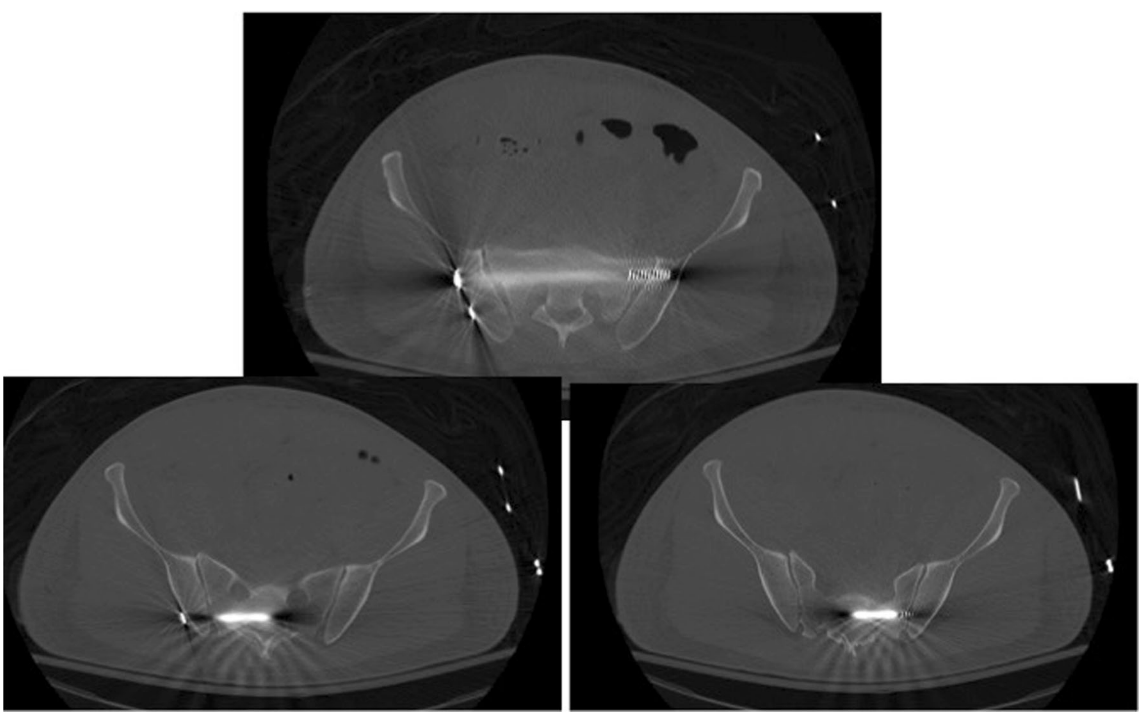

Fig. 8 Post-operative axial CT scan revealing trajectory of S1 and S2 trans-sacral trans-iliac screws, avoidance of sacral foramina and anatomical reduction of the sacro-iliac joint

fluoroscopic images should be carefully scrutinized to ensure the guidewire has not deviated from the planned pathway. Our preferred treatment algorithm can be seen in Fig. 4a and b.

Intra-operative tips and tricks

A flat, narrow square folded blanket can be used to elevate the patient off the OR bed to assist in draping posteriorly and allow for anteriorly directed SI screws when needed. Draping should be wide in case a lateral window is required to access the SI joint. Our experience has shown that the majority of vertical shear pelvic fractures or dislocations are both vertically and posteriorly translated. Longitudinal axial traction conferred by a distal femoral traction pin connected to a sterile rope and a bucket containing around 30 pounds usually corrects the vertical translation (Fig. 5a). A supra acetabular pin connected to a universal T-handle with a vector of pull towards the ceiling can address the reduction of the posterior hemipelvis translation (Fig. 5b). The use of a Thompson retractor that bolts to the table and allows attachment of the supra acetabular external fixator pin to it is a powerful tool to rely on the patient's body weight to correct posterior hemipelvis translation (Fig. 5c). Both vectors of displacement must be corrected before fixation (Fig. 5d) and Fig. 6. Our preferred sequence of events is to address the anterior ring with temporary fixation (Jungbuth clamp, K wires or Weber clamp) first combined with simulataneous reduction of the posterior ring displacement and definitive fixation of the back with TSTI screws when bony corridors can accommodate them. We then return to the front for definitive fixation, typically with a 6-hole pelvic reconstruction plate (Figs. 7 and 8). When tension band plating is indicated the use of a temporary posteriorly based external fixator to maintain reduction during definitive fixation can be a powerful tool [45].

