



Percutaneous fixation of acetabular fractures

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- The objective of surgery for acetabular fractures is to achieve precise reduction to restore joint congruence, fix internal bone fragments, avoid displacement of the fracture and allow rapid rehabilitation.
- Open reduction and internal fixation is the benchmark method for displaced acetabular fractures, but open reductions can increase morbidity, causing neurovascular injury, blood loss, heterotopic bone formation, infection and poor wound healing.
- An anatomical reduction with a gap of 2 mm or less is a predictor of good joint function and reduced risk of post-traumatic osteoarthritis.
- The percutaneous approach is associated with fewer complications than open techniques, but acetabular geometry makes percutaneous screw insertion a challenging procedure.
- The percutaneous technique is recommended for non-displaced or slightly displaced fractures, and in obese, osteoporotic and elderly patients who cannot receive total joint arthroplasty.
- We recommend the use of intramedullary cannulated screws.
- Fracture reductions are achieved by manual traction of the affected bones. If some fracture displacement remains, accessory windows can be used to introduce a ball spike pusher, a hook or a Steinmann pin which can be used as a joystick to rotate the fracture.
- In this paper, we describe the accessory windows for the anterior column, the quadrilateral plate and the posterior column. We detail the position, direction and kind of screws used to stabilize the anterior and posterior columns.

Keywords: acetabular fractures; percutaneous fixation; windows; corridor

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Introduction

Acetabular fractures are infrequent fractures with an incidence of 3/100 000 per year.¹ Judet and Letournel^{2,3} were the first to describe treatment for acetabular fractures. Their surgical treatment was based on anatomical reduction and internal fixation of fractures.² The objective of surgery is to achieve exact reduction to restore joint congruence, to adequately fix internal bone fragments, avoid displacement of the fracture and allow rapid rehabilitation.³ Open reduction and internal fixation (ORIF) of fractures, associated with rapid rehabilitation, is considered the 'benchmark' for treatment.⁴⁻⁸ Judet et al^{2,3,9} have shown that an anatomical reduction with a gap of 2 mm or less is a predictor of good joint function and reduced risk of post-traumatic osteoarthritis. Therefore, the surgeon should try to obtain reductions with zero displacement or up to 1 mm. The anatomical reduction and stable osteosynthesis of the acetabular dome are fundamental to successful joint congruence and permit normal transfer of body weight.^{10,11}

Unsatisfactory reductions result in chronic hip pain and limited movement. The interval between fracture and surgery affects fracture reduction. Mears et al¹² showed that surgery performed over 11 days after trauma was less likely to obtain anatomical reduction. Surgical treatment after three weeks is more difficult due to soft-tissue contracture, organization of the blood clot and callus formation.⁷ The type of fracture also affects the possibility of adequate anatomical reduction. Mears et al¹² have reported that anatomical reduction was achieved in 87% of patients with simple fractures and 59% of patients with associated fractures. Matta⁷ reported similar results in a study of 259 patients. Anatomical reduction was achieved in 96% of cases with simple fracture and 64% of patients with associated fractures. Osteopaenic bone and advanced age increase the risk of inadequate reduction and fixation of fractures.^{10,13,14}

In patients with obesity (BMI > 40) who are treated with ORIF, the risk of infection, thromboembolism and

operative bleeding increases two-fold.¹⁵⁻¹⁹ Blood loss during open surgical approach ranges from 400 cc to 1200 cc depending on the approach used and the fracture type.²⁰⁻²² Minimally-invasive fixation techniques reduce surgical time and blood loss.²³⁻²⁵ ORIF is the benchmark method for treatment in most displaced acetabular fractures, but open reduction can cause morbidity, including neurovascular injury, blood loss, heterotopic bone formation, wound infection and problems with wound healing.^{26,27}

The percutaneous approach is associated with fewer complications than open techniques.²⁶ However, acetabular geometry makes percutaneous screw insertion a challenging procedure. In order to achieve correct placement of the percutaneous screw, we need to know the exact points of insertion, direction and the angle of the screw. Acetabular fractures can be treated with percutaneous screws using fluoroscopic guidance in the inlet-iliac view and the outlet-obturator view. This procedure requires prolonged radiographic exposure to guide the positioning of the screws, and has a long learning curve since the orthopaedic surgeon must think in 3D and understand the radiographic visualization image and relevant anatomical landmarks it shows.²⁴ The surgeon must be able to correctly identify the dynamic landmarks of the anterior and posterior columns of the acetabulum as well as the dome zone in order to safely place the cannulated screw. Practice reduces the time needed for surgery.

