■ REVIEW ARTICLE

Percutaneous fixation of the pelvic ring

AN UPDATE

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With the development of systems of trauma care the management of pelvic disruption has evolved and has become increasingly refined. The goal is to achieve an anatomical reduction and stable fixation of the fracture. This requires adequate visualisation for reduction of the fracture and the placement of fixation. Despite the advances in surgical approach and technique, the functional outcomes do not always produce the desired result. New methods of percutaneous treatment in conjunction with innovative computer-based imaging have evolved in an attempt to overcome the existing difficulties. This paper presents an overview of the technical aspects of percutaneous surgery of the pelvis and acetabulum.

Since the early 1960's, after the pioneering work of Judet, Judet and Letournel,¹ there has been a gradual evolution in pelvic and acetabular surgery. A reduction in the size of the operative approach is anticipated, but the aim of achieving anatomical reconstruction of the acetabulum and near anatomical reconstruction of the posterior pelvic ring remains.² Over the last 20 years, open reduction and internal fixation has become the standard method of treating acetabular fractures with displacement of more than 2 mm or for those involving the weight-bearing dome,³⁻⁷ with reports of good results.^{3,8,9} Given the anatomical complexity of the intrapelvic structures, internal fixation is a challenging task and the definitive surgical treatment of injuries to the pelvic ring is still controversial.

Most injuries to the pelvic ring are due to high-energy trauma. The mortality rate is 10% to 20%, mainly due to haemorrhage and associated thoracic and head injury.¹⁰⁻²⁰

Classical techniques of internal fixation have traditionally required extensive surgical exposure of the deep structures of the pelvis, which can be associated with problems of wound healing, damage to major vessels or nerves and an incidence of infection of up to 25%.^{21,22}

Most of these complications are related to the surgical exposure itself, rather than to the initial injury. It therefore seems reasonable to consider less invasive alternatives.²³ In an attempt to overcome the morbidity of extensive

surgical approaches, percutaneous fixation of the pelvis has been receiving increasing attention.⁵ Routt et al¹⁸ described percutaneous fixation with an iliosacral screw, for sacroiliac dislocation and sacral fractures, demonstrating it to be a safe, reproducible method,²⁴ which is biomechanically stable with lower rates of bleeding and infection. Subsequently, percutaneous fixation with iliosacral screws has become increasingly common for treating complex injuries of the pelvic ring.^{18,23,25-28} Recently, closed reduction with percutaneous fixation of non-displaced or minimally-displaced fractures of the acetabulum using CT or fluoroscopic guidance has attracted interest,²⁹⁻³² with advances in the techniques of imaging and computer navigation facilitating such procedures.

This article presents an overview of the rationale for percutaneous fixation of pelvic and acetabular fractures and the techniques utilised in specific patterns of fracture.

Rationale, indications and contraindications

Percutaneous techniques may offer a shorter surgical time, reduce exposure-related hazards^{33,34} and decrease soft-tissue disruption. The soft-tissue planes remain unviolated, which facilitates later arthroplasty of the hip if it becomes necessary.³⁵ In patients with severe comminution and osteopenia, or when there is injury to the head of the femur, the percutaneous technique is useful as a means of preserving bone stock.³⁶ It does not decompress the pelvic hae-

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Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1d

Fig. 1e

Figure 1a – Radiograph of a fracture of the left anterior column amenable to percutaneous fixation with an antegrade screw. Figure 1b – The fluoroscopic identification of the entry point. Figures 1c and 1d – Advancement of the guide pin is under continuous fluoroscopic control. Figure 1e – Radiograph showing fixation of the fracture.

matoma and therefore surgical stabilisation is possible without the risk of additional haemorrhage.³⁷

Early and accurate closed reduction in association with stable fixation utilising percutaneous techniques may be an ideal treatment for specific disruptions of the pelvic ring, especially in polytrauma.^{38,39} Blood loss is significantly decreased, which is particularly important when treating patients with an underlying malignancy,⁴⁰ and due to decreased tissue trauma and the lack of a large open wound, a lower risk of infection may be anticipated.²⁹ Patients can often begin weight-bearing within two weeks after percutaneous fixation and do not have to recuperate from a major operation.²⁹

Percutaneous fixation is recommended when a number of essential criteria are met and only after an accurate reduction has been achieved, avoiding residual displacement which can endanger the adjacent neural and vascular structures associated with compromised outcomes and function.⁴¹ It may be used in patients with considerable soft-tissue damage, which would complicate or prevent open techniques, to provide a stable skeletal frame in anterior and posterior pelvic injuries. It is suitable for patients with severe open fractures, faecal or environmental contamination, extensive closed degloving injuries and abrasions or lacerations.^{42,43} It is applicable to unstable injuries of the pelvic ring if performed within the first five days after injury.¹⁸ Patients treated after seven days may require open reduction because of soft-tissue fibrosis which could prevent closed reduction.^{41,44} The technique is also useful as a

form of supplementary fixation for non-displaced portions of complex acetabular fractures.⁴⁵

Percutaneous fixation under image guidance with cannulated screws is a surgical option in cases of minimally-displaced transtectal acetabular fractures, high anterior-column fractures, posterior hemitransverse fractures of the anterior column or vertical fractures of the ilium (Fig. 1).⁵ In younger patients the technique should be limited to simple patterns of fracture which can sometimes be reduced by using closed or limited open methods. If pre-operative radiographs reveal a simple fracture which may be amenable to closed or limited open reduction, this option is offered to the patient with the understanding that failure of these methods will necessitate a traditional open approach.³⁶

Elderly patients may have comorbid conditions which put them at a greater surgical risk with an open reduction⁵ and can benefit from a percutaneous procedure,³⁶ while the rapid relief of pain, prompt initiation of active or active-assisted transfers and the potential for early discharge from the hospital are particularly advantageous.

