The Periacetabular Osteotomy

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Yuri A. Pompeu and Ernest Sink

Key Learning Points

- Acetabular dysplasia has many three-dimensional variations of acetabular undercoverage. The decreased bony and hyaline cartilage coverage of the femoral head may lead to cartilage and labral damage and eventual osteoarthrosis. The acetabular undercoverage may be global, anterior, posterolateral, or iatrogenic from acetabular rim resection.
- The correct diagnosis of dysplasia often requires extensive physical exam and three-dimensional imaging with CT scanning.
- The periacetabular osteotomy allows acetabular reorientation in multiple planes to maximize the hyaline cartilage support of the femoral head. The benefit of the PAO is the ability to medialize the hip joint to improve abductor mechanics, an abductor sparing approach, maintaining the posterior column, and the maintenance of acetabular vascularity.
- The indications are symptomatic acetabular dysplasia with minimal arthrosis (Tönnis 0–1) and a concentric joint. The relative contraindications are a noncentric hip joint and advanced arthrosis (Tönnis 2–4).
- Concurrent proximal femoral surgery such as proximal femoral osteotomies and surgical hip dislocation may be performed to increase concentricity and hip mechanics.
- There is the potential for femoroacetabular impingement (FAI) after PAO surgery so attention to acetabular positioning and version are critical. An arthrotomy and osteochondroplasty of the head and neck junction should be considered when there are risks of FAI.

Introduction

Developmental dysplasia of the hip (DDH) is a common condition affecting millions of people worldwide. Even though the precise etiology is still being debated, a number of risk factors have been identified and it is accepted that genetic susceptibility as well as environmental factors play a role in this condition. Some of the most commonly cited factors include ligamentous laxity,

Y. A. Pompeu
Hospital for Special Surgery, Department of Orthopaedic Surgery, New York, NY, USA
e-mail: pompeuyu@hss.edu

E. Sink (✉)
Hospital for Special Surgery, Department of Orthopaedic Surgery, New York, NY, USA

Weill Cornell Medical College, New York, NY, USA
e-mail: sinke@hss.edu

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genetics, prenatal positioning, and postnatal positioning [1–3]. Among the factors that support a genetic and intrinsic predisposition to DDH is the observation that girls are much more commonly affected than boys. In addition, some studies have shown that the rate of agreement between identical twins is as high as 34% [4].

Regardless of the identity of the principal driving forces in developmental dysplasia of the hip, it is a significant problem with the potential to cause lifelong morbidity and disability. While appropriate management of the condition in children usually results in excellent results, many patients develop sequelae and require treatment in adulthood. A dysplastic acetabulum can alter the static and dynamic forces of the hip joint significantly. This can lead to abnormal pressures on the articular cartilage as well as the labrum, capsule, and ligaments and increased strain on muscles of the hip. If left untreated, osteoarthritis and labral tears can develop at an accelerated rate. Some studies now estimate that up to 10% of all cases of hip arthritis in the USA are caused by underlying dysplasia. This number is even higher in those requiring total hip arthroplasty under the age of 40. Overall, estimates are that 350,000 adults in the USA have arthritis due to some level of dysplasia [5, 6].

The basic tenets in the management of hip dysplasia are to increase the contact area of the weight-bearing surface, to improve the lever arm and the hip to restore biomechanics, and to alleviate overloading of a short and shallow acetabular rim. The overall goal is to forestall the development of early degenerative disease and osteoarthritis [7, 8]. In the case of skeletally mature individuals, which in this chapter refers to those with a closed triradiate cartilage, there is very little potential for further acetabular remodeling. If any significant hip biomechanical change is to be achieved, redirectional osteotomies are needed [9].

Several techniques have been described including the triple innominate osteotomy, Wagner, and Eppright [9]. These techniques can be effective but do have several limitations. With these limitations in mind, the Bernese periacetabular osteotomy (PAO) was developed. Since its development, the technique has gained immense popularity and is now widely accepted as the surgery of choice for the management of hip dysplasia in the skeletally mature hip. This chapter will discuss in detail its history, indications, preoperative planning, techniques, benefits, and outcomes.

History of PAO

The Ganz or Bernese periacetabular osteotomy (PAO) was first described by Reinhold Ganz in 1983 [10]. Even in its initial states, the technique had several advantages over the other procedures being used at the time. This technique took into consideration the unique anatomy of the pelvis as well as its delicate blood supply which allowed for high rates of union of the osteotomy and minimization of the risk of acetabular avascular necrosis. The cuts are made in close proximity to the acetabulum (periacetabular) which allows for maximal repositioning and medialization of the acetabulum. They are designed to maintain an intact posterior column making it an inherently stable construct. Additionally, this osteotomy does not significantly change the volume of the true pelvis therefore avoiding some of the complications related to childbirth that had been described with some of the former techniques [9, 11].

The pelvis is approached through either a bikini-type incision with a Levine approach/dissection or a modified Smith-Petersen approach where the abductor musculature is preserved. An osteotomy just inferior to the infracotyloid notch is made; this is followed by the pubis, on the superior ramus adjacent to the acetabulum. The supra-acetabular osteotomy begins in the region of the anterior superior iliac spine, and after it is carried into the ilium, the cut is then redirected 120° posteriorly and inferiorly to meet the ischial cut. Great care is taken to avoid breach of the posterior cortex and violation of the greater sciatic notch. This is important to avoid vascular injury as well as destabilization from a broken posterior pelvic column. Figure 12.1 shows the location of the osteotomies as well as the most common configuration of the blood supply to the periacetabular region.

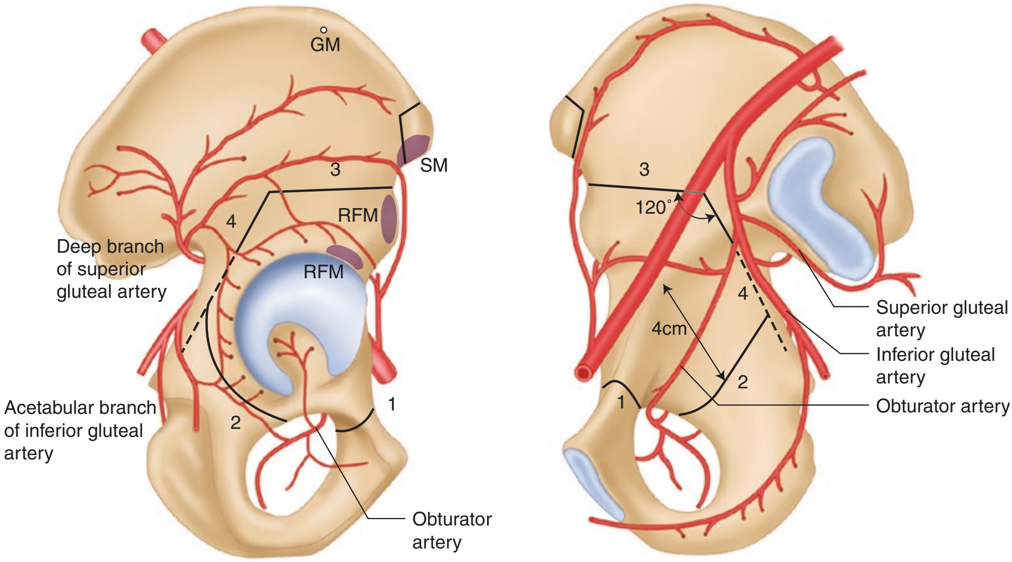

Fig. 12.1 Drawing of the acetabular blood supply on the external pelvic surface (left) and the internal hemipelvis surface (right). The large numbers represent the sequence and position of the osteotomies. GM gluteus medius, RFM rectus femoris head (direct and indirect), SM sartorius muscle [12]. (Reprinted from Leunig et al. [12] © 2001, https://journals.lww.com/jbjsjournal/Citation/2001/03000/Rationale_of_Periacetabular_Osteotomy_and.18.aspx, with permission from Wolters Kluwer Health, Inc.)

The periacetabular osteotomy may allow for significant improvement in hip pain and function. In comparison to total hip arthroplasty, there are no restrictions and hip precautions are less stringent. Many patients are able to return to sport activity near their baseline. Recently, Lerch et al. published 30-year follow-up results of the first 63 patients (75 hips) who underwent PAO for hip dysplasia between 1984 and 1987. Remarkably, hip survival rate defined as failure to convert to arthroplasty at 10, 20, and 30 years is 88%, 61%, and 29%, respectively [13]. The technique has continued to evolve as the incisions have become smaller and adjunct surgery, especially arthroscopy, is now widely employed to address intra-articular injury and femoroacetabular pathology. Despite advances in technology and techniques, the principles and the orientation of the bony osteotomies of the PAO remain unchanged.

Indications

The first and most widely accepted indication for the Bernese periacetabular osteotomy is global dysplasia. The clearest indication for a PAO is a concentric hip joint with radiographic acetabular dysplasia and very little arthrosis (Tönnis 0–1). An abnormally shaped and deficient acetabular volume leads to a decreased area of weight-bearing hyaline cartilage and overloading of the acetabular rim. If left untreated, arthrosis of the hip is possible and, in some cases, may happen at an accelerated rate. Some of the most frequent abnormalities encountered include a shallow acetabulum and acetabular roof that is oblique. Commonly used parameters to judge acetabular depth include the lateral center-edge angle, or angle of Wiberg [14], and anterior center-edge angle or angle of Lequesne and de Seze [15]. The Tönnis angle or roof angle [16] is a representation of the obliquity of the sourcil. Chapter 6 illustrates these measurements. These parameters can be measured on plain radiographs of the pelvis that include an AP and false profile view. Table 12.1 summarizes the most commonly used parameters in the evaluation of hip dysplasia.

In addition to the depth and obliquity of the acetabulum, acetabular version is another important parameter that is essential for a properly functioning hip joint. Either excessive anteversion or retroversion can lead to deficient femoral

Table 12.1 Acetabular measurements on plain radiographs

Condition	Parameter[a]
Normal	*LCEA (AP radiograph)* 25–35°
	Tönnis angle TA 0–10°
	ACEA (false profile radiograph) 25–35°
Acetabular dysplasia	*LCEA (AP radiograph)* < 25°
	Tönnis angle TA >10°
	ACEA (false profile radiograph) < 25°
Protrusio acetabuli	*LCEA (AP radiograph)* >40°
	Tönnis angle TA <0°
	ACEA (false profile radiograph) >40°
	Femoral head medial to ilioischial line
Acetabular retroversion	*LCEA, ACEA, TA* Variable
	"Crossover" sign, "Ischial spine" sign

[a]References for accepted parameters are embedded in text

head coverage anteriorly or posteriorly, respectively. Acetabular retroversion has historically been overlooked as a source of instability and hip pain. More recently, it has emerged as a well-described etiology of hip pain and arthrosis. It is estimated that 5% of the general population has acetabular retroversion. The prevalence however is as high as 20% in patients presenting with idiopathic hip osteoarthritis making this a significant cause of degenerative disease [17]. Acetabular retroversion can create a lack of posterior coverage as well as excess anterior coverage. This can result in abnormal stress in the capsule and posterior elements of the hip which can lead to pain and instability [18]. Furthermore, excessive anterior coverage can lead to femoral acetabular impingement (FAI) in the form of a "pincer" deformity even in the absence of abnormal osseous growth. Anteverting PAOs have been employed to treat acetabular retroversion with success [18–20].

Cases of excessive acetabular anteversion or anterior deficiency typically present with clinical signs of instability, and they may have mild or borderline dysplasia with center-edge angles in the 20–25° range but poor anterior acetabular coverage. Such cases may also be accompanied by increased femoral anteversion and manifest clinically primarily as iliopsoas or abductor fatigue symptoms [21]. The PAO and its potential for acetabular reorientation present a viable option for such patients [22].

