4 Pelvic Lateral Compression Fracture Patterns

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Anatomical Fracture Location: Radiograph of Fracture Pattern

The lateral compression (LC) pelvic injuries are a result of lateral force vectors according to the Young and Burgess classification system [1].

They represent about 80% of all pelvic ring injuries.

The LC pelvic injuries are divided into three subtypes:

- **Lateral compression type 1 (LC1)** characterised by:
  - Fractures of the sacrum medial to the sacroiliac joint (at a single or both sides; at any of the zones of the sacral wing according to Denis classification [2]).
  - Oblique fractures of the pubic rami (maybe ipsilateral or contralateral to the sacral fracture/s, or bilateral; these can affect any of the zones of the rami as per Nakatani classification [3] and even propagate to the symphysis pubis).
- **Lateral compression type 2 (LC2)** characterised by:
  - Fractures of the iliac wing (at one side, or rarely at both sides). The fracture of the iliac wing may affect to various extent the ipsilateral sacroiliac joint [4] leaving a crescent-shaped part of the ilium attached to the strong posterior sacroiliac ligaments.
  - Oblique fractures of the pubic rami (maybe ipsilateral or contralateral to the sacral fracture, or bilateral). They can affect any of the zones of the rami as per Nakatani classification [3].

When a crescent fracture is associated with a rupture of the symphysis pubis, then the pelvic injury should be most likely classified as an anteroposterior compression (APC3) or combined mechanism of injury (CMI) type of trauma.

- **Lateral compression type 3 (LC3)**:
- This subtype represents the most severe trauma in comparison to the LC1/2. It is an injury that results from a combination of force vectors (combined mechanism of injury—CMI). Typically, it is a result of a rollover trauma of a pedestrian versus vehicle. Due to its appearance, this subtype is also called windswept pelvis. More specifically:
- One side of the pelvis is subjected to a lateral compression force vector (typically producing a comminuted unilateral LC1 injury), and the

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P. V. Giannoudis (ed.), *Fracture Reduction and Fixation Techniques*,
https://doi.org/10.1007/978-3-030-24608-2_4

other hemipelvis is subjected to an anteroposterior compression force vector (typically producing an APC2–3 injury).
- Due to the significant differences between these three types of lateral compression fractures, this chapter is structured under three different subheadings.

LC1 Pelvic Injury

These injuries are a result of flexion/internal rotation of the hemipelvis (61-B1.2 according to the OTA classification). The presence of oblique fracture/s of the pubic rami, as well as a crush/compressed/buckling fracture of the sacrum, is the telltale sign of an LC1 injury.

LC2 Pelvic Injury

These types of pelvic trauma are rotationally and to a degree vertically unstable injuries (type C per Tile/AO-OTA classification). Due to the typically intact sacrotuberous and sacrospinous ligaments, the vertical displacement of the hemipelvis is limited [5]. Operative intervention is recommended for the vast majority of these injuries aiming for anatomical reduction and stable fixation.

LC3 Pelvic Injury

These types of pelvic trauma are complex in nature and represent a combined mechanism of injury (one side suffers lateral compression and the contralateral hemipelvis an anteroposterior compression), resulting to severe pelvic ring deformity, a mechanically unstable in rotation pelvic disruption, with often severe associated intrapelvic injuries. Operative intervention is most commonly necessary after the initial resuscitation and assessment of the patient.

Following the wide adoption of pelvic binders, even from the prehospital stages, caution is advised as the disruption/widening of the sacroiliac joint may be masked (especially if the posterior SI ligaments/posterior hinge is intact), and the LC3 injury can be initially misunderstood as a pure lateral compression type 1. The release of the binder and a secondary anteroposterior pelvic x-ray, or the presence of haematoma at the pre-sacroiliac joint space at the CT scan, or the widening of the sacroiliac joint during screening the pelvis in distraction can all assist on the correct characterisation of these lesions.

Brief Preoperative Planning

Preoperative planning should always include the careful assessment of the soft tissues around the pelvis and the perineal area, a neurological examination of the motor and sensory function of the lower extremities and the perineum (exempting unconscious patients), a digital rectal examination in all occasions and, if indicated (evidence of vaginal blood), a bimanual examination to exclude the presence of an open pelvic fracture.

The review of the available imaging including the CT scan/CT cystogram will allow the assessment of the specifics of the pelvic fractures and the characteristics of the pelvic ring deformity.

LC1 Pelvic Injury

These are very common pelvic injuries and are considered as mechanically stable in most of cases, but not always. This mainly depends on the amount of energy absorbed at the time of injury and the quality of bone stock. As previously reported, the subcategory of mechanically unstable LC1 pelvic fractures (i.e. requiring fixation) can be verified radiologically using specific radiologic findings [6, 7]; clinically by mobilising the patient under supervision, monitoring the level of pain experienced; or, more accurately and as previously published, following manipulation under anaesthesia [8, 9] (Fig. 4.1).

The presence of soft tissue injuries (Morel-Lavallee internal degloving, open wounds, contaminated pin sites at the iliac crest from the

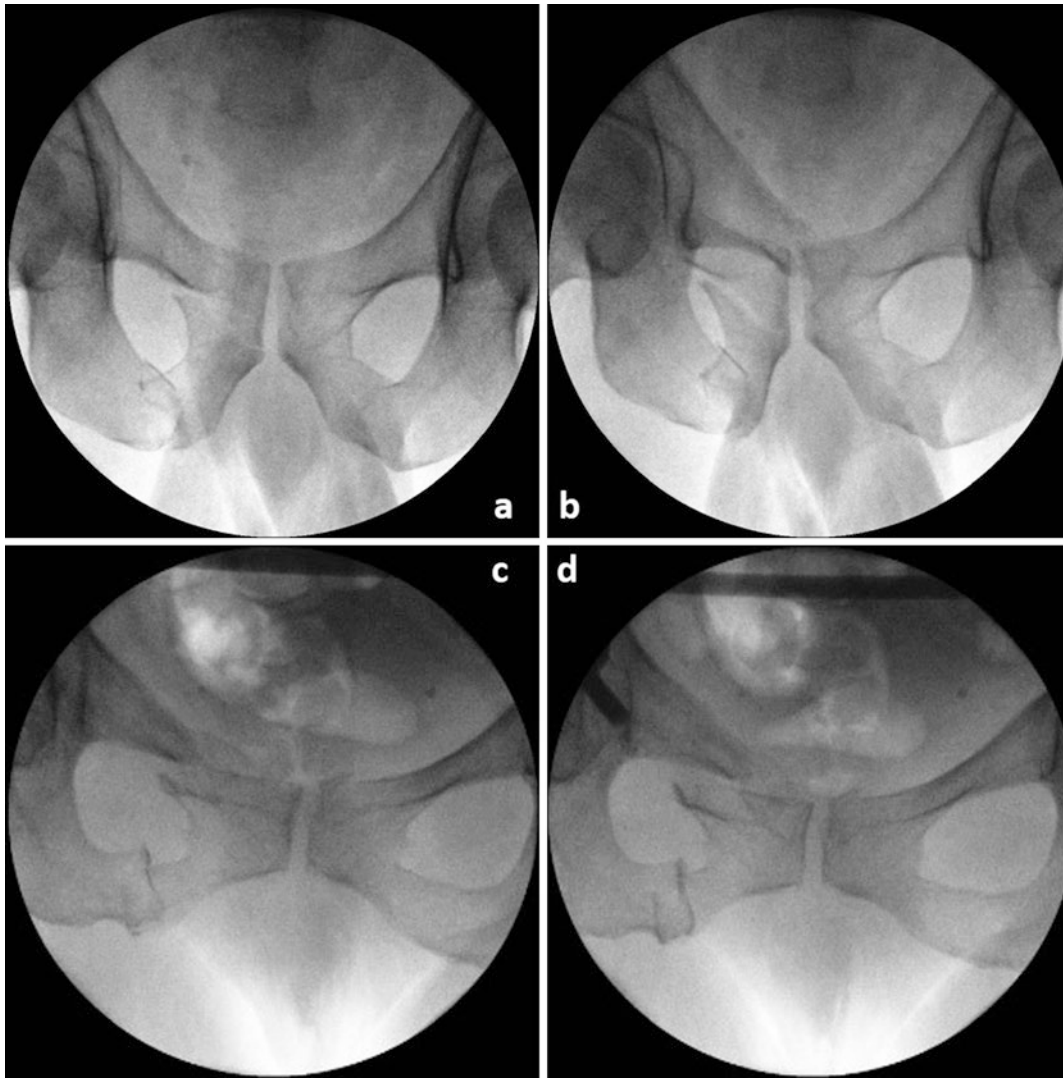

Fig. 4.1 Manipulation under anaesthesia (MUA) of a lateral compression injury. (**a**, **c**) Forcing external rotation/distraction—the oblique rami fracture reduced in length. (**b**, **d**) Forcing internal rotation/compression—the oblique superior rami fracture overlapping

insertion of damage control external fixators) often dominates the local clinical picture and dictates the surgical approach, as well as the fixation methods (Fig. 4.2).

Furthermore, the presence of neurological deficit of the lower extremities and the radiologic evidence of extensive comminution of the sacrum at the S1 sacral wing or foramina level with impinging fragments on the L5, S1 and S2 levels may also dictate different reduction/fixation strategies.

Clinical and radiologic evidence of bladder or urethral injuries may also dictate a different surgical approach, optimally at the preoperative planning stages.