Fractures of the posterior wall of the acetabulum are rarely amenable to percutaneous reduction and fixation. Reduction of marginal impaction is often necessary, dictating an open approach for debridement and reduction of the articular surface. The unstable fracture-dislocation of the posterior wall remains an indication for formal open reduction and internal fixation.⁴⁶

Fig. 2a

Fig. 2b

Fig. 2c

Percutaneous intramedullary screw fixation of an unstable fracture of the superior pubic ramus is achieved using fluoroscopic supervision after closed or open reduction. Diagrams showing retrograde insertion (a, b) from the pubic tubercle directed laterally and c) ante-grade insertion from the supra-acetabular area directed medially.

In general, fractures of the acetabulum which are potentially amenable to fixation by percutaneous techniques include non-displaced (1 mm to 3 mm), but potentially unstable fractures, involving the weight-bearing dome, slightly displaced (3 mm to 5 mm) injuries which may be reduced by lag-screw fixation, displaced fractures (5 mm) in which an acceptable closed reduction, can be achieved, dis-

placed both-column fractures with acceptable secondary congruence and displaced fractures in the morbidly obese.^{23,46}

The use of the technique is precluded in displaced fractures which are irreducible by closed means, sacral dysmorphism and other unusual pelvic anatomical variations.³⁷ Safe insertion of an iliosacral screw is impossible in such patients and is determined by the pre-operative radiological studies. The method cannot be used if intra-operative fluoroscopic imaging is inadequate because of morbid obesity or intra-abdominal contrast agents.

Imaging

In all patients with suspected disruption of the pelvic ring, conventional anteroposterior (AP), inlet and outlet radiographs of the pelvis are obtained illustrating the zones of injury, the patterns of displacement and potential anatomical variations.³⁷ With injuries involving the acetabulum, conventional AP, obturator and iliac oblique acetabular radiographs should be included to define the pattern of injury.¹ A true lateral view of the sacrum allows recognition of sacral dysmorphism and identifies unusual transverse fractures. The Judet oblique¹ biplanar images of the acetabulum are useful in providing an understanding of fractures of the pubic rami and disruption of the sacroiliac joint.

The obturator oblique, obturator inlet and obturator outlet views can provide excellent visualisation of the hemipelvis and the supra-acetabular area.³⁵

Two-dimensional CT is useful in evaluating the severity and geometry of the fractures, revealing obvious and subtle posterior injuries and is particularly helpful in characterising acetabular impaction involving the posterior wall or the femoral head.⁵ Such imaging is vital to exclude the presence of small free fragments of bone within the hip joint which indicates the need for an open procedure.²⁹ In the case of displaced or comminuted fractures, three-dimensional CT reconstruction demonstrates the rotational deformity of the fragments.⁵

Operative technique

The surgeon must be aware of the anatomical structures which lie in the path of percutaneously-placed devices. Surgery is performed under general anaesthesia. The use of nitrous oxide as well as the presence of contrast material in the gastrointestinal tract may obscure bony details when using fluoroscopy.⁴⁵ A radiolucent operating table is used. The patient lies supine for fractures of the anterior column, those involving both columns and injuries to the sacroiliac joint, and in the lateral decubitus position for transverse fractures, and fractures of the posterior column. There is no single manoeuvre which can reduce all fractures of the acetabulum in a closed manner. Under fluoroscopic control the application of various techniques such as leg traction, hip rotation and the use of Schanz pins or a temporary external fixator can be made in order to realign the fragments.

Fig. 3a

Fig. 3b

Stabilisation of a fracture of the wing of the ilium may be indicated for the management of pain, early mobilisation, and optimisation of pulmonary function in patients with multiple injuries. Diagrams showing percutaneous screws, inserted from a) the anterior inferior iliac spine and b) terminating in the posterior iliac crest, which are used to stabilise the inferior portion of the fracture.

In some cases, a limited open reduction can be performed, exploiting percutaneously-placed instruments such as ballspikes before placement of a lag screw.

Imaging throughout the whole procedure is extremely important in order to avoid iatrogenic injuries to neurovascular structures. The angles of introduction of Kirschner wires and screws may have to be adapted according to the bony anatomy and must always be verified under fluoroscopy with movement of the hip.

The management of particular patterns of fractures of the anterior pelvic ring

Fractures of the superior ramus: use of an antegrade and retrograde medullary screw (Fig. 2). This technique is an alternative to open reduction and internal fixation or external fixation for unstable fractures of the pubic ramus which are often associated with posterior pelvic disruption. Provided that satisfactory reduction can be obtained, the per-

Fig. 4a

Fig. 4b

Sacral fractures mostly occur in the sagittal plane and are located medially. Diagrams showing a) the sacral screw inserted through the articular surfaces of the sacroiliac joint from the pelvic outlet view and b) placed perpendicular to the fracture, thus allowing longer screw length to balance the fixation from the pelvic inlet view.

cutaneous medullary screw can be inserted either in an antegrade fashion from the supra-acetabular area and directed medially to the symphysis pubis or retrograde from the pubic tubercle and directed laterally above the acetabulum. Injuries to local structures during drilling and insertion of the screw can be avoided by using a soft-tissue sleeve and an oscillating drill. Reduction of the fracture, accurate insertion of the screws and prevention of penetration of the hip are monitored by frequent intra-operative imaging.⁴³ In fractures of the middle part of the ramus the screw does not have to extend beyond the hip.²⁴ Thick musculature of the buttock, obesity, anterior pelvic swelling or marked curvature of the ramus may prevent antegrade or retrograde placement of the screw. When symphyseal disruption and fracture of the ramus coexist, a retrograde screw can be combined with plating of the symphysis.²⁵

Injuries to the posterior pelvic ring

Fractures of the ilium managed by a medullary screw in the pelvic brim (Fig. 3). Fractures of the ilium occur infrequently due to direct trauma⁴⁷ and are usually associated with other disruptions of the pelvic ring, visceral injuries or damage to the superior gluteal vasculature.²²

Percutaneous fixation is limited by the anatomy of the bone but may be applied at the pelvic brim and iliac crest, thus precluding deep surgical exposure of the iliac fossa.