Take-home message

Vertical shear pelvic fractures remain an uncommon injury pattern, rarely seen in isolation. Most vertical shear injuries will be seen with an ipsilateral posterior translation of the hemipelvis. The initial management of patients presenting with this injury follows the ATLS protocol and Level 1 trauma centres should have a protocol in place to handle haemodynamically unstable pelvic fractures.

Definitive fixation strategies rely on a sound understanding of the initial injury often best seen on the initial AP pelvis. The CT scan can help plan surgical reduction and fixation but deformities may be masked by a well-placed external fixator, a pelvic binder or sheet. We recommend routine examination under anesthesia prior to proceeding to definitive fixation of pelvic ring fractures where a CT scan was obtained in a binder, sheet or in an external fixator to reduce the rate of missed contralateral pelvic ring fractures. A supra acetabular Schantz pin is a powerful tool to reduce the posterior translation while distal femoral traction helps restore the hemipelvis height.

The choice and planning of surgical fixation will depend on fracture location, degree of displacement, patients' anatomy and size of bony corridors. Most fractures will be amenable to percutaneous reduction and percutaneous fixation using TSTI screw fixation in S1 and or S2 for the posterior ring and ORIF for fixation of the anterior ring injury. Options such as posterior tension band plating or lumbo-pelvic fixation are options that should be considered when the former technique is not safely feasible. Future research should focus on prospective studies comparing various fixation strategies, assessment of reduction quality with different methodologies, and long-term follow-up studies looking at functional outcomes of these severely injured patients.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest to report in relation to the preparation of this work.

References

1. Balogh Z, King KL, Mackay P et al (2007) The epidemiology of pelvic ring fractures: a population-based study. J Trauma 63(5): 1066–1073
2. Gänsslen A, Pohlemann T, Paul C et al (1996) Epidemiology of pelvic ring injuries. Injury 27(1):13–20
3. Burgess AR, Eastridge BJ, Young JW et al (1990) Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 30(7):848–856
4. Pennal GF, Tile M, Waddell JP et al (1980) Pelvic disruption: assessment and classification. Clin Orthop Relat Res 151:12–21
5. Bucholz RW (1981) The pathological anatomy of Malgaigne fracture-dislocations of the pelvis. J Bone Joint Surg Am 63(3): 400–404
6. Tile M (1988) Pelvic ring fractures: should they be fixed? J Bone Joint Surg Br 70(1):1–12
7. Manson T, O'toole RV, Whitney A et al (2010) Young-Burgess classification of pelvic ring fractures: does it predict mortality, transfusion requirements, and non-orthopaedic injuries? J Orthop Trauma 24(10):603–609
8. Kellam JF, Meinberg EG, Agel J, Karam MD, Roberts CS (2018) Introduction: fracture and dislocation classification compendium-2018: international comprehensive classification of fractures and dislocations committee. J Orthop Trauma 32(1):S1–S10. https://doi.org/10.1097/BOT.0000000000001063
9. Guthrie HC, Owens RW, Bircher MD (2010) Fractures of the pelvis. J Bone Joint Surg Br 92(11):1481–1488
10. Starks I, Frost A, Wall P et al (2011) Is a fracture of the transverse process of L5 a predictor of pelvic fracture instability? J Bone Joint Surg Br 93(7):967–969
11. Edeiken-Monroe BS, Browner BD, Jackson H (1989) The role of standard roentgenograms in the evaluation of instability of pelvic ring disruption. Clin Orthop Relat Res (240): p. 63-76.
12. Abdelfattah AA, Moed BR (2016) CT-generated radiographs in patients with pelvic ring injury: can they be used in lieu of plain

