Intraoperative Imaging Challenges During Pelvic Ring Disruptions and Acetabular Fracture Surgery

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KEYWORDS

• Radiograph • Computer tomography • Fluoroscopic imaging • Pelvic ring • Acetabulum

KEY POINTS

- Early identification of patient obesity, excessive bowel gas, abdominal/pelvic packing, and contrast dye on preoperative plain radiographs can mitigate imaging challenges that may develop during surgery.
- Preoperative computer tomography studies, including three-dimensional reformatted sequences, can be used to anticipate intraoperative image angles, identify sacral dysmorphism, and define fracture planes and displacements in a similar manner as will be observed during surgery.
- Operating room setup, fluoroscopic equipment, and consistent use of instructional terminology help facilitate effective and efficient fluoroscopy workflow.

INTRODUCTION

Intraoperative imaging, most commonly via fluoroscopy, plays an important role in the successful surgical management of pelvic ring disruptions and acetabular fractures. It is the primary method in which clamp placement, reduction accuracy, and implant positioning are assessed. Intraoperative fluoroscopy is also routinely used to evaluate occult pelvic ring instability.[1] Technological advancements in intraoperative fluoroscopy have expanded the indications for percutaneous fixation of the pelvic ring and acetabulum. Some injuries that were previously treated with open approaches can now be reduced and stabilized using minimal incisions. The benefits of percutaneous fixation are multifactorial, including decreased blood loss, surgical time, wound complications, hospital stay, heterotopic ossification formation, and nonunion.[2]

However, obtaining clear and reliable intraoperative fluoroscopic images can be technically challenging. A complete understanding of the osteology and radiographic anatomy of the pelvic ring and acetabulum, including normal variations in sacral morphology, is mandatory. A single-view image is insufficient to accurately and reliably define reduction quality, osseous fixation pathways, and implant positioning. Instead, multiple images obtained in multiple planes are needed. Image angles must also be precise and reproducible; otherwise, misinterpretation can ensue. Fluoroscopic image quality can be compromised by patient positioning, body habitus, bowel gas, contrast dye, and equipment limitations. Fracture malreduction, errant implant placement, and neurovascular injury have all been attributed to inadequate intraoperative fluoroscopic imaging.[3–5]

The purpose of this article is to review common intraoperative imaging challenges during pelvic ring and acetabular fracture fixation surgery. Additionally, practical tips and evidence-

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based intraoperative imaging strategies will be discussed.

PREOPERATIVE PLANNING

A thoughtful preoperative plan is the first step toward achieving effective and efficient intraoperative fluoroscopy and may mitigate some of the frequently encountered challenges with imaging quality. The preoperative plan should include a careful evaluation of plain radiographs and computer tomography (CT) scans, including three-dimensional (3D) reconstruction images, to identify barriers to quality fluoroscopic imaging, measure anticipated image angles, and gain a better understanding of the patient-specific osteology, fracture planes, and displacements.

Pelvic ring disruptions and acetabular fractures frequently occur in polytraumatized patients. Although necessary, many of the nonorthopedic procedures and treatments that are performed acutely can compromise intraoperative fluoroscopic image quality. Excessive bowel gas accumulation, contrast dye, abdominal or pelvic packing, and wound vacuums are easily identified on preoperative plain radiographs (Fig. 1). A foley catheter is recommended for every pelvic and acetabular case and is also helpful for decompressing bladder contrast. Oral contrast agents should be avoided before surgery since bowel contrast is much more difficult to remedy. Abdominal or pelvic packing and wound vacuums, under most circumstances, can be removed before fracture fixation but should be coordinated with the general surgery team. Excessive bowel gas accumulation, in some cases, can make it impossible to reliably delineate the sacral foramina on intraoperative fluoroscopy. Nitrous oxide anesthesia has been associated with bowel gas accumulation and therefore should be avoided.[6] To improve image quality in the setting of excessive bowel gas shadows, Patel and colleagues suggests combining fluoroscopy beam collimation to improve image contrast with abdominal massage to manually displace gas shadows away from sacral neuroforamina.[7]

Obesity and morbid obesity pose significant challenges to obtaining high-quality intraoperative images during the surgical fixation of pelvic ring disruptions and acetabular fractures. The dense fat envelope attenuates fluoroscopic beam penetration and increases photon scatter resulting in low contrast, less-defined images (see Fig. 1).[8] Inlet and outlet tilt angles are physically restricted by the patient's abdominal and thigh girth. Often a view of the entire pelvic ring is not attainable in a single image because the image intensifier cannot be lowered sufficiently. Miller and colleagues found a high correlation between preoperative lateral scout CT and intraoperative fluoroscopic images in morbidly obese patients.[9] Specifically, when the lateral sacrum is not visualized on a preoperative scout CT, a reliable true lateral view of the sacrum cannot be obtained on intraoperative fluoroscopy. From a practical standpoint, mobilization of the abdominal pannus away from the image field with foam or silk tape before sterile prep and draping may be helpful. Additionally, increasing the peak kilovoltage and using bucky grids can improve beam penetration and reduce image scatter, respectively.[8] These methods, however, will also increase radiation exposure to both patient and surgeon.[10] Beam collimation or coning is a useful technique for reducing the radiation dose while simultaneously increasing image contrast.

Biplanar and triplanar intraoperative fluoroscopy is needed to achieve reductions and place implants safely through the bony corridors of the pelvic ring and acetabulum. The various images include the anterior posterior (AP) pelvis, inlet, outlet, lateral sacral, obturator oblique (OO), iliac oblique (IO), and combined obturator oblique outlet (COOO) and combined obturator oblique inlet (COOI) views (Table 1). The technical aspects for achieving these views and interpreting their findings have been well described.[11]

Various studies demonstrate the benefits of preoperative two-dimensional (2D) CT scans for anticipating intraoperative fluoroscopic view angles. Traditionally, inlet and outlet images are obtained by tilting the fluoroscopy beam 45° in the cranial and caudal direction, respectively. Multiple studies have since demonstrated that inlet and outlet angles are not orthogonal.[12–14] Eastman and Rout describe using a line drawn parallel to the anterior cortex of the S1 body and a line overlying the pubic symphysis to the center of the S2 body on a midsagittal CT reconstruction view for determining ideal inlet and outlet views, respectively (Fig. 2).[14] In their series, the average ideal inlet angle was 25° and the ideal outlet angle was 42°. This differed from the measured intraoperative fluoroscopic inlet and outlet angles by 4.4° and 0.45°, respectively. The authors thus concluded that intraoperative fluoroscopic inlet and outlet angles could be anticipated within 5° of preoperative CT measurements. Importantly, Ricci and colleagues demonstrated that ideal inlet and outlet angles can differ considerably between S1 and S2 bodies.[12] Therefore, a single tilt angle may

