The Periacetabular Osteotomy Technique

Navid M. Ziran, MD, Taysir Awad, MD,† and Joel M. Matta, MD**

Summary: Adult development dysplasia of the hip is characterized predominantly by deficient anterior and lateral femoral head coverage. Numerous pelvic and femoral osteotomies have been developed to help restore proper joint biomechanics and delay the onset of osteoarthritis. Reinhold Ganz developed the Bernese periacetabular osteotomy in 1984 to address acetabular dysplasia. The Ganz osteotomy 3-dimensionally reorients the acetabulum so that hip joint forces are more evenly distributed. Since then, the procedure has evolved slightly in the surgical approach and technique, but the fundamental osteotomies remain the same. The learning curve for the technique remains steep with potentially high complication rates and long operative times. The senior author has been performing this procedure since 1987 with nearly 500 procedures performed. Initial operative times for the senior author averaged ~3 hours and have decreased to ~60 to 75 minutes. This manuscript will demonstrate the senior author's surgical technique of the periacetabular osteotomy as it has evolved over nearly 30 years. The authors hope that this technique description can facilitate other surgeons' progress on the learning curve for this technically difficult but beneficial technique.

Key Words: periacetabular osteotomy—PAO—hip preservation surgery—joint preservation surgery—developmental dysplasia of hip—DDH.

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Acetabular dysplasia is the leading cause of degeneration of the hip resulting in end-stage osteoarthritis in 25% to 50% of the cases in patients younger than 50.[1] A joint preserving reorientation procedure is preferred over arthroplasty in this younger population. The Bernese periacetabular osteotomy (PAO) was developed in 1984 by Reinhold Ganz for the treatment of adult developmental dysplasia of the hip.[2] The purpose of the Bernese PAO is to correct the anterolateral deficient coverage of the femoral head by osteotomizing the acetabulum with subsequent 3-dimensional reorientation. The reorientation of the acetabulum distributes the contact forces over a more congruent and larger surface area with a subsequent decrease in contact pressures. The change in contact pressure may also be accompanied by biochemical changes of the cartilage matrix; a recent study has demonstrated changes in the cartilage matrix composition after PAO.[3]

The senior author published an initial study of the operative outcomes at a minimum of 2 years follow-up (average 4 y) and demonstrated good-excellent outcomes in 76%.[4] A recent survivorship study by the senior author has demonstrated ~59% 20-year survivorship of the native hip after PAO. Ganz also reported 60% hip preservation after 20 years in his outcome study.[5]

Blavier and Blavier[6] were the first to describe a spherical osteotomy in 1962. Wagner,[10] Eppright,[8] and Ninomiya[11] also described the spherical osteotomy which improved anterolateral coverage, but was not optimal in establishing anteversion and medial/lateral displacement of the acetabulum.[9–13] Further, intra-articular penetration of the spherical osteotomy may disrupt the acetabular blood supply since the radiographic-U or tear-drop is separated from the joint. Le Coeur[14] was the first surgeon to describe a triple innominate osteotomy. Hopf[9] also described the triple innominate osteotomy through the Smith-Petersen approach, although in his technique, the acetabulum was separated from the acetabular artery. Hopf described a high rate of osteonecrosis, presumably due to vascular disruption. Steel[12] described a triple osteotomy with the patient performed supine. The ischial osteotomy is performed through a separate approach exposing the ischium with the hip flexed. The iliac and pubic osteotomies are performed through an anterior iliofemoral approach with reflection of the abductors. Tonnis et al[15] described a triple pelvic osteotomy in which the ischial osteotomy was performed with the patient prone. The posterior column was osteotomized and the sacrospinous and sacrotuberous ligaments were left intact.

The Ganz triple innominate osteotomy was first performed by the Smith-Petersen approach. However, due to compromise of the abductors and heterotopic ossification, the technique was modified so the no lateral iliac wing dissection was performed. All the osteotomies, except the ischial osteotomy, are performed from inside the pelvis. After utilizing the modified Smith-Petersen interval with no lateral ilium dissection, the incidence of limp and heterotopic ossification decreased significantly. In 1999, Ganz described the technical complications of 508 consecutive osteotomies performed.[16] Eight-five percent of these complications occurred in the first 50 osteotomies that Ganz performed. These complications are important as they form a foundation of further improvements and are noted below:

(1) Potential intra-articular penetration (either inferior acetabulum, or worse, posterosuperior).
(2) Insufficient/excessive correction—this point is especially important in retroverted acetabulums as "typical" anterolateral correction can worsen the pathology.
(3) Resubluxation of the femoral head can be due to under/overcorrection of the dysplastic acetabulum as mentioned or from femoral dysplasia.
(4) Nerve palsy—although Ganz described sciatic and femoral nerve palsies, the lateral femoral cutaneous nerve is at greatest risk of a neurapraxia (~30%). Femoral nerve injury was seen in procedures performed by the direct anterior approach (2 patients) and revision PAO (1 patient). Sciatic nerve injury is most at risk with the infracotyloid (ischial) osteotomy and moreso, the posterior column osteotomy.
(5) Avascular necrosis can be prevented by the following (a) avoid stripping the soft tissues off the lateral ilium as this can compromise the inferior branch of the superior gluteal

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The authors declare that they have nothing to disclose.

For reprint requests, or additional information and guidance on the techniques described in the article, please contact Navid M. Ziran, MD, at navidziran@yahoo.com or by mail at 2001 Santa Monica Blvd Suite 760 Santa Monica, CA 90404. You may inquire whether the author(s) will agree to phone conferences and/or visits regarding these techniques.

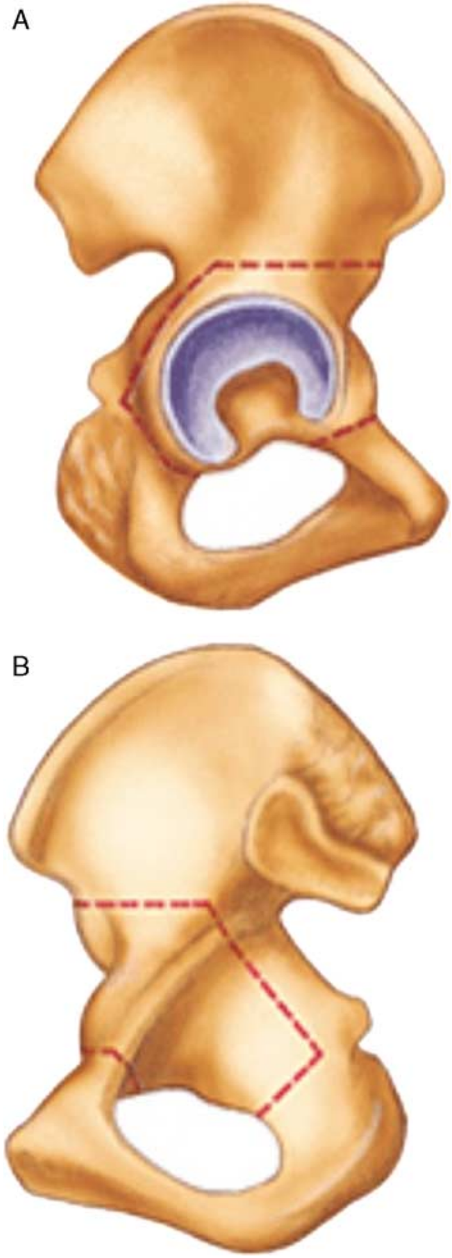

FIGURE 1. This illustration demonstrates the periacetabular osteotomies (dotted red line) on both the inner and outer aspects of the pelvis.

artery, (b) avoid inferior intra-articular penetration that separates the joint from the tear-drop as the acetabular artery can be disrupted, and (c) performing the ischial osteotomy proximal to the obturator externus since the medial femoral circumflex artery (of which the acetabular artery is a branch) runs distal to the obturator externus.