Kahler²⁸ reported that 1 minute of radiographic exposure of the pelvis under fluoroscopy is equal to 40 mSv of radiation or the equivalent of about 250 chest radiographs. Frank et al²⁹ reported that the average radiographic exposure time for placement of one cannulated screw in the anterior column using conventional methods is 3 minutes and 13 seconds. Decreasing radiation exposure for both the patient and the surgeon should be a priority of percutaneous surgery. Percutaneous screws for acetabular fracture can also be placed with a CT scan. Jaskolka et al³⁰ reported that the average dose for pre-operative/post-operative CT study was 11.5 mSv/12.3 mSv respectively, with a cumulative average dose of 23.8 mSv. The CT-guidance technique is a complex procedure for the surgical team, as the patient must be moved in and out of the CT scanner several times during surgery.

Recently, computer-assisted orthopaedic surgery has been used to improve the accuracy of percutaneous placement of acetabular screws. The learning curve for this technique is high. Percutaneous treatment of acetabular fractures with lag screws is only recommended for non-displaced or slightly displaced fractures which are easily reduced. Trans-rotationally displaced fractures with soft-tissue damage are more difficult to reduce. Percutaneous treatment is not effective for these fractures, or for comminuted fractures, both of which require intra-pelvic or open techniques.

Obese, osteoporotic and elderly patients who cannot receive total joint arthroplasty are also candidates for percutaneous fixation given the poor results of open surgery and internal fixation in these types of patients. Percutaneous surgery cannot currently replace ORIF in displaced fractures. A great deal of experience is required to properly treat acetabular fractures. It is not easy to correctly interpret images of the acetabulum: surgeons must understand radiological images in different positions and be familiar with the corridors of the pubic bone and the ischium where the screws are placed to achieve intramedullary fixation.

In 2002, we performed a cadaveric study and described the intra-pelvic portals for intramedullary fixation of fractures of the anterior and posterior column of the acetabulum.³¹ This study demonstrated the feasibility and safety of intramedullary fixation of the ilium, ischium and pubic bones and clearly identified the respective bone corridors where screws must be placed. Subsequently, the results of clinical applications of this technique were presented.^{32,33}

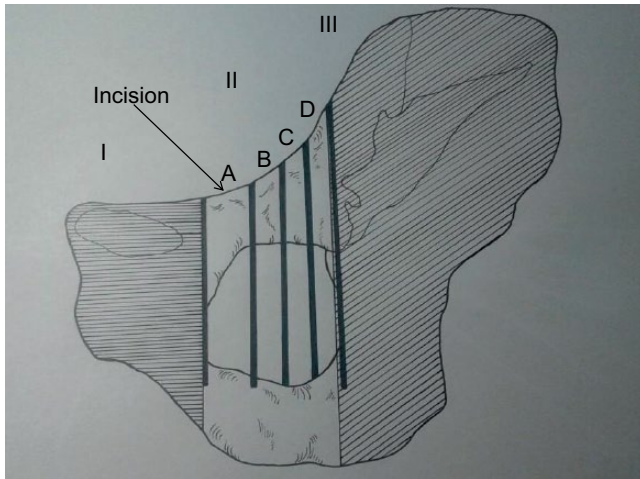
The approach for this technique is intra-pelvic. It uses the first window of the ilio-inguinal approach and reduction is done either by indirect manual traction or by direct manipulation of the fracture fragments from within the pelvis. The patient is placed in the supine position inclined 30° towards the midline, away from the affected side, and the technique we described is designed for this position. Once the patient is in this position, the C-arm must be placed 30° to the contralateral side to see the frontal view. This 30° correction is also needed in both oblique views, and can be achieved by moving the C-arm or by changing the position of the operating table.