LC2 Pelvic Injury

The degree of mechanical instability of the LC2 pelvic fractures, in most of the cases, dictates operative management. LC2 pelvic fractures

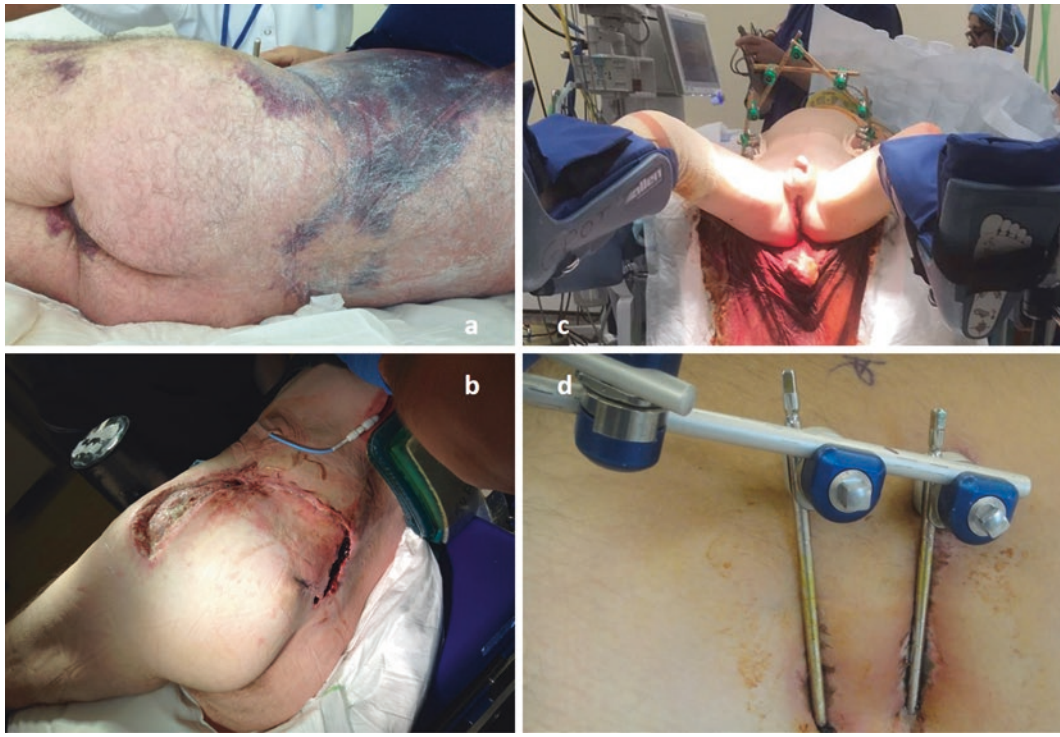

Fig. 4.2 Compromised soft tissues following pelvic trauma. (**a**) Extensive flank haematoma. (**b**) Morel-Lavallee lesion of a lateral compression pelvic injury. (**c**) Open pelvic fracture with perineal wound and urethral transection. (**d**) Infected pin sites and pressure sores at the iliac crest external fixator 3 days post their insertion

represent a spectrum of different injuries regarding the extent and comminution of the iliac wing, the degree of involvement of the sacroiliac joint, the type of anterior pelvic ring involvement as well as the condition of the overlying soft tissues.

The presence of soft tissue injuries (Morel-Lavallee internal degloving, open wounds, contaminated pin sites at the iliac crest from the insertion of damage control external fixators) often dominates the local clinical picture and dictates the surgical approach, as well as the fixation methods (Fig. 4.2).

According to the analysis of 16 LC2/crescent fractures by Day et al., and the classification system they introduced in 2007 [4], the degree of involvement of the sacroiliac joint, or else the size of the intact crescent fragment of the posterior ilium, can be used as an indicator of different management strategies.

More specifically, **type I fractures**, involving less than 1/3 of the sacroiliac joint, may benefit from direct exposure via the lateral window of an ilioinguinal approach (open reduction and plate internal fixation crossing the sacroiliac joint); **type II fractures**, involving between 1/3 and 2/3 of the sacroiliac joint, may be better managed with a posterolateral subgluteal approach and indirect reduction of the sacroiliac joint disruption (open reduction and plate internal fixation based at the outer iliac cortex); and **type III fractures** with the most extensive disruption of the sacroiliac joint, leaving a small superoposterior crescent fragment, can be attempted to be reduced by closed means and fixed with percutaneous iliosacral lag screws.

However, in my experience, the condition of local soft tissues, the ability to get the sacroiliac joint accurately reduced by indirect methods (or not, especially if delays to surgery have been

imposed for any reason) or even the presence of an ipsilateral acetabular fracture are mostly the parameters that dictate which operative strategy to follow (i.e. direct exposure and plate fixation using the lateral window of the ilioinguinal +/− iliosacral fixation OR indirect reduction and iliosacral screw fixation OR subgluteal posterolateral approach and plate fixation over the posterolateral ilium).

LC3 Pelvic Injury

Preoperative planning includes the correlation of all findings from the clinical examination and the imaging assessment. The challenge into these specific subtypes of pelvic fractures is that there is no uninjured side that can be used as a stable reference point. Rotation of one hemipelvis to reduce that deformity will result to exacerbation of the deformity of the contralateral side, as typically one represents an internal rotation injury and the other an external rotation one.

A careful stepwise approach is recommended to allow the reduction manoeuvres to have the desired result.

The condition of soft tissues, as well as the presence of local associated trauma, may dictate the surgical approach and fixation strategies, as analysed later in this chapter.

Patient Set-Up in Theatre

LC1 Pelvic Injury

The operation room is prepared so that it includes the anaesthetic machine, a radiolucent table, an image intensifier system (I/I), the Flowtron pump, the suction and the diathermy trailer. These are positioned around the laminar flow tent (except from the operating table and the trolleys with the surgical kit, which are under the tent).

- The patient is positioned *supine* in most of the occasions. The arms of the patient are positioned in crucifix position. Care is taken in order to have the patient well aligned to the long axis of the table. If the injury is unilateral to the sacrum, then aim to position the patient closer to the lateral end of the table at the side of the injury.
- Rarely, in neglected cases or in nonunions/malunions/revision surgeries, a *prone position* may be indicated, which allows direct access to the sacrum via a posterior approach [10]. If such an approach is decided, certain precautions should be taken to support the patient and to protect bony prominences with pressure relief gel pads (shoulders, axillae, elbows, nipples, breasts, genitalia). The neck/head needs to be supported and positioned in a neutral position, as well as the arms positioned so as to avoid stretching the brachial plexus (abducted shoulders >90°). To maximise access to the pelvis, the abdomen needs to be allowed to hang free in a dependent position (using paddings/pillows/bolsters).
- Axial traction is not required in these types of fractures, as these are only rotationally unstable injuries with no vertical displacement or elements of instability to that axis.
- The anaesthetic machine is positioned at the head of the patient.
- The screen of the I/I is positioned at the feet of the patient.
- The C-arm of the I/I is positioned at the contralateral side of the injured one (if the injury is unilateral; if it is bilateral, it remains at the discretion of the surgeon, but most commonly, the C-arm is positioned at the less injured side and may require its relocation to the contralateral side in the process of the surgery).
- The surgeon and the scrub nurse are positioned at the side of the injury (if the injury is unilateral; if it is bilateral, it remains to the discretion of the surgeon, but most commonly, they are positioned at the side of the most unstable part/the most injured side).
- The assistant surgeon is usually positioned during draping at the other side of the surgeon and, commonly during percutaneous procedures under I/I guidance, is relocated next to the surgeon and the scrub nurse, leaving the other side to the C-arm and the radiographer.

LC2 Pelvic Injury

The operation room is prepared so that it includes the anaesthetic machine, a radiolucent table, an image intensifier system (I/I), the Flowtron pump, the suction and the diathermy machine and the cell salvage equipment.

These are positioned around the laminar flow tent (except from the operating table and the trolleys with the surgical kit, which are under the tent).

- The patient can be positioned most commonly supine, but also can be in prone or even in a lateral position. This depends on the surgical approach chosen to address the crescent fracture (if the sacroiliac joint is affected), i.e. lateral window of ilioinguinal OR subgluteal posterolateral approach.
- *If in supine position*, the arms of the patient are positioned in crucifix position. Care is taken to have the patient well aligned to the long axis of the table. Aim to position the patient closer to the lateral end of the table at the side of the injury.
- Skeletal or foot boot traction can be useful, as these fractures are vertically and rotationally displaced. If this is chosen, a well-padded perineal post is inserted at the table, as well as the contralateral leg is attached to a traction boot so that it prevents the shift of the patient's body towards the injured side when axial traction is applied. There are other systems of axial traction that can be utilised depending on their availability and the surgeon's preference, including table frames, the STAR frame, external fixators and even the femoral distractor.
- If the subgluteal posterolateral approach is chosen, then the patient can be positioned *prone or lateral*, as long as all precautions are taken supporting the patient and protecting bony prominences with pressure relief gel pads (shoulders, axillae, elbows, nipples, breasts, genitalia). The neck/head needs to be supported and positioned in a neutral position as well as the arms positioned so as to avoid stretching the brachial plexus (abducted shoulders >90°). To maximise access to the pelvis in the prone position, the abdomen needs to be allowed to hang free in a dependent position (using paddings/pillows/bolsters).
- Care should be also taken during draping so that axial traction can be achieved.
- The anaesthetic machine is positioned at the head of the patient.
- The screen of the I/I is positioned at the feet of the patient.
- The C-arm of the I/I is positioned at the contralateral side of the injured ilium (if the injury is unilateral; if it is bilateral, it remains to the discretion of the surgeon, but most commonly, the C-arm is positioned, at least at the beginning, at the less injured side).
- The surgeon and the scrub nurse are positioned at the side of the injury (if the injury is unilateral; if it is bilateral, it remains to the discretion of the surgeon, but most commonly, the surgeon starts positioned at the most unstable part/the most injured side).
- The assistant surgeon is usually positioned at the other side of the surgeon, and during the phases of using the I/I guidance, he/she relocates carefully to allow access to the C-arm and the radiographer.

LC3 Pelvic Injury

The operation room is prepared so that it includes the anaesthetic machine, a radiolucent table, an image intensifier system (I/I), the Flowtron pump, the suction and the diathermy trailer and the cell salvage equipment.

These are positioned around the laminar flow tent (except for the operating table and the trolleys with the surgical kit, which are under the tent).