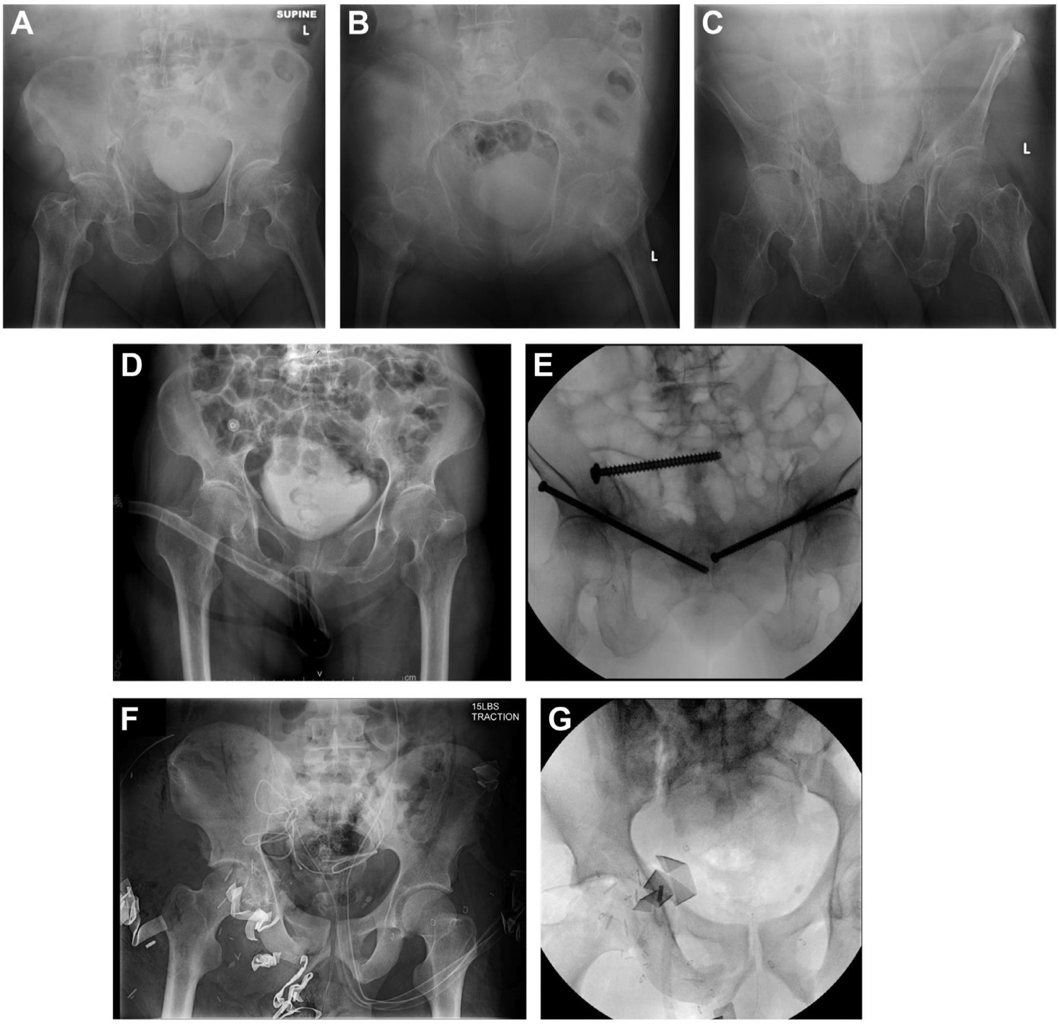

Fig. 1. Examples of barriers to optimal intraoperative imaging seen on preoperative plain radiographs. A 63-year-old man with a right anterior column posterior hemitransverse acetabular fracture (*A–C*). Preoperative AP, inlet and outlet radiographs with poor image quality due to patient's obesity, bladder contrast, and poor bone quality. A 92-year-old female with an unstable lateral compression type 1 pelvic ring injury (*D*, *E*). Preoperative AP radiograph with poor image quality due to excessive bowel gasses and bladder contrast (*D*) and intraoperative fluoroscopic outlet image of the same patient demonstrating difficult visualization of the S1 neuroforamen (*E*). A 48-year-old man with a lateral compression type 3 pelvic ring injury. Preoperative AP pelvis radiograph demonstrating abdominal and pelvic packing near the right pubic root (*F*). Intraoperative fluoroscopic AP pelvis image demonstrating incomplete visualization of the right pubic root and acetabulum (*G*).

not be reliable for placing iliosacral screws at multiple upper sacral levels (Fig. 3). Axial CT images are also useful for planning ideal oblique image angles (see Fig. 2).

The normal sagittal alignment of the sacrum can vary widely between patients and because of traumatic injury, such as with spinopelvic dissociation (Fig. 4).[15,16] This can be easily observed on preoperative sagittal CT imaging. Because of this, the angles needed to obtain reliable inlet and outlet views intraoperatively will also vary widely. Ricci and colleagues describe the ideal outlet view as perpendicular to the upper sacral segment body.[12] This makes achieving reliable outlet views difficult in the setting of increased upper sacral flexion, as commonly seen in a spinopelvic dissociation. The vertical orientation of a flexed sacrum when supine requires a high outlet tilt angle to achieve a reliable image. In some instances, this can exceed the C-arm clearance as the patient's body or undersurface of the table interferes with higher tilt angles. We have found that positioning a sacral bump more distally under the patient to extend

Table 1
Injury location/fixation pathway and fluoroscopy view

Injury location/ Fixation Pathway	Fluoroscopy View
Pubic symphysis	Inlet and outlet
Supra-acetabular, LC2	COO, IO, COI, and lateral sacral
Gluteal pillar, iliac crest external fixation	IO and OO
Iliac crest	IO, OO, COOI
Iliosacral/transiliac transsacral	Inlet, hyperinlet, outlet, COOI, and lateral sacral
Anterior column/ superior pubic ramus	COO and inlet
Posterior column	AP, IO, and lateral sacral
Anterior wall	OO and IO
Posterior wall	OO and IO

Abbreviations: AP, anterior posterior pelvis; COO, combined obturator oblique; COOI, combined obturator oblique inlet; IO, iliac oblique; OO, obturator oblique.

the sacrum can help decrease the necessary outlet tilt to an unobstructed range.