radiographs? J Orthop Surg Res 11:26. https://doi.org/10.1186/s13018-016-0361-6
13. Fang C, Alabdulrahman H, Pfeifer R, Tarkin IS, Pape HC (2017) Late reconstruction of severe open-book deformities of the pelvis—tips and tricks. Int Orthop 41(9):1777–1784. https://doi.org/10.1007/s00264-017-3549-4
14. Tornetta P III, Matta JM (1996) Outcome of operatively treated unstable posterior pelvic ring disruptions. Clin Orthop Relat Res 329:186–193
15. Kabak S, Halici M, Tuncel M et al (2003) Functional outcome of open reduction and internal fixation for completely unstable pelvic ring fractures (type C): a report of 40 cases. J Orthop Trauma 17(8):555–562
16. Elnady B, Shawky A, Abdelrahman H et al (2017) Posterior only approach for fifth lumbar corpectomy: indications and technical notes. Int Orthop 41(12):2535–2541. https://doi.org/10.1007/s00264-017-3570-7
17. Beckmann NM, Cai C (2016) CT incidence of Morel-Lavallee lesions in patients with pelvic fractures: a 4-year experience at a level 1 trauma center. Emerg Radiol 23(6):615–621
18. Poenaru DV, Popescu M, Anglitoiu B et al (2015) Emergency pelvic stabilization in patients with pelvic posttraumatic instability. Int Orthop 39(5):961–965. https://doi.org/10.1007/s00264-015-2727-5
19. Dyer GS, Vrahas MS (2006) Review of the pathophysiology and acute management of haemorrhage in pelvic fracture. Injury 37(7):602–613
20. Whitbeck MG Jr, Zwally HJ II, Burgess AR (2006) Innominosacral dissociation: mechanism of injury as a predictor of resuscitation requirements, morbidity, and mortality. J Orthop Trauma 20(1):S57–S63
21. Giannoudis PV, Grotz MR, Tzioupis C et al (2007) Prevalence of pelvic fractures, associated injuries, and mortality: the United Kingdom perspective. J Trauma 63(4):875–883
22. Holstein JH, Culemann U, Pohlemann T (2012) What are predictors of mortality in patients with pelvic fractures? Clin Orthop Relat Res 470(8):2090–2097
23. Starr AJ, Griffin DR, Reinert CM et al (2002) Pelvic ring disruptions: prediction of associated injuries, transfusion requirement, pelvic arteriography, complications, and mortality. J Orthop Trauma 16(8):553–561
24. Karadimas EJ, Nicolson T, Kakagia DD, Matthews SJ, Richards PJ, Giannoudis PV (2011) Angiographic embolisation of pelvic ring injuries. Treatment algorithm and review of the literature. Int Orthop 35(9):1381–1390
25. Cothren CC, Osborn PM, Moore EE et al (2007) Preperitonal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. J Trauma 62(4):834–839
26. Fu CY, Wang YC, Wu SC, Chen RJ, Hsieh CH, Huang HC, Huang JC, Lu CW, Huang YC (2012) Angioembolization provides benefits in patients with concomitant unstable pelvic fracture and unstable hemodynamics. Am J Emerg Med 30(1):207–213
27. Tosounidis TH, Mauffrey C, Giannoudis PV (2017) Optimization of technique for insertion of implants at the supra-acetabular corridor in pelvis and acetabular surgery. Eur J Orthop Surg Traumatol 28(1):29–35
28. Jang JY, Shim H, Jung PY, Kim S, Bae KS (2016) Preperitoneal pelvic packing in patients with hemodynamic instability due to severe pelvic fracture: early experience in a Korean trauma center. Scand J Trauma Resusc Emerg Med 24:3. https://doi.org/10.1186/s13049-016-0196-5
29. Tai DK, Li WH, Lee KY, Cheng M, Lee KB, Tang LF, Lai AK, Ho HF, Cheung MT (2011) Retroperitoneal pelvic packing in the management of hemodynamically unstable pelvic fractures: a level I trauma center experience. J Trauma 71(4):E79–E86
30. Osborn PM, Smith WR, Moore EE, Cothren CC, Morgan SJ, Williams AE, Stahel PF (2009) Direct retroperitoneal pelvic packing versus pelvic angiography: a comparison of two management protocols for haemodynamically unstable pelvic fractures. Injury 40(1):54–60