- The patient can be positioned most commonly *supine*.
- The arms of the patient are positioned in crucifix position. Care is taken in order to have the patient well aligned to the long axis of the

table. Aim to position the patient closer to the lateral end of the table at the side of the injury.
- The anaesthetic machine is positioned at the head of the patient.
- The screen of the I/I is positioned at the feet of the patient.
- The C-arm of the I/I is positioned usually at the contralateral side of the widened sacroiliac joint, but since LC3 pelvic fractures represent bilateral pelvic ring injuries, it remains to the discretion of the surgeon.
- The surgeon and the scrub nurse are positioned at the contralateral side from the C-arm.
- The assistant surgeon is usually positioned at the other side of the surgeon during the surgical approach and the open reduction internal fixation manoeuvres. During the phases of using the I/I guidance, or when closed reduction fluoroscopic guided fixation techniques are applied, he/she relocates carefully to allow access to the C-arm and the radiographer.
- Rarely, in neglected cases or in nonunions/malunions/revision surgeries, the *prone position* is indicated, which allows direct access to the sacrum via a posterior approach [10]. If such an approach is decided, certain precautions should be taken to support the patient and to protect bony prominences with pressure relief gel pads (shoulders, axillae, elbows, nipples, breasts, genitalia). The neck/head needs to be supported and positioned in a neutral position, as well as the arms positioned so as to avoid stretching the brachial plexus (abducted shoulders >90°). To maximise access to the pelvis, the abdomen needs to be allowed to hang free in a dependent position (using paddings/pillows/bolsters).

Closed Reduction Manoeuvres

LC1 Pelvic Injury

In the clear majority of LC1 cases that undergo operative treatment, indirect reduction techniques are used.

Anteroposterior pelvic and inlet views are quite useful to demonstrate the degree of rotational instability intraoperatively (manipulation under anaesthesia, MUA) (Fig. 4.1), as well as the restoration of the anatomy following reduction [8, 9].

However, quite often the deforming forces are applied in more than one planes, resulting in obliquely orientated fractures requiring the application of oblique reduction forces to restore the anatomy. In these cases, the combination of pins at the anterior iliac crest at the healthy side and of a supra-acetabular half pin at the side of internal rotation and flexion allows the realignment of the pelvic ring using an oblique distracting external fixation as nicely described in 2012 [11] (Fig. 4.3).

Fig. 4.3 Combined pelvic external fixator, with oblique distracting bar (*yellow arrows*) applied initially reducing a vertical and rotationally deformed hemipelvis, combined with a standard triangular alpha frame

Segmental fragments of the rami, or rare conditions (as the locked symphysis), can be reduced by indirect methods (using of distracting external fixator or positioning the extremity in a figure-of-four position, respectively) but most commonly require an open reduction using joystick manoeuvres, leavers or direct visualisation and use of reduction clamps (Figs. 4.4 and 4.5).

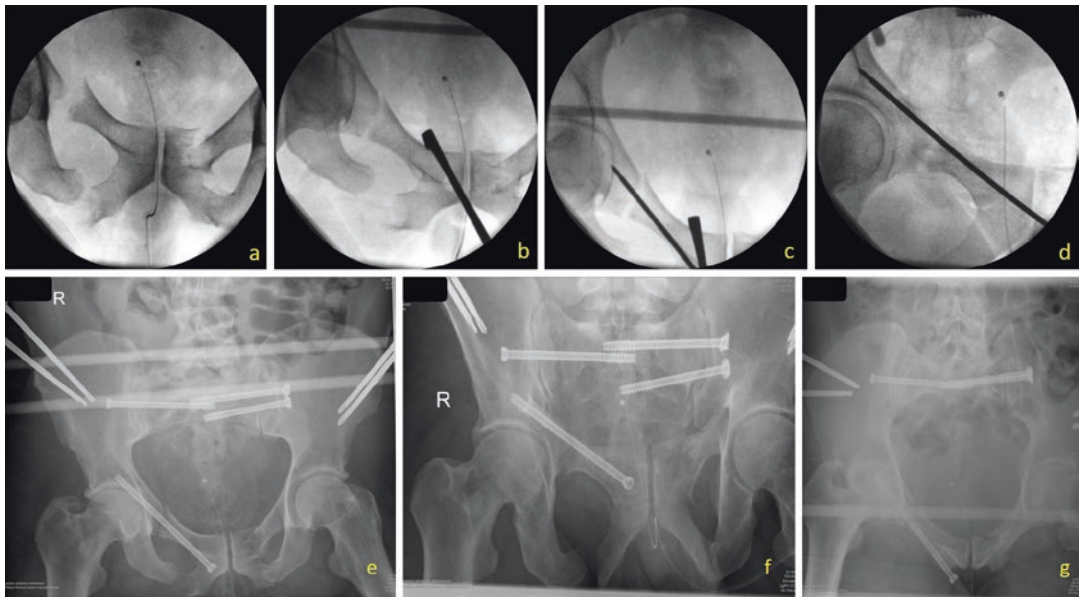

Fig. 4.4 Mini-open reduction of displaced bilateral rami fractures (right Nakatani type III and left type I (**a**)) with the use of a small Langenbeck retractor (**b**, **c**) and a distracting iliac crest external fixator. Reduction of the alignment of the pelvic ring and fixation with a right retropubic cannulated lag screw 6.5 mm (**d**–**f**), as well as a combination of bilateral iliosacral screws. Maintenance of the external fixator for the first 4–6 weeks until evidence of callus formation at the anterior pelvic ring

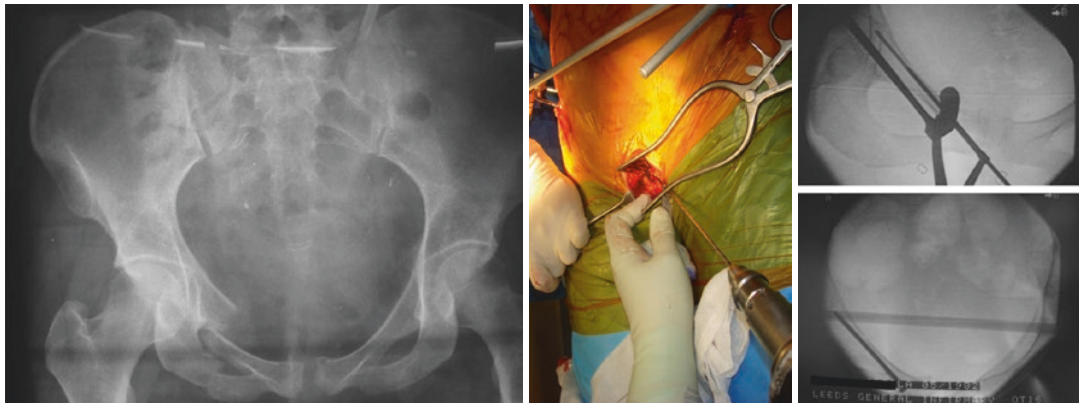

Fig. 4.5 Use of the iliac crest external fixator as a reduction tool, mini-open approach over the pubic tubercle and use of the Langenbeck retractor and a joystick facilitating the reduction of the rami and subsequently fixation using a long 3.5 mm screw due to the narrow canal of the superior ramus

LC2 Pelvic Injury

Axial traction via a Denham pin at the distal femur can facilitate fracture reduction from the cranial migration of the iliac wing.

Hip flexion (if in supine position and using the lateral window of the ilioinguinal approach) relaxes the iliopsoas musculature and facilitates dissection and exposure of the iliac fossa and the sacroiliac joint (Fig. 4.6).

LC3 Pelvic Injury

Most commonly, the first lesion to address is the disrupted SI joint, as it represents a challenging ligamentous type of injury, which can lead into chronic pain and instability if left malreduced or not well fixed. At the same time in most of the occasions, its anatomic reduction and fixation can be achieved with closed/mini-invasive techniques and the use of iliosacral lag screw fixation, thus with minimal distress of the patient's physiology and blood loss (Fig. 4.7).

Use of an external pelvic fixator in compression mode (closing the book), having the legs in internal rotation and tightened together and

Fig. 4.6 Hip flexion in supine is maintained using a sizeable support pillow in order to relax the iliopsoas muscle and facilitate dissection at the iliac fossa and reduction of the ilium

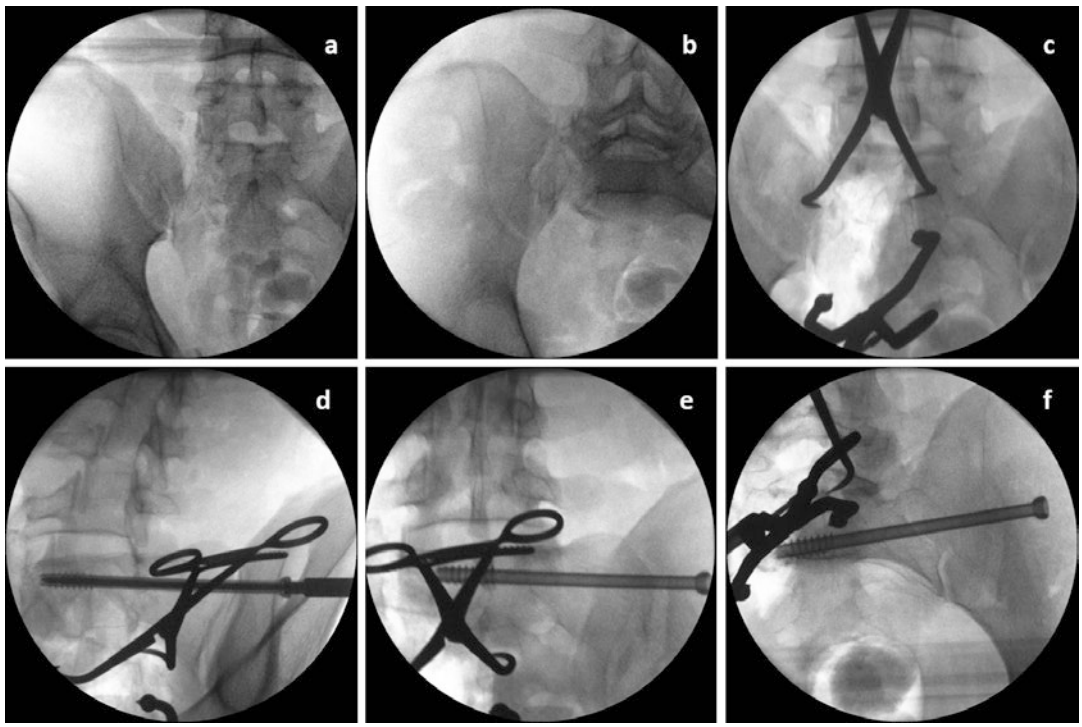

Fig. 4.7 Example of LC3 pelvic injury with right sacral comminution and a left sacroiliac joint disruption (**a**–**c**). The patient was operated in prone position and following a temporary control of the right sacral fracture with a Weber clamp (**c**). Then the definitive reduction/fixation of the LC3 pelvic fracture starts with a percutaneously inserted left S1 iliosacral 8.0 mm lag screw (**d**–**f**)