Three-dimensional Reconstructions

Reliable fluoroscopic imaging of dysmorphic sacra can be particularly challenging to obtain. Pekmezci and colleagues used surface and volume-rendered 3D CT images to recreate the "perfect" inlet and outlet view in dysmorphic and nondysmorphic sacra.[17] Each 3D image of the pelvis was rotated around a vertical axis in 1° increments until an ideal inlet and outlet image was obtained. The ideal inlet view was defined when the sacral promontory overlapped the anterior cortex of S1, and the ideal outlet view was defined when the pubic symphysis was superimposed over the S2 body (Fig. 5). In dysmorphic sacra, the ideal inlet view was achieved with 25° of caudal tilt, and the ideal outlet view was achieved with 43° of cranial tilt. The authors also found good correlation between surface-rendered and volume-rendered CT images. Inlet angles between dysmorphic and nondysmorphic sacra were similar, whereas dysmorphic sacral required on average an additional 5° of cranial tilt. Conflitti and colleagues correlated the findings of preoperative 3D surface-rendered and volume-rendered CT images with intraoperative fluoroscopy when placing S2 transsacral screws in dysmorphic sacra.[18] In this study, the authors demonstrated that 3D CT reconstruction images highlight the anterior cortical indentations of the upper sacral segment alar zones on an inlet view, and the steep medial to lateral alar slopes on an outlet view. Twenty of 24 patients demonstrated complete intraosseous screw placement, whereas 4 of 24 patients had juxtaforaminal screws.

Three-dimensional CT reconstruction also plays an important role in the preoperative planning of acetabular fractures. Fracture planes, displacements, and spatial orientations can be studied on perfect AP, judet, inlet, outlet, and lateral sacral views. Additionally, femoral head subtraction allows for the direct visualization of articular fracture lines. This information is vital for planning reduction maneuvers, fixation constructs, and implant placement because it will be seen on intraoperative fluoroscopic images. Scott and colleagues reviewed the preoperative plain radiographs, 2D CT scans, and 3D CT reconstruction images of 40 acetabular fractures.[19] Review of the 3D surface-rendered images resulted in a change in surgical approach and treatment in 30% of cases.

EQUIPMENT, SETUP, AND COMMUNICATION

Having the right fluoroscopy equipment and operating room (OR) setup is key to efficient fluoroscopy workflow. The basic equipment needed includes a radiolucent flat top table and large C-arm that facilitates unobstructed clearance of the OR table, table attachments, patient, and surgical instruments. The OR should be large enough to allow easy side-to-side transitions between the C-arm machine and sterile back table when bilateral fixation is needed. A 12″ image intensifier (or larger) is ideal so that a view of the entire pelvic ring can be obtained in a single image. This will be helpful for judging symmetry and trajectories, such as during transsacral-transiliac screw placement. Flat panel image intensifiers, compared with circular, are associated with less image distortion secondary to parallax but are not mandatory.[20] In general, targeting the focal point of the image centrally in the image field minimizes the effective parallax.[21] Most modern C-arms have a roll over the top range from 25° to 55°. A higher roll over the top range provides greater versatility for obtaining oblique images. The basic fluoroscopy setup consists of the C-arm stationed opposite from the surgeon with the

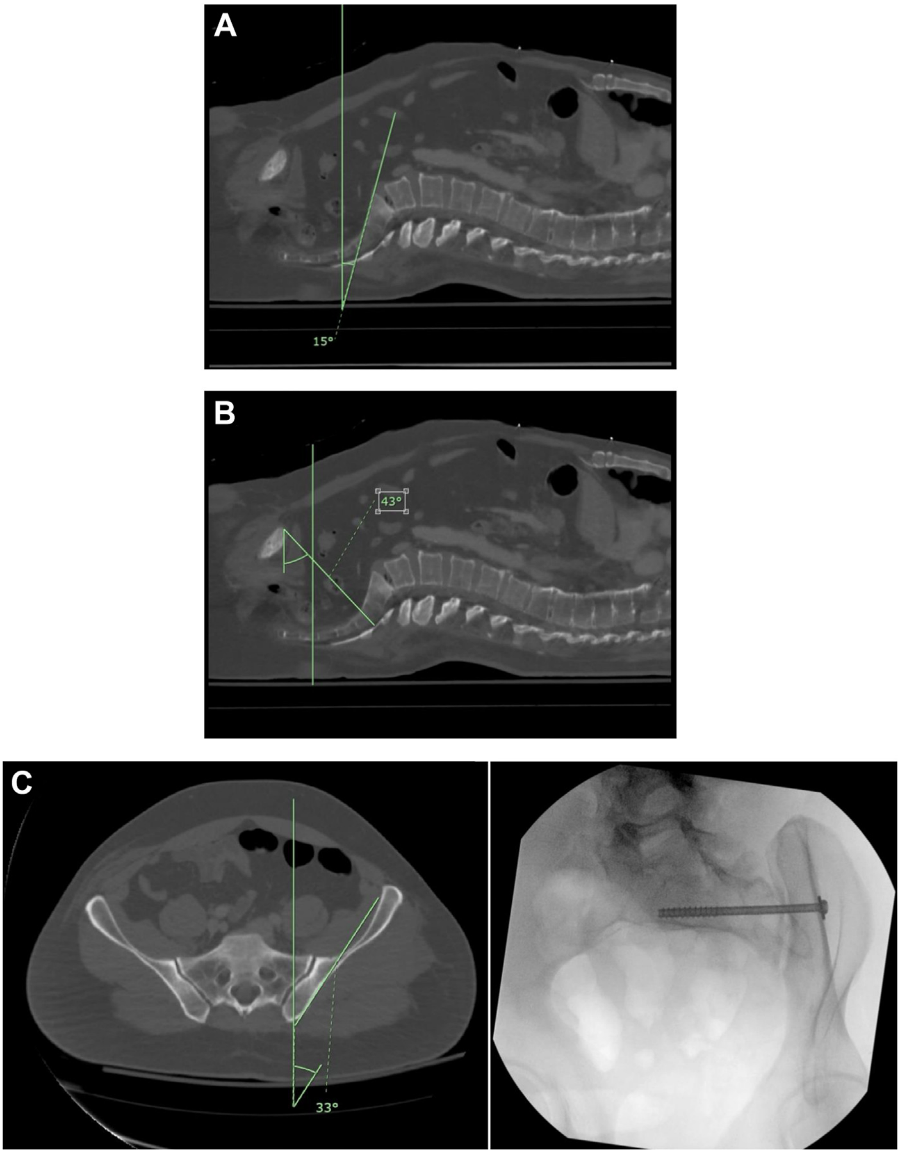

Fig. 2. Preoperative planning intraoperative image angles. Midsagittal CT image demonstrating an S1 inlet angle measurement of 15° (*A*). Midsagittal CT image demonstrating an outlet angle measurement of 43° (*B*). Axial CT image at S1 demonstrating an obturator rollover angle measurement of 33° (*C*) and the corresponding COOI intraoperative fluoroscopic image. COOI, combined obturator oblique inlet.

base oriented perpendicular to the patient. When imaging, the C-arm should be positioned centrally over the pelvis or hip in such a way that biplanar imaging can be repeated with minimal translation of the C-arm base. Tilt angles and base positions should be marked for more efficient transition in and out with the C-arm. Cords and lines should be secured outside of the image field and not impede movements of the C-arm base or gantry. Similarly, the surgeon should have an easy unobstructed view of the fluoroscopy monitor. Typically, the monitor is stationed at the foot of the bed. Patient positioning devices and table attachments can also compromise fluoroscopic image quality. This includes sacral bumps, chest rolls, traction attachments, and arm board holders among others (Fig. 6). We have found using folded blankets as sacral bumps and rolled blankets for chest rolls to be less radiopaque compared with sheets and gel pads. All unnecessary table attachments should be removed.