A 7.0 mm medullary screw is inserted at the anterior inferior iliac spine and passed above the greater sciatic notch into the posterior iliac spine. Thinner screws may fail and bend, leading to loss of reduction.³⁷ Comminuted fractures of the ilium are not suitable for this technique and require stabilisation by plates and screws.

Sacral fractures (Fig. 4). Denis, Davis and Comfort⁴⁸ classified fractures of the sacrum as alar (zone I), transforaminal (zone II) and involving the sacral body (zone III), describing other variations as U-, H-, and Y-shaped patterns. Various techniques have been described for the stabilisation of these fractures.⁴⁹⁻⁵¹

Sacral fractures are located more medially than sacroiliac disruptions and are orientated more vertically. Hence the percutaneous fixation of the fractures is different than for injuries to the sacroiliac joint. The screw is introduced from

Fig. 5a

Fig. 5b

Diagrams showing that sacroiliac screws avoid the chondral surfaces, being orientated obliquely to remain perpendicular to the disrupted sacroiliac joint. a) the pelvic outlet view and b) the pelvic inlet view.

the lateral ilium in a more horizontal direction and aimed perpendicular to the fracture into the upper part of the body of the sacrum, beyond the vertebral midline preferably into the contralateral alar. The length of the screw is also greater in order to maximise fixation.¹⁸ Subsequently, the risk of error in placement of the screws is increased because the sloping alar zone is crossed by the screw bilaterally. Because of the risk of neural complications, injuries in zone II merit particular care.

Open debridement and reduction without compression of a sacral fracture should be undertaken before utilisation of fully-threaded screws in order to prevent the occurrence of a lag screw compression effect.¹⁸

Iliosacral screw fixation of U-, H- and Y-shaped sacral fractures can be used after closed or open reduction using long screws, inserted bilaterally whenever possible and crossing the fracture on both sides.

Sacroiliac joint disruptions (Fig. 5). Traumatic disruptions of the sacroiliac joint are often accompanied by other injuries to the anterior pelvic ring.⁵¹⁻⁵³ The application of a pelvic external fixator or reduction and fixation of the anterior pelvic ring may worsen posterior disruption. It is essential to obtain an anatomical reduction of the hemipelvis before introducing iliosacral screws. The upper posterior quadrant, formed by the intersection between a line parallel to the femoral diaphysis and another line perpendicular to the anterosuperior iliac spine, is the site of insertion. Under imaging control, a guide wire is passed from the lateral edge of the ilium, perpendicular to the sacroiliac joint towards the body of the first sacral vertebra. Lateral views of the sacrum are taken to confirm the correct positioning of the guide wire within the safe zone, avoiding the placement of an 'in-out-in' screw, as described by Routt et al.³⁸ A 7.0 mm cannulated screw is then inserted and directed perpendicularly to the sacroiliac articulation while the chondral surfaces are avoided. Following placement of the first screw, a second screw is used as necessary.

Fractures of the wing of the ilium. Fracture dislocations involving the sacroiliac joint may occur in combination with a fracture of the posterior part of the ilium, usually after a lateral compression injury.¹³ The extent of the

Fig. 6a

Fig. 6b

Diagrams showing that anterior-column screws can be placed in a) a retrograde or b) antegrade fashion. Usually retrograde placement is easier unless the patient is obese. During placement of the guide wire the femoral nerve, artery, vein and spermatic cord could be injured.

fracture of the ilium is determined by CT. Small fragments are amenable to percutaneous fixation by a sacroiliac screw with or without supplementary fixation. In patients with large fractures of the wing of the ilium, plates and screws should be utilised to stabilise the iliac fracture and disruption of the sacroiliac joint.²²

Fractures of the acetabulum

Fractures of the anterior column (Fig. 6). Screws can be placed in the anterior column in either an antegrade (cephalad to caudad) or retrograde (caudad to cephalad) direction. The insertion point for antegrade placement is determined by a line drawn between the tip of the greater trochanter and the thick part of the iliac crest, about 4 cm to 5 cm posterior to the anterosuperior iliac spine. In obese patients a more proximal entry point is advisable. A skin incision of about 1 cm is made and deep dissection performed by spreading the soft tissues with a clamp down to bone, with care taken to avoid the lateral femoral cutaneous nerve. Imaging control using the outlet-obturator oblique and inlet-iliac oblique views allows safe passage of a 2.8 mm guide wire down the superior pubic ramus towards the symphysis pubis, avoiding penetration of the cortex. After drilling, a 7.3 mm cannulated screw is passed over the guide wire. For retrograde placement an incision 1 cm long is made inferior and lateral to the ipsilateral pubic tubercle. A guide wire is passed at 45° from medial to lateral through the superior pubic ramus across the fracture and above and anterior to the hip. Obturator-outlet and iliac-inlet views are helpful, although standard Judet views¹ may be adequate. Care must be taken to avoid damage to the femoral vessels or nerve, or to the spermatic cord in men. If the point of entry of the guide wire lies too inferior, the obturator nerve and artery may be damaged.⁵⁴ A 7.3 mm screw is used in men,

Fig. 7a

Fig. 7b

Diagrams showing a) retrograde and b) antegrade pathways for placement of a posterior-column screw. Hip flexion relaxes the sciatic nerve which is at risk during the procedure.

Fig. 8

Diagram showing utilisation of both anterior and posterior retrograde screws for the stabilisation of a transverse fracture.

but placement of the screw may not be possible in women because of differences in the pelvic anatomy. It may then be necessary to use a plating technique through an open approach.