There has been much debate on whether or not concomitant femoral head deformity and higher degrees of dysplasia are absolute contraindications to a PAO. Early evidence suggested that severely subluxed hips or severe dysplasia could be addressed with a PAO [23]. Subsequently, good outcomes have been published for cases where severe deformity is present including dysplasia that is secondary to neuromuscular disorders and patients with Legg-Calvé-Perthes disease. Recent literature shows some promising results in patients with complex dysplasia where congruency is achieved when treated with PAO alone or combined with femoral osteotomy [24, 25].

Some studies have pointed to lesser degrees of dysplasia as being a potential risk factor for poor outcomes after PAO. Many authors hypothesized that in hips with a lesser degree of dysplasia, i.e., acetabular index less than 15° and lateral center-edge angle greater than 15°, correction would lead to femoral acetabular impingement. However, a subsequent study by Grammatopoulos et al. [26] showed no differences in complication or reoperation rates in hips with lesser degree of dysplasia undergoing PAO when controlling for variables such as age, preexisting chondroplasty, and impingement. Therefore a lesser degree of dysplasia could be an indication in carefully selected patients with or without the need for concomitant chondroplasty [27, 28]. Arthroscopy can be a powerful complement to a PAO in relieving pain and addressing other etiologies of hip pain in certain patients. However, care should be taken not to miss significant dysplasia. Ross et al. examined patients who presented after "failed" arthroscopy and showed that 67% had radiographic evidence of dysplasia based on lateral center-edge angle (LCEA) and 93% had acetabular inclinations >10° [29].

Several studies have attempted to identify the biggest predictors of failure in periacetabular osteotomies. One of the most commonly cited and agreed upon predictor failures is preexisting osteoarthritis. Tönnis grades 2 and 3 are consistently shown to be strongest predictors of failure. Conversely, more satisfactory and predictable results were obtained in patients with Tönnis grades 0 and 1 [30, 31]. Cost-effectiveness analysis suggested that a PAO is indicated for Tönnis grades 1 and 2, while in Tönnis grade 3 arthrosis, a total hip arthroplasty may be a better operation [32]. Murphy et al. showed that improved hip scores and preservation of joint space can be achieved in patients with Tönnis grade 3 arthrosis at midterm follow-up if a congruent joint was present on functional radiographs [33]. These data may suggest that a PAO may be a viable option to total arthroplasty, especially in young patients with a congruent hip who would certainly outlive their prosthesis.

Early studies of PAO outcomes had suggested that increasing age is associated with worse outcomes. In the initial report of the first 63 patients to undergo the procedure, Steppacher and Ganz [34] had shown that increasing age was associated with worse outcomes. Mid- and long-term follow-up studies have shown that most predictable and satisfactory results are obtained in patients under 35 years of age with Tönnis grades 0 and 1 on plain radiographs. More recently, however, studies have shown some positive results in patients over 35 of a well-preserved joint space with a concentric hip on preoperative radiographic assessment. Interestingly, recently published results of the ANCHOR study [35] showed that obesity and increased age were actually associated with better patient-reported outcomes. Consequently, even though advanced age and preexisting arthritis have historically been considered relative contraindications for a PAO, newer results suggest that these factors alone should not exclude patients from the procedure.

Severe deformity of the femoral head and lack of congruency in the joint can lead to failure due to accelerated cartilage and labral degeneration. Correction via a PAO may increase bony coverage either anteriorly or posteriorly which can worsen impingement. Similarly, a dysplastic femoral head may continue to cause abnormal stress and lead to rapid arthritis in spite of acetabular correction. Although these factors have historically been described as contraindications to a PAO, many authors today agree that some of these patients may still benefit from an acetabular osteotomy if adjuvant surgery is employed to correct the deformity and improve congruency [25, 36].

Contraindications

Absolute contraindications for the PAO are patients with advanced arthrosis (Tönnis 3 or 4) disease, an incongruent joint, or a neuropathic hip joint. Because of the risk of triradiate cartilage injury, the PAO is contraindicated in patients under age 10 years. Other contraindications are relative, and the indications for a PAO may be considered based on a number of patient-specific factors such as age, congruency, range of motion, and a shared decision with the surgeon and patient. If there are Tönnis 2 changes, indications are dependent on age and congruency. For example, a patient in their 20s with grade 2 arthrosis and a congruent joint and good motion would more likely benefit from a PAO than a 40-year-old with the same arthrosis. In patients older than 36 years, the decision to perform a PAO is based on several factors. To recommend PAO in older patients, there should be Tönnis 0–1 changes, no significant cartilage degradation on MRI, good range of motion, and a congruent joint. Other factors to consider are general health, previous hip arthroscopy surgery, and the magnitude of pain. It may also benefit the patient to have a consideration of both a PAO and arthroplasty to make the decision best for the specific patient.

The long-term studies on PAO use congruency and Tönnis classification on radiographs. With advanced MRI techniques looking at cartilage quality (dGEMRIC, T1Rho, T2 mapping), the level of arthrosis may be interpreted as more severe on MRI than radiographs and may impact the indications for PAO. A study by Cunningham et al. utilized delayed gadolinium-enhanced MRI (dGEMRIC) to analyze the outcomes in 43 hips with similar age, sex, and Tönnis grade that had a PAO. A dGEMRIC index less than 370 (milliseconds) especially in the anterior joint was predictive of failure after PAO [37].

As the surgical technique has become less invasive and more efficient and our understanding of the different forms of dysplasia as a cause of pre-arthritic hip improves, it is likely that indications continue to further expand. Furthermore, as attention to the dynamics of hip motion and the need to address FAI become more apparent, the patient selection process may become more personalized.

Presentation and Initial Evaluation

Only a few patients are aware of dysplasia as a cause of their hip pain and dysfunction because they were treated as children [38]. The majority of patients present with hip pain as an adolescent or young adult [36]. Patients will often complain of anterior groin pain which can be attributed to the hip joint or lateral hip pain thought to be from lateral abductor fatigue [21, 39]. The pain is often exacerbated by exertion and long periods of walking or standing. Pain that is caused by prolonged time sitting down is also common in patients with hip dysplasia. A common complaint is "it hurts when I sit or stand to long." Some patients may have a Trendelenburg limp that is either caused by pain or abnormal biomechanics of the abductor musculature. It is important to assess hip range of motion and perform provocative maneuvers. Patients with hip dysplasia may have increased hip flexion and internal rotation compared to those with femoroacetabular impingement. The latter group often has limited hip flexion and internal rotation at 90°. The provocative maneuver that indicates hip irritation and may be positive in both impingement and DDH is the "impingement test." This is performed by passively placing the hip in a position of combined flexion, adduction, and internal rotation (FADIR). Those reporting pain with provocative maneuvers and have decreased range of motion may have concomitant impingement pathology. These may include labral tears and/or femoral acetabular impingement syndrome which may also require surgical treatment [28, 40]. Patients with significant dysplasia and instability may have a positive "apprehension sign" on clinical exam. This is elicited by extending and externally rotating the affected hip [10]. Version of the femur should be evaluated clinically on gait evaluation and supine and prone hip rotation.

Initial radiographic evaluation should include a standing (preferred by senior author) or supine anteroposterior radiograph of the pelvis, a 45° or 90° Dunn lateral view, a false profile view, and a functional view with the affected hip abducted and internally rotated.

Acetabular dysplasia is most commonly identified as deficient lateral femoral head coverage on AP radiograph. However, acetabular deficiency should be evaluated in all regions of the acetabulum such as global, lateral, posterior-lateral, or anterior undercoverage. Evaluation includes measurement of the lateral center-edge angle (LCEA) [14] and Tönnis angle [16] and measurement of the anterior and posterior wall indexes [41]. A LCEA of 25° or less is defined as abnormal, whereas a Tönnis or acetabular roof angle should be in the 0–10° range. Anteroposterior AP radiographs are also useful for evaluating joint space narrowing and preexisting osteoarthritis. The AP radiograph also allows for evaluation of Shenton's line with its disruption indicating a subluxed hip. Acetabular version could also be gauged from AP images. Posterior wall should be in line or lateral to the center of the femoral head, and the anterior wall should meet the posterior wall at the lateral rim of the acetabulum. An anterior wall crossing over the posterior wall likely represents acetabular retroversion, and this is known as "crossover" sign.

A false profile view allows for measurement of the anterior center-edge angle (ACEA) [15] as well as for evidence of posterior articular arthrosis [41]. The 45° lateral Dunn view is used to evaluate head-neck offset. The alpha angle is used to calculate the sphericity of the femoral head with values greater than 50° consistent with a cam-type lesion. Abduction and internal rota-

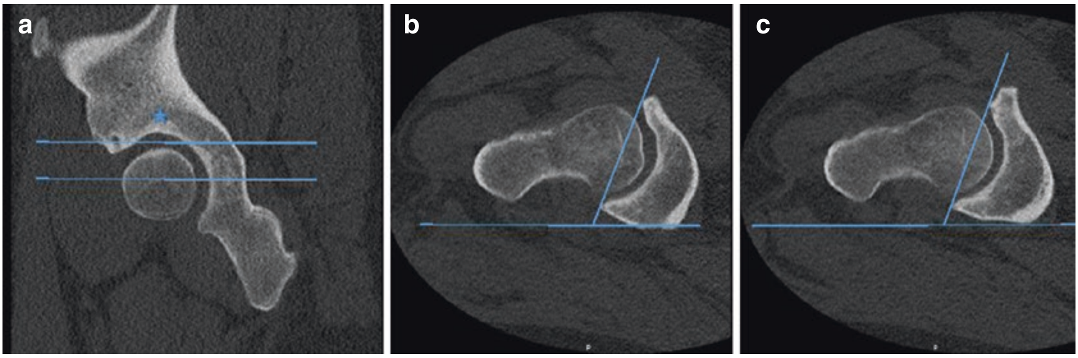

Fig. 12.2 Computed tomography of the right hip. Panel **a** shows a sagittal view with the 12 o'clock (blue star), 1 o'clock (upper line), and the 3 o'clock (lower line) positions marked. Panel **b** shows the measured version through the 1 o'clock position. Panel **c** shows the same through the 3 o'clock position. The true femoral version is measured with the posterior condylar axis in the distal femur as the reference, which is omitted here for clarity

tion views are used to assess hip congruency after potential correction as an incongruent joint may lead to unsatisfactory outcomes.

Computed tomography (CT) is a powerful tool in preoperative planning. The advent of 3D reconstructions allows for a detailed visualization of the architecture of the acetabulum as well as the femoral head and neck [42]. CT imaging allows for measurement of acetabular version (Fig. 12.2), posterior-lateral, or anterior deficiency and a careful evaluation of the anterior inferior iliac spine (AIIS). This is particularly important since the AIIS can become a source of impingement after reorientation of the acetabulum. An MRI is the study of choice for patients in whom additional pathology is suspected. These include preexisting arthrosis, labral delamination and tears, and bursitis. Several authors have described the use of cartilage-specific sequences such as delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) [37], T1rho, and T2 mapping [43]. Existing intra-articular damage is a negative prognostic factor. Kim et al. have demonstrated that dGEMRIC measures correlate with pain and severity of acetabular dysplasia and may be an early indicator of OA [44]. These can therefore influence decision-making and alter patient expectations.

As unaddressed deformity and lack of congruency have been associated with failure after PAO, in select patients the surgeon should consider the use of functional radiographs. The most commonly used images are anteroposterior radiograph of the pelvis with the hip in full abduction and a false profile view with the hip in flexion. These positions mimic the femoral head coverage that will be obtained after repositioning of the acetabulum.