The benefits of establishing clear and consistent communication between surgeon and radiology

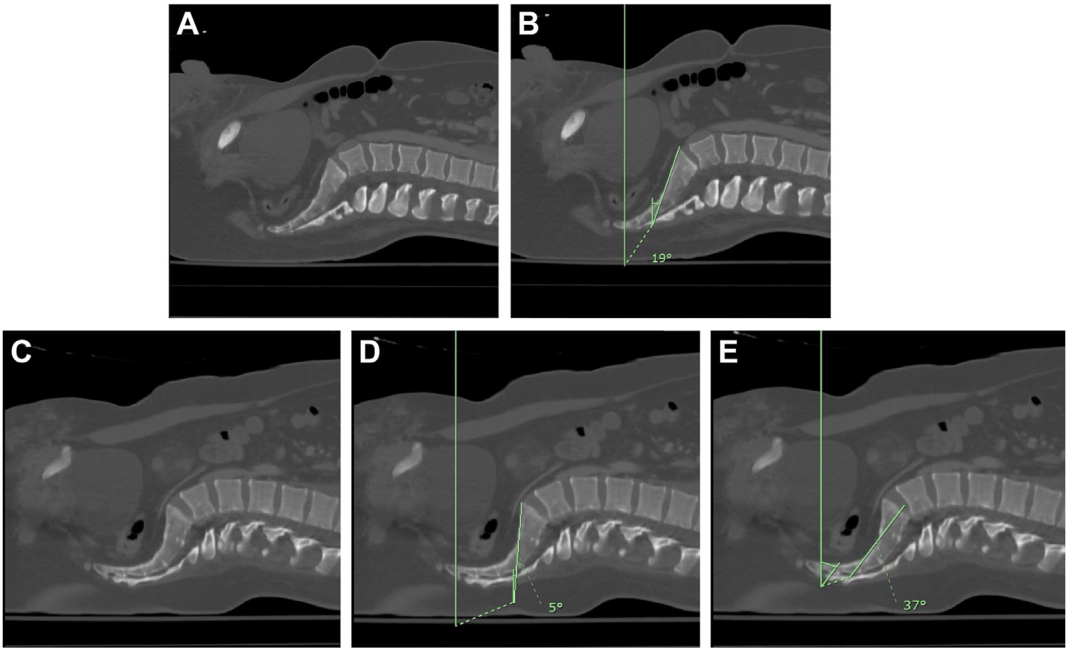

Fig. 3. Preoperative midsagittal CT S1 and S2 inlet angle measurements. Colinear S1 and S2 inlet angles (*A*). S1 and S2 inlet angles measured at 19° (*B*). Noncolinear S1 and S2 inlet angles (*C*). S1 inlet angle measurement of 5° (*D*). S2 inlet angle measurement of 37° (*E*).

technician have been well documented. The use of common fluoroscopic language has been shown to reduce fluoroscopy time as well as the number of images taken.[22–24] Burke and colleagues investigated the effects of a standardized intraoperative fluoroscopy language education protocol on the perceived quality of communication and efficiency in the OR.[24] Forty orthopedic surgeons and 41 radiology technicians were surveyed. Overall, the education protocol resulted in a significant increase in the perceived quality of intraoperative communication and decrease in perceived intraoperative confusion, C-arm movement corrections, and need for repeat fluoroscopic images. Mean fluoroscopy time also significantly decreased after the education protocol (90 + 106 seconds vs 52.7 + 39.2 seconds, $P < .004$).

Instructions should be communicated to the radiology technician in a systematic fashion beginning with the specific C-arm movement, followed by the direction, and quantification of the desired movement (Table 2). When a combination of movements is needed, distinct instructions should be given for each movement. For example, “Tilt toward the head 25°, then roll over the top 30°.” A key point when transitioning between views, consideration

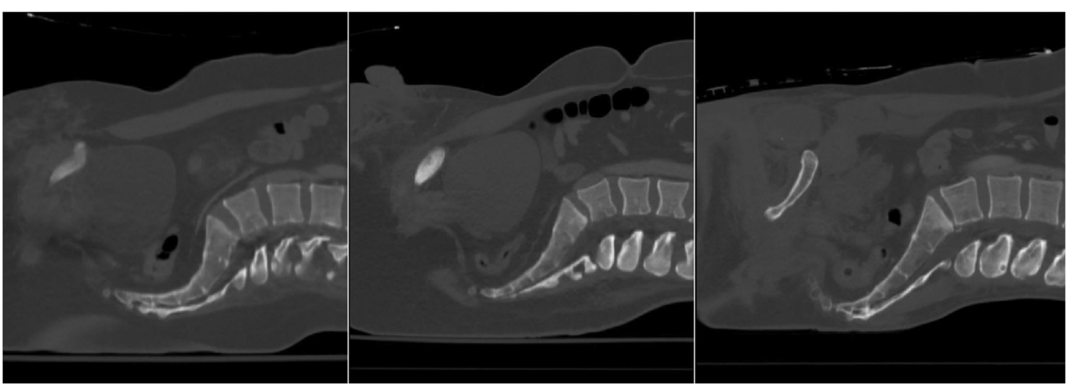

Fig. 4. Variations in sagittal sacral alignment.

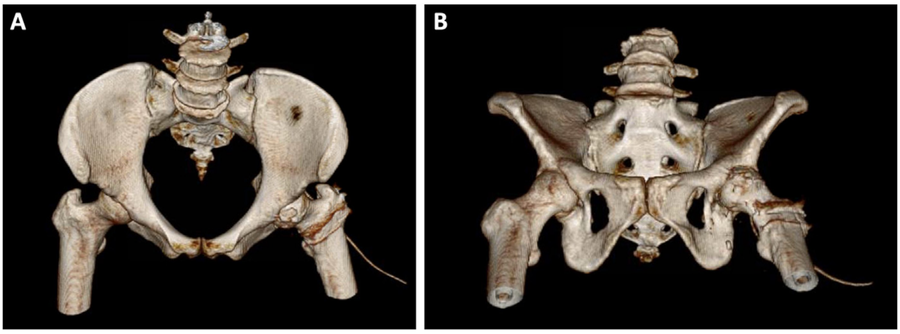

Fig. 5. Ideal inlet (*A*) and outlet (*B*) 3D surface-rendered image views.

should be given to the movement sequence that allows the C-arm to move/rotate around the surgeon and surgical instruments, rather than the surgeon around the C-arm. This allows the surgeon to maintain important reductions, start points, and trajectories throughout the image sequence.