Principles

We recommend the use of intramedullary cannulated screws because they resist the rotational, axial and compressive forces within the pelvic ring and help to hold the fracture. Open reduction and definitive internal fixation should always be prepared and planned for as a valid option in case of failed reduction, insufficient stability and re-displacement intra-operatively.

Positioning

The patient is placed on the operating table in the supine position, with a liquid pad under the ipsilateral buttock, placing the pelvis inclined 30° towards the midline. The cadaveric study carried out in 2002 by our Department of Orthopaedics³¹ showed that this position provides a good view of the internal pelvis as the viscera slide towards the medial zone. In addition, this position enables the surgeon to manipulate fractures and perform reduction more easily. The patient is also immobilized with a padded strap, placed across the inguinal region opposite the



Nakatani classification of pubic bone I, II, III

Classification of obturator foramen, IIA, IIB, IIC, IID

Fig. 1 Division of pubic bone. Nakatani classification of pubic bone I, II, III. Classification of obturator foramen, IIA, IIB, IIC, IID.

fracture and attached to the contralateral edge of the operating table. This strap prevents displacement during manual traction of the fractured limb. This 30° inclination is the preferred position in all fractures except fractures of the posterior wall. It allows intra-pelvic access when minimally-invasive reduction techniques are unsuccessful. The patient is only positioned in lateral decubitus when over 50% of the posterior wall of the acetabulum is fractured. These fractures can only be accessed posterolaterally.

Fracture reduction

Fracture reduction is achieved by manual traction of the affected limb by applying a force contrary to the direction of fracture displacement, usually perpendicular to the direction of fracture (lag screw). The image intensifier is used to manually position the fragments and to place the screws along the corridors of the anterior and posterior column, depending on the pattern of the fracture. If some fracture displacement remains after manual reduction, accessory windows can be used to introduce a ball spike pusher or a hook, or a Steinmann pin can be used as a joystick to rotate the column. If fluoroscopic images reveal inadequate manual reduction, the intra-pelvic approach is used to internally fix the fracture. Intramedullary fixation is preferred when the fracture line permits it. If not, the plates and screws are placed on the inner side of the pelvis.

Accessory windows

There is one accessory window for the anterior column, one for the quadrilateral plate and there are two for the posterior column.

Anterior window

The anterior window is used to reduce the anterior column, which is generally displaced and rotated medially. Starr et al³⁴ divided the pubic bone into three anatomical zones. The first zone is medial to the obturator foramen, the third is lateral to the obturator foramen and the second is between zones I and III. Access to the superior window is in zone II. We divide the obturator foramen into four parts. The most medial area, which we call IIA, is occupied by the pectineus muscle and is a safe access zone. Zone IIB includes the corona mortis, the femoral canal and part of the femoral vein. Part IIC includes part of the femoral vein and the femoral artery. Zone IID includes the femoral nerve and the psoas muscle. The obturator nerve generally exits the obturator hole in zone IIB, below the pubic bone (Fig. 1).

The inguinal canals are situated just above the medial half of the inguinal ligament. The canals transmit the ilio-inguinal nerves in both sexes and the spermatic cord in male patients. Starr et al³⁴ described closed reduction by hip adduction and external rotation. When this was unsuccessful, the iliac wing was grasped and external rotation force was applied to roll the lateral ramus fragment into better alignment, or internal rotation force was used to close fracture gaps. In our centre, when closed reduction is unsuccessful, the anterior window is accessed by an incision in region IIA, in the upper quarter of the anterior face of the pubic bone. The pubic bone is accessed through an incision and dissection, and a second incision at the antero-superior edge of the pubic bone is used to insert a Cobb Elevator (Sklar Surgical Instruments, West Chester, PA, USA) and expose the bone surface. It is important to stop before the inferior edge of the pubic bone is reached (Fig. 2).

