Results of periacetabular osteotomy in adolescent and young adult hip dysplasia

Mohamed Adel Abdelhamid, Eissa Ragheb, Mahmoud Seddik

Background Dysplasia of the hip is one of the most common causes of secondary osteoarthritis because of its associated structural instability. The Bernese periacetabular osteotomy (PAO) now is the preferred and the gold standard procedure for the treatment of symptomatic acetabular dysplasia.

Objective The primary aim of our study was to evaluate the results of PAO in the treatment of adolescent and young adult patients with symptomatic hip dysplasia.

Patients and methods This prospective case series' study included 22 patients (26 hips, 13 left hips, 13 right hips) with hip dysplasia after surgical reorientation of the acetabulum by PAO procedure. This study included three male patients and 19 female patients. The mean age of our patients was 23 years (13–40 years). The mean follow-up period was 15 months (6–24 months). Twenty-one hips had undergone isolated PAO, while five hips had undergone combined surgery with the PAO at the same time (three hips had proximal femoral varus osteotomy and two hips had arthrotomy and osteochondroplasty).

Results Twenty-five hips had good clinical and radiographic outcomes with respect to hip function and radiographic parameters. One patient developed avascular necrosis (AVN) of the femoral head 6 months after PAO and was treated by total hip replacement 1 year after PAO. The mean lateral central edge angle was 10.57°±11.61° preoperatively and was corrected to a mean value of 31.96°±4.42° with a mean correction of 21.38°. The mean postoperative acetabular index was 7.57°±1.81°, with a mean correction of 15.34°. In our series, the mean postoperative Harris hip score was 91.36±4.14, and the mean improvement was 29.08.

Conclusion The PAO is an effective and valuable method for preservation of the natural hip joint and should be learned in a specialized center before using it in clinical practice.

Sci J Al-Azhar Med Fac, Girls 2019 3:227–236

The Scientific Journal of Al-Azhar Medical Faculty, Girls
2019 3:227–236

Keywords: acetabular dysplasia, adolescent and young adult hip, periacetabular osteotomy

Orthopedic Department, Faculty of Medicine, Al-azhar University, Cairo, Egypt

Correspondence to Mohamed Adel Abdelhamid, MSc Orthopedic Surgery, Orthopedic department, Faculty of Medicine, Al-azhar University, 11675, Cairo, Egypt. Mob: 00201004310863; fax: +2 25128927; e-mail: mohamedadel@azhar.edu.eg

Received 1 February 2019 **Accepted** 1 February 2019

Introduction

Hip dysplasia is a pathological entity that reflects a disturbed relation between the acetabulum and the femoral head and encompasses a spectrum of abnormal features related to both morphology and instability [1].

Hip dysplasia is a treatable disease when it presents early in life, but, if neglected, it leads to chronic disability. It can present in infancy, which is termed developmental dysplasia of the hip, or only arise later in adolescence or young adulthood, which is referred to as acetabular dysplasia [2].

Hip dysplasia is characterized by a shallow acetabulum that does not cover the femoral head sufficiently. This anatomical abnormality produces dynamic instability of the hip and increased mechanical stress or overload at the acetabular rim, leading to hypertrophy, tearing of the fibrocartilaginous acetabular labrum and rapid degeneration of the hyaline articular cartilage. If left untreated, it will cause pain, decreased function, and eventually result in hip osteoarthritis [2].

The incidence of hip dysplasia is reported to range from 1.7 to 20% in the general population, with most studies finding the incidence between 3 and 5% [3]. Female individuals have a 2–4 times increased the relative risk of hip dysplasia. However, male individuals with hip dysplasia tend to have a higher incidence of concomitant hip deformities such as acetabular retroversion that may need additional consideration during hip dysplasia surgery to prevent iatrogenic creation of femoroacetabular impingement [4]. Female sex, primiparity, breech position, and family history are known risk factors for hip dysplasia [5]. A family history of hip dysplasia also increases the risk of having hip dysplasia by 1.4–1.7%. More than 50% of patients with hip dysplasia have a positive family history of hip disease [6].

Hip dysplasia is the major cause of early-onset hip osteoarthritis before the age of 60 years. In a recent study of patients under 50 years of age undergoing total hip replacement for osteoarthritis, 48.4% were found to have hip dysplasia as the etiology of hip osteoarthritis [7].

The most common presenting symptoms of acetabular dysplasia in the adolescent and young adult are the insidious onset of activity-related groin pain and/or lateral hip pain. Diagnosis is made through physical examination and radiographic findings. Up to 48% will have a limp during gait, and 97% have a positive anterior impingement test [8].