Fractures of the posterior column (Fig. 7). Provided that a satisfactory reduction can be achieved, the entry point is just inferior to the anterior inferior iliac spine. After skin incision and deep dissection with a periosteal elevator, a 2.8 mm guide wire is inserted under fluoroscopic guidance inferior to the anterior inferior iliac spine and angled posteriorly to the hip to engage the dense cortical bone of the ischial tuberosity. A 7.3 mm cannulated screw is then placed over the guide wire. For retrograde fixation, the hip and knee are held flexed to relax the sciatic nerve and to allow palpation of the tuberosity. A guide wire is passed

Fig. 9

Diagram showing that percutaneous fixation is performed by the insertion of two screws into the anterior inferior spine, directed posteriorly, so that they cross the fracture line perpendicular to its axis. The first screw is similar to the lateral compression screw, and the second starts at the anterior inferior iliac spine and is angled toward the ischial spine.

through the centre of the tuberosity under fluoroscopic control and then behind the acetabulum to the brim of the true pelvis, taking into consideration the course of the sciatic nerve which lies lateral to the tuberosity. One or two 7.3 mm partially-threaded cannulated cancellous screws of appropriate length are drilled and tapped over the guide wire and subsequently tightened to achieve inter-fragmentary compression.

Fractures of both columns. A combination of the techniques described above can be used to achieve a stable percutaneous fixation.

Transverse fractures (Fig. 8). High (supratotal) fractures which can be reduced using closed methods are amenable to percutaneous fixation. A lag screw placed perpendicular to the fracture line usually reduces the gap. Image guidance using true AP and true lateral projection verifies safe placement of the screw. Additional screws can be placed in the anterior column using an antegrade or retrograde technique, and in the posterior column using a retrograde technique through the ischial tuberosity.⁵⁵

Combined pelvic and acetabular fractures (Tile C3 injuries)⁵³

Fractures high in the anterior column (Fig. 9). These fractures pass through the superior weight-bearing dome of the acetabulum, exiting through the wing of the ilium. Reduction of the fracture is achieved using closed methods and is checked by fluoroscopic images including AP, Judet¹ iliac and obturator oblique views with a true lateral view of the pelvis.

Percutaneous fixation is performed by the insertion of two screws into the anterior inferior spine, directed posteriorly, so that they cross the fracture line perpendicular to its axis. The first screw is similar to the lateral compression

Fig. 10

Diagram showing that the lateral compression screw is placed from the anterior inferior iliac spine towards the posterior inferior iliac spine or *vice versa*.

Fig. 11

Diagram showing that the screw is placed starting on the oblique surface of the iliac wing at a point cephalad and posterior to the acetabulum exiting the bone along the inner cortex of the quadrilateral plate at or near the ischial spine.

screw, and the second starts at the anterior inferior iliac spine and is angled toward the ischial spine.⁴⁶

Lateral compression type-II fractures (Fig. 10). These fractures are a consequence of a force to the lateral aspect of the pelvis with the fracture line in the ilium usually arising from, or just anterior to, the sacroiliac joint, and exiting through the iliac crest.

Reduction usually requires external rotation of the affected hemipelvis with longitudinal traction on the leg, and is confirmed by an iliac oblique radiograph. If an acceptable reduction cannot be achieved, open reduction and internal fixation are carried out.

If the fracture is reducible, a small incision is made over the anterior inferior iliac spine and forceps are used to dissect bluntly down to the bone. A guide wire is then inserted under fluoroscopic guidance from the anterior inferior iliac spine, passing through a broad column of bone just above the acetabulum and above the sciatic notch, terminating near the posterior iliac spine adjacent to the sacroiliac joint. Again, fluoroscopic imaging is used to judge progression towards the back of the ilium and to ensure that the guide wire does not enter the greater sciatic notch. The 'teepee'⁵⁶ view can be used to ensure that it does not deviate medially or laterally out of the ilium. A 7.3 mm cannulated screw is then introduced. Two or three screws can usually be placed in the ilium in this manner.

Magic screw (Fig. 11). This screw is used to maintain reduction of the quadrilateral plate. Reduction is achieved utilising a pelvic reduction clump with the inner spike seated on the quadrilateral plate and the outer spike placed in the supra-acetabular region.

The guide wire is inserted on the oblique surface of the wing of the ilium at a point cephalad and posterior to the acetabulum, passing towards the ischial spine and exiting the bone along the inner cortex of the quadrilateral plate at or near the ischial spine.⁵⁶

Complications

The surgical treatment of pelvic and acetabular fractures is technically challenging. Percutaneous procedures may well save operating time and reduce exposure-related hazards, but they can endanger intrapelvic organs because of the narrow 'safe zones'. Detailed pre-operative planning is based on a thorough understanding of the pelvic anatomy, the pattern of injury and the imaging which will help the surgeon to avoid intra-operative accidents.

The technical problems are compounded by difficulties in radiological interpretation and variations in the anatomy of the posterior pelvis.

Positioning sacroiliac screws percutaneously using fluoroscopic guidance is a difficult procedure because of the possibility of damage to sacral nerves. The risk of neurological injury after positioning of sacroiliac screws have been reported to be between 0.5% and 7.7%.^{28,57,58} However, with the use of high-quality image intensification and with due regard to the anatomy of the sacrum, the rates of complication have been low.^{59,60}

Damage to the superior gluteal artery has also been reported.¹² Templeman et al⁶¹ showed that malposition of the screw by as little as 4° could cause damage to neurovascular structures.