Author's Preferred Technique

Anesthesia and Blood Loss

Every patient should be evaluated for their surgical risk by the anesthesia as in any surgical procedure. Periacetabular osteotomy can be safely performed with either general anesthesia or spinal neuraxial anesthesia. One advantage of the latter strategy is that the catheter may be left in place in the early postoperative period to aid in pain control and minimize systemic narcotic use. Additionally, some data support the use of regional anesthesia in hip surgery is associated with lower blood loss and risk of DVT [45]. Patients may choose to preemptively donate autologous blood and be transfused in the morning after surgery. Intraoperatively, a cell saver device is employed as well.

Studies have tried to assess the efficacy of blood loss prevention strategies such as the use of preoperative antifibrinolytic agents [45, 46]. We routinely administer intravenous tranexamic acid (TXA) for all patients without absolute contraindications.

Surgical Technique

Patients are carefully positioned on a Jackson table. Next, diligent padding of all upper and lower extremity vulnerable areas is performed in order to minimize risk of iatrogenic neuropraxias or skin damage. There are different incisions utilized for the PAO, but our preference is for a curved more transverse incision, or "bikini incision," lateral to the anterior superior iliac spine (Fig. 12.3).

This potentially improves scarring since it is more in line with the skin creases. The fascia over the tensor fascia lata is carefully opened, and an effort to identify and protect the proximal branches of lateral femoral cutaneous nerve is made. This incision is bluntly dissected further to expose the direct and indirect head of the rectus femoris muscle. The lateral aspect of rectus femoris fascia is incised and the rectus femoris is mobilized medially. Through the floor of the rectus fascia, the iliocapsularis muscle is visualized and then dissected

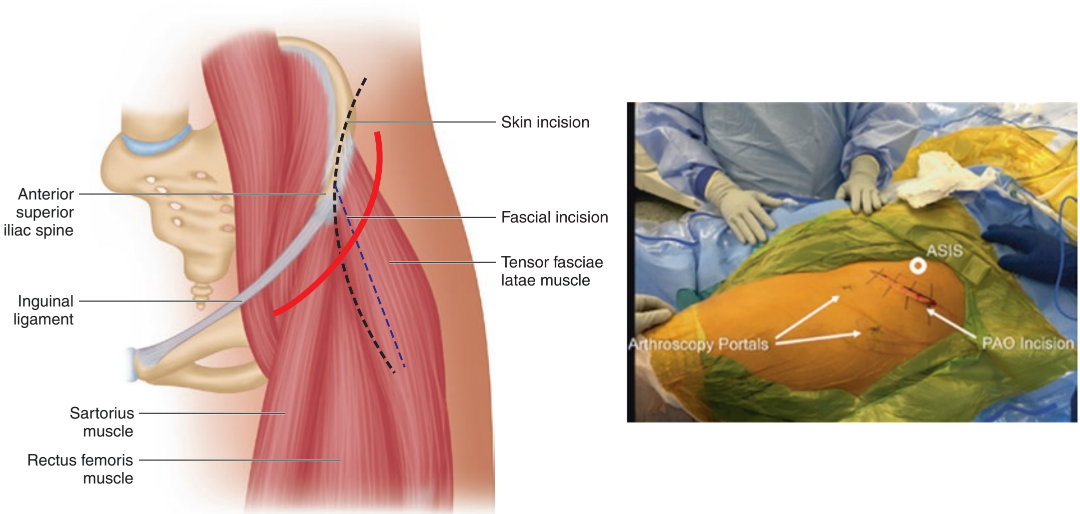

Fig. 12.3 Panel **a** illustrates the landmarks for the incision and the muscle interval for the PAO. The solid red line represents the author's preferred incision. The dotted line is the classic incision. Panel **b** shows clinical intraoperative picture of patient landmarks as well as portal site for combined hip arthroscopy. (Panel **a** Reprinted from Leunig et al. [12] © 2001, https://journals.lww.com/jbjs-journal/Citation/2001/03000/Rationale_of_Periacetabular_Osteotomy_and.18.aspx, with permission from Wolters Kluwer Health, Inc. [12]. Panel **b** Reprinted from Arthroscopy Techniques, Vol. 6/Issue 5, Spiker et al. [47] ©2017, with permission from Elsevier [47])

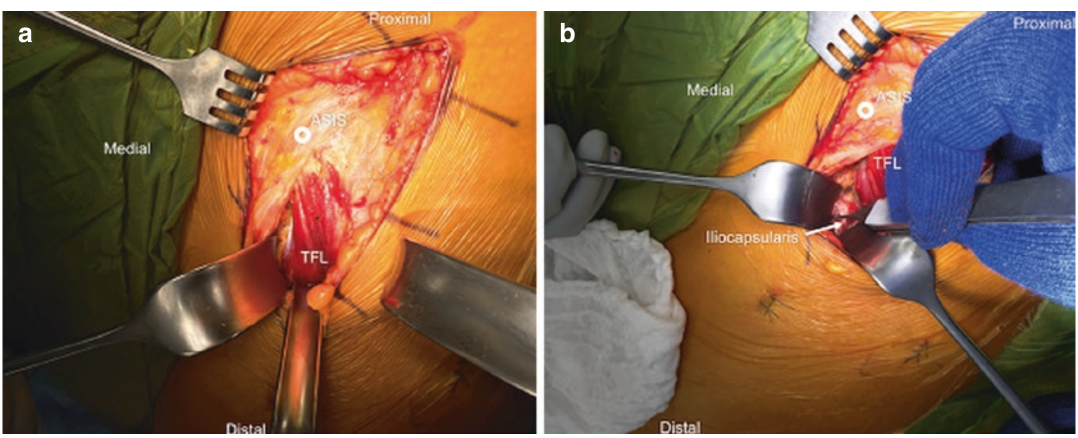

Fig. 12.4 Panel **a** showns a clinical intraoperative photographs of the superficial dissection of the muscle interval between the tensor fascia lata (TFL) and the sartorius. Panel **b** shows the iliocapsularis which lies on the floor of the interval, below the rectus femoris muscle

medially off the hip capsule underneath the rectus muscle (Fig. 12.4).

Once the iliocapsularis is retracted medially, a soft tissue flap containing a portion of the sartorius and inguinal ligament is created. An osteotomy containing a small cortical bone fragment of the anterior superior iliac spine (ASIS) is made. A larger ASIS fragment is performed by many surgeons although we have decreased this as the ASIS screw is often symptomatic and, in our experience, may lose fixation in the pelvis.

The insertion of the distal third of the external oblique fascia is incised to allow a subperiosteal dissection on the inner table of the ilium toward the brim of the pelvis. The medial aspect of the rectus tendon proximal to the tendon muscle junction is identified and mobilized laterally to expose the lateral aspect of the prior dissected iliocapsularis. The dissection is carried medially elevating the iliocapsularis distally and the iliacus proximally, releasing the iliocapsularis from the anterior inferior iliac spine. These muscles are dissected medially until the iliopsoas bursa is localized.

Once the iliopsoas bursa is opened up, the leg is flexed and adducted to allow mobilization of the iliopsoas tendon sheath. This permits a complete subperiosteal dissection on the superior ramus and then eventually over the quadrilateral plate. Distally, the psoas bursa is bluntly dissected to create a plane between the medial hip capsule and the iliopsoas tendon sheath. Curved scissors are used to dissect over the medial hip capsule deep to the tendon sheath until the ischium can be palpated and this interval will be used for the ischial cut.

A subperiosteal dissection is done on the dorsal aspect of the superior ramus underneath the iliopsoas tendon, medial to the hip joint, about 1.5–2 cm medial to the eminence. A sharp Hohmann retractor was placed into the ramus and the leg is flexed and adducted. Crego retractors and a reverse blunt Hohmann are used to perform a subperiosteal dissection of the quadrilateral plate toward the ischial spine. Then retractors are used to subperiosteally dissect around the superior pubic ramus protecting the obturator nerve and vessel. The pubic osteotomy can be performed with a Gigli saw, oscillating saw, or osteotome. The saw or chisel should be directed at approximately 40° from vertical to ensure avoiding the medial hip joint (Fig. 12.5).

Once this is completed, attention is turned to the ischial osteotomy. Although this author performs this step as the second osteotomy, some surgeons perform the ischial osteotomy as the initial cut. Blunt retractors are placed between the medial hip capsule and the iliopsoas tendon sheath. This step allows for placement of an angled or curved "Mast" chisel down to the subcotyloid ischium. The ischial osteotomy is performed in two to three separate steps depending on the width: one addressing the medial cortex and the second addressing mid ischium and then the lateral cortex using a combination of fluoroscopy AP and false profile views. The starting point of the chisel is distal to the joint in the subcotyloid groove and curving toward the base of the ischial spine. The depth is approximately 10–15 mm for this osteotomy roughly to the midpoint of the

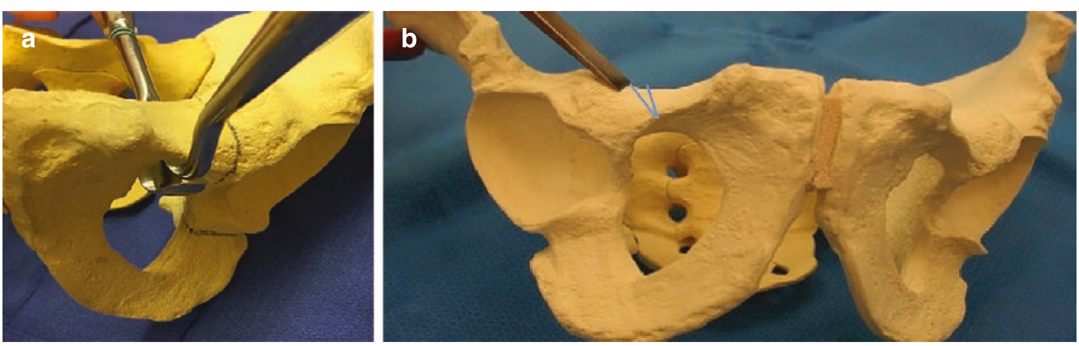

Fig. 12.5 Saw bone models showing the use of curved retractors Panel **a** to both aid in dissection and to protect the obturator nerve and vessel deep the superior ramus. Panel (**b**) illustrates the location and direction of the superior ramus

ischium. The lateral portion of the osteotomy is performed with the leg slightly extended abducted and external rotated. This maneuver relaxes and moves the sciatic nerve away from the pelvis. Additionally, the chisel should be angled toward the contralateral shoulder also in an effort to minimize a risk of iatrogenic neurological injury. It is important to understand that the ischium narrows from anterior to posterior (Fig. 12.6).