We place a blunt hook in the space thus created, in contact with the posterior aspect of the pubic bone, and use it to reduce the fracture by traction and rotation. Fluoroscopic imaging is used to verify reduction.

Medial window

The medial accessory window can be used to complete the reduction of fracture fragments in transverse fractures. In 2014, Farouk et al³⁵ reported using the mini-para-rectus approach to manipulate and reduce transverse fractures when manipulation under fluoroscopy failed. The incision is placed within ‘Hesselbach’s triangle’, described in 1814 by Hesselbach (Germany) as the triangular area bordered by the deep epigastric vessels, the lateral border of the rectus muscle, and the superior pubic ligament (Cooper’s ligament).³⁶ Farouk et al³⁵ reported that the fracture site is palpated by the finger and a long blunt bone impactor is inserted to manipulate the fracture and achieve fracture reduction. In 2016, Mauffrey et al³⁷ described the reduction of a transverse fracture by the pressure exerted on the quadrilateral plate with a spike

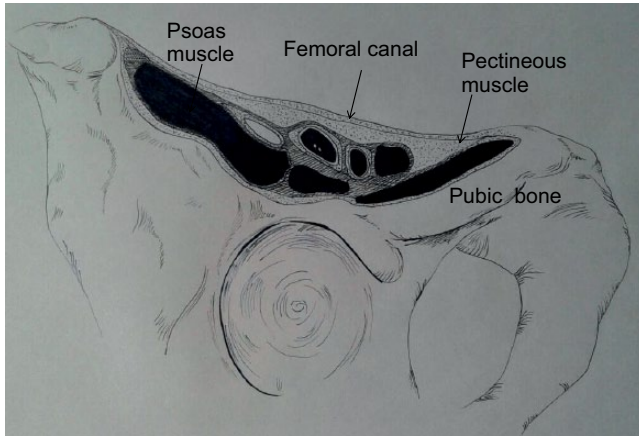


Fig. 2 Supra-pubic bone anatomic division.

ball, using fluoroscopic imaging and laparoscopic assistance. Approach to the quadrilateral plate is through a laparoscopic retroperitoneal access with classic port placement for retro pubic prostatectomy.^{38,39} The incision is made vertically at the infra-umbilical site and blunt dissection is performed down to the fascia. The 12-mm balloon trocar is inserted under direct visualization with a flexible laparoscope and the retro-pubic space is created and insufflated with CO₂ (15 mm Hg). Fasciae are closed with absorbable sutures.³⁷

Posterior window

In the posterior window there are two modes of access, upper and lower.

The upper port is on the iliac crest, at the point where a line projected from the posterior edge of the obturator foramen and directed upwards along the edge of the greater sciatic notch intersects the iliac crest. A Steinmann pin is placed at this point between the two walls of the iliac wing and introduced until it reaches the sciatic notch parallel to the line described above. This Steinmann pin can be used as a joystick and facilitates the reduction of high fractures of the posterior column. We divide the acetabulum into regions like the face of a clock, using the position of the hour arrow hand to indicate different areas. We describe high fractures of the posterior column as those fracture lines that are above hour '3' of the acetabular margin (Fig. 3).

In terms of lower access, the ischial tuberosity is palpated and a 3.0-mm Steinmann pin is placed percutaneously and inserted 10 mm into the ischial bone. The position of the nail is confirmed by means of fluoroscopic imaging. The outlet view is used to confirm medial-lateral nail placement. Anterior-posterior placement of the nail is checked with an iliac oblique view. If the position of the nail is correct, it is introduced another 40 mm which is