Strict adherence to the principles concerning the time of intervention, the quality of reduction, the adequacy of imaging and meticulous utilisation of instrumentation will minimise the risk of iatrogenic injuries. A well-informed and compliant patient will contribute to a successful outcome decreasing the potential for early failure.⁶²

Table I. Clinical results of studies using percutaneous fixation in various patterns of fracture

Authors	Fracture pattern	Number of patients	Navigation techniques	Percutaneous technique	Results*	Conclusions
Gay et al ²⁹	Sagittal and coronal with posterior column extension	6 (3 male, 3 female)	CT-guided	Acetabular screws	All screws successfully placed. No blood loss or degenerative changes 1 infection	The technique can be performed easily and reproducibly
Roult et al ³⁸	Displaced posterior pelvic-ring disruptions	177 (102 male, 75 female) mean age 32 yrs	Fluoroscopy	Anterior pelvic reduction and fixation Percutaneous iliosacral screws	No posterior pelvic infection Minimal blood loss Inadequate fluoroscopy in 18 patients due to obesity and abdominal contrast 1 transient L5 neuropraxia 2 sacral nonunion	Difficult technique Low rates of infection, blood loss, and non-union can be expected
Starr et al ³⁶	Group I: 13 elderly with complex fractures Group II: 11 young with simple fractures	24 Group I: mean age 66 yrs Group II: mean age 29 yrs	Fluoroscopy	Anterior- and posterior-column acetabular screws after closed or limited open reduction	No infections or wound complications HHS: Group I 85 Group II 96 5 THR in group I 1 transient femoral nerve palsy	Demanding procedure Acceptable reduction possible only with simple fractures. Broader indications in older persons
Nork et al ⁷⁸	U-shaped sacral fractures	13	Fluoroscopy	Percutaneous sacroiliac fully-threaded 7.0 mm screws	Accurate screw insertions without neuroforaminal or sacral spinal canal violations in all patients. All fractures healed clinically and radiologically. 2 residual neurological abnormalities	Percutaneous fixation diminishes potential blood loss and operating times
Tonetti et al ⁷³	Sacroiliac joint disruptions	34	Computer-assisted surgery (4) Fluoroscopy (30)	Sacroiliac screws	Fluoroscopy group: 7 neurological deficits 12 malpositioned screws	Computer-assisted technique more accurate, faster and safer for personnel
Crowl and Kahler ²³	Anterior-column fractures	23	CT-guided (10) Fluoroscopy (4) Computer-assisted (9)	Large-bore percutaneous cannulated screws	No loss of reduction No symptomatic HO No infection No loss of reduction HHS 91	Safe and effective alternative to formal ORIF, [†] with a low anticipated complication rate and excellent outcome
Van den Bosch et al ⁶⁹	Posterior pelvic ring disruption	88	Fluoroscopy	Percutaneous sacroiliac screws	Malposition ranging from 2.1% to 6.8% of the screws 7 re-operations due to neurological complaints	Safe technique in experienced hands
Mosheiff et al ⁷⁴	25 pelvic fractures 5 acetabular fractures	29	Fluoroscopy-based computerised navigational system	Sacroiliac screws Pubic ramus screws, Posterior column screws, and a supra-acetabular transverse screw	One wire tip error	This navigation system saves fluoroscopic radiation exposure, yet improves the precision of the procedure
Mouhsine et al ⁷⁵	8 transverse fractures 7 two-column fractures 6 T-Type 6 fractures	21	Fluoroscopy	Two retrograde cannulated cancellous 7.3 mm screws	No degenerative changes No screw failure Matta score: ⁴ 94%	Safe technique for specific acetabular fracture patterns
Griffin et al ⁷⁶	Vertically unstable pelvic fractures	62 (32 fracture-dislocation, 30 vertical sacral fracture)	Fluoroscopy	Percutaneous sacroiliac fully-threaded 7.0 mm screws	4 fixation failures (all sacral fractures) No significant association between failure and anterior fixation method, iliosacral screw arrangement	Useful technique in the management of vertically unstable pelvic fractures High level of suspicion for failure in vertical sacral fracture
Moed and Geer ⁷⁷	Disruptions of the posterior pelvic ring	49 (aged 14 to 71 yrs)	Fluoroscopy	S2 percutaneous sacroiliac screws	No intra-operative iatrogenic nerve injuries Post-operative loss of reduction in 2 cases Satisfactory screw position in all cases	S2 iliosacral fixation is a safe technique Use with caution in osteopenic patients

* HHS, Harris hip score; THR, total hip replacement; HO, heterotopic ossification

† ORIF, open reduction and internal fixation

Discussion

The surgical treatment of pelvic and acetabular fractures is technically demanding. The aim is to achieve anatomical or near anatomical restoration of the articular surface and accurate reduction of the pelvic ring in mechanically-

unstable injuries.^{15,38,48} The advantage of open reduction and internal fixation is that it allows near anatomical reduction, permitting earlier mobilisation of the patient and a shorter period of bed rest.^{63,64} Satisfactory results have been reported after internal fixation of these inju-

ries.^{9,64-66} However, this may require extensive exposure involving major blood loss and can be associated with significant complications.^{10,67} Unstable pelvic lesions are also associated with high morbidity and mortality.³⁷ It is therefore reasonable to explore options for fixation which allow adequate reduction and stabilisation of the articular surface while minimising the invasiveness of the surgical procedure. Percutaneous pelvic fixation has been receiving more attention in an attempt to avoid extensile surgical approaches^{23,25,54} and the use of iliosacral screws are increasingly used.⁶⁸⁻⁷¹ Although percutaneous management of acetabular fractures has been described, the available accounts have been confined to the fixation of non-displaced or minimally-displaced fractures,^{29,35} stabilisation of a well-aligned nonunion³¹ or as an adjunct to traditional open reduction and internal fixation.⁷² It is now being applied to displaced fractures in certain situations with encouraging results.³⁶

The early results of percutaneous fixation have shown a decrease in hospital stay and morbidity in longitudinal studies and in case reports of selected fractures^{23,29,36,38,69,73-78} (Table I). Improvements in fluoroscopic imaging have facilitated the procedure^{41,71} and C-arm fluoroscopy is frequently used by trauma surgeons during percutaneous placement of screws in various trajectories around the pelvis and acetabulum. However, such imaging is generally available in only one plane at a time and exposes both the patient and the surgeon to radiation, particularly because of the increased soft-tissue mantle and the precise oblique projections necessary for adequate viewing.³⁷ The development of image-guided surgery has reduced this risk. Gay et al²⁹ were the first to describe successful percutaneous fixation of acetabular fractures using CT guidance. Three-dimensional CT-guided navigation can be used for fixation of fractures of the acetabulum, but the pre-operative data set used for navigation cannot be altered after a closed reduction manoeuvre in the operating theatre, which prevents the application of this technology to displaced fractures.^{36,72}

However, in actual clinical use for fixation of the posterior pelvic ring, both the operating time and fluoroscopic time have been reported to be significantly reduced when compared with the standard technique, and malposition of the screws was not noted.^{79,80} Virtual fluoroscopy (fluoroscopic navigation) was refined and approved for clinical use in 1999. Software algorithms were developed for powerful computer workstations which allowed manipulation of the C-arm images to make them optically correct and allow their use for guidance.