After the ischial cut is complete, preparation is made for the supra-acetabular iliac osteotomy. Some authors will do instead the posterior column cut as it is easier to line the supra-acetabular cut to the posterior column compared to the reverse. In order to avoid this, utilizing a 50° false profile view, the senior author marks the starting point of the posterior column osteotomy and the endpoint of the supra-acetabular osteotomy with a straight osteotome. This point is

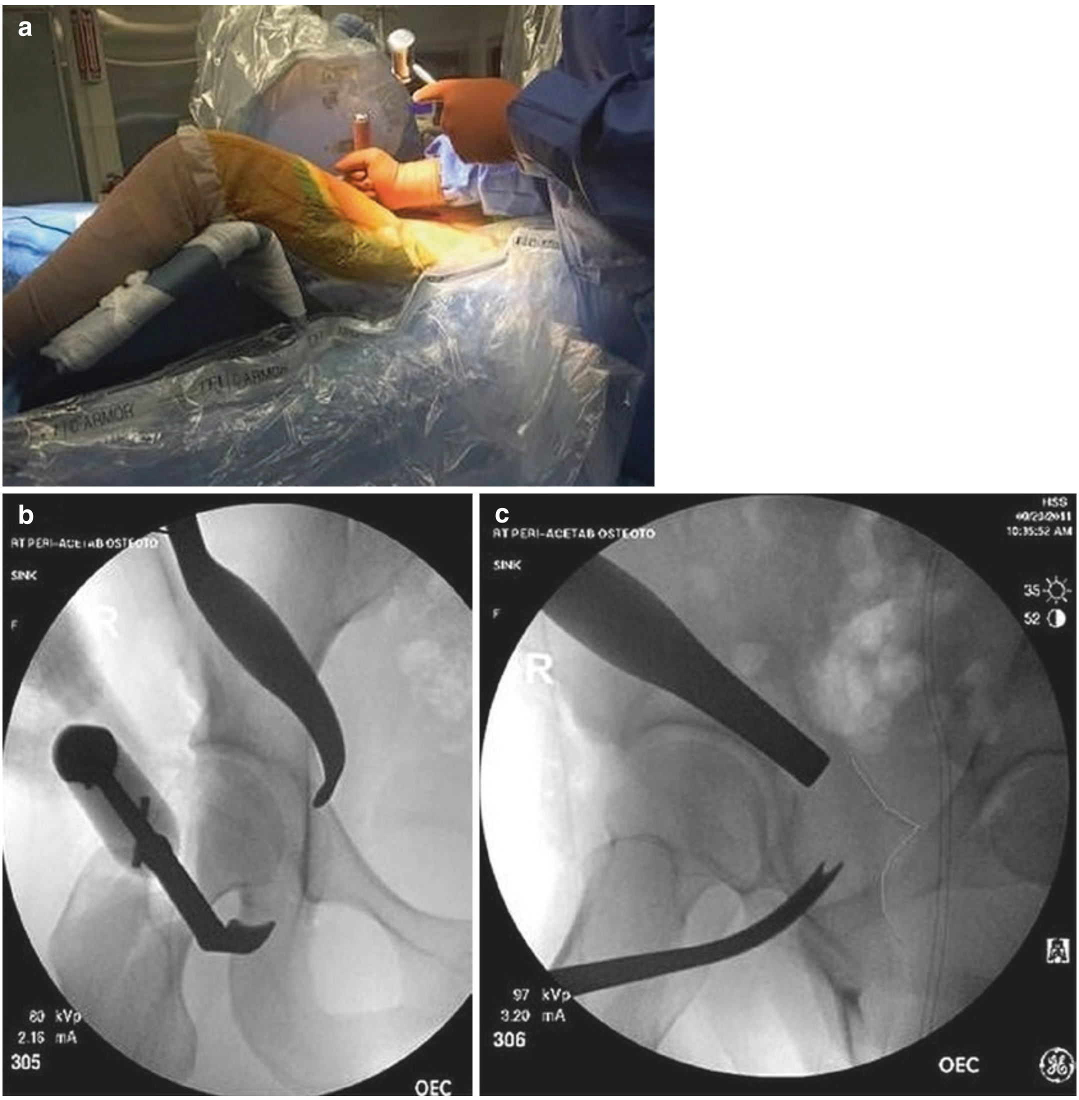

Fig. 12.6 Panel **a** is an intraoperative photograph demonstrating the position of patient, surgeon, and C-arm in a false profile view of pelvis. Panels **b** and **c** show actual intraoperative fluoroscopic views of the pelvis as AP and false profile. These views are used to guide the ischial cut

approximately 1 cm lateral to the pelvic brim and in line with the apex of the sciatic notch. Our preference is to use the burr to mark the starting point for the posterior column osteotomy and cut the inner cortex over the brim of the pelvis. The benefit of the burr is the cortex of the brim is thick; therefore, a burr facilitates starting the chisel for the posterior column osteotomy. The burr point also marks the endpoint of the supra-acetabular osteotomy. A subgluteal window is developed with subperiosteal dissection of the lateral ilium. A retractor is placed to protect the lateral soft tissue. An oscillating saw is used to perform the supra-acetabular osteotomy with the cut being directed toward the posterior column osteotomy starting point created by the burr. The saw blade should be perpendicular to the patient and not the pelvic wing in order to avoid violating the acetabulum (Fig. 12.7).

Next, the posterior column osteotomy is initiated. Using a 50° false profile view, a wide straight osteotome is placed halfway between the sciatic notch and the acetabulum. The cut is directed toward the previously completed initial osteotomy (Fig. 12.8). One method to assess the appropriate position of the osteotome is to ensure that it appears narrow and sharp projection on the false profile view fluoroscopic image. This will assure the osteotome is angled from anterior-medial to posterior-lateral and therefore being

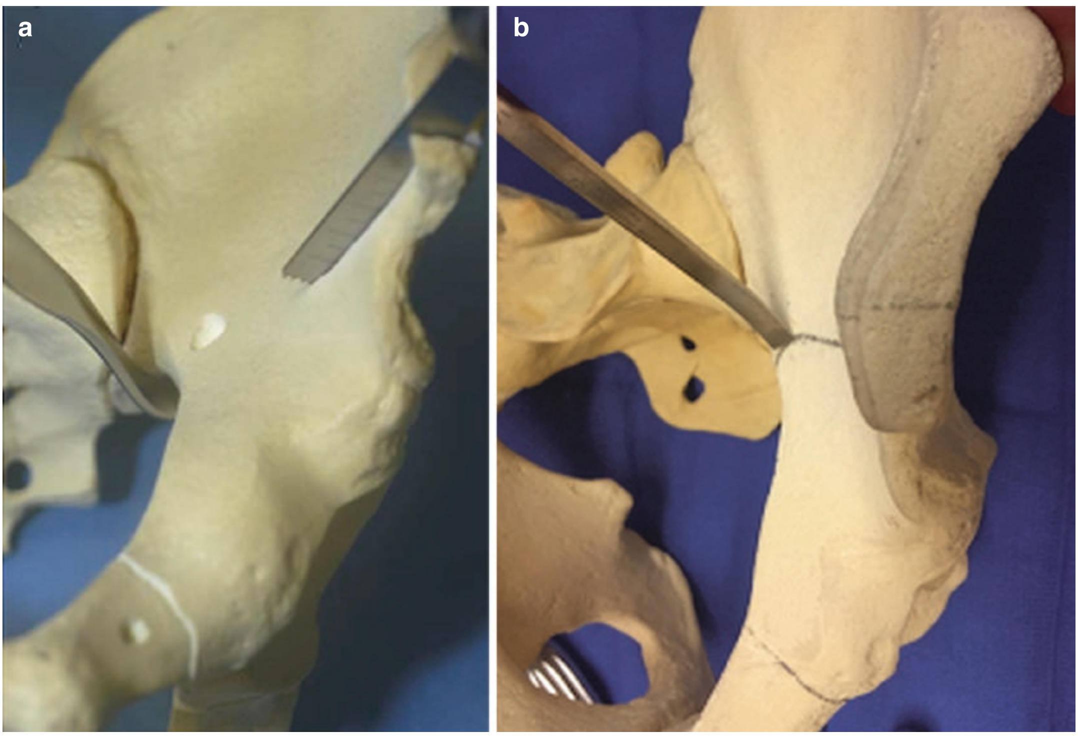

Fig. 12.7 Panel **a**, when performing the supra-acetabular osteotomy, the saw is perpendicular to the patient and directed from the ASIS toward the start or the posterior column osteotomy where the burr has created the starting point. (Reprinted from Clohisy et al. [48] https://journals.lww.com/jbjsjournal/toc/2006/03001, © 2006, with permission from Wolters Kluwer Health, Inc. [48]. Panels **a** and **b**, illustrate locating the start of the posterior column osteotomy and the end of the supra-acetabular osteotomy. A burr is used to open the cortex in this region. Panel **a**, when performing the supra-acetabular osteotomy, the saw is perpendicular to the patient and directed from the ASIS toward the start or the posterior column osteotomy where the burr has created the starting point. Panel **b**, an osteotome is placed in this region to confirm the starting point and direction of the posterior column cut. This will outline where the burr will be used to open the inner cortex at the start of the posterior column osteotomy. The cortex is very thick in the region, and the burr facilitates the ability to direct the osteotome over the brim with necessary adjustments to direction and orientation)

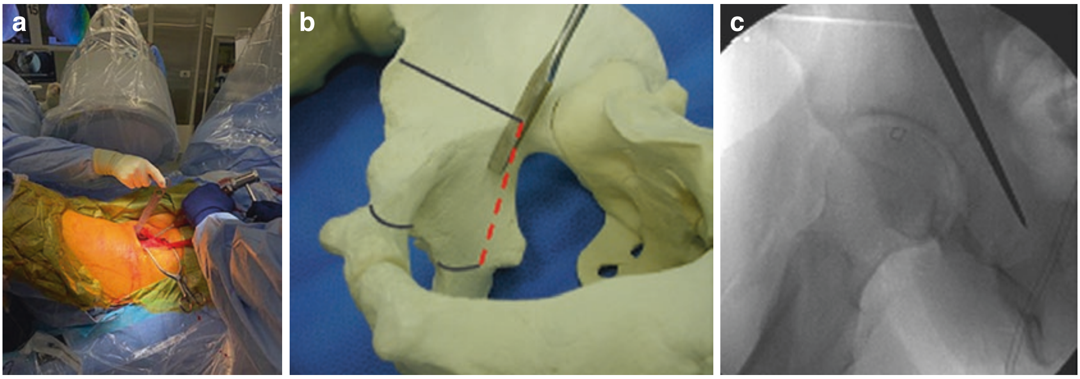

Fig. 12.8 Panel **a** shows and intraoperative photograph. The C-arm is positioned for a false profile view of the hemipelvis. Panel **b** shows a saw bone model illustrating the position and direction of the posterior column osteotomy. Black lines show the superior ramus, ischial, and supra-acetabular cuts. The red dotted line shows the planned posterior column osteotomy. Panel **c** shows a fluoroscopic false profile view. This view allows for performing osteotomy and avoids violating the hip joint or sciatic notch

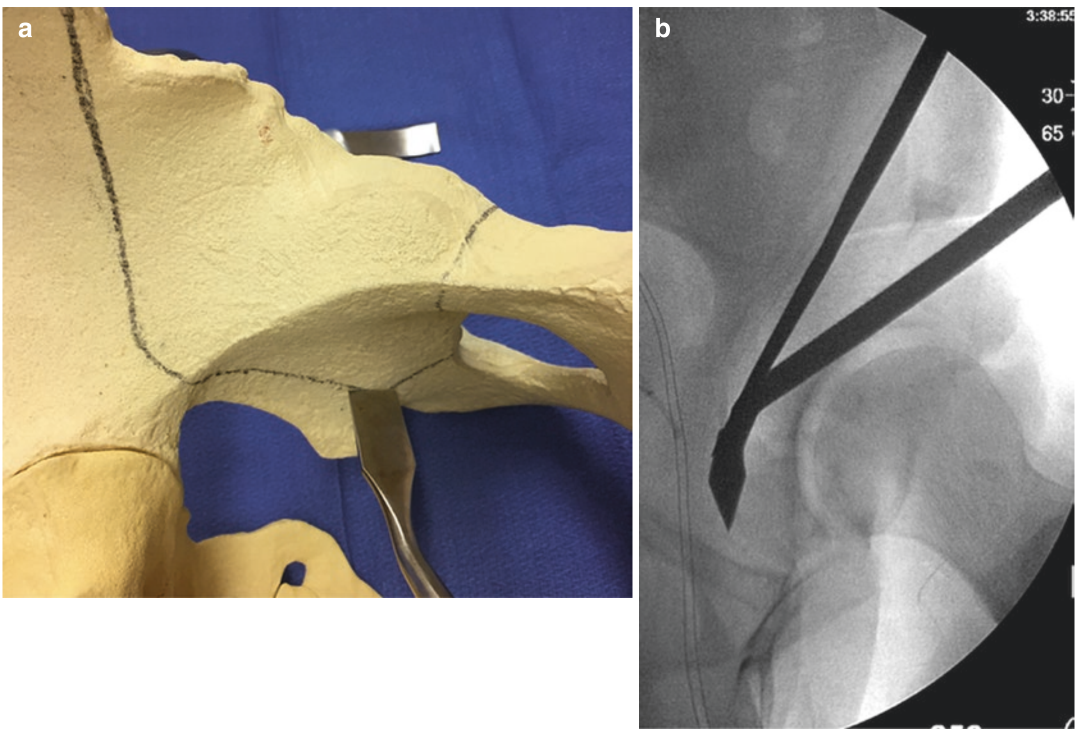

Fig. 12.9 Panels **a** and **b** show an angled osteotome to complete the medial cuts and connecting the posterior column osteotomy to the ischial osteotomy. This creates one continuous osteotomy

perpendicular to the ischium and avoid the hip joint. The osteotome is then advanced carefully under fluoroscopic guidance to avoid violating the hip joint or drifting into the sciatic notch. Once the path is approaching the previous ischial osteotomy, the author's preference is to use an angled chisel to complete the medial osteotomy connecting the straight posterior column cut with the prior ischial osteotomy (Fig. 12.9). This functions to connect and round out the distal posterior column. Surgeons differ in their technique of the posterior column osteotomy. Some surgeons use a curved or an angled osteotome for the majority of the posterior column.