(6) Nonunion of the ischial (2 cases), pubic (3 cases), or iliac (1 case) bone—all but one of the cases occurred in patients with significant interfragmentary gaps (> 10 mm).

(7) Fixation failure or symptomatic implants—initially, Ganz utilized 4.5-mm screws, but this caused patients pain, especially when lying on their side. After changing to 3.5-mm screws, which are less prominent, the incidence of symptomatic implants decreased.

In this paper, we describe the senior author's PAO technique after performing over 500 surgeries from 1987. Although the technique has evolved, the technical goals remain the same: (1) a horizontal, or slightly undercorrected, roof (2) congruous femoral head centered under the radiographic roof, (3) adequate anterior plus posterior rim coverage of the femoral head with anteversion, (4) medial displacement of the pubic bone without loss of contact of the superior pubic ramus, (5) medialization of the femoral head to within 5 to 15 mm of the ilioischial line, and (6) improvement in the Shenton line.

Preoperative radiographs entail an anteroposterior (AP) pelvis, abduction-internal rotation view, and a false-profile view. The abduction-internal rotation view demonstrates anticipated lateral head coverage and potentially corrects "artificial" joint space narrowing caused by potential anterolateral head subluxation. The false profile view demonstrates anterior wall coverage. Murphy and Deshmukh[7] described the value of functional radiographs (abduction-internal rotation view and hip flexion to 90 degrees during the false profile view). He has demonstrated that dysplastic Tonnis grade 3 dysplastic hips that have coverage with functional radiographs can actually improve and remodel despite the degree of arthritis. Dysplastic grade 3 hips with asphericity and inadequate coverage are at highest risk for failure. These concepts may guide indications for the surgeon considering to perform a PAO on a patient with more advanced arthritis. The senior author's current indications include symptomatic patients who demonstrate a lateral and anterior center-edge angle of <20 degrees and who have a Tonnis grade of 0 or 1. However, there are select patients with a Tonnis grade of 2 or 3 who may benefit from a PAO—as also described by Murphy above. The factors which dictate success or failure after PAO in patients with advanced hip arthritis are still unknown.

The procedure will be discussed in the following order: (1) positioning and exposure, (2) medial ischial osteotomy, (3) lateral ischial osteotomy, (4) superior pubic ramus osteotomy, (5) false profile (supra-acetabular) osteotomy, (6) posterior column osteotomy, (7) acetabular reorientation and fixation, and (8) closure. An overview of the periacetabular osteotomy is shown in Figures 1A and B. Each osteotomy will be demonstrated by intraoperative pictures, bone model correlates, and fluoroscopy. Many pelvic/acetabular surgeons have communicated the steep learning curve of this operation with potential for morbid complications. The authors hope to communicate the details of the senior author's refinements so that other surgeons can avoid making the same mistakes.

METHODS

The patient is placed supine on a radiolucent Jackson flat-top table. After administration of general anesthesia, muscle paralysis, and preoperative antibiotics, the affected extremity is prepped and draped in sterile fashion. The entire extremity is prepped up to the xyphoid and medial to the pubis. Both arms are placed out to the sides. If the ipsilateral upper extremity is placed over the chest, it can potentially interfere with the ischial cut. The lower extremity stockinette is split, and straddles the thigh. Drapes and Ioban are applied as shown in Figure 2A.

One of the 2 incisions can be made: the classic Smith-Peterson incision or an inguinal transverse incision. The

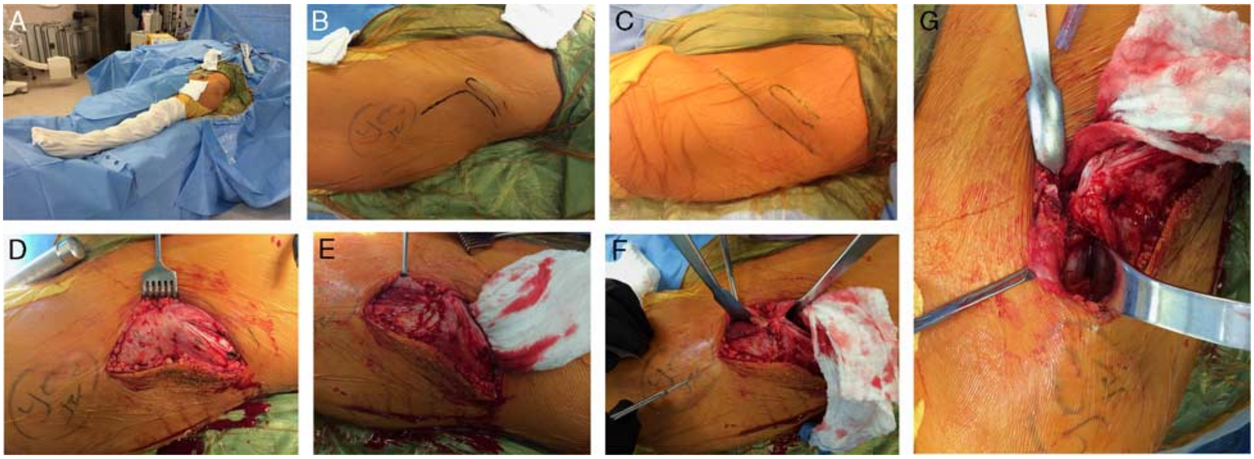

FIGURE 2. A, Lower extremity is draped as shown. B, Hip marked for modified Smith-Peterson Approach with the iliac portion of the incision slightly posterior to the crest. C, Hip marked for transverse inguinal incisional (“bikini-line” incision) approach. D, The external abdominal oblique aponeurosis is sharply released from the iliac crest. E, The tensor fascia is sharply incised and elevated with an Allis clamp. F, A Hohmann retractor is placed lateral to the femoral neck and another is placed in internal iliac fossa to increase tension on the sartorius-inguinal ligament. G, Sartorius-inguinal ligament is sharply incised off the ASIS; there can be anatomic variations of the lateral femoral cutaneous nerve that can be in close proximity.

modified Smith-Peterson approach (Fig. 2B) starts lateral to the iliac crest and posterior to the gluteus medius tubercle. It parallels the iliac crest until it reaches just lateral to the anterior superior iliac spine (ASIS). It is then directed distal and lateral to a point even with the symphysis pubis. The alternate incision, now more commonly performed by the senior author, is the inguinal transverse incision or the “bikini-line” incision (Fig. 2C). This incision parallels the iliac crest about 3 cm distal to the crest and proceeds medially along the flexor crease of the hip. The incision is continued until the proximal level of the symphysis pubis. Elevation of the subcutaneous tissue in the medial aspect of the bikini-line incision should be avoided as it can impair anterior thigh sensation. As mentioned, the bikini-line incision has a greater risk of impairing anterior thigh sensation; however, it is more cosmetic and preferred by females. The classic Smith-Peterson incision allows for better intrapelvic exposure and it is better in muscular, male patients. Despite the different skin incisions, the underlying deep dissection is the same.