Anteroposterior pelvic radiographs in acetabular dysplasia show a lateral central edge angle (LCEA) less than 25°, an anterior central edge angle (ACEA) less than 20°, and a more obliquely oriented sourcil of the acetabulum, with an elevated acetabular index (Tönnis angle) greater than 10° [9].

The end result of hip dysplasia whether from residual childhood developmental dysplasia of the hip or adolescent onset acetabular dysplasia is hip instability and increased hip contact stresses that lead to early joint destruction. Therefore, the treatment of acetabular dysplasia in the adolescent and the young adult patient is aimed towards reconstructing normal mechanical forces within the dysplastic hip [2].

Various corrective hip osteotomy techniques have been proposed for the treatment of symptomatic dysplasia These techniques include a simple innominate osteotomy described by Salter [10], but it is beneficial in children. LeCoeur [11] published a technique for triple osteotomy of the pelvis. His method divides the pubis and the ischium close to the symphysis pubis; hence, it is not strictly 'periacetabular'. In addition, improvements in coverage with this osteotomy are limited by the size of the fragment, the attached muscles and the ligamentous connections to the sacrum. Tonnis [12] described another technique for reorientation of the acetabulum through the juxta-articular triple osteotomy, which gives more correction but requires special effort for stabilization. Aspherical or rotational osteotomy have been described by Wagner in Europe and by Ninomiya and Tagawa [13] in Japan. These osteotomies provide good lateral and anterior coverage, but not optimal in regard to the correction of anteversion and mediolateral displacement.

Given the listed limitations and difficulties of the previous techniques, professor Ganz *et al.* [14] developed a new periacetabular osteotomy (PAO) in 1983 on the basis of a series of osteotomies on bone models in addition to operations on cadaveric specimens.

The PAO has several advantages that are summarized as follows: (a) one approach is used; (b) a large correction can be obtained in all directions; (c) blood supply to the acetabulum is preserved; (d) the posterior column of the hemipelvis remains mechanically intact, allowing immediate crutch walking with minimal internal fixation; and (e) the shape of the true pelvis is unchanged, permitting normal child delivery, which is an important factor, because many patients with hip dysplasia are young women [15].

The PAO allows complete reorientation of the acetabulum to provide more lateral and anterior femoral head coverage by the acetabulum, reduce hip subluxation and medialize the hip joint center, redistribute the high-contact stresses from the acetabular rim to the entire articular surface and transform the dysplastic hip's shear stresses across the articular cartilage into compressive stresses that are more favorable for cartilage longevity [2].

Materials and methods

From July 2016 to December 2018 a prospective case series' study was undertaken at Al-Azhar University Hospital (Al-Hussein University Hospital), Cairo, Egypt, Vall De Hebron, University Hospitals, Barcelona, Spain, and Gruca Orthopaedic Teaching Hospital, Otwock, Poland, on patients with symptomatic hip dysplasia treated with PAO. Patients with established osteoarthritis Tonnis grade 3, those with complete dislocation with secondary acetabulum and patient who had an incongruent hip joint on 30° functional abduction view were excluded from our study. This prospective case series study included 22 patients (26 hips, nine left hips, nine right hips and four bilateral) with symptomatic hip dysplasia after treatment by PAO. This study included 19 female individuals and three male individuals. The mean age of our patients was 23 years (13–40 years). The mean duration of symptoms before the operation was 2.34±0.68 years. The mean follow-up period was 15 months (6–24 months). The mean preoperative LCEA was 10.57°±11.61°. The mean preoperative acetabular index or Tonnis roof angle (acetabular index) was 22.92°±6.75°. The Harris hip score (HHS) was evaluated for all patients preoperatively, and its mean was 62.5°±8.20°.

Surgical technique

Preoperative requisites

The following were required before the start of surgery:

A radiolucent operating table, imaging (C-arm), oscillating power saw and bone wax.

Figure 1

Periacetabular osteotomy instrumentation set.

Instrumentation set (Fig. 1) including the following (and they are):

(1) A 30° angled notched osteotome, curved double-tip osteotome.
(2) Curved and straight osteotomes.
(3) Curved blunt and pointed Homan retractors.
(4) A sterile leg holder, Schanz pins, toothed lamina spreaders, 2.5 mm Kirschner wires, 3.5 mm screws ranging from 40 to 120 mm in length and appropriate drill.

The same operative technique was used by all surgeons in the three orthopaedic centers included in this study, and all PAOs were performed under spinal – epidural anesthesia. The patient was positioned supine on a radiolucent table, and a modified Smith–Petersen approach was used. All patients underwent a PAO under fluoroscopic guidance, as described by Ganz *et al.* [14].