Fig. 4.8 Use of the C-clamp as a reduction tool, allowing the mini-invasive closure of the widened sacroiliac joint (mostly helpful in APC2–3 injuries but can be useful for LC3 fractures as well)

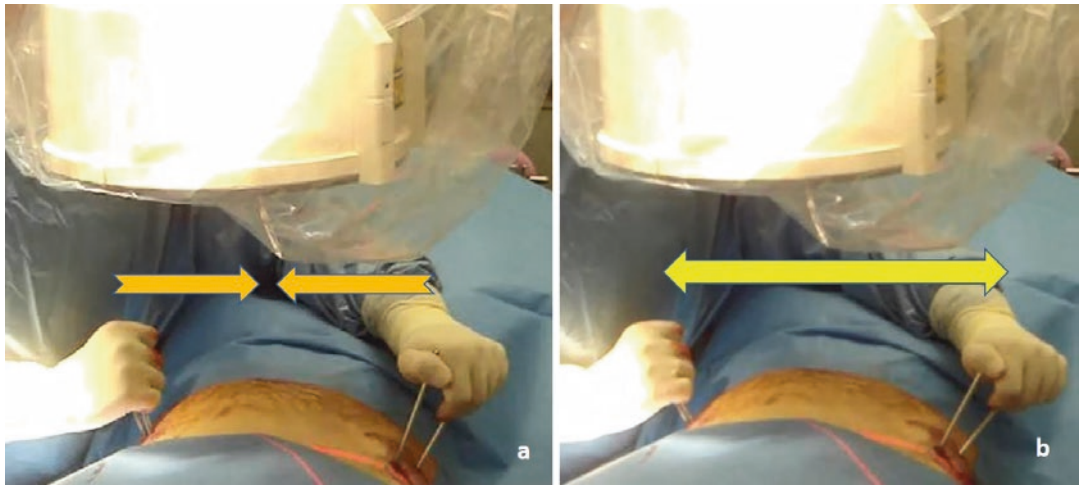

Fig. 4.9 Use of the half pins (5.0 mm ×2) of an iliac crest external fixation for a manipulation under anaesthesia and potential reduction of a rotationally unstable pelvic ring (Fig. 4.7a, screening of the pelvis in internal rotation (orange arrows); Fig. 4.7b, in external rotation (yellow arrows))

sometimes using the pelvic C-clamp as a maxi peri-tongue clamp (Fig. 4.8) can all provide closed or mini-invasive means of reduction of the disrupted sacroiliac joint. The lag effect of the partially threaded iliosacral screws tightened sequentially provides further compression and final reduction and stable fixation of that hemipelvis.

After the completion of the reduction/fixation of the sacroiliac joint, the contralateral internally rotated hemipelvis can be addressed using the external fixator as now means of distracting the pelvic ring, addressing the side deformed in internal rotation (Fig. 4.9).

Reduction Instruments

In general, a wide range of clamps (Farabeuf, Weber, 2 × 1/1 × 1 jaws reduction forceps, Matta reposition clamps) from the pelvic kit, a combination of Schanz pins as joysticks, sandbags and the traction table can all assist to the reduction (Fig. 4.10).

5.0–6.0 mm half pins for the iliac crest or supra-acetabular corridors (Fig. 4.9) and 4.0–5.0 mm half pin at the pubic tubercle can be used in conjunction to an iliac crest half pin to distract the rami fracture and regain its length in a displaced internally rotated hemipelvis.

Fig. 4.10 Set of standard reduction instruments useful to pelvic surgery. (**a**) Pusher/ball spike with pointed ball tip and disks/washers; (**b**) 5.0 mm Schanz pin; (**c**) Farabeuf clamps medium and large; (**d**) Weber universal point clamps; (**e**) long asymmetrical reduction forceps; (**f**) long reduction forceps 2 × 1 jaws; (**g**) straight and angled Matta reposition forceps

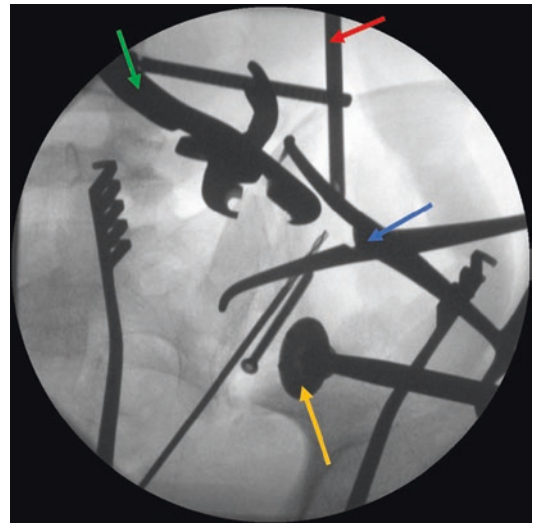

Fig. 4.11 Image intensifier view of a left crescent—LC2 pelvic fracture addressed via a subgluteal approach in prone. Red arrow Schanz pin at the ilium used as a joystick; blue arrow Weber clamp over the posterior iliac crest; orange arrow Pointed ball spike with washer disk; green arrow Farabeuf clamp used as bone-holding clamp of the small crescent fragment at the posterior ilium

- Schanz pins can be used to control external rotation of the ilium (Fig. 4.11).
- Weber clamp/pointy reduction forceps can be useful anchoring over the iliac crest via shallow drill holes (Fig. 4.11).
- Farabeuf clamp can be useful for the manipulation of the iliac wing by grasping over the iliac crest (Fig. 4.11).
- Farabeuf clamp can be also useful as a reduction forceps with provisional screws (for example, across the sacroiliac joint providing reduction and compression of the dislocated joint) (Fig. 4.12).
- The long asymmetric reduction clamp can be useful, when the lateral window of the ilioinguinal approach is used, anchoring with a washer at the outer iliac cortex and at the supero-anterior corner of the sacral lateral mass at the S1 level (Fig. 4.13).
- After the completion of the posterior ring fixation, the anterior ring can be sometimes addressed with the use of a pelvic external fixator in distraction mode (reversing the deforming forces of a lateral compression mechanism) to reduce and infrequently also to stabilise the anterior ring elements (rami/symphysis fractures) if the state of the local soft tissues does not allow safe internal fixation or in order to avoid an extensive surgical approach. More often, mini-invasive retropubic (Figs. 4.4 and 4.5) or antegrade anterior column screw fixations (Fig. 4.14) are offered to supplement the fixation of the posterior lesions or else open reduction plate fixation of the anterior pelvic ring (especially in the presence of symphysis pubis disruption).