The abdominal muscle insertion is released from the iliac crest from lateral to medial (Fig. 2D). The iliacus is bluntly dissected off the internal iliac fossa from posterior to the gluteus medius tubercle to the ASIS using a Cobb elevator and packed with a laparotomy sponge. Next, the translucent fascia over the tensor fascia lata is incised sharply (Fig. 2E). The fascial sheath is elevated from the medial tensor, and a Hohman is placed in the interspinous notch to retract the tensor fascia medially. Another Hohman is placed in the internal iliac fossa to tension the abdominal muscles (Fig. 2F). These Hohman retractors facilitate the next step. The external abdominal oblique aponeurosis,

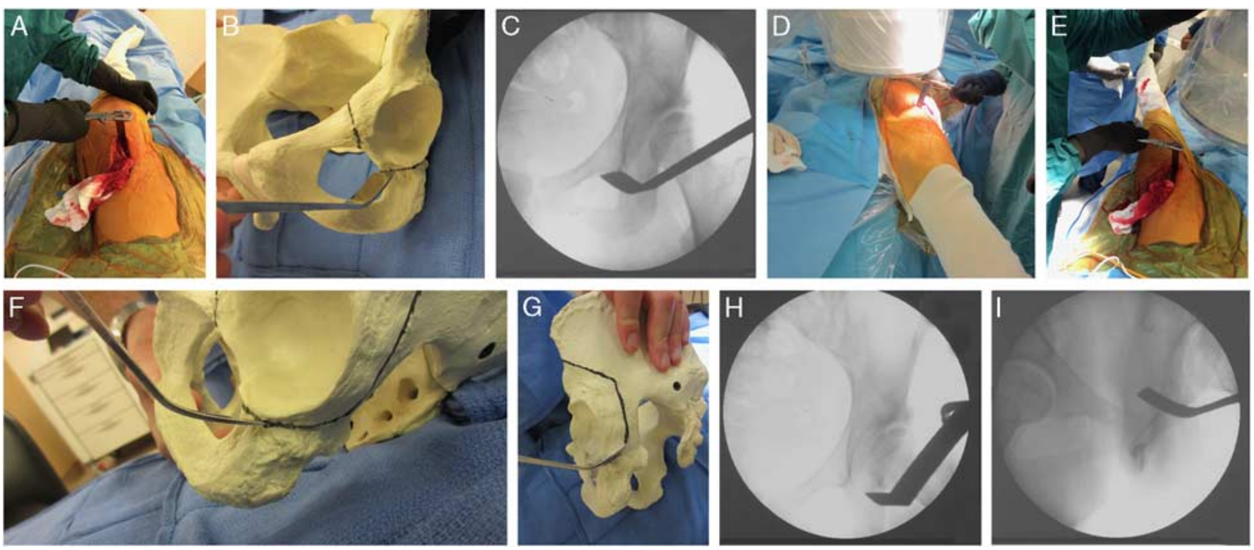

FIGURE 3. A to C, Intraoperative image (A) of the osteotome before the medial ischial cut with corresponding bone model (B) and fluoroscopic image (C). D to I, Intraoperative image (D, E) of the lateral ischial cut with corresponding bone model (F, G) and fluoroscopic image (H, I). Note the osteotome extends slightly medial to the subacetabular groove to ensure complete corticotomy.

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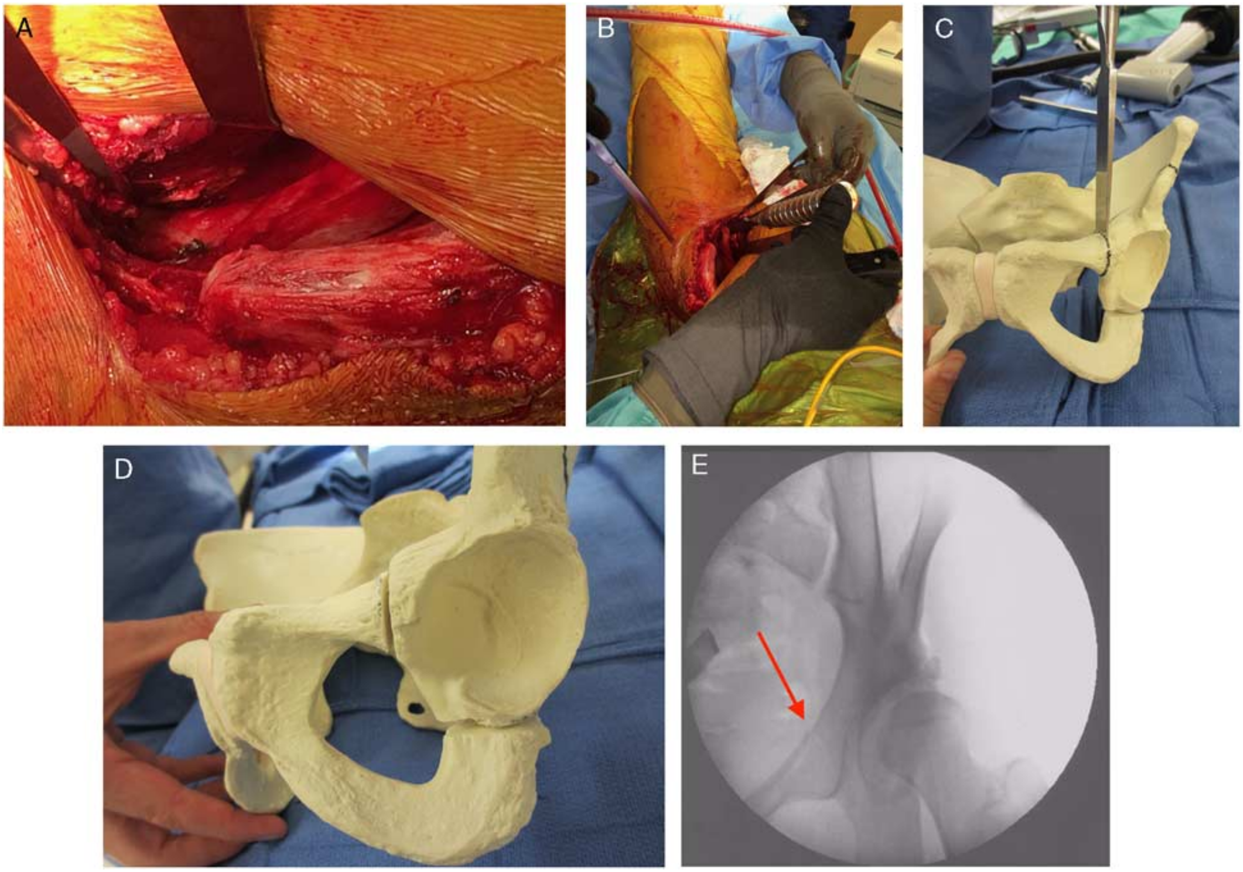

FIGURE 4. A, Intraoperative image exposing superior pubic ramus with Eve retractor, Cobb elevator, and small Hohmann. B to E, Intraoperative image (B) showing the superior pubic ramus cut using 20-mm straight osteotome with corresponding bone model (C, D) and fluoroscopic image (E).

inguinal ligament, and sartorius are sharply released from the ASIS (Fig. 2G). Soft tissue is then released from the distal and medial aspect of the ASIS to expose the interspinous notch. The senior author prefers to leave the rectus femoris origin intact on the anterior inferior iliac spine (AIIS). However, dissection is performed medial to the rectus origin about 3 to 4 cm distal to the AIIS. More distal dissection in this area could potentially endanger the innervation to the rectus femoris muscle. The hip capsule is then exposed.