31. Schwartz DA, Medina M, Cotton BA, Rahbar E, Wade CE, Cohen AM, Beeler AM, Burgess AR, Holcomb JB (2014) Are we delivering two standards of care for pelvic trauma? Availability of angioembolization after hours and on weekends increases time to therapeutic intervention. J Trauma Acute Care Surg 76(1):134–139
32. Chiara O, di Fratta E, Mariani A, Michaela B, Prestini L, Sammartano F, Cimbanassi S (2016) Efficacy of extra-peritoneal pelvic packing in hemodynamically unstable pelvic fractures, a propensity score analysis. World J Emerg Surg 11:22–29
33. Brenner ML, Moore LJ, DuBose JJ, Tyson GH, McNutt MK, Albarado RP, Holcomb JB, Scalea TM, Rasmussen TE (2013) A clinical series of resuscitative endovascular balloon occlusion of the aorta for hemorrhage control and resuscitation. J Trauma Acute Care Surg 75(3):506–511
34. Costantini TW, Coimbra R, Holcomb JB et al (2016) AAST pelvic fracture study group. Current management of hemorrhage from severe pelvic fractures: results of an American Association for the Surgery of Trauma multi-institutional trial. J Trauma Acute Care Surg 80(5):717–723
35. Jain S, Bleibleh S, Marciniak J et al (2013) A national survey of United Kingdom trauma units on the use of pelvic binders. Int Orthop 37(7):1335–1339. https://doi.org/10.1007/s00264-013-1828-2
36. Langford JR, Burgess AR, Liporace FA et al (2013) Pelvic fractures: part 1. Evaluation, classification, and resuscitation. J Am Acad Orthop Surg 21(8):448–457
37. Pizanis A, Pohlemann T, Burkhardt M et al (2013) Emergency stabilization of the pelvic ring: clinical comparison between three different techniques. Injury 44(12):1760–1764
38. Papathanasopoulos A, Tzioupis C, Giannoudis VP et al (2010) Biomechanical aspects of pelvic ring reconstruction techniques: evidence today. Injury 41(12):1220–1227
39. Berber O, Amis AA, Day AC (2011) Biomechanical testing of a concept of posterior pelvic reconstruction in rotationally and vertically unstable fractures. J Bone Joint Surg Br 93(2):237–244
40. Langford JR, Burgess AR, Liporace FA et al (2013) Pelvic fractures: part 2. Contemporary indications and techniques for definitive surgical management. J Am Acad Orthop Surg 21(8):458–468
41. Sagi HC, Ordway NR, DiPasquale T (2004) Biomechanical analysis of fixation for vertically unstable sacroiliac dislocations with iliosacral screws and symphyseal plating. J Orthop Trauma 18(3):138–143
42. Gardner MJ, Routt ML Jr (2011) Transiliac-transsacral screws for posterior pelvic stabilization. J Orthop Trauma 25(6):378–384
43. Keating JF, Werier J, Blachut P et al (1999) Early fixation of the vertically unstable pelvis: the role of iliosacral screw fixation of the posterior lesion. J Orthop Trauma 13(2):107–113
44. Stover MD, Sims S, Matta J (2012) What is the infection rate of the posterior approach to type C pelvic injuries? Clin Orthop Relat Res 470(8):2142–2147
45. Martin MP 3rd, Rojas D, Mauffrey C (2017). Reduction and temporary stabilization of Tile C pelvic ring injuries using a posteriorly based external fixation system. Eur J Orthop Surg Traumatol. Dec 5. https://doi.org/10.1007/s00590-017-2104-8
46. Suzuki T, Hak DJ, Ziran BH et al (2009) Outcome and complications of posterior transiliac plating for vertically unstable sacral fractures. Injury 40(4):405–409
47. Reilly MC, Bono CM, Litkouhi B et al (2006) The effect of sacral fracture malreduction on the safe placement of iliosacral screws. J Orthop Trauma 20(1):S37–S43