Once the medial cuts are completed, an osteotome is used to assure the supra-acetabular and the lateral cortex of the superolateral iliac osteotomy is completed. This allows a laminar spreader to be used proximally to widen the osteotomy and to allow for any intact lateral posterior column bone to be carefully osteotomized and fractured. Completion of these steps achieves fragment mobilization. The authors will utilize a long curved osteotome working within the plane of the osteotomy carefully completing the distal and lateral portion of the osteotomy while the lamina spreader further opens the supra-acetabular osteotomy (Fig. 12.10).

A Schanz pin is inserted in the supra-acetabular bone to obtain control of the fragment. Utilizing the Schanz pin and a Weber clamp, the acetabular fragment can be completely mobilized to perform the appropriate correction. The fragment is usually flexed to improve anterior coverage and abducted to improve lateral coverage and the version is corrected. The last step may be performed to varying degrees given each patient's unique coverage deficit.

Once the desired fixation is obtained, K-wires can be used to fix the acetabular fragment to the ilium and fluoroscopy is utilized to assess the correction. A combination of AP and false profile views is utilized. The fluoroscopy is positioned and rotated to match the view of a standing AP pelvis radiograph. Some surgeons prefer to obtain a flat plate radiograph to assess correction and not rely solely on the fluoroscope image. However, some studies have concluded that intra-operative fluoroscopy, in particular the LCEA, can be utilized [49] with acceptable reliability.

Several considerations must be made when reorienting the acetabular fragment. In general, the goal is to balance the sourcil over the femoral head on the AP and false profile views. The best correction may be slightly different for each hip. The following five parameters are routinely assessed intraoperatively:

1. The sourcil should be horizontal (Tönnis angle) but not negative [50], as this can create FAI.
2. The center-edge angle should be between 25° and 40° and with 80% lateral femoral head coverage.
3. The hip center should be medialized with a distance of the ilioischial line to the medial femoral head 0–10 mm to improve mechanics and joint reactive forces. Excessive medialization (medial to the ilioischial line) however can lead to protrusion [50].
4. The tear drop should be more medial than pre-operatively, i.e., closer to the ilioischial line.
5. The acetabular version should be assessed by seeing the anterior and posterior walls cross at the lateral edge of the joint. A crossover sign may imply overcorrection and can lead to FAI.

Once a satisfactory position is obtained, this is secured with 3.5–4.5 mm fully threaded cortical screws from the stable ilium into the acetabular fragment (Fig. 12.11). Some surgeons secure fixation with a retrograde screw from the acetabular fragment to the ilium just proximal to the sciatic notch. The resulting bony prominence of the flexed ilium is routinely removed and used as a bone graft as this can cause irritation particularly in patients with lower BMIs.

Once the osteotomy is secure, it is important to evaluate the range of hip motion to ensure that the new position of the acetabulum does not cause overt femoroacetabular impingement. This is a more likely scenario if there is over-coverage anterior often with malposition of the fragment with retroversion or concomitant deformity of the femoral head and neck (Fig. 12.12). When there is the possibility of impingement after fragment positioning or a concomitant dysplasia and FAI, it is recommended to perform an anterior arthrotomy and offset correction if needed. Lastly, the anterior superior iliac spine osteotomy and soft tissue are reduced and repaired with a through bone tunnels, or some surgeons prefer screw fixation. The external oblique fascia and tensor fascia lata muscles are repaired with running sutures. The skin is closed in standard fashion.

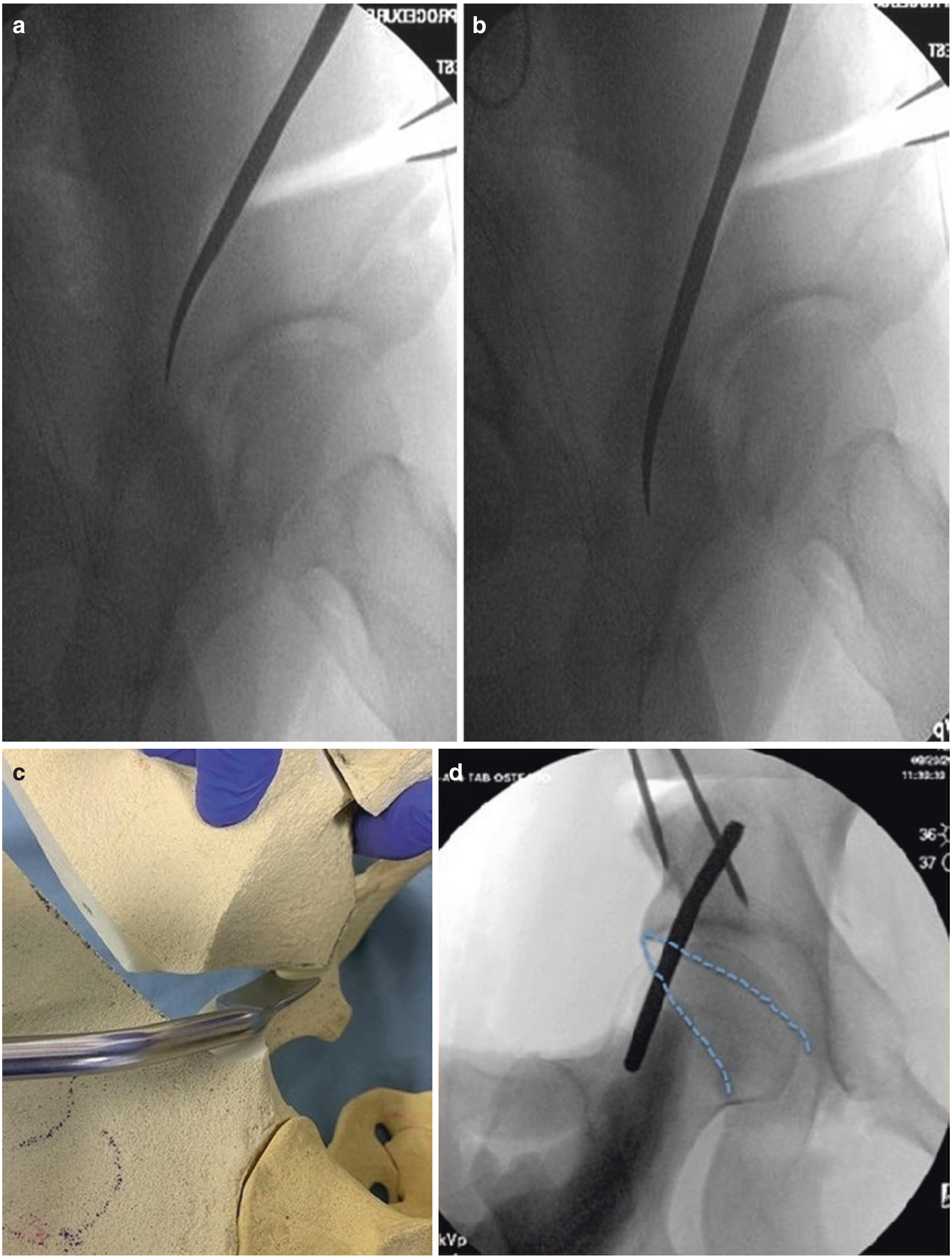

Fig. 12.10 Panels **a** and **b** show intraoperative fluoroscopic false profile views of completion and the posterior column osteotomy using the curved osteotome and laminar spreader. Panel **c** shows sawbone model illustrating the completion of the posterior column with a curved osteotome. Panel **d** shows provisional fixation of the acetabular fragment after mobilization/correction with Schanz pin

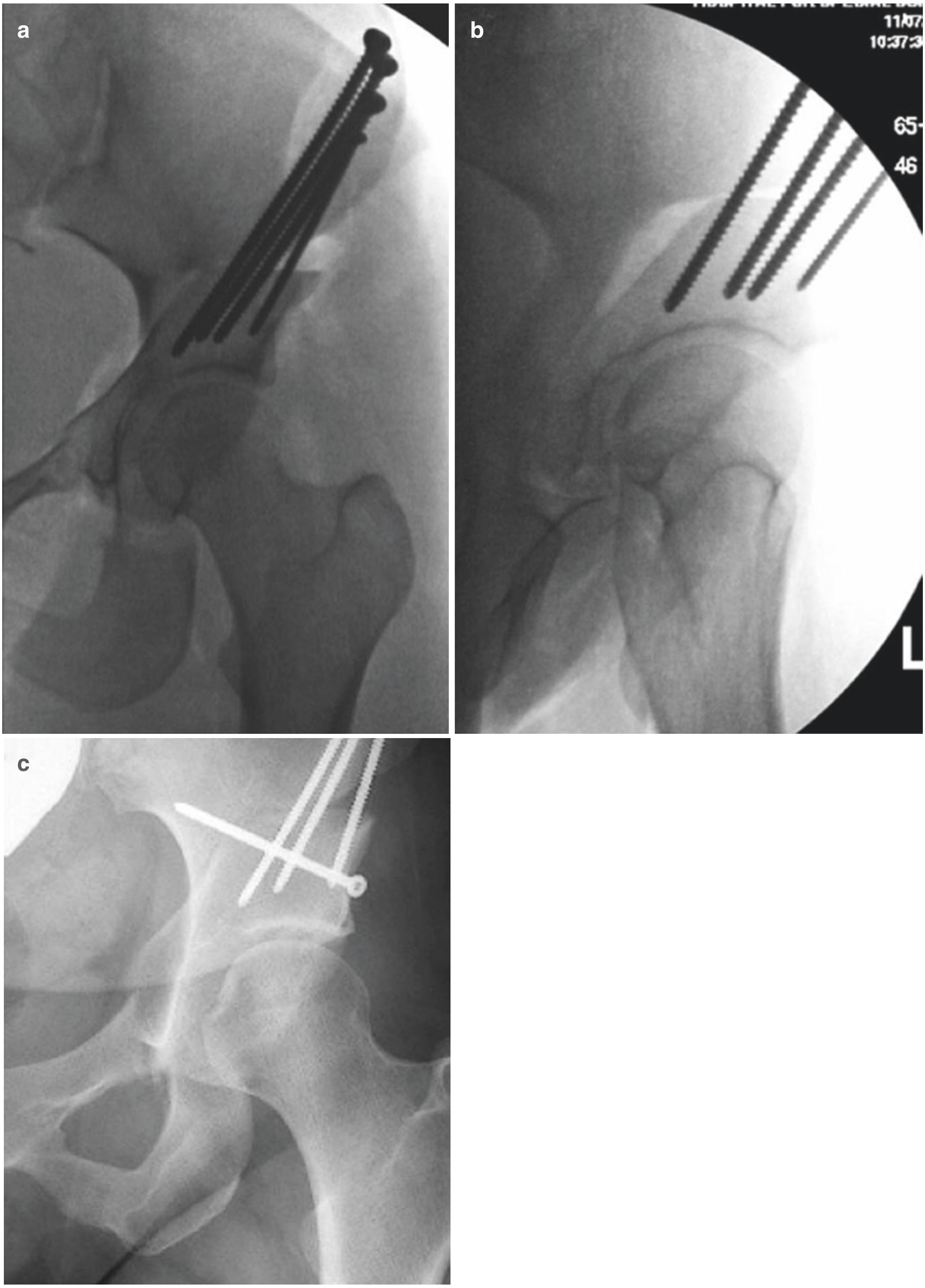

Fig. 12.11 Panels **a** and **b** from intraoperative fluoroscopy views show fixation with four antegrade screws. Panel **c** shows fixation with three antegrade screws and one retrograde screw for additional fixation which is surgeon dependent or utilized in major corrections when more fixation is required