Crowl and Kahler²³ demonstrated that the closed reduction of displaced anterior acetabular fractures is possible using virtual fluoroscopic surgical navigation. However, only experienced fracture surgeons should attempt the procedure using four real-time fluoroscopic standard views.

Newer surgical navigation systems using fluoroscopy for image acquisition allow the surgeon to update a virtual

model of the patient in the operating theatre after closed reduction. Virtual fluoroscopy has greatly expanded the potential applications of surgical navigation in the routine care of fractures. The benefits of computer-assisted navigational systems include reduction in radiation exposure to both the patient and surgeon, diminished operating time, accurate assessment of alignment and improved precision in the placement of internal fixation.^{37,73,74,78} However, the equipment and instruments required are costly, and financial considerations will probably hinder their widespread acceptance in the short term.

Summary

Percutaneous screw fixation of fractures of the pelvis and acetabulum is a relatively new procedure and the indications for its use are not yet fully defined. Only experienced surgeons with a thorough knowledge of the bony and soft-tissue anatomy of the pelvis should undertake these techniques. The surgeon must always be prepared to convert to a formal open approach in the event of inadequate imaging or reduction by a percutaneous technique. Although inadequately reduced fractures treated by the percutaneous technique are unlikely to have a better outcome compared with anatomical open reduction, the decreased complication rate may compensate for this and allow the surgeon to accept slightly more articular displacement. Virtual fluoroscopy could eventually replace real-time C-arm procedures in orthopaedic practice, giving decreased invasiveness and superior precision of management compared with a standard operative technique.

References

1. Judet R, Judet J, Letournel E. Fractures of the acetabulum: classification and surgical approaches for open reduction: preliminary report. *J Bone Joint Surg [Am]* 1964;46-A:1615-46.
2. Stockle U, Krettek C, Pohlemann T, Messmer P. Clinical applications: pelvis. *Injury* 2004;35(Suppl):46-56.
3. Matta JM, Anderson LM, Epstein HC, Hendricks P. Fractures of acetabulum: a retrospective analysis. *Clin Orthop* 1986;205:230-40.
4. Matta JM. Fractures of acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. *J Bone Joint Surg [Am]* 1996;78-A:1632-45.
5. Mears DC. Surgical treatment of acetabular fractures in the elderly patients with osteoporotic bone. *J Am Acad Orthop Surg* 1999;7:128-41.
6. Mouhsine E, Garofalo R, Borens O, et al. Acute total hip arthroplasty for acetabular fractures in the elderly: 11 patients followed for 2 years. *Acta Orthop Scand* 2002;73:615-18.
7. Rommens PM, Hesmann MH. Acetabulum fractures. *Unfallchirurg* 1999;102:591-610 (in German).
8. Matta JM, Mehne DK, Roffi R. Fractures of the acetabulum: early results of a prospective study. *Clin Orthop* 1986;205:241-50.
9. Giannoudis PV, Grotz MR, Papakostidis C, Dinopoulos H. Operative treatment of displaced fractures of the acetabulum: a meta-analysis. *J Bone Joint Surg [Br]* 2005;87-B:2-9.
10. Kaempffe FA, Bone LB, Border JR. Open reduction and internal fixation of acetabular fractures: heterotopic ossification and other complications of treatment. *J Orthop Trauma* 1991;5:439-45.
11. Reinert CM, Bosse MJ, Poka A, et al. A modified extensile exposure for the treatment of complex or malunited acetabular fractures. *J Bone Joint Surg [Am]* 1988;70-A:329-36.
12. Altman DT, Jones CB, Routh ML Jr. Superior gluteal artery injury during iliosacral screw placement. *J Orthop Trauma* 1999;13:220-7.
13. Borrelli J, Koval KJ Jr, Helfet DL. The crescent fracture: a posterior fracture dislocation of the sacroiliac joint. *J Orthop Trauma* 1996;10:165-70.
14. Browner BD, Cole JD, Graham JM. Delayed posterior internal fixation of unstable pelvic fractures. *J Trauma* 1987;27:998-1006.
15. Matta J, Saucedo T. Internal fixation of pelvic ring fractures. *Clin Orthop* 1989;242:83-97.