The interval between the indirect head of the rectus femoris and the anterior neck capsule is identified. A Cobb elevator is passed along the lateral aspect of the hip capsule, and a Cobra retractor is used to retract the abductors from the lateral hip capsule. The hip is then flexed 45 degrees, and the anterior hip capsule is exposed by using a Cobb elevator over the anterior hip capsule directed medially and posteriorly. A Cobra retractor is placed around the medial hip capsule. To get further exposure, it may be necessary to sharply dissect tissue off the anterolateral hip capsule and sometimes release a portion of the reflected head of the rectus femoris. An angled periosteal elevator is then passed between the medial hip capsule and the iliopsoas tendon. The tip of the elevator is utilized to palpate the flat surface of the proximal ischium—just distal to the posterior rim of the acetabulum and the ischial border of the obturator foramen. Spreading a large curved Mayo scissor with the tip around the inferior hip capsule can facilitate the future passage of the first osteotome through this "window" to the ischium.

Osteotomy #1 and #2—Medial and Lateral Ischial Osteotomy

A 1/2" curved osteotome is passed through the previously developed interval inferior to the hip capsule and placed against the medial ischium (Fig. 3A). The osteotome tip is slid proximally so that it rests in the most inferior portion of the posterior acetabular rim. The osteotome position is checked using the fluoroscope. The medial tip of the osteotome should be adjacent to the medial border of the obturator foramen (Fig. 3B). The osteotome is then advanced ~20 mm using a mallet. The rotation of the osteotome is critical to ensure that the osteotomy is retroacetabular. The corresponding fluoroscopic image of the medial cut is shown in Figure 3C.

In a similar fashion, the lateral ischium is osteotomized. Hip abduction ~20 degrees facilitates this lateral ischial cut (Figs. 3D, E) to prevent interference with the femoral neck. The osteotome is positioned in the subacetabular groove just distal to the posterior rim of the acetabulum (Figs. 3F, G). The posterior edge of the osteotome tip should be in a position to cut the subacetabular groove (Fig. 3H). The osteotome should be advanced in a posterior direction. A 50-degree iliac oblique fluoroscopic view is taken to confirm the retroacetabular path and extra-articular position of the osteotomy (Fig. 3I). The tip of the osteotome should be posterior and inferior to the acetabulum with the tip directed toward the ischial spine. If there is significant bleeding from this area, withdraw the osteotome and pack it with a laparotomy sponge.

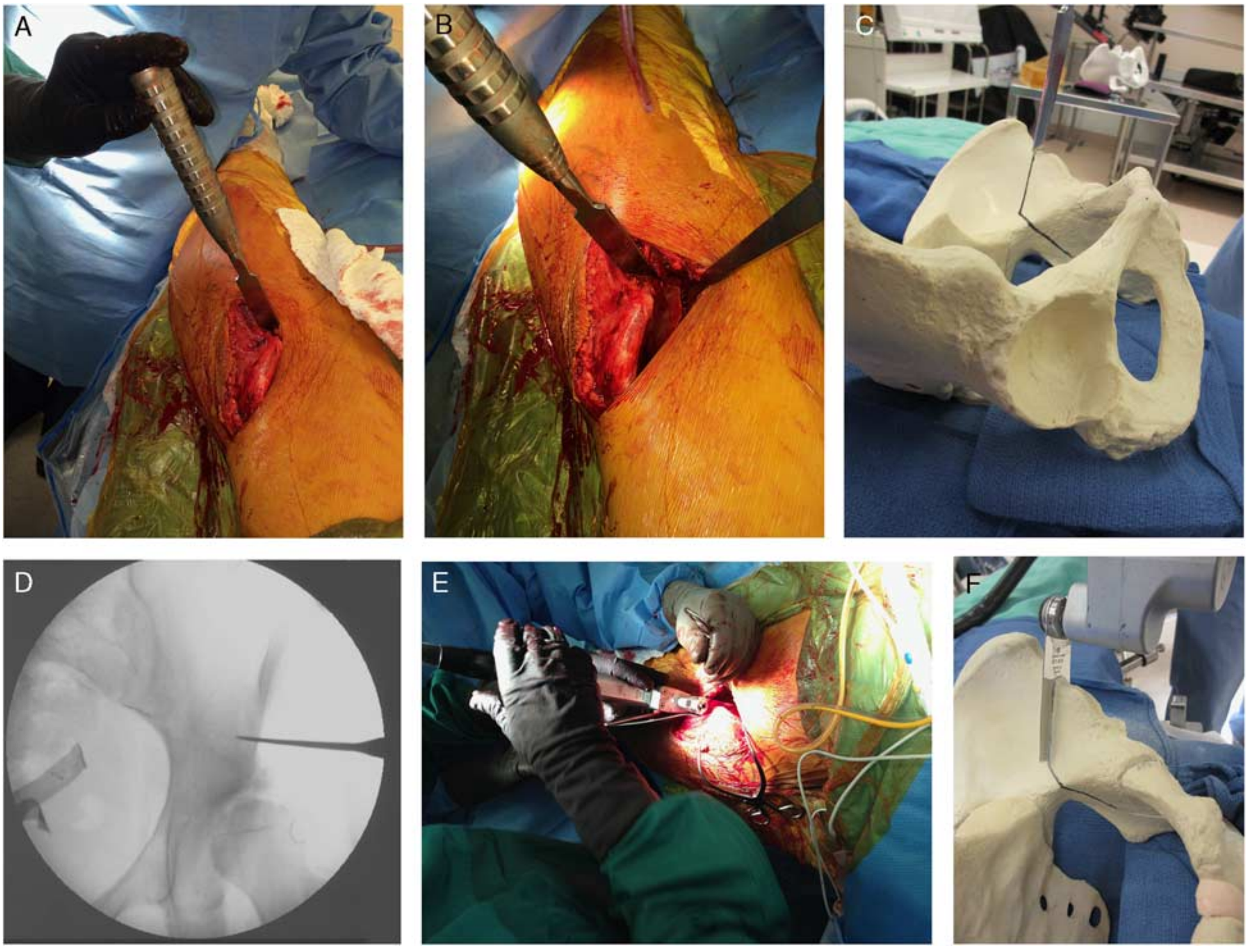

FIGURE 5. A, Intraoperative images (A, B) showing position of osteotome ~20 mm proximal to the joint in the interspinous notch. Corresponding bone model and fluoroscopic image shown (C, D). The cut is completed with an oscillating saw (E, F).