POSTERIOR PELVIC RING

As previously discussed, the preoperative planning is critical to success with posterior fixation in the pelvic ring. One thing the surgeon must remember is that manipulative reduction maneuvers, closed or open, may change the osseous

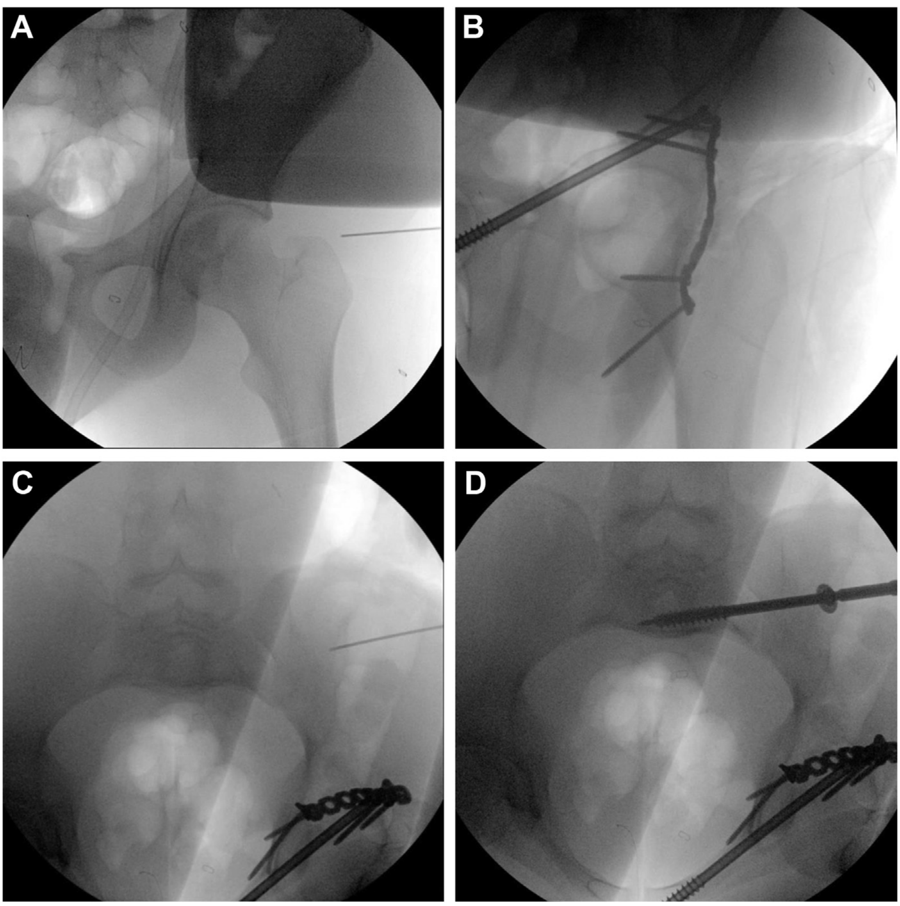

Fig. 6. 17 year-old male patient with a combined left transverse posterior wall acetabular fracture and ipsilateral incomplete sacroiliac joint injury placed in the prone position. Gel pad chest rolls creating radiopaque shadows over the supra-acetabular (*A*, *B*) and sacral alar (*C*, *D*) regions.

Table 2
C-arm movements, terminology, and direction

C-arm Movement	Terminology	Direction
Arm driven		
Raise and lower	Raise Lower	Up Down
In and out	Push in Pull out	Toward "me" Toward "you"
Cant	Tilt	Toward the head (ie, Inlet) Toward the feet (ie, Outlet)
Axial rotation	Roll Orbit "C"	Over (the top) Under
Wag	Wig wag	Toward the head (ie, Proximal) Toward the feet (ie, Distal)
Base driven		
Slide	Slide	Toward the head (ie, Proximal) Toward the feet (ie, Distal)
In and out	Push in Pull out	Toward "me" Toward "you"
Wag	Wig wag	Toward the head (ie, Proximal) Toward the feet (ie, Distal)

fixation pathways visualized on preoperative imaging and anticipated angles required for visualization.

For the upper sacral segment, identifying sacral dysmorphism is critical to safely place implants without causing damage to the L4, L5, and S1 nerve roots. Preoperative 3D surface-rendered reconstruction views allow the surgeon to visualize the "indentation" in the upper sacral segment that is visualized on an inlet image (Fig. 7). By ensuring all instrumentation remains posterior to indentation, risk of damage to the L4 and L5 nerve roots is minimized. The first implant in an iliosacral vector should be placed in a low and anterior position in the upper sacral segment as positions too cranial on an outlet image risk damage to L4 and L5 nerve roots unless the implant is cranial and posterior. When a cranial and posterior implant is chosen, frequent with multiple screws in the upper sacral segment, it is important to establish the posterior limits of the sacral osseous fixation pathway. Although the traditional inlet view establishes the anterior cortical limit of the sacrum, it does not provide a reliable view of the posterior cortical limit. The "hyperinlet" images, as described by Gosselin and colleagues, add additional inlet tilt to a traditional inlet view in order to delineate the anterior border of the sacral canal.[25] This can be measured preoperatively on a midsagittal CT scan by defining the angle formed by a vertical line and one that parallels the posterior aspect of S1 (Fig. 8). In their case series, the additional inlet tilt required to achieve a hyperinlet view averaged 17°.

For patients without sacral dysmorphism, transsacral-transiliaic (TSTI) vectors can be used in the upper sacral segment and the anterior cortical limits of the upper and second sacral segments are usually collinear. The "hyperinlet" image is useful when 2 screws are placed in a TSTI pathway, with one screw low and anterior and the second screw cranial and posterior (Fig. 9). Fixation in the second sacral segment may be safely placed just posterior to the anterior cortex of the sacrum on an inlet radiograph and at the junction of a line dividing the middle and caudal thirds of the space between the S1 and S2 foramina on the outlet image (see Fig. 8).

In a patient with sacral dysmorphism, implant placement should be done in the upper sacral segment before the second sacral segment because an implant in proper position in the second sacral segment will prevent visualization of the indentation in the upper sacral segment on inlet imaging (see Fig. 8).