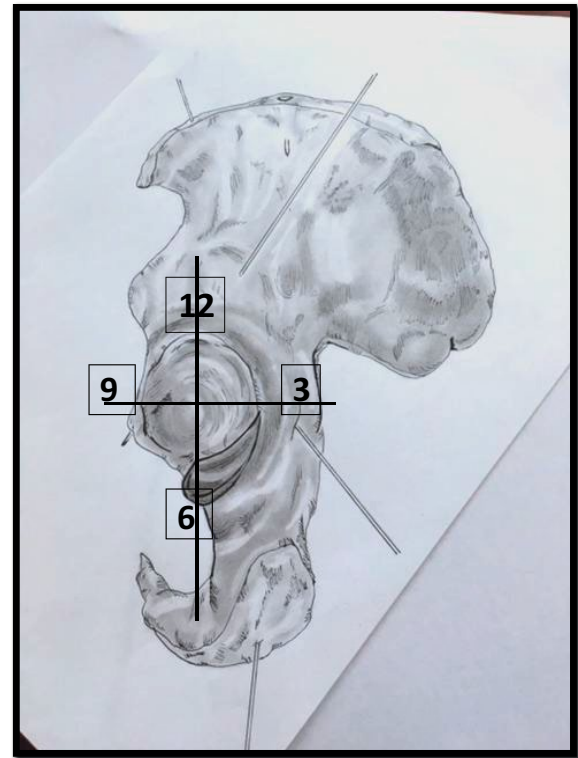


Fig. 3 Clock diagram of acetabular fracture.

sufficient to use it as a joystick to facilitate the reduction of low fractures of the posterior column. We define low fractures of the posterior column as those fracture lines that are below the hour '9' of the acetabular margin.

Corridors

We call the intramedullary spaces through which screws can be inserted to fix the osseous fragments 'corridors'. There are three corridors for fractures of the acetabulum: the iliac-pubic bone, the iliac-ischial bone and the dome zone. The stabilization of one corridor is sufficient in simple column fractures but more than one corridor must be stabilized in complex fractures. Corridors can also be used to add intramedullary screws to plates and screws for stable internal fixation.

Dome corridors

The acetabular dome is part of the anterior and posterior column and therefore the anterior column and posterior column corridors pass through it. The corridor we call the acetabular dome is the one that crosses the upper edge of the acetabulum and allows access from the outer edge of the ilium to the quadrilateral plate. The area of the dome where the supracetabular screw is placed is small and only has room for a single screw.

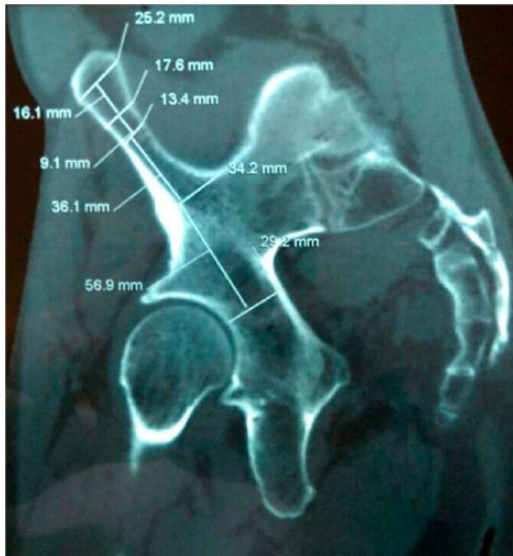


Fig. 4 Posterior pillar corridor.

Anterior column corridor

The anterior column corridor runs from the outer lateral side of the pelvis to Katani's Zone I in the pubic bone. Shahulhameed et al⁴⁰ studied the periacetabular bone stock of 22 hemipelves. Bone narrowing was found in the middle of the pubic ramus: 20.2 mm SD 4.1 (mediolateral diameter) and 15.9 mm SD 2.4 (superior-inferior diameter). A second narrowing area was located in the centre of the acetabulum: 38.2 mm SD 4.1 (mediolateral diameter) and 15.1 mm SD 1.8 (superior-inferior diameter). Ochs et al²⁷ showed that implant length for this corridor was 111.5 mm SD 7.4 in men and 100.6 mm SD 7.6 in women. The maximum possible implant diameter was 7.0 mm SD 1.0 in women. They reported that 6.5-mm screws can be safely used in men. Other authors mention the use of 7.3-mm screws in the anterior column.^{27,41,42} Ochs et al²⁷ reported that 15.4% of female patients required screws under 6.5 mm. Routt et al⁴³ recommended the 3.5-mm and 4.5-mm screws in the anterior column for women and men, respectively. Chinese patients (164 hemipelves) were found to have a similar implant length (men: 113.8 7.1 mm; women: 105.2 8.5 mm) and slightly different implant diameters (men: 8.8 1.0 mm; women: 7.6 1.1 mm).⁴⁴