STRUCTURE AT RISK = SCIATIC NERVE

Osteotomy #3—Superior Pubic Ramus Osteotomy

The hip is flexed 45 degrees. An Eve retractor is placed in the internal iliac fossa with its tip on the quadrilateral surface. The periosteum along the pelvic brim and quadrilateral surface is elevated using a Cobb or angled elevator. The Eve retractor is now placed in this "pocket" created by the elevated periosteum and the tip should be near the ischial spine. It is not desirable to place the tip of the retractor in the greater sciatic notch.

Next, place a small Hohman retractor with the tip just lateral to the origin of the superior pubic ramus and distal to the anterior acetabulum (Fig. 4A). Use sharp dissection to cut the periosteum along the pectineal eminence and elevate the periosteum to expose the bone. Then, detach the iliopectineal fascia from the pelvic brim to a point distal to the pectineal eminence. The periosteal elevator should be used along the proximal quadrilateral surface distally enough to visualize/palpate the origin of the obturator canal. The pubic osteotomy is performed using a 20-mm straight osteotome (Fig. 4B). The goal of the pubic cut is to osteotomize the thickest portion of the pubic bone just distal to the anterior acetabulum (Figs. 4C, D). The thicker portion of the pubic bone increases the surface area of the osteotomy for bone healing. The tip of the osteotome is perpendicular to the pelvic brim and directed posterior and distal. It is helpful for the medial tip of the osteotome to extend medially over the pelvic brim. As the osteotome is driven into the pubis, it is useful to place a finger medial to the pelvic brim to palpate depth of insertion of the osteotome. Too deep insertion of the osteotome should be avoided to prevent injury to the obturator nerve. This osteotome penetrates ~20 mm. It is then withdrawn, replaced into the same cut, and directed more lateral. After satisfactory penetration, the osteotome is rotated with a Farabeuf clamp to complete the osteotome with an audible crack. In the case of a right hip, the osteotome is rotated clockwise and vice versa for a left hip. The goal of rotation is to not fracture the medial portion of the pubic cut on the acetabular fragment. This area should be left intact as it may be necessary to place a pointed clamp in this osteotomy to aid in rotation of the acetabular fragment. Fluoroscopic image of this osteotomy is shown in Figure 4E.

STRUCTURE AT RISK = OBTURATOR NERVE

Osteotomy #4—False Profile (Supra-acetabular) Osteotomy

Before this osteotomy, the surgeon should detach the tensor origin from the interspinous notch to gain access to the

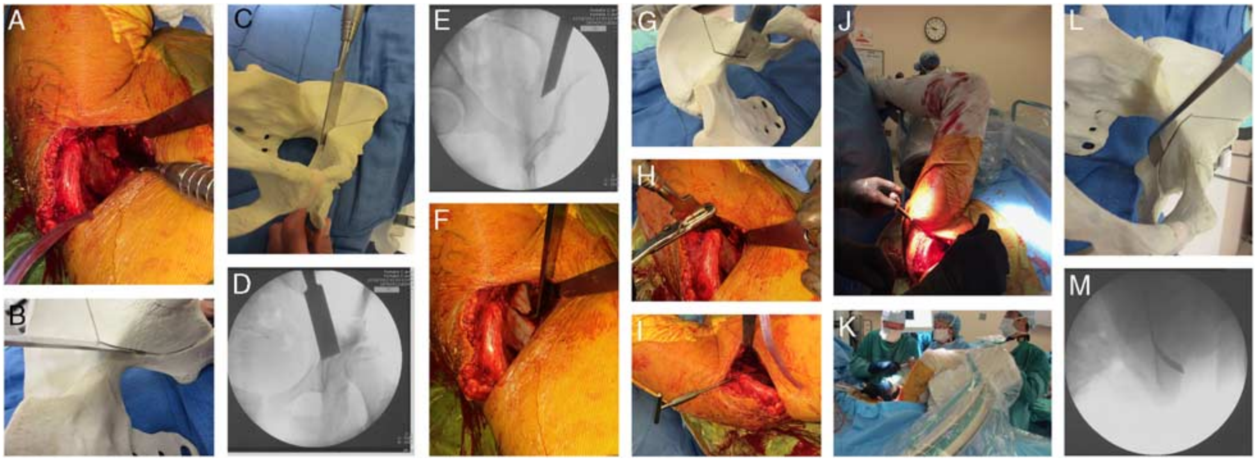

FIGURE 6. A to E, Intraoperative image showing exposure and initiation of the posterior column cut with Eve retractor on the quadrilateral surface and osteotome at the pelvic brim. Corresponding bone model (B, C) and fluoroscopic images (D, E); note the osteotome is anterior and parallel to the sciatic notch. F and G, Intraoperative (F) and bone model (G) image of curved osteotome at proximal edge of the pelvic brim cut with tip angled posterior and lateral; the purpose of this osteotomy is to cut the outer cortex. H, Intraoperative image showing 30-mm broad osteotome with Farabeuf clamp in place used to mobilize the iliac osteotomy. I, Intraoperative image showing Schanz screw placed lateral to AIIS and parallel to the iliac cut. J, Intraoperative image with hip and knee flexed to 90 with tibia in a horizontal position. K, Intraoperative image showing position of the leg and fluoroscope for completion of posterior column cut. L and M, Bone model (L) and fluoroscopic image (M) showing osteotome position with the tip along the quadrilateral surface just distal to the posterior rim of the acetabulum.

outer aspect of the ilium. An Eve retractor is placed lateral to the ilium through the interspinous notch just distal to the ASIS and proximal to the AIIS. The tip of a Hohman is placed over the pelvic brim.

A 20-mm straight osteotome is placed along the anterior border of the innominate border at the appropriate level of the iliac osteotomy. Check the preoperative AP pelvis and false profile view to determine the correct starting position. The osteotomy should begin ~20 mm proximal to the joint (Fig. 5A). It is typically made in the interspinous notch but will vary in position from the upper border of the AIIS to the inferior border of the ASIS. Occasionally, a small segment of the ASIS is trimmed with this osteotomy or an osteotomy starting just distal to the ASIS may be directed slightly proximal to obtain the proper distance from the acetabulum. The 20-mm osteotome is used to mark the anterior border of the iliac crest and should be confirmed with the fluoroscope (Figs. 5B–D). The osteotomy is performed with an oscillating power saw (Figs. 5E, F) in the transverse plane of the body and normally directed anterior to posterior. This iliac osteotomy will cut the inner and outer cortices of the ilium and will stop ~10 mm short of the pelvic brim. The cut parallel to the greater sciatic notch is now performed.