48. Camino WG, Zderic I, Gras F et al (2016) Analysis of sacro-iliac joint screw fixation: does quality of reduction and screw orientation influence joint stability? A biomechanical study. Int Orthop 40(7): 1537–1543. https://doi.org/10.1007/s00264-015-3007-0
49. Lindahl J, Hirvensalo E (2005) Outcome of operatively treated type-C injuries of the pelvic ring. Acta Orthop 76(5):667–678
50. Moed BR, O'Boynick CP, Bledsoe JG (2014) Locked versus standard unlocked plating of the symphysis pubis in a type-C pelvic injury: a cadaver biomechanical study. Injury 45(4):748–751
51. Harvey-Kelly KF, Kanakaris NK, Obakponovwe O, West RM, Giannoudis PV (2014) Quality of life and sexual function after traumatic pelvic fracture. J Orthop Trauma 28(1):28–35
52. Van Zwienen CM, van den Bosch EW, Snijders CJ et al (2004) Biomechanical comparison of sacroiliac screw techniques for unstable pelvic ring fractures. J Orthop Trauma 18(9):589–595
53. Albert MJ, Miller ME, MacNaughton M et al (1993) Posterior pelvic fixation using a transiliac 4.5-mm reconstruction plate: a clinical and biomechanical study. J Orthop Trauma 7(3):226–232
54. Giannoudis PV, Tzioupis CC, Pape HC et al (2007) Percutaneous fixation of the pelvic ring: an update. J Bone Joint Surg Br 89(2: 145–154
55. Hao T, Changwei Y, Qiulin Z (2009) Treatment of posterior pelvic ring injuries with minimally invasive percutaneous plate osteosynthesis. Int Orthop 33(5):1435–1439
56. Schildhauer TA, Ledoux WR, Chapman JR et al (2003) Triangular osteosynthesis and iliosacral screw fixation for unstable sacral fractures: a cadaveric and biomechanical evaluation under cyclic loads. J Orthop Trauma 17(1):22–31
57. Sagi HC, Militano U, Caron T et al (2009) A comprehensive analysis with minimum 1-year follow-up of vertically unstable transforaminal sacral fractures treated with triangular osteosynthesis. J Orthop Trauma 23(5):313–319
58. Papakostidis C, Kanakaris NK, Kontakis G et al (2009) Pelvic ring disruptions: treatment modalities and analysis of outcomes. Int Orthop 33(2):329–338
59. Burlew CC, Moore EE, Mauffrey C, Stahel PF et al (2017) Preperitoneal pelvic packing reduces mortality in patients with life-threatening hemorrhage due to unstable pelvic fractures. J Trauma Acute Care Surg 82(2):233–242
60. Poelstra KA, Kahler DM (2005) Supra-acetabular placement of external fixator pins: a safe and expedient method of providing the injured pelvis with stability. Am J Orthop (Belle Mead NJ) 34(3):148–151
61. Ponsen KJ, Joosse P, Van Dijke GA et al (2007) External fixation of the pelvic ring: an experimental study on the role of pin diameter, pin position, and parasymphyseal fixator pins. Acta Orthop 78(5): 648–653