Posterior column corridor

The posterior column begins on the iliac crest, approximately 4 cm posterior to the anterosuperior iliac spine and from this point runs straight to the ischial tuberosity, passing between the iliac walls, through the acetabular dome corridor, to reach the ischium. We have not found publications that describe using this corridor to stabilize the posterior column or fractures compromising the iliac crest, posterior supra acetabular and posterior column

fractures. CT scans show the narrow area of this corridor to be approximately 6.1 mm × 140 mm long. Therefore 4.5-mm screws can be used in this corridor (Fig. 4).

Screws

Screws for the quadrilateral plates

The fracture of the quadrilateral lamina is difficult to reduce and even more complex to fix. When these fractures are successfully fixed, they are very stable and the screw used in these cases has been called the 'magic' screw.⁴⁵ Ruan et al⁴⁶ reported successful fixation of the quadrilateral plate in five patients using percutaneous 3D fluoroscopically navigated screws. The entry site of the screw is 1 cm above the acetabular ring at hour '11' and 2 cm posterior to the anterior inferior iliac spine. The direction is lateral to medial (10° in relation to the lateral cortex of the iliac wing) and 20° superior to inferior. A Kirschner wire is placed up to the medial cortex without entering it to avoid damage to neurovascular structures. A cannulated drill bit is used and the length measured. Finally, a cannulated 4.5-mm screw is placed.

Screws for the anterior column

Percutaneous screw fixation for anterior column fractures is technically demanding as insertion can be associated with damage to surrounding neurovascular structures with intra-articular penetration.⁴⁷

Anterior antegrade screw for the lateral cortex

The iliac entry point for the antegrade column screw is at the intersection of two lines. The first is a vertical line to the ceiling at the level of the anterosuperior iliac spine, and the second is parallel to the floor and crosses the acetabular border at hour '11'. The drill rod is tilted to 25° of abduction and 10° toward the ceiling. A Kirschner wire is placed in the anterior corridor using fluoroscopic guidance. The obturator oblique view shows the cephalocaudal plane and the inlet view shows the drill position in the anteroposterior plane. We drill until reaching the medial superior pubic ramus. We prefer 6.5-mm cannulated screws. If non-cannulated screws are used, the drill bit is used to open the path in the corridor of the anterior column. The length of the screw is measured with the drill's millimetric guide or by the programme included in the fluoroscan and the correct screw is placed.

Retrograde anterior column screw fixation

The point of entrance for the retrograde pubic screw is medial to the pubic tubercle. The surgeon must be aware of anatomical landmarks in male patients: the spermatic cord is lateral to the pubic tubercle. The position of the drill bit is parallel to the long axis of the superior pubic

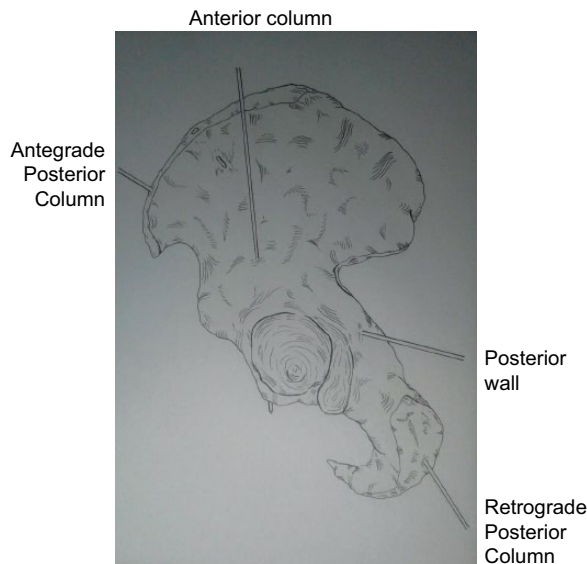


Fig. 5 Lateral view percutaneous illustration of acetabulum.