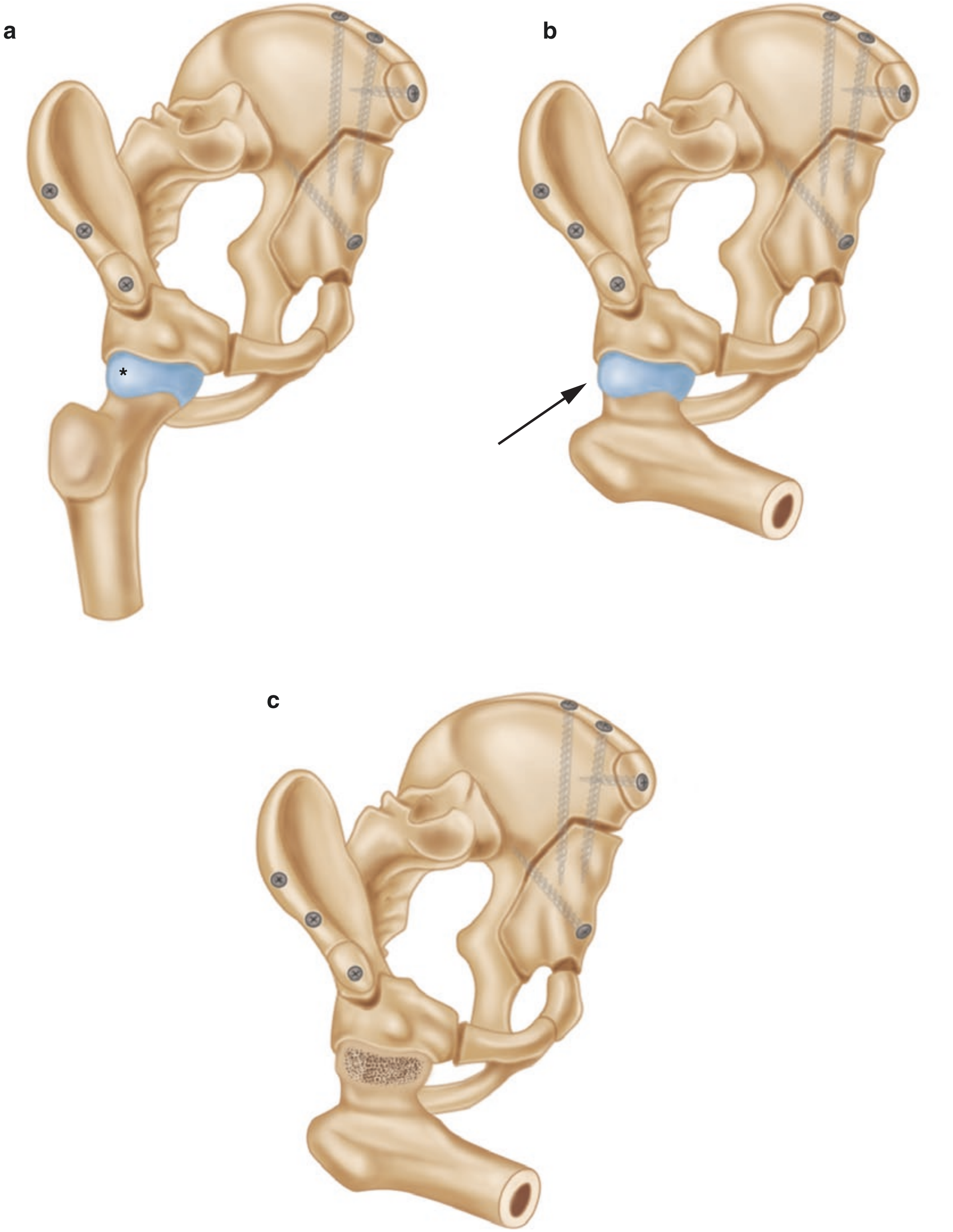

Fig. 12.12 Panel **a** shows a cam-type lesion (black star) in a hip after PAO. Panel **b** shows dynamic impingement. Panel **c** shows relief after osteochondroplasty [20]. (Reprinted from Albers et al. [20], ©2013.https://journals.lww.com/clinorthop/fulltext/2013/05000/Impingement_Adversely_Affects_10_year_Survivorship.31.aspx, with permission from Wolters Kluwer Health, Inc.)

Postoperative Protocol

Postoperatively patients are transferred to an inpatient unit bed equipped with overhead trapeze to facilitate movements while in bed. Most surgeons will use both mechanical and pharmacologic DVT prophylaxis, and these preferences differ by center and surgeon. Even though the incidence of heterotopic ossification has dramatically decreased since the routine preservation of the abductor muscles, most surgeons utilize a few weeks of NSAIDs for heterotopic ossification (HO) prophylaxis.

All patients are evaluated and treated by trained physical therapists while in the hospital. The weight-bearing status is initially 20% toe touch only with a walker or crutches for assistance. If there is normal evidence of bone healing at the 6-week follow-up appointment, the weight-bearing status will be advanced to as tolerated [51]. Typically, at the 3-month follow-up appointment, patients are allowed to return to normal activities gradually. We like to see patients at 6 and 12 months postoperatively for overall assessment of activity level and functionality.

Outcomes

Since its first description by Ganz in 1984, the periacetabular osteotomy has become the definitive treatment for hip dysplasia. Early, midterm, and long-term outcomes have been reported, and most patients show significantly improved outcome scores in the studies.

In 1988, the first results were published from the first 75 patients all with a minimum of 1-year follow-up. In this series, the sole indication was dysplasia of adult or adolescent hips (ages 12–56) requiring correction of congruency and containment. Of note, 18 patients had significant osteoarthritis present at the time of operation, and 6 operations were performed in patients with spina bifida or cerebral palsy. Interestingly, they reported that all clinically significant complications occurred in the first 18 procedures. By the end of the follow-up, only one patient had required total hip arthroplasty due to acetabular protrusion. One patient required reoperation due to excessive lateral placement of the acetabular fragment, and at reoperation a femoral palsy occurred which resolved. Ectopic bone formation occurred in four patients causing limitation in flexion to 90° [10].

Recently, Lerch et al. published a 30-year follow-up on the first 63 patients who underwent PAO for dysplasia between 1984 and 1987 [13]. At that time hip dysplasia was the only indication, and conversion to total hip arthroplasty was defined as failure. Medial and lateral center-edge angle was 6° with an acetabular index of 26° preoperatively compared to lateral center-edge angle of 34° with an acetabular index of 6° postoperatively. Hip survival rate at 10, 20, and 30 years is 88%, 61%, 29% respectively [13]. Additionally, they found that low preoperative Harris hip score, Merle d'Aubigné-Postel score, and preoperative osteoarthritis were predictive of poor outcomes. One notable difference between the original patients described in the Ganz series and more recent studies is the prevalence of arthrosis. In the original indications, many (18/63) of the patients had osteoarthritis on radiographs as Tönnis grade ≥2, whereas recent studies tend to not include patients with known arthrosis. In summary, the authors concluded that PAO is not an effective technique for the treatment of hip dysplasia in the adult hip but caution against treating those with preexisting osteoarthritis with a PAO.

More recent studies continue to try to identify patient and disease characteristics that may predict outcomes after PAO. Matheney et al. reported on 135 hips and documented a 76% survivorship at 9 years [31]. Those authors identify to predictors of failure defined as total hip arthroplasty or high pain score. These included age greater than 35 at time of surgery and poor preoperative joint congruency. Interestingly, recent data from the ANCHOR study group [35] have shed some light on patient selection, and preoperative risk factors can affect patient-reported outcomes. In a large prospective cohort multicenter study, authors showed that, while all patients reported improved scores postoperatively, male sex and mild acetabular dysplasia were associated with worse patient-reported outcomes. Increasing age, BMI indicative of overweight or obesity, and female sex were predictive of improved outcomes in certain metrics. Authors hypothesized that these observations are related to preoperative expectations in certain patient populations.

Grammatopoulos et al. [26] carried out a prospective multicenter study evaluating 244 hips undergoing PAO. Their study compared those with lesser dysplasia – defined as acetabular index less than 15° and a LCEA greater than 15° – to a comparison group of pronounced dysplasia. The cohort was case control matched for BMI, age, Tönnis grade, and congruency. The study showed that similar improvements were seen in both groups postoperatively. The primary outcomes were patient-report outcomes and ability to correct acetabular dysplasia.

Clohisy et al. [52] performed a systematic review of the literature to define the level of evidence, deformity correction, and clinical results and determine complications associated with the PAO. Notably, all studies reported deformity correction and improvement in hip function. Most studies did not correlate radiographic and clinical outcomes. Clinical failures were most commonly associated with preoperative osteoarthritis. Conversion to total hip arthroplasty was reported and 0–17% of all cases, with follow-up ranging from 2.8 to 11 years. Major complication rates varied widely and were reported in 6–37% of all procedures. They also concluded that level of evidence for the studies of PAO is generally low. In their assessment, 11 of the 13 articles meeting inclusion criteria were level IV evidence.

Since its inception, the PAO has continued to evolve and as surgeons' understanding and expertise expand so because the indications. One particular example is the use of the PAO in cases of global retroversion which can be accompanied by anterior pincer-type femoral acetabular impingement. Siebenrock et al. published the 10-year follow-up results on patients who underwent a PAO for retroversion [18]. They report that Merle d'Aubigné scores improved significantly postoperatively. Significant improvements in hip range of motion compared to preoperative status were also reported. No significant increase in the mean Tönnis grade was observed in this interval. The survivorship of the PAO was 100% with zero conversions to THA. Additionally, predictors for poor outcome were found to be lack of femoral offset and overcorrection leading to excessive anteversion.

The PAO has become the treatment of choice for dysplasia of the hip and skeletally mature individuals. Overall, the majority of patients have significantly improved outcome scores and are able to avoid significant arthritis and the need for arthroplasty. The longest follow-up data available indicate that at 20 and 30 years from surgery, 61% and 30% of all hips avoid THA, respectively. If only those with no radiographic evidence of arthritis are included, 82% and 41% avoid arthroplasty at 20 and 30 years respectively. As the technique continues to evolve and the knowledge base expands, more factors influencing outcomes will come to light. As some of the subtler relevant patient and disease characteristics are elucidated, surgeons and patients are able to discuss the expectations and indications for surgery on a more individualized basis for even better outcomes.