ANTERIOR COLUMN/SUPERIOR PUBIC RAMUS

Percutaneous anterior column/superior pubic ramus intramedullary fixation remains a technically challenging skill for many surgeons. The combination of fluoroscopic views that most accurately and reliably demonstrate the cortical limits of the anterior column/superior pubic ramus osseous fixation pathway has been debated. Traditionally, pelvic inlet and COOO views have been used to assess the anterior-posterior and cranial-caudal cortical limits, respectively.[11] More recently, additional views have been recommended.[26–28] Cunningham

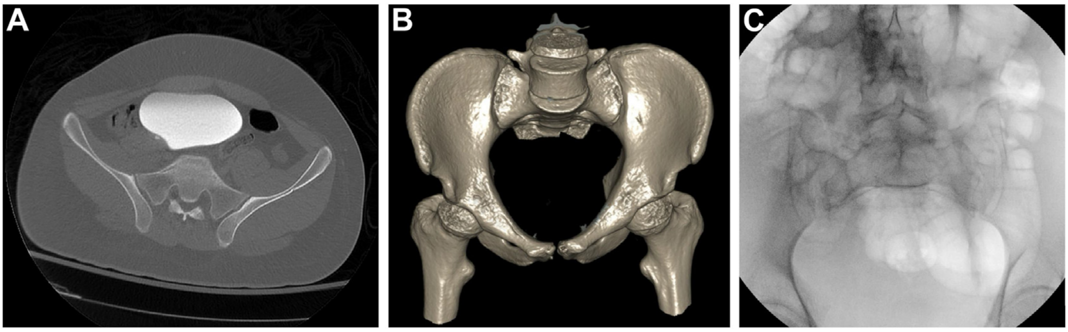

Fig. 7. Axial and inlet views of a dysmorphic sacrum. Axial CT image at S1 (*A*), 3D surface-rendered CT inlet image (*B*) and intraoperative fluoroscopic inlet image (*C*). Note the easy visualization of the sacral alar indentations on the 3D surface-rendered CT image.

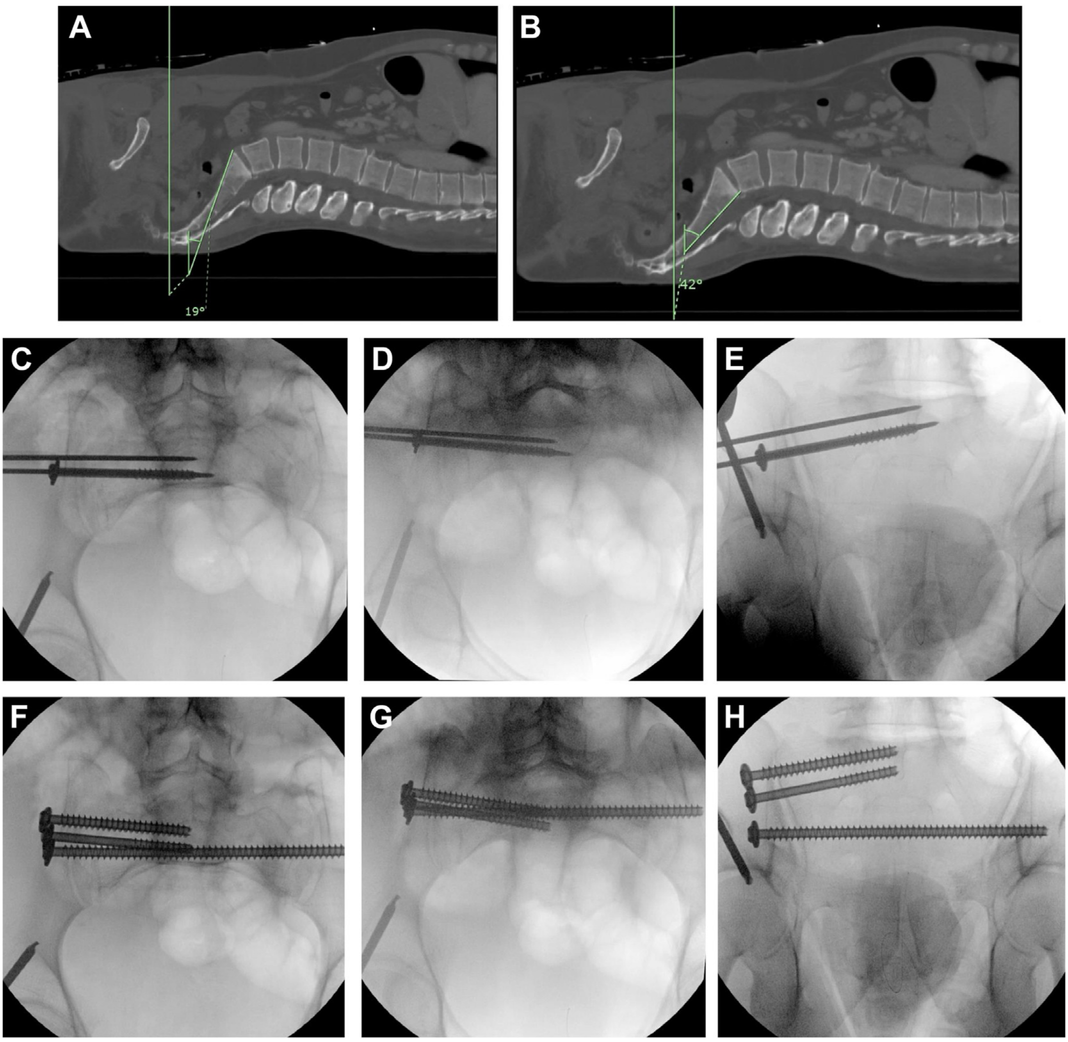

Fig. 8. Inlet and hyperinlet views, multiple S1 iliosacral screws, and S2 transsacral transiliac screw. A 46-year-old man with a lateral compression type 3 pelvic ring injury. Preoperative midsagittal CT inlet angle measurement of 19° (*A*) and hyperinlet angle measurement of 42° (*B*). Intraoperative fluoroscopic inlet (*C*, *F*) and hyperinlet (*D*, *G*) images. Caudal anterior and cranial posterior S1 iliosacral screw positioning (*C–H*). Well-positioned S2 transsacral transiliac screw placed after S1 iliosacral screws.