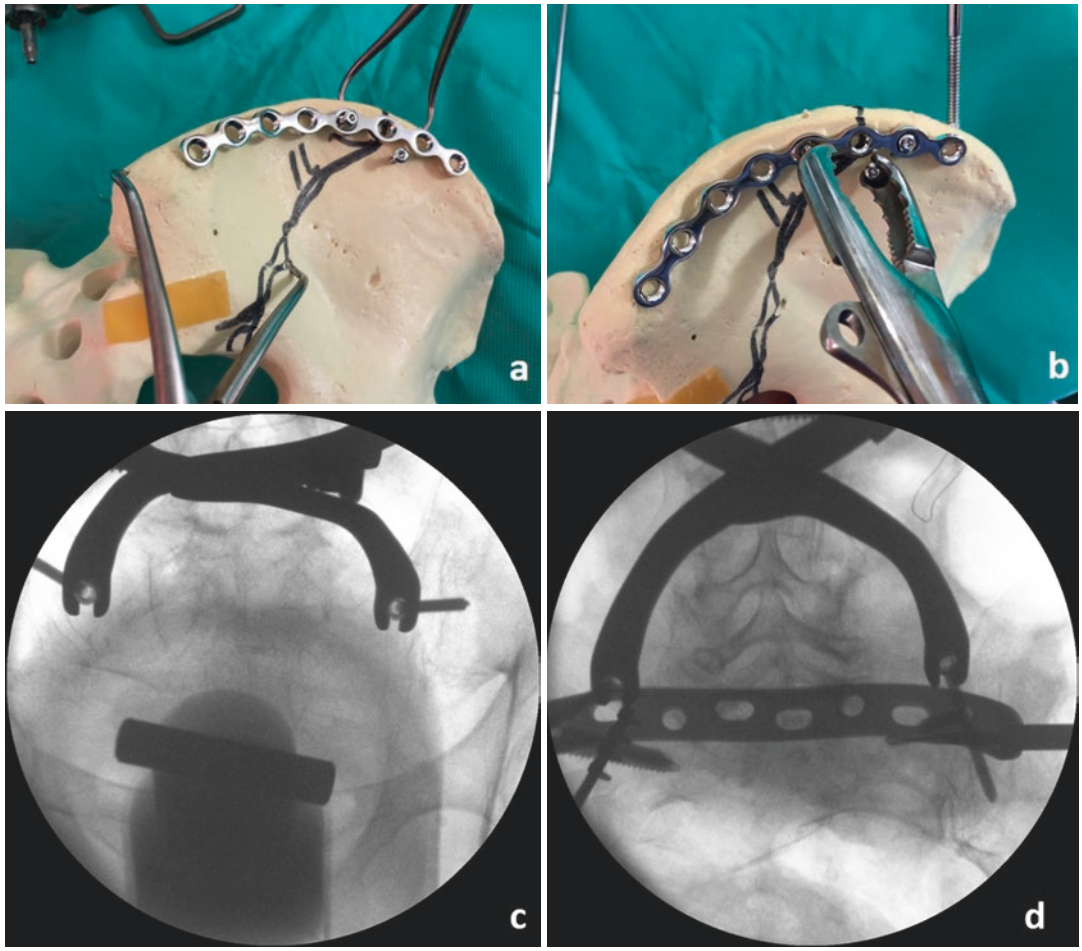

Fig. 4.12 Use of the Farabeuf or the Jungbluth clamp with a 3.5 or 4.5 mm screws as a reduction tool of the ilium allows the control of two fragments in three planes (can be also useful on the reduction of the sacroiliac joint via an anterior approach or of the symphysis pubis (in APC injuries)). (**a**, **b**) demonstrate in a saw bone model the use of Weber clamp, a Schanz pin, and Farabeuf clamp to manipulate and compress an iliac crest fracture (access via a subgluteal approach in prone or lateral decubitus—useful for crescent/LC2 fractures). Neutralisation plate (contoured 3.5 mm reconstruction plate) offers the means of fixation. Observe the use of 1 free screw as the second anchor of the Farabeuf clamp, which facilitates the insertion of the fixation screws through the plate with limited exposure besides the presence of the bulky Farabeuf clamp. (**c**) shows image intensifier views with the patient in prone position and the insertion of 4.5 mm screws into the right and left posterior superior spines which slot into the Jungbluth jaws allowing the manipulation of the posterior pelvis into reduction and the insertion of a posterior tension band plate, (**d**), in a bilateral comminuted LC1 pelvic fracture

Surgical Approach

LC1 Pelvic Injury

As mostly closed reduction techniques are applied or mini-invasive assisted reduction methods using the iliac crest or the supra-acetabular corridors for the insertion of half pins and external fixators for the reduction in external rotation/distraction of the pelvic ring, the description of the surgical approach is obvious and well described in the following articles [12, 13].

LC2 Pelvic Injury

The lateral window of the ilioinguinal approach, or else called Avila approach [14], is the workhorse of approaches for the reduction and fixa-

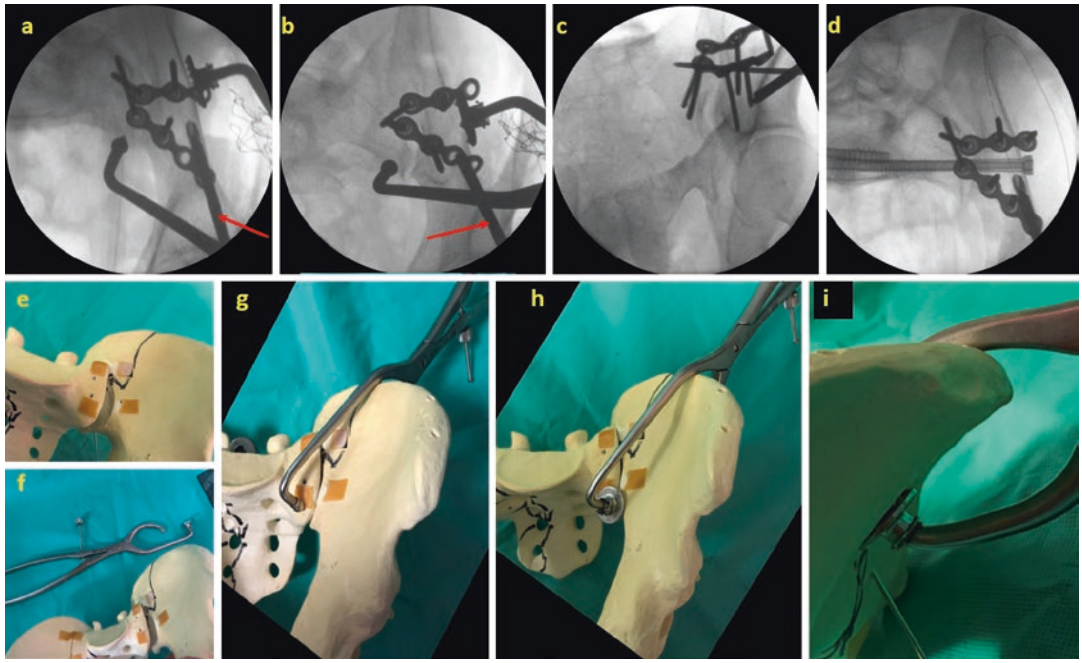

Fig. 4.13 Use of the long asymmetric reduction clamp (**f**) in a clinical case as demonstrated in sequential image intensifier views (**a**, **b**). Patient in supine position, approach via the iliac fossa, use of a supra-acetabular Schanz 6.0 mm pin as a reduction joystick (red arrow), application of two reconstruction plates bridging the left sacroiliac joint and a left S1 iliosacral lag 8.0 mm screw for the reduction of the crescent fracture/dislocation (**c**, **d**). In the series of photographs from a saw bone demonstration of an LC3 pelvic fracture (left crescent fracture/dislocation and right sacral ala fracture, (**e**)). Application of the asymmetric clamp (**f**) via the iliac fossa window anchoring with (**h**) or without (**g**) a washer disc at the superior-anterior corner of the left S1 sacral ala and at the outer iliac table (**i**)

tion of the iliac wing fracture, as well as for the reduction and fixation of the sacroiliac fracture/dislocation (in the case of a crescent fracture). In supine position, on a radiolucent table, often a mild tilt of the table to the contralateral site (to displace medially the bulk of the abdomen) and ipsilateral hip flexion (to relax the iliopsoas muscle permitting easier dissection anteriorly) allow comfortable access to the iliac fossa, the inner table of the iliac wing and the sacroiliac joint.

In a prone or even lateral position, a subgluteal posterolateral approach allows access over the outer posterior iliac wing, direct visualisation of the fracture lines between the iliac wing and the intact crescent fragment and fracture reduction and fixation at the exposed surface of the iliac crest and the lateral cortex of the ilium. Indirect reduction of the sacroiliac joint is expected, if anatomic reduction and stable fixation of the fragments of the iliac wing are achieved. Furthermore, and if required, compression of the sacroiliac joint can be achieved with the insertion of iliosacral lag screw/s under fluoroscopy guidance.

LC3 Pelvic Injury

When a closed reduction of the widened SI joint is not feasible or ineffective (delayed presentation, loss of the posterior hinge and severe displacement), open reduction manoeuvres are often employed, which obviously require an open surgical approach. The lateral window of the ilioinguinal approach, or else called Avila approach, is commonly used in these scenarios [14]. In supine position, on a radiolucent table, often a mild tilt of the table to the contralateral site (to displace medially the bulk of the abdomen) and ipsilateral hip flexion (to relax the iliopsoas muscle permitting easier

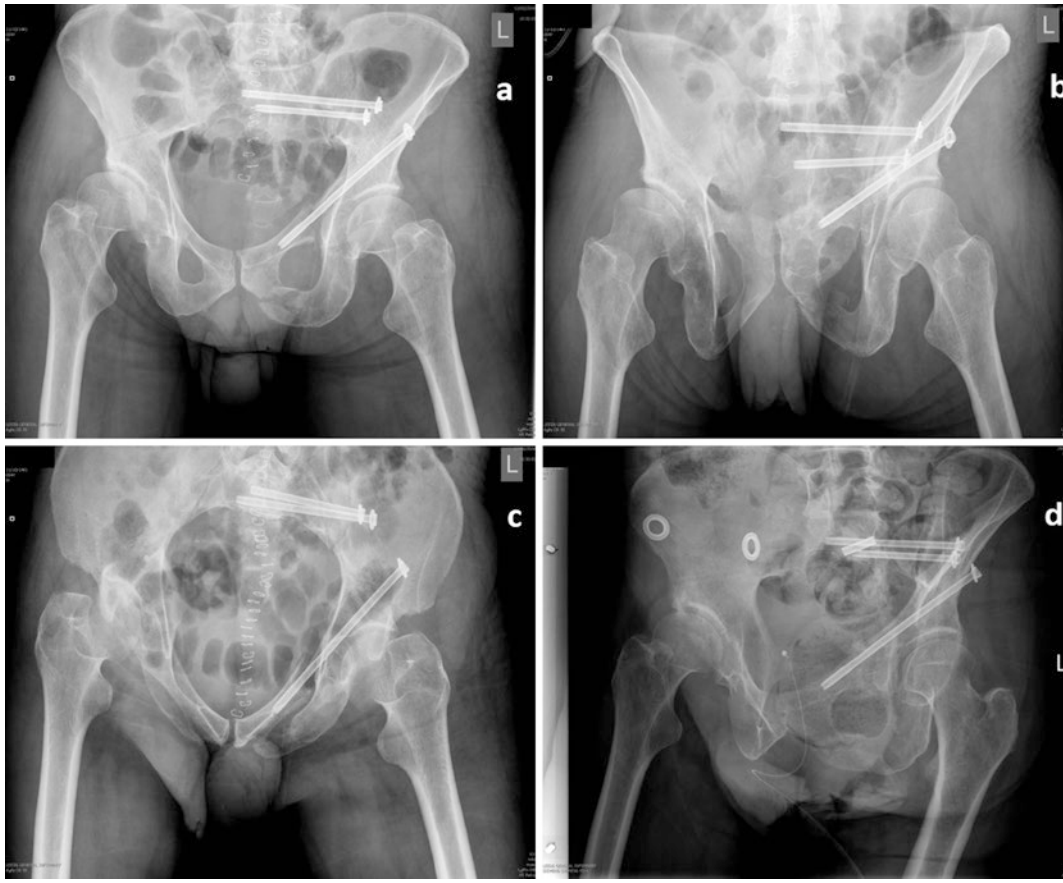

Fig. 4.14 Immediate postoperative films (outlet, anteroposterior, inlet) of a polytrauma patient with a head injury and complex visceral intra-abdominal trauma as well as a unilateral LC1 pelvic fracture—treated with MUA, followed by closed reduction and percutaneous fixation including a left antegrade anterior column 6.5 mm cannulated lag screw and two left 8.0 mm iliosacral screws

dissection anteriorly) allow comfortable access to the iliac fossa, the inner table of the iliac wing and the sacroiliac joint.