Risks and Complications

The PAO is a technically demanding surgical procedure requiring a high degree of surgical expertise. Historically, the complication rates after PAO range from 5.9% to 45% depending on the series [50, 53–57]. The complexity of the anatomy and proximity to important neurological and vascular structures place a great deal of importance on surgeon's expertise. Due to the proximity to the osteotomy, sciatic nerve injury is a risk that concerns surgeons. Posterior bone spikes causing sciatic palsy and nerve palsies involving the peroneal nerve have been described [54]. A cadaveric study by Kalhor et al. found that the sciatic nerve is at risk if the osteotome perforated the lateral cortex of the ischium and the ilioischial junction by >10 mm. The obturator nerve may be injured if the osteotome penetrates greater than 5 mm and the osteotome is not directed 45° medial and 2 cm for the iliopectineal eminence. The femoral nerve may be stretched or entrapped if there is significant prolonged medial traction when performing the pubic osteotomy or if there is significant displacement (>2 cm) of the acetabulum [55]. The femoral, obturator, gluteal, and iliac arteries are present in the surgical field in different portions of the procedure which creates risk of bleeding. Fortunately, life-threatening bleeds are exceedingly rare [57].

During the posterior column osteotomy, fracture may occur requiring internal fixation. Avascular necrosis of the acetabulum is a rare but devastating complication and has been attributed to excessive soft tissue stripping and disruption of the branches of the superior gluteal and inferior gluteal arteries that supply the acetabulum [54]. Similarly, preservation of the obturator artery branch that enters the joint inferiorly through the acetabular notch and supplies the acetabulum is strongly advocated. Pubic ramus and ischial nonunions have been well described. However, these may not require fixation for a satisfactory clinical outcome as they are often asymptomatic. To help minimize the risk of nonunions, we prefer to keep our patients non-weight-bearing for at least 6 weeks postoperatively [51].

Excessive correction of the acetabular fragment can lead to problems in the form of femoroacetabular impingement. In our practice, we will routinely utilize preoperative computed tomography with 3D reconstructions to assess the configuration of the anterior inferior iliac spine and its potential for impingement post-correction. Furthermore, excessive version of the acetabular fragment can lead to iatrogenic lack of coverage and instability either posteriorly or anteriorly. This may lead to persistent pain and clinical instability postoperatively.

More recently, Zaltz et al. [54] prospectively followed 205 consecutive unilateral PAOs performed in the period between August 2007 and August 2009. Major complications occurred in 12 or 5.9% of all patients and 30 or 15% with any grade complication. 77% of grades 1 and 2 complications resolved spontaneously. Major complications, grades 3–4, were defined as those requiring surgical endoscopic or radiographic intervention, life-threatening, or non-treatable with potential disability and death. The most commonly observed complication in the late follow-up (at an average of 14 months postoperatively) was heterotopic ossification or HO. 21 out of 34 were Brooker grade 1. Only one patient had HO Brooker grade 3 that requires surgical excision. In our practice, a typical HO prophylaxis protocol is 75 mg of indomethacin for the first 3 days followed by 500 mg of naproxen for up to 6 weeks. They reported a trend toward an association between male sex and obesity and an increased risk of complications; however, this was not statistically significant.

Other reported complications, not unique to the PAOs, include wound dehiscence, hematoma or infection, and venous thrombotic embolism. The overall reported incidence of venous thromboses with or without PE is low, with a rate of 0.94–1.46% [56, 57], and can typically be managed medically without further complications.

Although this has not been clearly defined, there is a general consensus that major complications in PAO are associated with a so-called learning curve. In his original description, Ganz reported that all clinically important complications occurred within the first 18 procedures. Subsequently, other authors have shown a substantial decrease in the rate of complications after the first 21–35 procedures [10, 53, 54, 58]. As the surgery is popularized and surgeons become more experienced, it is expected that complication rates should continue to drop.

Combined Hip Deformities and the Use of Adjuvant Surgeries

Not too long after his initial description of the periacetabular osteotomy for the treatment of acetabular dysplasia, Ganz recognized the impact of inadequate femoral head coverage on other structures of the hip joint. He described an acetabular rim syndrome in which the shallow acetabular is abnormally loaded on its superolateral edge causing labral hypertrophy, eventual labral rupture, and sometimes accompanied by separation of a bony fragment or “os acetabuli” [39]. As the understanding of hip biomechanics advanced, Ganz and others recognized that impingement played a major role in the symptomatology and etiology of osteoarthritis of the hip joint [59]. Some data revealed that up to 65% of patients undergoing PAO had labral and chondral lesions [60]. Both cam-type and pincer-type femoral acetabular impingement can thus negatively affect the outcome of PAO in the treatment of hip dysplasia.

The fact that femoral head is typically aspherical in developmental dysplasia of the hip increases the risk of a cam-type deformity. Some series have shown that up to 48% of all patients will have symptomatic impingement symptoms after reorientation of the acetabulum [61]. In cases of preexisting deformity, such as high α angles or low head-neck offset, the incidence may be even higher if that deformity is unaddressed. Similarly, during reorientation of the acetabular fragment, excessive retroversion can lead to a pincer-type deformity with excessive anterior bony coverage.

In addition to intra-articular pathology, the shape of femoral head and the proximal femur can also affect the effectiveness of the PAO and its outcomes. One of the main objectives of the PAO is to create improved coverage and biomechanical parameter of the hip joint. However, if there is significant deformity, reorientation of the acetabulum may never lead to a congruent joint and the operation will likely fail. One study of hips who had a PAO suggested that coxa valga is present in 44% and inadequate sphericity and head-neck offset in up to 75% [61].

These observations have made popular the use of concomitant procedures for patients undergoing PAO. It also highlights the importance of a thorough evaluation of the hip joint before proceeding with surgical to ensure that coexisting deformities or other intra-articular process is addressed to maximize the success of the treatment.

Adjuvant Hip Arthroscopy

Thorough evaluation of the patient with hip dysplasia is essential when planning the surgical treatment. Many studies have shown that a high percentage of patients undergoing a PAO will have intra-articular injury to the labrum and cartilage. One small series reports that 100% of the patients examined showed signs of intracapsular pathology such as labral tears and chondral wear. High pretest probability should always prompt the physician to evaluate for mechanical symptoms from labral tears or chondral lesions. This leads some authors to advocate for the use of hip arthroscopy in conjunction with the PAO. Outcomes of many studies conclude results were comparable to a PAO alone without introducing any increase and complications [62].

Ricciardi et al. compared patients undergoing combined hip arthroscopy and PAO to patients undergoing PAO only. The study found that, for those with evidence of labral tears, the improvement in the preoperative iHOT (International Hip Outcome Tool) was greater than the PAO alone group. The authors noted that a combined arthroscopy was able to be performed without significantly increasing the operative time of the PAO and with a comparable safety profile. They concluded that combined arthroscopy is a safe and effective tool intruding hip dysplasia were concomitant labral pathology [28].

Currently hip arthroscopy is a useful adjuvant to PAO surgery that can be performed safely without compromising the PAO. The indications for use are still center dependent and the effect on overall long-term outcomes is still unknown. In our center, the technique is routinely used for the treatment of patients with hip dysplasia and other concomitant hip disorders. Early data show that this approach can be efficacious and safe, and current studies are ongoing.

Adjuvant Hip Arthrotomy

Since its initial description by Ganz, femoroacetabular impingement has rapidly become widely recognized as an important source of hip disability [59]. Furthermore, its role in hip dysplasia and acetabular correction osteotomy outcomes continues to be elucidated [42]. As the evidence for addressing impingement grows, more surgeons advocate for addressing FAI at the time of the PAO.

Scott et al. reported on the importance of addressing concomitant pathology when treating hip dysplasia through hip models. After reviewing CT scans and using finite element analysis, they showed that hips with an increased joint contact stress after PAO showed statistically significantly higher α angles compared to those hips that showed a postoperative decrease in joint contact stress. Furthermore, their model supported that α angles above 60° would lead to increased joint contact stresses. The authors then concluded that unaddressed cam deformities would have a detrimental impact on the outcome of the PAO as a hip preservation procedure [63]. Other studies have also corroborated the importance of appropriately addressing impingement in the outcomes of PAO [20, 64, 65] (Fig. 12.13).

The anterior inferior iliac spine (AIIS) is a significant source of impingement when performing acetabular reorientation. This of course can be exacerbated by preexisting cam-type deformities. It is this author's preference to utilize the preoperative CT scan as well as additional radiographic views to evaluate the presence of a cam lesion that would require concomitant offset correction. In addition, we routinely evaluate for impingement intraoperatively after acetabular correction. Any change in hip range of motion that may be attributed from decreased femoral head/neck offset or from the anterior inferior iliac spine would lead to consideration of arthrotomy (Fig. 12.13).

Many surgeons may elect to perform offset correction through an anterior arthrotomy or a partial AIIS debridement to decrease potential impingement. An arthrotomy also allows for an osteochondroplasty of the neck to be performed safely in cases of cam-type lesions. Both of these techniques are routinely utilized in our center. It is important to note that while the use of adjuvant arthrotomy and osteochondroplasty can provide added benefit, excessive bony resection or debridement can be deleterious. Excessive bony debridement without reestablishment of acetabular coverage can lead to destabilization of the hip joint. Similarly, excessive disruption of the capsular tissue can add laxity and instability as well [66].

Adjuvant Femoral Osteotomy

The relationship between acetabular dysplasia and deformities of the proximal femur is complex and intertwined. Some experts think that a discussion about what is the cause and the consequence is in some ways analogous to a "chicken and the egg" discussion. Femoral deformities such as excessive varus, valgus, version abnormalities, and head non-sphericity are quite common in hip dysplasia. Besides the obvious role in congruency and containment, proximal deformity can lead to abnormal biomechanics of hip abductor and flexors. Historically 10% of patients with a PAO underwent a proximal femoral osteotomy, but this number has decreased more recently [67]. Some of the more common scenarios in which additional femoral osteotomies should be considered include Legg-Calvé-Perthes (LCP), pediatric head deformity (SCFE, fracture), version abnormalities, and lack of congruency.

As with the evaluation of FAI in hip dysplasia, femoral deformity should be carefully evaluated by the surgeon when planning a PAO. Additional radiographs including hip abduction views with or without flexion and internal rotation and Dunn views can be quite useful in assessing containment and congruency.