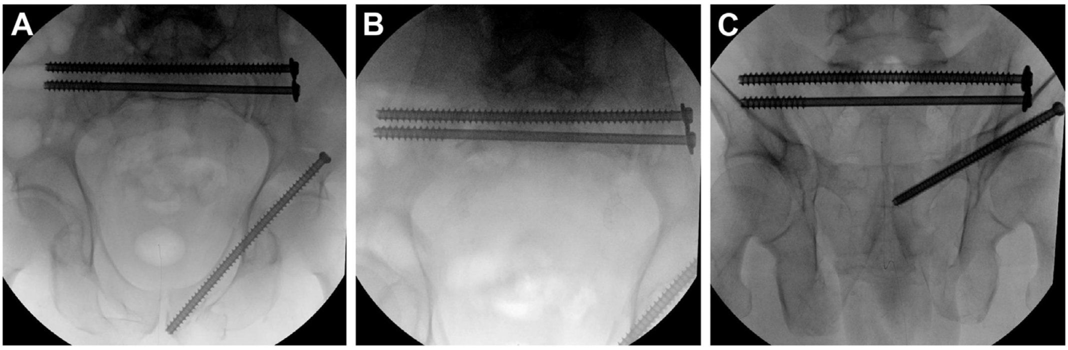

Fig. 9. Two transsacral transiliac screw in S1 with a low and anterior and cranial and posterior screw in the corridor. (*A*) Inlet (*B*) Hyperinlet (*C*) Outlet views after screw placement.

describe a modified iliac oblique-outlet view (MIOO) as an alternative to the pelvic inlet.[26] Two distinct advantages of the MIOO were discussed. First, the MIOO and COOO views are orthogonal. This facilitates C-arm, start point and trajectory adjustments to occur in one plane. Second, the MIOO is easily obtained in the lateral position, unlike the pelvic inlet view, which is often obstructed by arm boards and the patient's body, particularly if they are of large habits. Guimaraes and colleagues found the OO and COOO views most accurate and reliable for determining extra-articular screw position, and the pelvic inlet and MIOO views most accurate and reliable for intraosseous positioning.[29] It is our practice to use pelvic inlet and COOO views when placing antegrade or retrograde anterior column/superior pubic ramus screws. Similar to Bishop and Routt, we aim to achieve an inlet beam angle tangential to the posterior cortex of the superior pubic ramus, such that the superior and inferior rami are not superimposed.[11] On the COOO view, outlet tilt and obturator roll over are adjusted in small increments until the widest cranial caudal corridor at the acetabular isthmus is observed. Ideal positioning of intramedullary implants should be tangential to the apex of the posterior border of the superior ramus on the inlet view and above the acetabulum and obturator foramen on the COOO view (Fig. 10).

POSTERIOR COLUMN

Although many posterior column injuries are preferentially stabilized with open posterior approaches and plate and/or screw fixation, some fracture patterns may be amenable to percutaneous or columnar fixation of the posterior column. These often include minimally displaced fracture or more caudal transverse fracture patterns that do not affect the congruency of the cranial femoral head and the dome of the acetabulum. The AP (or outlet) and iliac oblique images are used for the placement of these implants, which can be placed in an antegrade fashion (through the lateral window of the ilioinguinal approach) or in a retrograde fashion using percutaneous techniques. On the AP image, the implant should be just lateral to the quadrilateral surface. Screws directed peripheral from the quadrilateral surface often exit the osseous fixation pathway near the ischial recess just peripheral to the lesser sciatic notch. An obturator outlet image can be used in addition to the AP (or outlet) view to visualize an extraosseous implant. The iliac oblique view ensures the screw is anterior to the greater and lesser sciatic notches and posterior to the joint. Implants placed in an antegrade fashion usually terminate just distal to the ischial spine because the rib cage often prevents the surgeon from directing the implant to the most caudal aspect of the ischial tuberosity. With retrograde placement, the implant begins on the ischial tuberosity and is directed toward the pelvic brim. The surgeon must ensure the screw is not too long into the iliacus fossa. A lateral sacral view can aid the surgeon in determining the proper ending point of a retrograde posterior column screw. The iliac cortical density represents the pelvic brim and provides the surgeon an excellent marker of a safe endpoint for a retrograde posterior column screw (Fig. 11).

ACETABULAR FRACTURES

Most acetabular fractures will undergo open reduction before internal fixation. Anterior column screws are commonly placed using fluoroscopic guidance for fractures in transverse-family when a Kocher-Langenbeck approach is chosen. Fluoroscopic imaging should be used to confirm that all

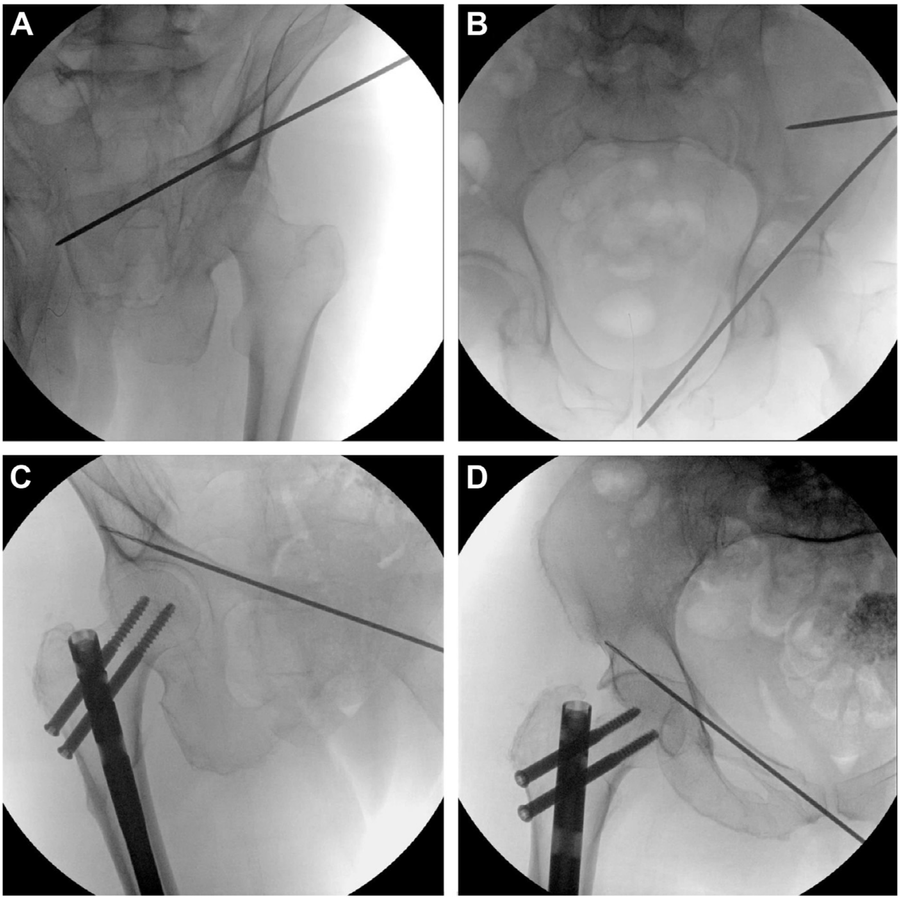

Fig. 10. Well-positioned antegrade guidewire placement on COOO and inlet views (*A*, *B*). Well-positioned retrograde drill bit placement on COOO and inlet views (*C*, *D*). COOO, combined obturator oblique outlet.