Another option in these case scenarios (delayed presentation, loss of the posterior hinge and severe displacement) is to position the patient prone in a radiolucent table utilising a posterior surgical approach and open or mini-open assisted reduction techniques. As far as the surgical approach in prone position, two options are most commonly employed. A midline lower lumbar/sacral surgical approach is described at the spinopelvic fixation chapter of this textbook or the double-incision posterior pelvis approach [15]. The latter, as presented in the publication by Fowler et al. [10], offers the advantages of direct visualisation, mobilisation and effective reduction of the displaced hemipelvises. The modified surgical approach as described previously is very useful if followed into its detail, as it results to limited postoperative wound problems.

Open Reduction Manoeuvres

LC1 Pelvic Injury

As mostly closed reduction techniques are applied or mini-invasive assisted reduction methods using the iliac crest or the supra-acetabular corridors for the insertion of half pins and external fixators for the reduction in external rotation/

distraction of the pelvic ring, the description of the surgical approach is obvious and well described in the following articles [12, 13].

LC2 Pelvic Injury

Open reduction manoeuvres include typically the use of Weber clamps over the iliac crest, ball spiked pushers, joystick Schanz pins over the anteroinferior iliac spine or the iliac crest, Farabeuf clamps, lag ("inter-table") screws between the medial/lateral cortices into the diploe of the iliac wing or their modification (skiver screws) as described by Cole et al. [16]. The use of two Schanz pins rather than a single one can improve the fine adjustment of reduction in 6° of freedom before insertion of the reconstruction plates/lag-skiver screws.

Via the lateral window of the ilioinguinal approach, direct visualisation of the anterosuperior facet of the sacroiliac joint allows the accurate reduction of crescent fractures. The use of a Farabeuf clamp over position screws allows the careful apposition and to a degree compression of the sacroiliac joint (Figs. 4.12 and 4.13). The level of exposure of the sacrum due to the course of the L5 nerve route, as well as the quality of bone stock and anchorage of any screw of the lateral mass of the S1, is limited. Thus, careful dissection at this area, as well as intermittent use of soft tissue retractors (wide Cobb periosteal elevators, Deaver or sharp Hohmann inserted into the lateral mass of the S1), should be utilised in order not to cause an L5 neurapraxia or fracture of the S1 lateral mass.

A useful reduction trick in the presence of a crescent fracture is the use of the asymmetric reduction clamp, as shown in Fig. 4.13, with its long arm anchoring at the anterior surface of S1 lateral mass and its short arm anchoring over the lateral iliac crest.

The posterior approach does not allow for any visualisation of the SI joint; thus, joint congruence can be difficult to attain as its indirect reduction can be hindered by plastic deformation, displaced fragmentation and small key-in areas of the ilium.

LC3 Pelvic Injury

Open reduction manoeuvres for this type of pelvic fracture are composite as is also the nature of the deforming forces and planes of displacement for the LC3 injuries. As previously mentioned at the reduction section of this chapter, common strategy is to start reduction and fixation from the sacroiliac joint disruption (Fig. 4.13). Subsequently, it is common to address the internally rotated contralateral hemipelvis by mini-invasive reduction techniques and iliosacral screw fixation in regard to the posterior pelvic ring. As far as the anterior pelvic ring, if open reduction/fixation is chosen, a Pfannenstiel/intrapelvic approach is common which allows the reduction of the pubic rami unilateral or bilaterally and their fixation with retropubic screws or with plating (Figs. 4.15, 4.16 and 4.17).

Implant Insertion

LC1 Pelvic Injury

The fixation of LC1 pelvic ring fractures most commonly requires mini-invasive techniques. These commonly include the use of percutaneously inserted iliosacral screws at the S1 and/or S2 levels for the fixation of the sacral component. The anterior pelvic ring can be addressed either by keeping the distracting external fixator used for the closed reduction of the laterally compressed pelvic ring (Fig. 4.18) or by inserting of retropubic or antegrade anterior column rami screws (Figs. 4.4 and 4.15) or less frequently with the use of internal fixation (bridge plating of the rami or by using devices as the infix [17]).

LC2, LC3 Pelvic Injuries

The fixation of LC2 and LC3 pelvic fractures includes mostly reconstruction plates and free or lag screws. For fractures managed via the lateral window of the ilioinguinal approach, the reconstruction plates are inserted into the iliac fossa, across the sacroiliac joint or over the iliac crest.

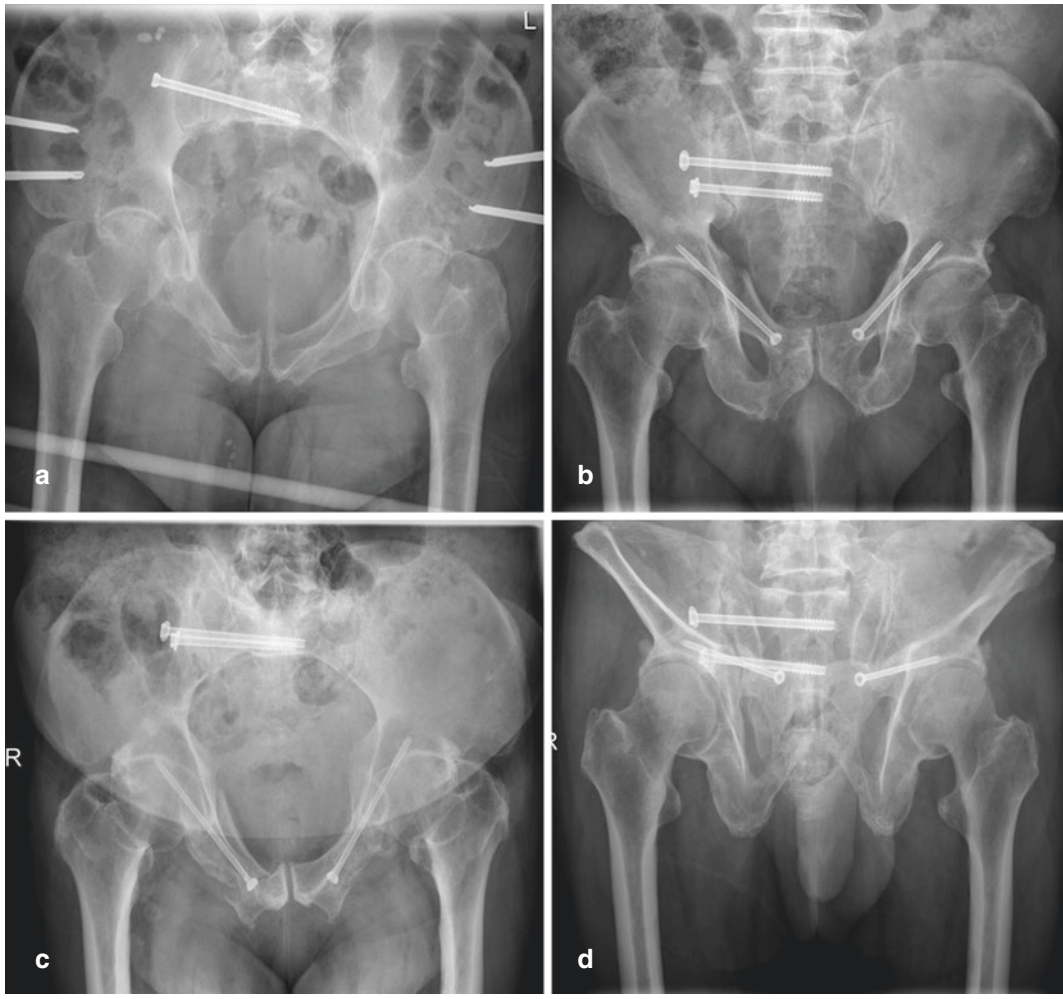

Fig. 4.15 Fixation of an LC fracture with a distraction iliac crest external fixation and right iliosacral screw fixation at the levels of S1 and S2. Subsequently using the external fixator as an indirect method of reducing the anterior ring, insertion of bilateral retropubic screws splinting internally the anterior ring and removal of the external fixator to avoid pin site problems

Free "inter-table" 3.5 mm screws are either inserted horizontally into the diploe of the iliac bone from front to back or less frequently vertically into the diploe, from the top of the iliac crest towards the sciatic buttress and the posterior column. The use of at least two reconstruction small fragment plates, or two small fragment screws or a combination of screws and plates, is recommended as far as the iliac wing fragmentation to provide stability in 6 degrees of freedom.

Fluoroscopy-guided iliosacral cannulated 6.5–8.0 mm screw fixation of the sacroiliac joint, at the S1/S2 levels, is often necessary, if a crescent fracture dislocation is present. The insertion of S1/S2 cannulated lag screws with washers is performed as previously described, using all four fluoroscopic projections (true lateral of the sacrum, inlet, outlet, obturator inlet).