Osteotomy #5—Posterior Column Osteotomy

The hip is flexed ~45 degrees. Place the tip of an Eve retractor on the quadrilateral surface into the previously created periosteal pocket. The tip of the osteotome is placed at the posterior extent of the iliac osteotomy in the internal iliac fossa. This osteotome will be directed in a distal and posterior direction ~40 degrees from the horizontal. It should cross the pelvic brim and be directed parallel to the sciatic notch and 20 mm anterior to the posterior border (Figs. 6A–D). This osteotome should cut the quadrilateral surface and underlying bone in a distal direction to a point anterior to the ischial spine. It is necessary to insert this osteotome 4 to 5 cm posterior and distal to the pelvic brim to reach the level of the ischial spine (Fig. 6B). An iliac oblique view can be used to confirm the osteotomy is parallel and anterior to the notch and heading toward osteotomy #1 (ischial osteotomy) (Fig. 6E). Withdraw

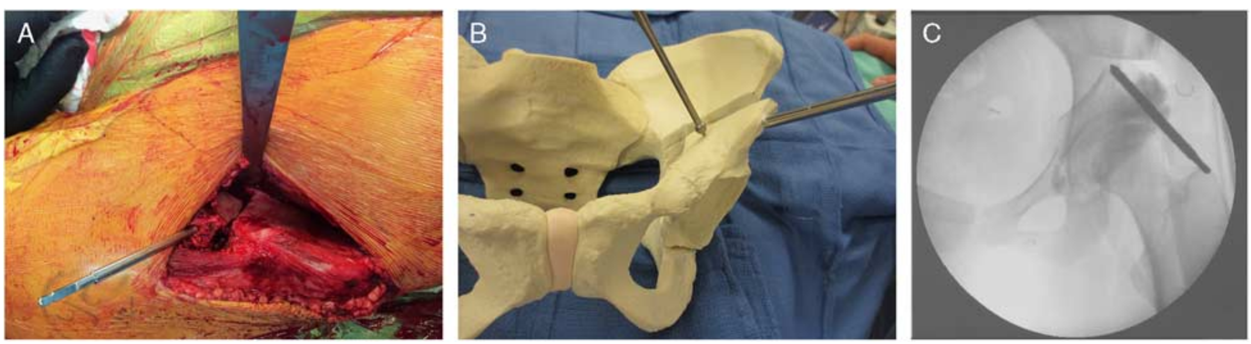

FIGURE 7. Intraoperative image (A) of mobilized periacetabular osteotomy. Corresponding bone model (B) and fluoroscopic image (C) demonstrate the use of the ball-spike pusher to mobilize the osteotomy to provide anterior and lateral femoral head coverage.

the osteotome and place the tip of an angled osteotome into the proximal portion of the last cut and direct the tip in a lateral and slightly posterior direction (Figs. 6F, G). Extend the hip and strike the osteotome firmly; this should complete the cut to the outer aspect of the innominate bone. The hip is extended to relax the sciatic nerve and allow it to fall posteriorly away from the greater sciatic notch. Place a 30 mm or wider broad osteotome into the iliac cut. Torque the osteotome with a Farabeuf clamp to mobilize the iliac osteotomy (Fig. 6H).

Next, a 4.5-mm drill bit is used just lateral to the AIIS and directed parallel to the iliac cut and iliac fossa. Then, a 6.0-mm Schanz screw is placed into the hole and inserted as far as possible but short of the osteotomy (Fig. 6I). Pull the Schanz screw in an anterior and lateral direction with the T-handle attached to the Schanz screw and place a spreader into the most proximal portion of the osteotomy that crossed the pelvic brim. It is possible that the entire PAO may be mobile at this point and easy to position. If the osteotomy still has a "springy" feel and resists rotation, continue on to the next acetabular cut.

Flex the hip and knee 90 degrees with the tibia in a horizontal position (Fig. 6J). Place the tip of an Eve retractor on the quadrilateral surface and the angled osteotome with the tip on the quadrilateral surface (Figs. 6K, L). The handle of the osteotome should be directed in a posterior-inferior direction with the handle ~40 degrees to the horizontal. The image intensifier is placed in a 50-degree cephalad position and should show the tip of the osteotome parallel to the direction of the image view; the osteotome tip is resting along the quadrilateral surface just distal to the posterior rim of the acetabulum (Fig. 6L). Push the handle of the osteotome in a medial direction and strike the osteotome with a mallet. It is necessary to take multiple views with the image intensifier to watch the course of the tip of the osteotome. This osteotome should traverse just distal to the posterior rim of the acetabulum, but proximal to the ischium. It should enter the subacetabular groove. If the osteotome passes too distal into the ischium, it will enter the origin of the hamstring and make rotation of the osteotomy difficult. The assistant should hold the leg during this procedure. It may be necessary to slightly internally rotate the hip in order for the image intensifier not to run into the foot/leg. The assistant should also place a hand on the T-handle of the Schanz screw and pull gently in a lateral direction to aid with the cutting of the ischial osteotomy. The tip of the osteotome should penetrate the quadrilateral surface just anterior to the osteotomy paralleling the greater sciatic notch (Fig. 6M). If necessary, pass this osteotom tip closer to the obturator foramen and more anterior to the initial point of insertion. The acetabular osteotomy should now be mobile and ready for positioning.

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Manipulation and Fixation

First, mobilize the osteotomy by pulling anterior on the T-handle of the Schanz screw and then in a distal and lateral direction (Fig. 7A). Place the tip of a ball-spike against the acetabular osteotomy near the pelvic brim and push the corner of the osteotomy in a posterior and lateral direction to create the lateral and anterior rotation that is necessary (Fig. 7B). If the osteotomy is resistant to positioning, it may be necessary to place a lamina spreader into the osteotomy near the pelvic brim to distract the medial cortex of the ilium. Then, place the tip of the spreader deeper into the osteotomy so that the tips contact cortex of the retroacetabular surface and spread forcefully to distract the osteotomy on the outer aspect of the innominate bone and thereby, mobilize the soft tissues from this area.

As the acetabular fragment rotates, the pubic portion of the acetabular segment should displace in a medial and slightly proximal direction (Fig. 7C). The entire proximal iliac segment of the osteotomy will displace in a lateral direction though the two surfaces in the internal iliac fossa should remain roughly parallel. The AIIS will displace in a distal direction. The main problem positioning the acetabulum is that the acetabular fragment can be retroverted or levered into a more lateral position. Usually, the cause of this is an incomplete cut of the ischium. Another strategy for positioning a resistant acetabular fragment is to place the point of a Weber clamp into the pubic osteotomy and the other point in the iliac osteotomy. Torque this clamp as the fragment is manipulated with the Schanz screw. Sometimes, it is necessary to place the tip of a 20-mm osteotome into the pubic osteotomy and torque the osteotome