16. Mehlman C, DiPasquale T. Radiation exposure to the orthopaedic surgical team during fluoroscopy: how far away is far enough? *J Orthop Trauma* 1997;11:392-8.
17. Moed BR, Karges DE. Techniques for reduction and fixation of pelvic ring disruptions through the posterior approach. *Clin Orthop* 1996;329:102-14.
18. Routt ML Jr, Kregor PJ, Simonian PT, Mayo KA. Early results of percutaneous iliosacral screws placed with the patient in the supine position. *J Orthop Trauma* 1995;9:207-14.
19. McLaren A. Long-term pain and disability in relation to residual deformity after displaced pelvic ring fractures. *Can J Surg* 1990;33:492-4.
20. Henderson R. The long-term results of non-operatively treated major pelvic disruptions. *J Orthop Trauma* 1989;3:41-7.
21. Kellam JF, McMurtry RY, Paley D, Tile M. The unstable pelvic fracture: operative treatment. *Orthop Clin North Am* 1987;18:25-41.
22. Routt ML Jr, Simonian PT, Swiontkowski MF. Stabilization of pelvic ring disruptions. *Orthop Clin North Am* 1997;28:369-88.
23. Crowl AC, Kahler DM. Closed reduction and percutaneous fixation of anterior column acetabular fractures. *Comput Aided Surg* 2002;7:169-78.
24. Simonian PT, Routt MLC, Harrington RM, Mayo KA, Tencer AF. Biomechanical simulation of the anteroposterior compression injury of the pelvis: an understanding of instability and fixation. *Clin Orthop* 1994;309:245-56.
25. Barei DP, Bellabarba C, Mills WJ, Routt ME Jr. Percutaneous management of unstable pelvic ring disruptions. *Injury* 2001;32(Suppl 1):33-44.
26. Blake-Toker AM, Hawkins L, Nadalo L, et al. CT-guided percutaneous fixation of sacroiliac fractures in trauma patients. *J Trauma* 2001;51:1117-21.
27. Ebraheim NA, Memmer M, Xu R, Yeasting RA. Radiological evaluation of S1 dorsal screw placement. *J Spinal Disord* 1996;9:527-35.
28. Shuler TE, Boone DC, Gruen GS, Peitzman AB. Percutaneous iliosacral screw fixation: early treatment for unstable posterior pelvic ring disruptions. *J Trauma* 1995;38:453-8.
29. Gay SB, Siström C, Wang GJ, et al. Percutaneous screw fixation of acetabular fractures with CT guidance: preliminary results of a new technique. *AJR Am J Roentgenol* 1992;158:819-22.
30. Jacob AL, Suhm N, Kaim A, et al. Coronal acetabular fractures: the anterior approach in computed tomography-navigated minimally invasive percutaneous fixation. *Cardiovasc Intervent Radiol* 2000;23:327-31.
31. Zura RD, Kahler DM. A transverse acetabular nonunion treated with computer-assisted percutaneous internal fixation: a case report. *J Bone Joint Surg [Am]* 2000;82-A:219-24.
32. Parker PJ, Copeland C. Percutaneous fluoroscopic screw fixation of acetabular fractures. *Injury* 1997;28:597-600.
33. Mears DC, Velyvis JH. In situ fixation of pelvic nonunions following pathologic and insufficiency fractures. *J Bone Joint Surg [Am]* 2002;84-A:721-8.
34. Carmack DB, Moed BR, McCarroll K, Freccero D. Accuracy of detecting screw penetration of the acetabulum with intra-operative fluoroscopy and computed tomography. *J Bone Joint Surg [Am]* 2001;83-A:1370-5.
35. Parker P. Fluoroscopic and 3-D computed tomographic guidance in percutaneous fixation of acetabular fractures. *J Bone Joint Surg [Am]* 2001;83-A:299-300.
36. Starr AJ, Jones AL, Reinert CM, Borer DS. Preliminary results and complications following limited open reduction and percutaneous screw fixation of displaced fractures of the acetabulum. *Injury* 2001;32(Suppl 1):45-50.
37. Routt ML Jr, Nork SE, Mills WJ. Percutaneous fixation of pelvic ring disruptions. *Clin Orthop* 2000;375:15-29.
38. Routt ML Jr, Simonian PT, Mills WJ. Iliosacral screw fixation: early complications of the percutaneous technique. *J Orthop Trauma* 1997;11:584-9.
39. Routt ML Jr, Simonian PT, Ballmer F. A rational approach to pelvic trauma: resuscitation and early definitive stabilization. *Clin Orthop* 1995;318:61-74.
40. Ebraheim NA, Biyani A. Percutaneous computed tomographic stabilization of the pathologic sacroiliac joint. *Clin Orthop* 2003;408:252-5.
41. Routt ML Jr, Simonian PT. Closed reduction and percutaneous skeletal fixation of sacral fractures. *Clin Orthop* 1996;329:121-8.
42. Tseng S, Tornetta P 3rd. Percutaneous management of Morel-Lavallée lesions. *J Bone Joint Surg [Am]* 2006;88-A:92-6.
43. Routt ML Jr, Simonian PT, Grujic L. The retrograde medullary superior pubic ramus screw for the treatment of anterior pelvic ring disruptions: a new technique. *J Orthop Trauma* 1995;9:35-44.
44. Keating JF, Werier J, Blachut P, et al. Early fixation of the vertically unstable pelvis: the role of iliosacral screw fixation of the posterior lesion. *J Orthop Trauma* 1999;13:107-13.
45. Starr AJ, Reinert CM, Jones AL. Percutaneous fixation of the columns of the acetabulum: a new technique. *J Orthop Trauma* 1998;12:51-8.
46. Kahler DM. Percutaneous screw insertion for acetabular and sacral fractures. *Tech Ortho* 2003;18:174-83.
47. Burgess AR, Eastridge BJ, Young JW, et al. Pelvic ring disruptions: effective classification system and treatment protocols. *J Trauma* 1990;30:848-56.
48. Denis F, Davis S, Comfort T. Sacral fractures: an important problem. *Clin Orthop* 1988;227:67-81.
49. Schildhauer TA, Josten Ch, Muhr G. Triangular osteosynthesis of vertically unstable sacrum fractures: a new concept allowing early weight-bearing. *J Orthop Trauma* 2006;20(Suppl 1):44-51.
50. Levine AM. Fixation of fractures of the sacrum. *Operative Tech Orthop* 1997;7:221-31.