If the posterior subgluteal approach is chosen, then implant selection and insertion postreduction follows standard open reduction/fixation techniques with the use of 3.5 mm reconstruction plates in a buttress mode, lag screws as well as interfragmentary "inter-table" screws inserted to

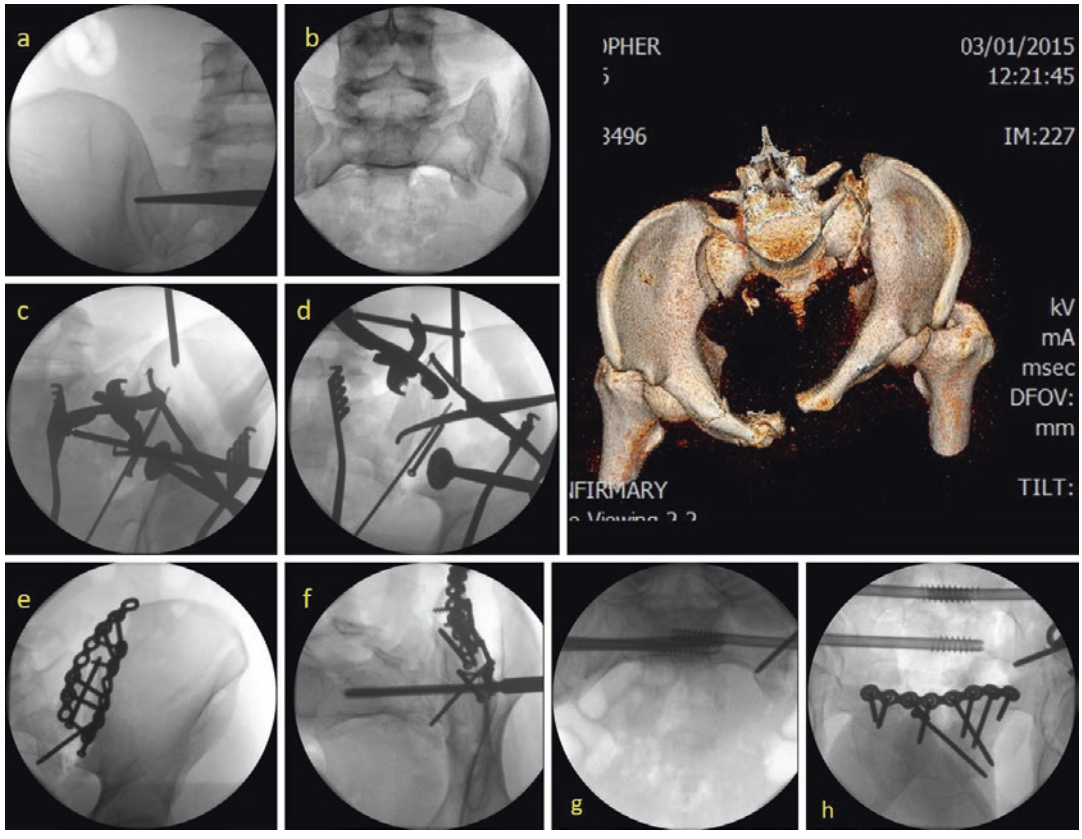

Fig. 4.16 Example of complex LC3 pelvic fracture, with a right sacroiliac dislocation (**a**), a left crescent fracture dislocation (**b**), image intensifier views in prone with initial left subgluteal approach and open reduction and internal plate fixation of the crescent fracture (**c**–**e**). Subsequently insertion of a left S1 iliosacral 8.0 mm lag screw (**f**), and two right iliosacral 8.0 mm lag screws to the right (**g**). Finally, the patient was turned supine, and the anterior pelvic ring was addressed via a Pfannenstiel approach with open reduction and internal fixation of the rami fractures and the symphysis pubis dislocation (**h**)

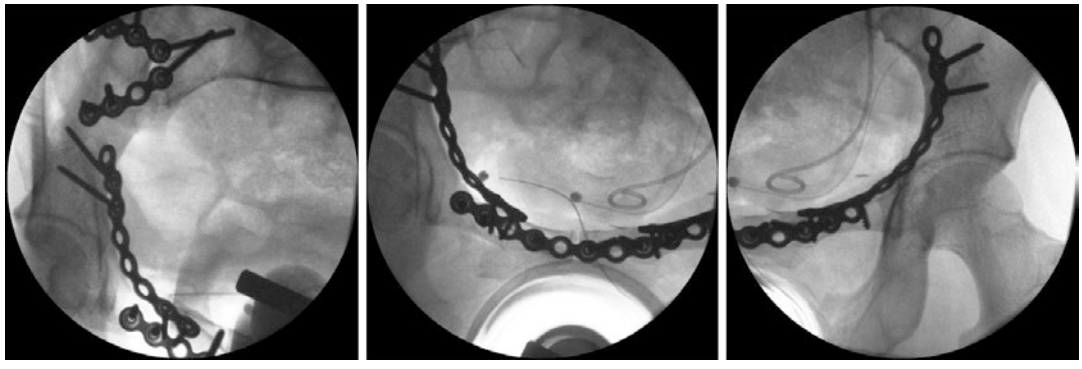

Fig. 4.17 Image intensifier views demonstrating the results of pelvic fixation of the anterior ring following an LC3 pelvic fracture and the use of bilateral intrapelvic extension of a Pfannenstiel approach

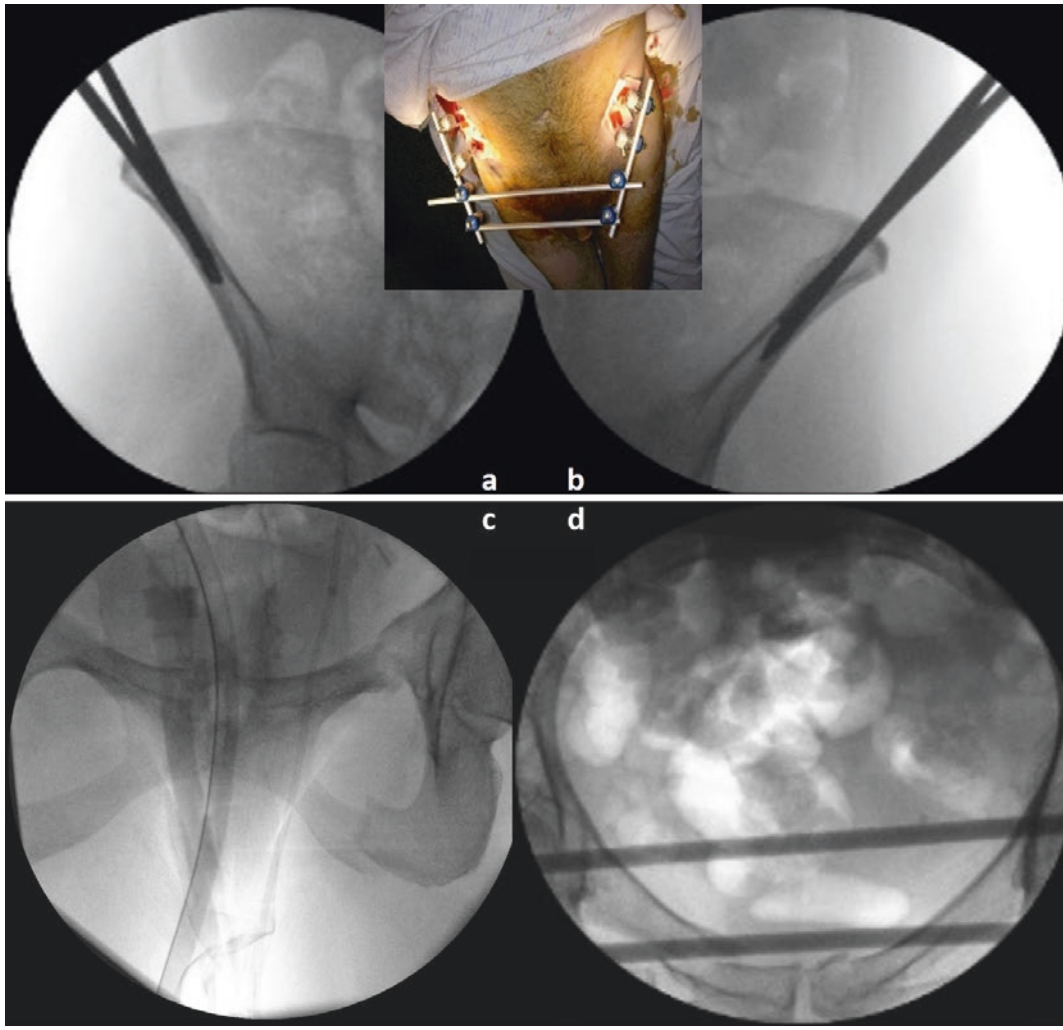

Fig. 4.18 Example of LC1 pelvic fracture treated with a distracting external fixator and mobilisation with crutches as pain allows. No posterior ring fixation was offered due to the limited involvement of the sacrum. (**a**, **b**) Outlet views of the right and left ilium demonstrating the 5.0 mm half pins of the external fixator used as reduction and fixation method. (**c**, **d**) Outlet and inlet views demonstrating the reduced anterior pelvic ring fractures. Clinical image of the rectangular iliac crest external fixator in distraction mode

the ilium. Free ("inter-table") lag screws into the diploe of the sciatic buttress can also be used starting from the posterior superior iliac spine towards the anterior inferior iliac spine. Careful use of these lag screws is advised as the compression from such an interfragmentary screw may result in shear as the plane of the fracture usually is not at right angles to the plane of the diploe corridor (Figs. 4.13, 4.19 and 4.20).

Posterior pelvic ring fixation commonly is supplemented with open or closed reduction and internal fixation of the anterior pelvic ring (plat-

Fig. 4.19 Example of a left LC2 crescent pelvic fracture addressed with ORIF of the ilium, left iliosacral 8.0 mm lag screw fixation posteriorly and an antegrade 3.5 mm position screw addressing the left pubic rami fracture (Nakatani type 3)

ing of the symphysis pubis, retropubic screw fixation or plating of pubic rami fractures) (Figs. 4.16 and 4.17).