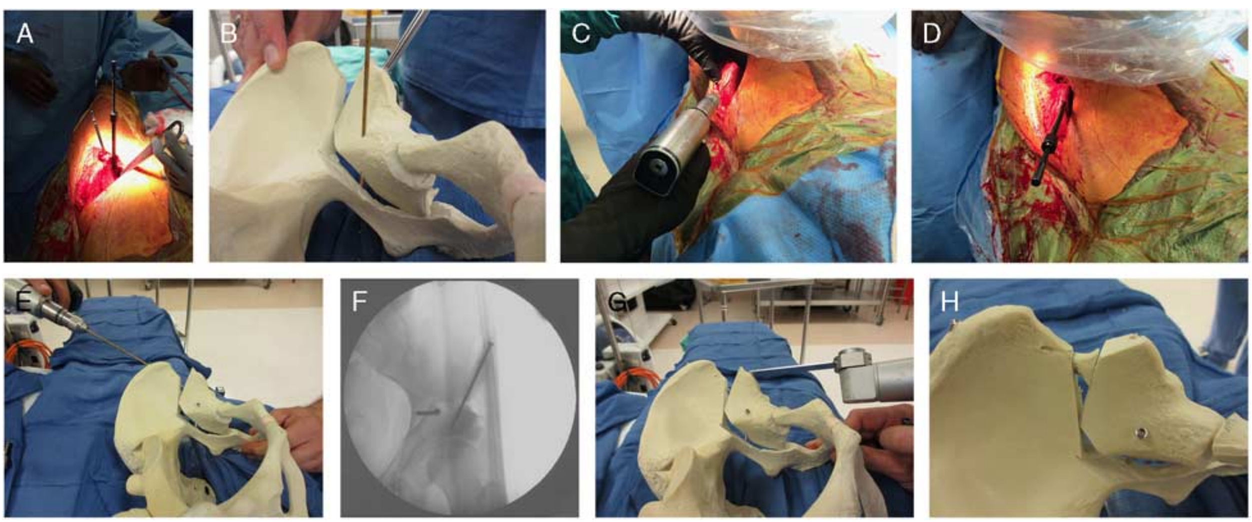

FIGURE 8. A and B, Intraoperative image (A) and bone model (B) showing initial 3.5-mm posterior column fixation screw. C to F, Intraoperative images (C, D) and bone model (E) showing the second 3.5-mm fixation screw in the anterior column. Final fluoroscopic image is shown in (F). G and H, Bone model images showing spike of bone that is used as a graft.

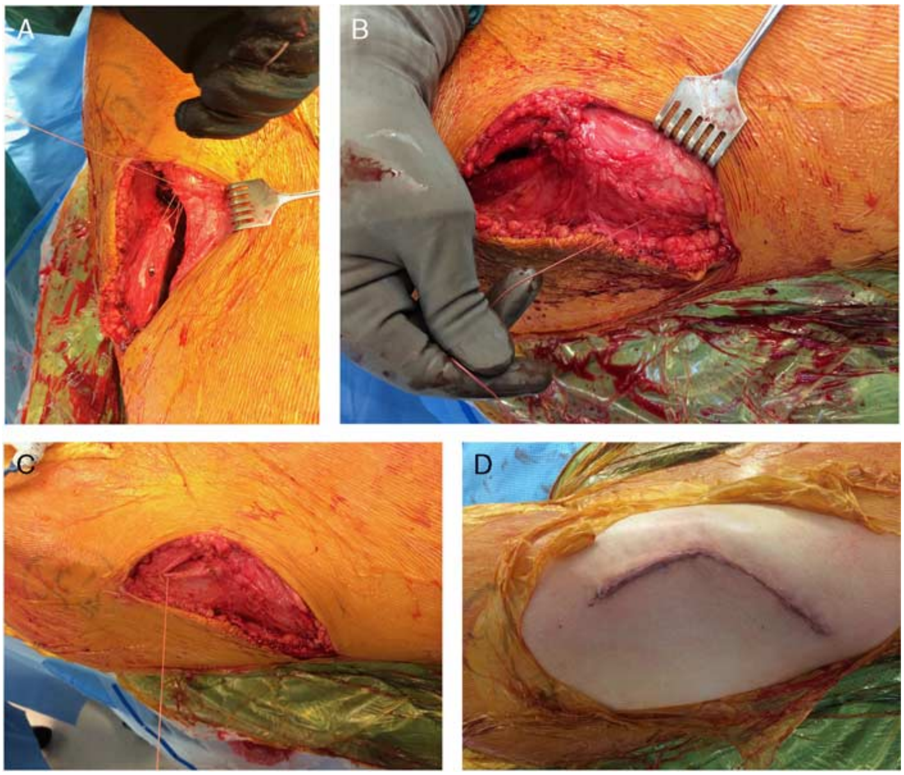

FIGURE 9. A, Intraoperative images showing the reattachment of the sartorius/inguinal ligament to its origin (A), closure of the external abdominal oblique aponeurosis (B), closure of the tensor fascia (C), and skin closure (D).

to aid in displacing the pubis. For a right hip, a clockwise torque is indicated and vice versa for a left hip. After positioning the osteotomy, the osteotomy will typically be relatively stable in the displaced position and does not need an active force to maintain its position. Check the position with the image intensifier. The image intensifier is centered over the acetabulum and angled 5 to 10 degrees using the orbital control to simulate the x-rays beam direction of an AP pelvis. Use the rotation function of the image intensifier to place the hip in a more vertical position to best assess the acetabulum. The ilioischial line is used as a guide for placing the hip in a vertical position. Typically, dysplasic hips have a more vertical ilioischial line and sometimes even a slightly abducted ilioischial line. The ideal position for the osteotomy is with the roof of the acetabulum centered over the femoral head (Fig. 7C). The roof should be horizontal. The pubis will be seen to be displaced in a medial direction. The anteversion of the acetabulum should demonstrate satisfactory anterior rim coverage of the femoral head but more posterior rim coverage. Another check for anteversion is that the anterior and posterior rim images converge at the most lateral portion of the acetabular roof. The posterior wall line should cover ½ of the head or more and the anterior wall line should cover about ¼ of the head. There should be no crossover sign (anterior and posterior wall should not crossover indicating retroversion). It is typically necessary to make small adjustments until the coverage is ideal. There needs to be adequate coverage but also avoid overcoverage—which would mean an acetabular roof with reverse obliquity which could lead to a protrusio-type arthritis. Much of the correction of the acetabulum can be done with the Schanz screw. Place a finger along the posterosuperior corner of the acetabular fragment. Lever the Schanz screw in a distal or proximal direction as necessary. With distal advancement of the T-handle, anterior and lateral coverage will increase and with proximal displacement, the reverse is true. The medial iliac surface of the acetabular fragment should be lateral to the surface of the internal iliac fossa and the AIIS distal to the ASIS and not lateral to the ASIS. If the position is satisfactory, perform initial fixation with a 3.5-mm screw which goes from the pelvic brim of the acetabular fragment and directed in a posterior and slightly proximal direction and exits the greater sciatic notch (Figs. 8A, B). Use the oscillating drill when drilling through the notch to avoid injury to the structures. Place a screw of the appropriate length. The length of the screw should be checked with a depth gauge but also checked with the image intensifier to ensure it is not protruding into the notchmore than a few millimeters.