ramus in 3D space. The drill should only be introduced 1 cm into the medullary pubic bone. The position of the drill is controlled by fluoroscopic imaging in the inlet position to ensure that the posterior cortex is not penetrated. The point of insertion is checked in the anteroposterior inlet-outlet view. In women, we recommend a 3.5-mm cortical screw and in men a 4.5-mm cortical screw. The screw is placed 1 cm into the hole made by the drill. Before starting, the position of the screw is confirmed by fluoroscopic imaging. Once the screw is in the medullary channel, it is self-guided. Its progression within the corridor is corroborated with inlet and obturator oblique views. This screw can be used in fractures of the anterior column that affect the pubic bone up to the hour '7' position in the acetabular ring.

The anterograde iliac posterior column screw

This screw is used to stabilize the upper fractures of the posterior column. The entrance portal for this screw is on the iliac crest, approximately 4 cm from the anterosuperior iliac spine. The inclination of the drill bit is 30° posterior (relative to the ceiling). The drill bit proceeds between the medulla of the iliac bone and through the acetabular dome to the sciatic notch. Fluoroscopic imaging is used to place a Kirschner wire in the posterior column corridor and guide it to the sciatic notch. The iliac oblique view shows the screw position in the cephalocaudal plane and the inlet view shows the position in the anteroposterior plane. A cannulated drill bit is used to drill through the posterior corridor to reach the sciatic notch. It is very important not to penetrate the medial cortex of the pelvis, either with the Kirschner wire or with the cannulated drill,

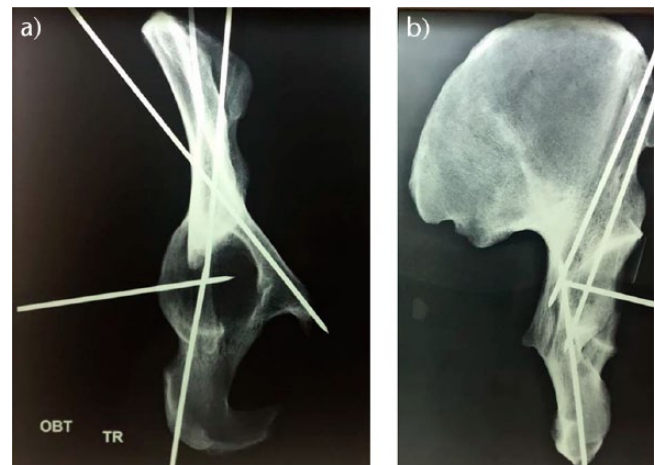


Fig. 6 a) Obturator view of percutaneous illustration of acetabulum in cadaveric bone; b) iliac view of percutaneous illustration of acetabulum in cadaveric bone.

to avoid neurovascular and visceral lesions. The length is measured and the screw is placed (Figs 5 and 6).

The anterograde acetabulum posterior column screw

This screw is used when there is posterior column fracture below the acetabular dome and when less than 50% of the posterior column is affected. An iliac posterior screw must be used for fractures associated with the iliac wing. The exact point of entrance is the intersection between a line joining the anterior inferior iliac spine and the sciatic notch with another line from the iliac tubercle to the ischial tuberosity. This point is located at the hour '1' position of the ring of the acetabulum. The drill bit should be parallel to the iliac wing facing the ischial tuberosity. A Kirschner wire is placed using both oblique views in fluoroscopic imaging to avoid penetrating the hip joint and inner pelvis. A 6.5-mm cannulated screw is used.