51. Taguchi T, Kawai S, Kaneko K, Yague D. Operative management of displaced fractures of the sacrum. *J Orthop Sci* 1999;4:347-52.
52. Tile M. Pelvic ring fractures: should they be fixed? *J Bone Joint Surg [Br]* 1988;70-B:1-12.
53. Tile M. Describing the injury: classification of pelvic ring injuries. In: Tile M, ed. *Fractures of the pelvis and acetabulum*. Philadelphia: Lippincott, Williams & Wilkins, 1995:66-101.
54. Mouhsine E, Garofalo R, Borens O, et al. Percutaneous retrograde screwing for stabilization of acetabular fractures. *Injury* 2005;36:1330-6.
55. Zura RD, Kahler DM. A transverse acetabular nonunion successfully treated with computer assisted percutaneous internal fixation: a case report. *J Bone Joint Surg [Am]* 2000;82-A:219-24.
56. Starr AJ, Walter JC, Harris RW, Reinert CM, Jones AL. Percutaneous screw fixation of fractures of the iliac wing and fracture-dislocations of the sacro-iliac joint (OTA Types 61-B2.2 and 61-B2.3, or Young-Burgess "lateral compression type II" pelvic fractures). *J Orthop Trauma* 2002;16:116-23.
57. Jacob AL, Messmer P, Stock KW, et al. Posterior pelvic ring fractures: closed reduction and percutaneous CT-guided sacroiliac screw fixation. *Cardiovasc Intervent Radiol* 1997;20:285-94.
58. Templeman D, Goulet J, Duwelius PJ, Olson S, Davidson M. Internal fixation of displaced fractures of the sacrum. *Clin Orthop* 1996;329:180-5.
59. Moed BR, Ahmad BK, Craig JG, Jacobson GP, Anders MJ. Intraoperative monitoring with stimulus-evoked electromyography during placement of iliosacral screws: an initial clinical study. *J Bone Joint Surg [Am]* 1998;80-A:537-46.
60. Moed BR, Anders MJ, Ahmad BK, Craig JG, Jacobson GP. Intraoperative stimulus evoked electromyographic monitoring for placement of iliosacral implants: an animal model. *J Orthop Trauma* 1998;12:85-9.
61. Templeman D, Schmidt A, Freese J, Weisman I. Proximity of iliosacral screws to neurovascular structures after internal fixation. *Clin Orthop* 1996;329:194-8.
62. Ziran BH, Smith WR, Towers J, Morgan SJ. Iliosacral screw fixation of the posterior pelvic ring using local anaesthesia and computerised tomography. *J Bone Joint Surg [Br]* 2003;85-B:411-18.
63. Moed BR, Willson Carr SE, Watson JT. Results of operative treatment of fractures of the posterior wall of the acetabulum. *J Bone Joint Surg [Am]* 2002;84-A:752-8.
64. Moed BR, Carr SEW, Gruson K, Watson JT, Craig JG. Computed tomography assessment of fractures of the posterior wall of the acetabulum after operative treatment. *J Bone Joint Surg [Am]* 2003;85-A:512-22.
65. Matta J. Anatomic joint fracture fixation and long term results. *Procs Hip Society, 30th Open Scientific Meeting*, 2002.
66. Kreder HJ, Rozen N, Borkhoff CM, et al. Determinants of functional outcome after simple and complex acetabular fractures involving the posterior wall. *J Bone Joint Surg [Br]* 2006;88-B:776-82.
67. Moed BR, Smith ST. Three-view radiographic assessment of heterotopic ossification after acetabular fracture surgery. *J Orthop Trauma* 1996;10:93-8.
68. Tonetti J, Carrat L, Lavalée S, et al. Percutaneous iliosacral screw placement using image guided techniques. *Clin Orthop* 1998;354:103-10.
69. Van den Bosch EW, Van Zwienen CM, Van Vugt AB. Fluoroscopic positioning of sacroiliac screws in 88 patients. *J Trauma* 2002;53:44-8.
70. Routt ML Jr, Simonian PT, Agnew SG, Mann FA. Radiographic recognition of the sacral alar slope for optimal placement of iliosacral screws: a cadaveric and clinical study. *J Orthop Trauma* 1996;10:171-7.
71. Routt ML Jr, Simonian IT. Internal fixation of pelvic ring disruptions. *Injury* 1996;Suppl 2:B20-30.
72. Brown GA, Willis MC, Firozbakhsh K, et al. Computed tomography image-guided surgery in complex acetabular fractures. *Clin Orthop* 2000;370:219-26.
73. Tonetti J, Carrat L, Blendea S, et al. Clinical results of percutaneous pelvic surgery: computer assisted surgery using ultrasound compared to standard fluoroscopy. *Comput Aided Surg* 2001;6:204-11.
74. Mosheiff R, Khoury A, Weil Y, Liebergall M. First generation computerized fluoroscopic navigation in percutaneous pelvic surgery. *J Orthop Trauma* 2004;18:106-11.
75. Mouhsine E, Garofalo R, Borens O, et al. Percutaneous retrograde screwing for stabilization of acetabular fractures. *Injury* 2005;36:1330-6.
76. Griffin DR, Starr AJ, Reinert CM, et al. Vertically unstable pelvic fractures fixed with percutaneous iliosacral screws: does posterior injury pattern predict fixation failure? *J Orthop Trauma* 2006;20(1 Suppl):30-6.
77. Moed BR, Geer BL. S2 iliosacral screw fixation for disruptions of the posterior pelvic ring: a report of 49 cases. *J Orthop Trauma* 2006;20:378-83.
78. Nork SE, Jones CB, Harding SP, Mirza SK, Routt ML Jr. Percutaneous stabilization of U-shaped sacral fractures using iliosacral screws: technique and early results. *J Orthop Trauma* 2001;15:238-46.
79. Kahler DM, Zura R. Evaluation of a computer integrated surgical technique for percutaneous fixation of transverse acetabular fractures. In: Troccaz J, Grimson E, Mösges R, eds. *Procs of First Joint Conference Computer Vision, Virtual Reality and Robotics in Medicine and Medical Robotics and Computer-Assisted Surgery (CVRMed-MRCAS'97)*, 1997. Lecture noted. Berlin: Springer, 1997:565-72.
80. Kahler DM, Mallik K. Computer assisted iliosacral screw placement compared to standard fluoroscopic technique. *Comput Aided Surg* 1999;4:348.