At this point, remove the Schanz screw and check the position of the acetabular fragment with the image intensifier. If it appears satisfactory, a second screw is placed from the iliac crest between the 2 tables; this screw crosses the iliac portion of the osteotomy and enters the anterior portion of the acetabular fragment (Figs. 8C–E). This screw typically enters the AIIS or anterior to the acetabulum. On the AP view, the screw may appear to cross the subchondral bone of the acetabulum; however, a cephalad projection of the image intensifier will typically show the screw is extra-articular (Fig. 8F). There may be a spike of bone just proximal to the AIIS. If this is present, trim this spike of bone and place into the iliac osteotomy as a graft (Figs. 8G, H). Most PAOs do not require an intra-articular exposure. Indications for intra-articular exposure may be lack of offset of the proximal femur which is identified on the preoperative x-rays. Another indication for intra-articular exposure is a labral tear. It is the senior author's

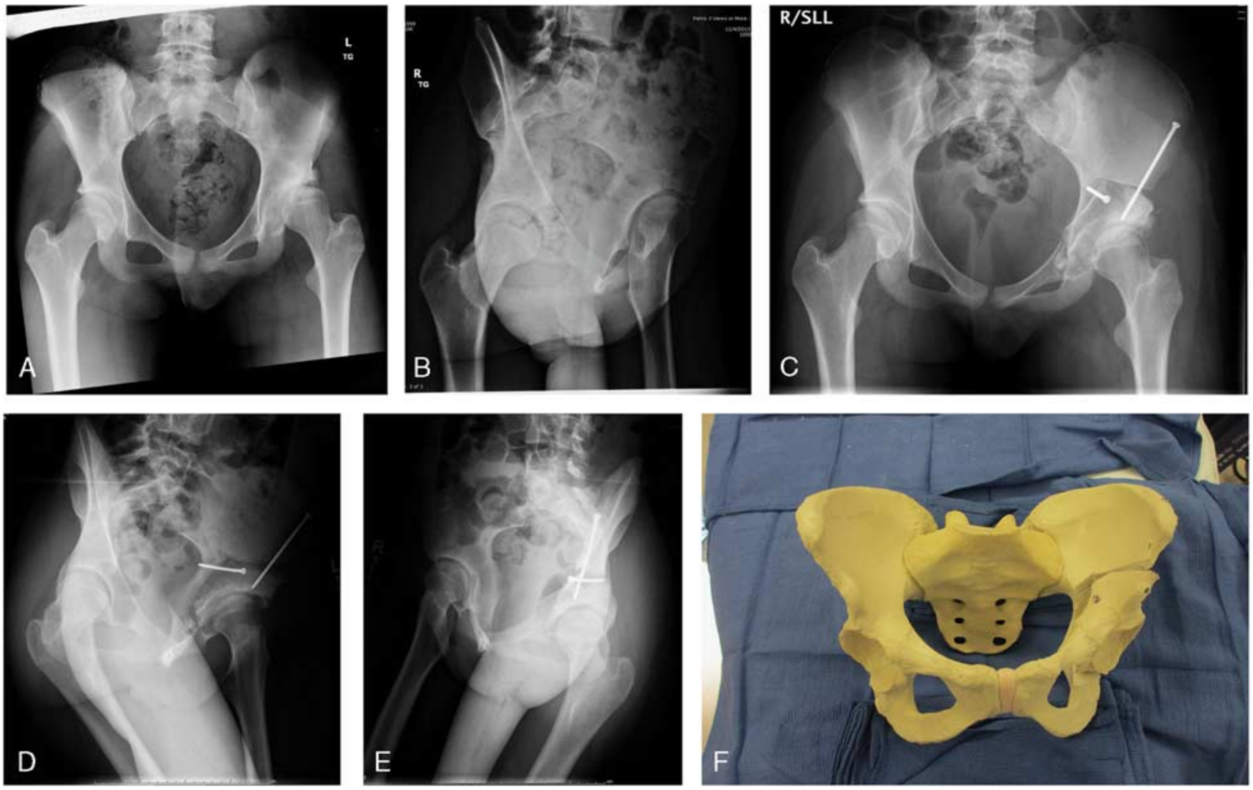

FIGURE 10. Preoperative (A, B) and postoperative (C–E) x-ray images showing the periacetabular osteotomy. Note the improved anterior and lateral femoral head coverage on the postoperative x-rays as well as a horizontal radiographic roof. Final bone model image after periacetabular osteotomy is shown in (F).

finding however that preoperative labral tears, if ignored, may heal on their own or become asymptomatic because of the redistribution of force away from the labrum.

The incision is irrigated with antibiotic solution. A hemovac is placed if necessary though most often is not. Closure of the incision begins with reattachment of the sartorius origin/inguinal ligament to the ASIS. Drill a 2.5-mm hole transversely through the anterior portion of the ASIS. Reattach the sartorius/inguinal ligament origin with a suture that is placed through the soft tissue and drill hole twice and is tied over the soft tissue. (Fig. 9A). Continue this suture as a running suture in a proximal direction to suture the abdominal muscles over the anterior portion of the iliac crest to the fascia lata origin along the lateral edge of the iliac crest (Fig. 9B). Close the fascia lata with a running suture over the anterior-lateral thigh (Fig. 9C) and continue this running suture over the anterior portion of the crest to reinforce the previous suture line. Close the subcutaneous tissue in 1 layer and then place a subcuticular stitch and Dermabond to complete the incision closure (Fig. 9D). Apply a sterile dressing. Before wound closure, the position of the osteotomy and the fixation is confirmed with an AP view of the hip with the image intensifier tilted 5 to 10 degrees away from the hip (Fig. 8F). Also a 50-degree iliac oblique view is obtained to confirm that there is satisfactory anterior coverage and the osteotomy is properly performed and that the screw directed toward the greater sciatic notch is of proper length. Preoperative and postoperative radiographs are shown in Figures 10A–E; bone model is shown in Figure 10F. The anterior and lateral coverage of the acetabulum has improved after the PAO.

DISCUSSION

Although the author's technique adheres to the fundamental principles of the Bernese osteotomy, we will briefly mention how the described technique differs from other current PAO techniques.

Clohisy et al[13] performs the surgery in a similar fashion. Whereas Clohisy osteotomizes the ASIS, we detach the sartorious/inguinal ligament complex. Further, we do not detach the direct head of the rectus femoris from the AIIS. We currently utilize two 3.5-mm screws for fixation, whereas Clohisy utilizes three to four 4.5-mm screws. Ganz and Clohisy perform an arthrotomy with possible osteoplasty of the femoral neck and labral repair if necessary. The authors do not perform an arthrotomy. The authors have found that once mechanical correction of the acetabulum is achieved, this unloads the labral avulsion and possible bony attachment and allows it to heal.

Millis and Murphy perform the PAO through the direct anterior approach which, as described in their article, involves the lateral and middle window of the ilioinguinal approach. The iliopectineal fascia is left intact and the ASIS is osteotomized. They have demonstrated excellent access to the pelvis for the osteotomies. As mentioned before, Ganz described 2 cases of femoral nerve palsy associated with this approach, whereas the originator of the approach did not observe this complication in his cohort.

The authors would like to again highlight 2 of the most difficult portions of the procedure. First, liberating the acetabulum for reorientation can be challenging as it can be hinged at the junction of the first and last osteotomy (ischial hinging). Second, correction is also difficult as the surgeon needs to understand the individual patient's deformity and precisely correct it. Undercorrection or overcorrection has clinical consequences. Approximately 15% of dysplastic acetabuli are retroverted and will demonstrate a "crossover sign" and/or "posterior wall sign." These cases need to be identified as mentioned before, as typical anterolateral correction will worsen the acetabular position and cause impingement.

CONCLUSIONS

Many surgeons have demonstrated that the PAO is an effective surgery to reduce pain and maintain function in a young, active individual with acetabular dysplasia. Indications for the PAO are still not completely understood and can add to the complexity of the procedure. Close attention should be paid to the complete liberation of the acetabulum with optimal positioning. The authors hope that this step-by-step technique description will help other surgeons improve their understanding of the PAO, decrease intraoperative time, and reduce potential complications of this technically challenging procedure.

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