The retrograde posterior column screw

The entrance portal for the retrograde posterior screw is the same as for the lower posterior accessory window. Placing the patient at 30° lateral decubitus facilitates access to the ischial zone. The affected limb should be brought to hip and knee flexion, to allow the surgeon's manoeuvres to take place. The ischium should be punctured and the surgeon should avoid going medially to prevent damage to the pudendal bundle, or lateral to where the sciatic nerve and the inferior gluteal artery and vein are located. A cannulated drill bit is used to drill through the posterior corridor to reach the dome of the acetabulum or the iliac wing. The length is measured and the screw is placed. A Kirschner wire is placed in the posterior column corridor using obturator oblique and iliac oblique views via fluoroscopic imaging.

Fractures of the posterior wall

Pure fractures of the posterior wall that do not present comminution or impaction of the posterior wall can be treated percutaneously in patients with good bone quality. The patient is placed in the lateral decubitus position. A neuro-stimulator is introduced into the corridor of the screw to make contact with the bone fragment and avoid the sciatic nerve. A ball spike impactor with a tip is placed in the same corridor and used to reduce the fracture; the fragment is fixed with two screws. Lei et al⁴⁸ developed a finite model of the pelvis and evaluated three fixation methods for fractures of the posterior wall of the acetabulum: two lag screws, a single reconstruction plate with two lag screws, and a single reconstruction plate with two T-shaped mini-plates.

Lei et al⁴⁸ concluded that all three fixation systems could significantly enhance biomechanical stability of posterior wall acetabular fractures. Nonetheless, the system which combines a reconstruction plate with T-shaped plates was more beneficial due to uniform stress distribution, balanced force transfer and minor displacement difference as compared with the normal model.

Iliac wings screw

This screw is used in iliac wing fractures, which are associated with acetabular fractures. The screws can be placed anywhere in the iliac crest area. They are always intramedullary and must be placed between the cortical faces of the iliac bone and perpendicular to the fracture line.

Mechanical stability control

Intramedullary screws are used to fix fractures of the anterior and posterior columns, based on Chang et al's⁴⁹ biomechanical study which states that 'a biomechanical test verified that lag screw fixation for transverse or T-shaped fractures was at least as stiff as plate fixation'. Before leaving the operating theatre, a fluoroscopic test of stability after fixation by lag screws is necessary to ensure that fracture stability has been achieved.

Fixation in elderly patients

Elderly patients with displaced fractures or non-displaced fractures with severe pain and associated comorbidity can be treated with a percutaneous technique to reduce pain and facilitate early mobilization. The procedures are performed under general anaesthesia.

Preferred technique

Percutaneous treatment using window access is preferred in single non-displaced or slightly displaced acetabular fractures. In comminuted fractures or trans-rotationally

displaced fractures with soft-tissue damage, intra-pelvic reduction and fixation are used.

Post-operative rehabilitation

All patients with fractures that have been stabilized by intramedullary means can begin hip mobilization and weight bearing post-operatively. Patients with intramedullary stabilization of the anterior and posterior column can begin walking 48 hours after surgery, with weight bearing of 50%. Patients with pure posterior wall fractures should begin 50% weight bearing at four weeks.

Complications and limitations of this technique

To avoid neurovascular injury and damage to soft tissues, the fracture must be reduced and the intramedullary screw must be carefully introduced into the described corridors, using C-arm imaging to guide progress. This technique is not suitable for comminuted or highly displaced fractures. Surgeons must have experience with percutaneous technique. In future, techniques, such as computer-assisted orthopaedic surgery will undoubtedly improve reduction and fixation techniques.

Conclusions

Percutaneous intramedullary osteosynthesis, a minimally-invasive procedure with low morbidity, should benefit polytrauma patients. Percutaneous treatment can be used in single non-displaced or slightly displaced acetabular fractures. It is not appropriate for comminuted or highly displaced fractures, which must be treated by intrapelvic reduction.

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