Summary of Tips and Tricks-Pitfalls

- The insertion of a Foley catheter is recommended in all occasions.
- Good quality of fluoroscopy is essential.
- Use the fluoroscopy to mark the midline of the patient as the anatomy and symmetry of the pelvic ring may be distorted.
- During team brief, inform the theatre team (scrub nurse, circulation team, assistant surgeon, anaesthetist, ODP) of the history of the patient, presence of associated injuries (if any), planned patient positioning, implant and kits that will be required, surgical steps of the procedure and the anticipated blood loss.
- Evaluation under anaesthesia can assist decision-making as described previously [8, 9]. Mini-invasive techniques are most commonly required—use of an external fixator as a reduction tool in distraction/external rotation, as well as a fixation device of the anterior pelvic ring or percutaneously inserted retropubic/antegrade pubic rami screws. Percutaneous iliosacral fixation represents the standard sacral fracture fixation method.
- Utilisation of the established safe bone corridors and careful adherence to surgical techniques of insertion of external fixation half pins as well as of the iliosacral screws under fluoroscopic guidance is of paramount importance [18, 19].

Fig. 4.20 Inner table/diploe screws addressing an iliac wing fracture

- Anatomic realignment of the sacroiliac joints and rigid fixation are very important in order to avoid loss of reduction and chronic pain and minimise the need for secondary procedures/fusion.
- In bilateral types of injuries (bilateral rami fractures/bilateral sacral fractures/bilateral iliac wing fractures/LC3 type of injuries), it is usually useful to start reduction from the less comminuted lesion and subsequently address the rest of the injured regions, in order to establish reliable reference points and gradually achieve as near as possible anatomical reduction of the pelvic ring.

Things to avoid:

- Tension or pressure of the half pins on the soft tissues at the entry point as this will lead to pin site infection and patient discomfort compromising the duration that the external fixator can be maintained (on average 4–6 weeks). Careful planning of direction and orientation of the incisions (in obesity/abdominal distention/grossly deformed pelvic ring, use transverse to the iliac crest incisions) (Fig. 4.2d)
- Inadequate insertion of the half pins into the ilium, and/or insertion in the wrong trajectories, as this would lead even to iliac wing fracture at the time of attempted reduction or early loosening, pin site infection and patient discomfort, compromising the duration that the external fixator can be maintained (on average 4–6 weeks). Careful insertion of the half pins between the cortices of the ilium, using the fluoroscopy views (outlet to outlet/obturator fluoroscopy trajectories for the iliac crest pins (Fig. 4.21c, d) and tepee, inlet obturator and

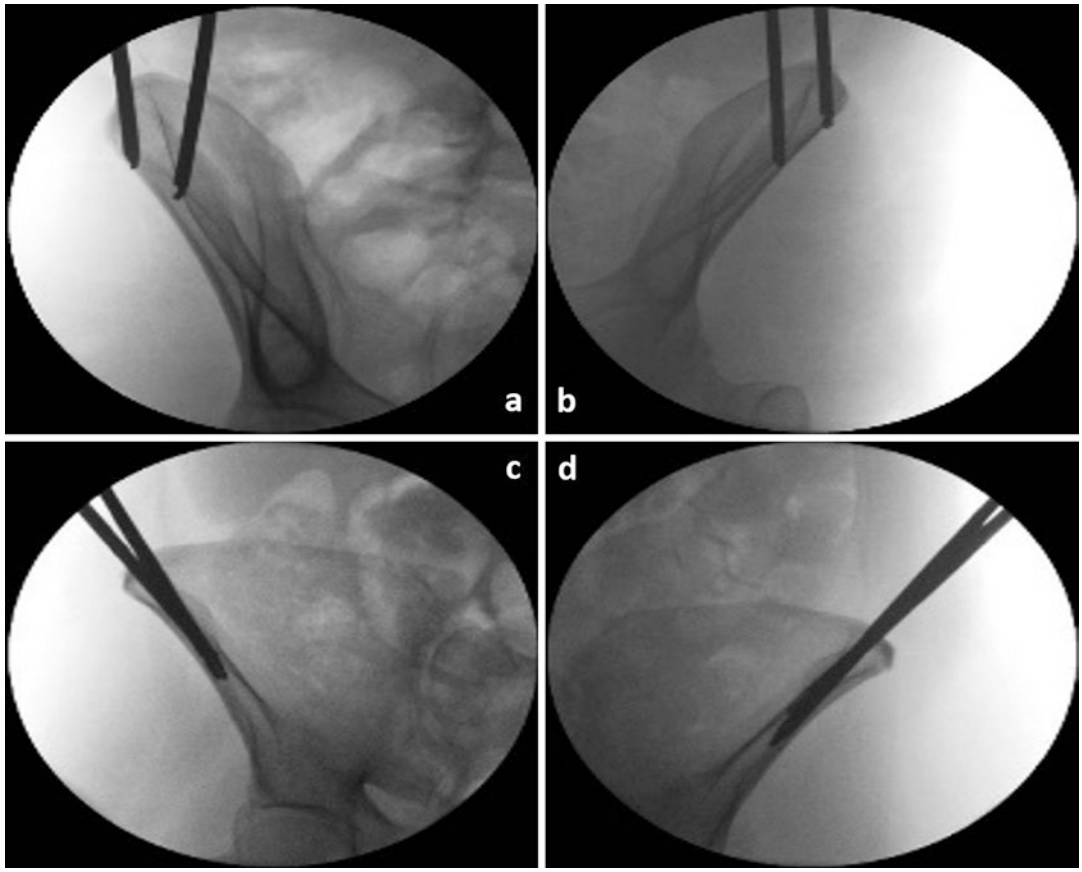

Fig. 4.21 Example of badly inserted half pins to the iliac crest (**a**, **b**) and corrected ones using the outlet fluoroscopy views (**c**, **d**) to verify the positioning of the half pins into the diploe/gluteus medius pillar of the iliac wings

iliac oblique trajectories for the supra-acetabular pins (Fig. 4.22)), with low-speed power tools or manually, can minimise such iatrogenic complications.

- Avoid misguidance of the iliosacral screws into the sacrum endangering the lumbosacral nerve plexus (L5 nerve root at its intrapelvic course over the sacral wing at the S1 level; S1, S2 nerve roots before or at their exit from the sacral foramina), as well as the iliac and gluteal vessels. Careful screening of the available pelvic CT images for any evidence of sacral dysmorphism (presence of mamillary processes; acute alar slope; sacrum not recessed in the pelvis; residual disc between S1 and S2; noncircular sacral foramina). Avoidance of using the technique in case of poor-quality fluoroscopic views (morbid obesity, severe bowel distention, bladder/bowel full of contrast), as well as the use of all necessary fluoroscopy views (true lateral of the sacrum, inlet, outlet, inlet obturator views) and the strict adherence to the radiologic landmarks, allows the safe use of iliosacral screw fixation [20, 21]. Furthermore, iliosacral screw fixation using CT navigation techniques, or of advanced intraoperative imaging with the O-arm, or even of intraoperative neurophysiological monitoring during their insertion, is advocated by several clinicians [22–25].

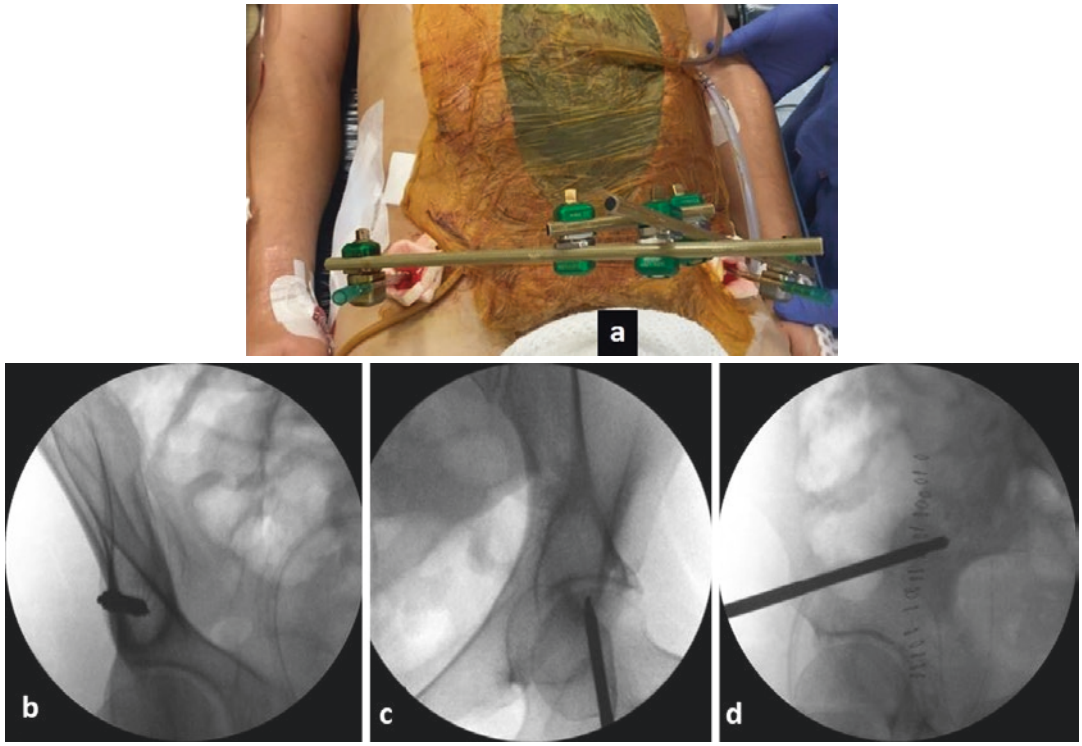

Fig. 4.22 (**a**) Clinical picture demonstrates stabilisation of an anterior ring pelvic injury with an A-frame configuration supra-acetabular fixator. (**b–d**) Fluoroscopic images: tepee, inlet obturator and iliac oblique trajectories demonstrating the safe corridor for insertion of supra-acetabulum pin

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