Surgeons should consider the femoral version in the decision to perform concomitant osteochondroplasty as impingement may be more likely with femoral retroversion and less likely with femoral anteversion. Sankar et al. have shown that version of the femur is the most important determinant for hip range of motion in patients undergoing PAO [68]. In cases of significant version abnormalities, femoral osteotomies allow for correction relatively simply. Figure 12.14 illustrates a case of DDH with

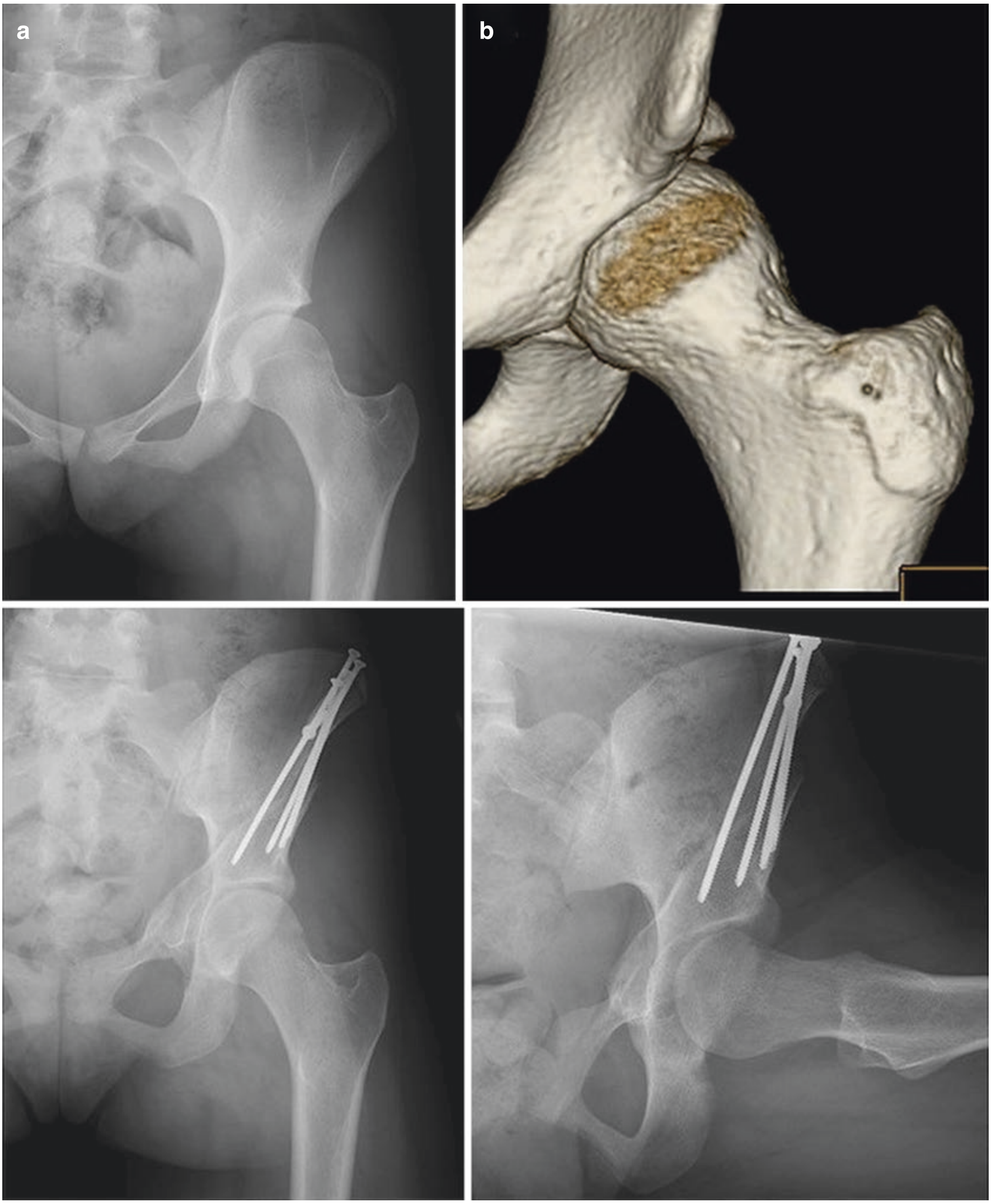

Fig. 12.13 Panels **a** and **b** are preoperative radiograph and 3D reconstruction of a left hip with dysplasia and coexisting cam-type deformity. Panels **c** and **d** are postoperative radiographs after PAO and osteochondroplasty

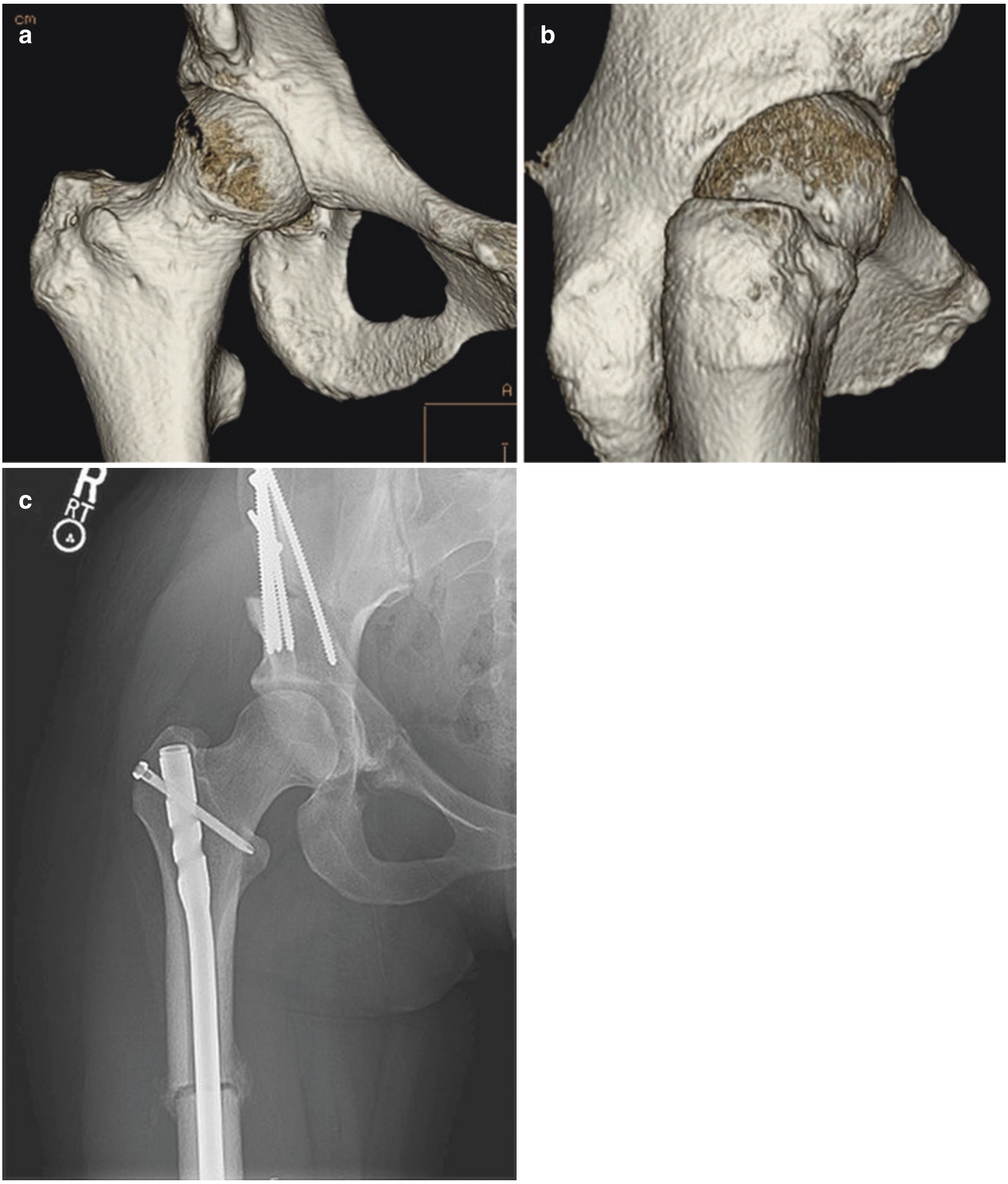

Fig. 12.14 Panels **a** and **b** show 3D reconstruction images of a right hip with measured anteversion of 46° and clinical symptoms of impingement. Panel **c** is a post-operative radiograph of PAO with a combined femoral osteotomy with intramedullary fixation to correct version abnormality

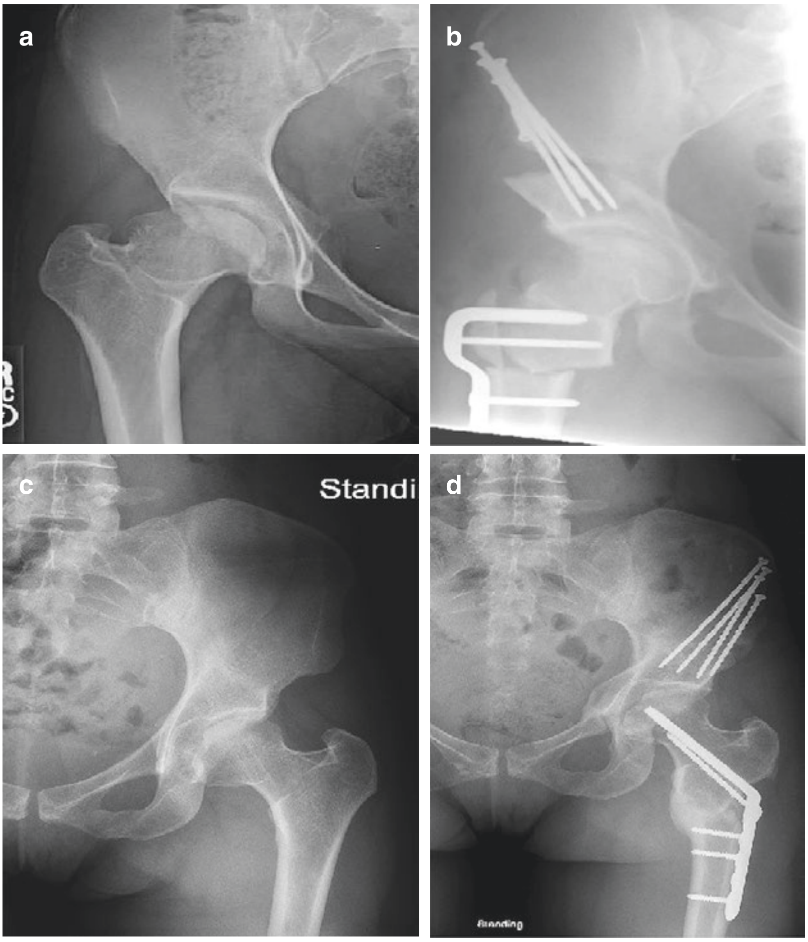

Fig. 12.15 Panels **a–b** show cases of acetabular dysplasia with deformity of the proximal femur that required combination surgery. A femoral valgus osteotomy with a relative neck lengthening was performed in combination with a PAO for adequate congruency and containment in a patient with Legg-Calvé-Perthes. Panels **c** and **d** from severe DDH with coxa vara that had a concurrent valgus to maintain congruency and improve hip function

excessive femoral anteversion (46°) and the final radiographs after PAO and proximal femoral osteotomy PFO.

Legg-Calvé-Perthes (LCP) can result in significant deformity of the femoral head as coxa plana and coxa valga leading to an inappropriately contained or congruent hip joint. Figure 12.15 shows cases of DDH treated with PAO and a proximal femoral valgus osteotomy to improve congruency of the hip joint.

Summary

The PAO is a powerful tool in treating hip dysplasia and is associated with a relatively low complication rate. The operation can delay the need for arthroplasty for at least 20 years in the vast majority of patients. The outcomes are even more successful in those with and without any evidence of osteoarthritis on radiographs preoperatively. Patients with global acetabular retroversion may also benefit from the procedure as a means to relieve anterior impingement. Patients with concomitant pathology in the form of a labral tear or chondral lesions may undergo PAO with combined hip arthroscopy resulting in excellent results and relief of pain. Those with significant impingement, preexisting or iatrogenic, may benefit from adjuvant arthrotomy to address FAI. Similarly, it is important to note that lack of congruency and containment can be secondary to proximal femur deformities, and additional proximal femoral osteotomy PFO may be warranted. Given the complexity and nuances of appropriate surgical treatment of DDH with PAO, patients should seek expert opinion before committing to surgical interventions. Luckily, PAOs have proven to be a powerful and effective tool in treating DDH and have become very safe with modern techniques.

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