implants are extra-articular during the surgery because only one image demonstrating a screw is extra-articular is needed to confirm the absence of intra-articular implants. Several studies have investigated the optimal view for determining extra-articular screw placement. Norris and colleagues demonstrated that any one view of the acetabulum demonstrating separation between screw and articular surface is sufficient to confirm extra-articular positioning.[30] In their study, a true lateral view of the pelvis was found to be most accurate for determining extra-articular position of posteriorly based screws. Axial or "on end" fluoroscopic views have been shown to be equivalent to postoperative CT for detecting intra-articular screw positioning in patients operated on in the lateral position.[31,32] This view typically requires iliac oblique rotation and varying degrees of inlet or outlet tilt until an on end view of the screw head is achieved.[32] For acetabular fracture surgery done prone, Tosoundidis and colleagues demonstrated the effectiveness of a combined inlet obturator oblique view for extra-articular placement of posterior wall lag screws.[33] Regardless of patient position, Wu and colleagues demonstrated that peripheral-based posterior wall plate screws along the lateral brim are at the highest risk for intra-articular penetration.[34] Therefore, because the screw entry point along the posterior wall shifts from medial to peripheral, greater screw angulation is needed to avoid penetrating the joint.

INTRAOPERATIVE COMPUTER TOMOGRAPHY

There are times during pelvic ring and acetabular fracture surgery when intraoperative fluoroscopy, despite all attempts, is insufficient to accurately and reliably confirm reduction quality and implant position. Additionally, in certain patients, there is little correlation between preoperative and intraoperative image findings. For example, circumferential compression devices placed before preoperative CT imaging have the potential to mask or accentuate pelvic ring injury severity.[35] Additionally, preoperative CT

Fig. 11. Lateral sacral view of a retrograde posterior column screw with the screw tip positioned caudal to the pelvic brim.

imaging of fracture dislocations are sometimes performed in an unreduced state without repeat imaging obtained after closed reduction attempts and before surgery. In these situations, surgeons are required to make important intraoperative decisions based on suboptimal information. This can place patients at risk for inadequate reductions, misplaced implants, and revision surgeries.[36]

Multiple studies investigating the utility of advanced intraoperative imaging during pelvic ring and acetabular fracture surgery have been undertaken. Acetabular fracture fixation and iliosacral screw placement under CT image guidance has been associated with improved quality of reduction and screw positioning.[37–39] In contrast, other authors have found no differences regarding screw positioning when comparing computer-navigated and conventional fluoroscopic guided iliosacral screw placement.[40] Although the results of this study may have been influenced by surgeon experience.

Intraoperative multidimensional fluoroscopy (IMF) using the Ziehm Vision RFD 3D (Ziehm Nuremburg, Germany) has become popularized during the recent years. Shaw and colleagues reported on 52 cases of unstable posterior pelvic ring disruptions.[41] Guide pin insertion for percutaneous iliosacral or transiliac transsacral screw fixation was performed under traditional fluoroscopy. IMF was then obtained after screw fixation. No screws were found to be intraforaminal on IMF or postoperative CT. Forty-two percent of patients received more than one IMF spin, 5 patients received IMF before guide pin placement to assess the available bony corridor after a reduction maneuver, 3 patients underwent IMF after guide pin insertion but before definitive screw fixation, and 2 patients underwent screw revision after reviewing the IMF findings. Routt and colleagues reported on several cases where IMF was helpful for identifying retained intra-articular loose bodies, malreduced dome comminution, and misdirected screws.[36] Additionally, specific mention was made regarding the usefulness of IMF in morbidly obese patients and combined acetabular pelvic ring injuries.

SUMMARY

Obtaining clear and reliable intraoperative images during pelvic ring and acetabular fracture fixation surgery is challenging due to the complex osteology and injury patterns involved, as well as the unique characteristics of each patient and the technical demands of the procedure. A meticulous and comprehensive preoperative plan can help anticipate and mitigate many of these challenges, thereby preventing them from devloping during the surgery. Preoperative plain radiographs offer valuable insight into potential challenges that can compromise intraoperative image quality, such as body habitus, bowel gases, contrast dye, and abdominal packing. These factors can be identified and addressed before surgery to ensure optimal imaging intraoperatively. Preoperative CT studies provide an opportunity to proactively anticipate image angles and gain a deeper understanding of the osteology and bony displacements because they will be seen intraoperatively. It is essential not to overlook the significance of appropriate fluoroscopy equipment, room setup, and consistent communication between the surgeon and radiology technician. These factors play a crucial role in ensuring the effectiveness of intraoperative imaging and promoting efficient workflow. When achieving high-quality intraoperative imaging is not possible, advanced imaging techniques such as CT and multidimensional fluoroscopy can be highly effective. The information provided by these specialty devices may eliminate uncertainty of safe screw corridors and appropriate reduction while reducing unnecessary secondary surgeries by identifying problems in real time.

CLINICS CARE POINTS

- Suboptimal intraoperative fluoroscopic imaging can lead to fracture malreduction, errant implant placement, and neurovascular injury.[3–5]
- When excessive bowel gas is present, image quality can be improved with abdominal massage to displace bowel gases away from sacral neuroformina and beam collimation to enhance image contrast.[7]
- In morbidly obese patients, a reliable lateral sacral fluoroscopic image is unachievable when the lateral sacrum cannot be visualized on a preoperative lateral scout CT image.[9]
- Inlet and outlet image angles are nonorthogonal and can be anticipated with reasonable accuracy when measured on preoperative midsagittal CT scans.[14]
- Inlet and outlet image angles will vary widely between patients due to the wide range of sagittal sacral tilt present.[15]
- Standardized fluoroscopy language can improve OR communication and fluoroscopy efficiency.[24]
- When multiple or a cranial posterior iliosacral screw is planned, a hyperinlet view is useful for delineating the posterior cortical limit of the upper sacral segments.[25]
- The modified iliac oblique outlet view is an alternative view for determining accurate and safe positioning of anterior column/superior pubic ramus screws.[26]
- Extra-articular screw positioning during acetabular fixation can be confirmed with a single view demonstrating separation between the articular surface and implant.[30]
- IMF is a useful tool for confirming reduction accuracy and safe implant placement when optimal intraoperative imaging is unachievable.[41]

DISCLOSURE

I.G. Hasegawa has nothing to disclose. J.L. Gary has something to disclose. Detailed relevant disclosure information is available at AAOS.org/disclosure.

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