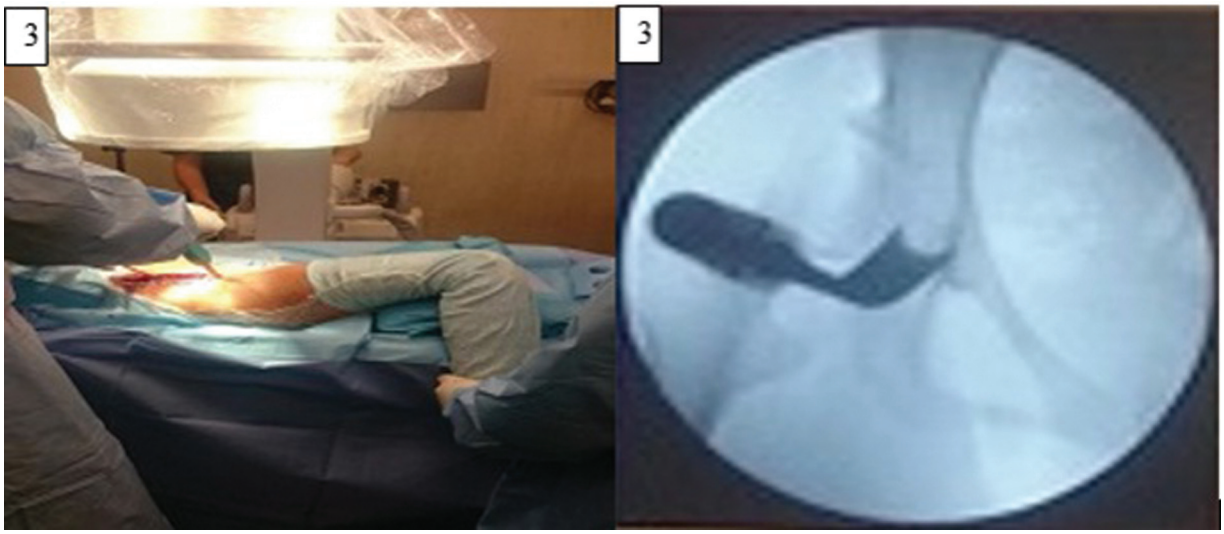
Osteotomies were performed consequently: first ischial osteotomy was performed blind under fluoroscopy, followed by second pubic osteotomy, third supra-acetabular osteotomy, and fourth retroacetabular osteotomy and, finally, controlled fracture of the posteroinferior bone bridge was performed to connect the first ischial cut with the retroacetabular cut. The previous steps were carried out in a special position to avoid injury to the neurovascular structure, as described by Kalhor *et al.* [16].

Figure 2

Curved C-shaped incision.

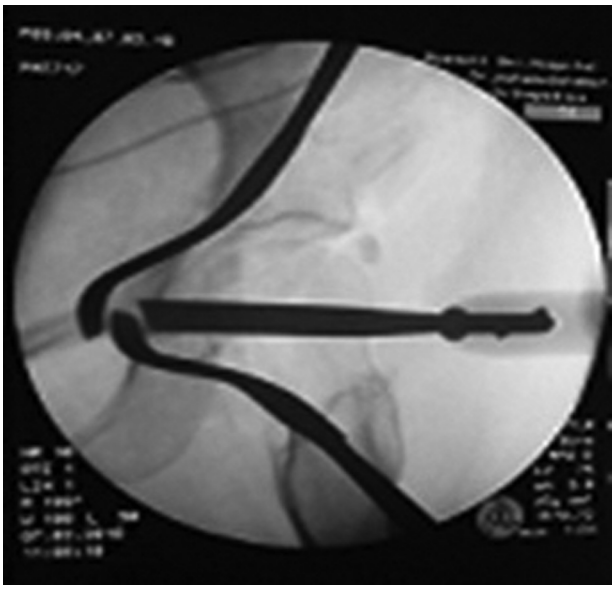
(1) To avoid lateral femoral cutaneous nerve (LFCN) injury, we performed a C-shape incision (Fig. 2), which is similar to the course of the nerve proximal and distal to ASIS, then identification of the fatty tissue between the tensor muscle and Sartorius, which contains the LFCN, was performed along with incision of the fascia over the tensor muscle and mobilization of it laterally. Thereafter, we performed ASIS osteotomy and mobilized the osteotomized fragment with attached Sartorius and the subperiosteally detached iliacus muscle medially
(2) To protect the femoral nerve, we never transect the psoas tendon to enable easier approach to the ischium and pubis, and we insert a sharp Hohmann retractor into the pubic bone under the soft-tissue flap about 2–2.5 cm medial to the iliopectineal eminence with the hip flexed, neutral

Figure 3



Ischial osteotomy: the osteotome is directed to the contralateral shoulder and the hip is extended and abducted and the knee flexed to relax the sciatic nerve.

Figure 4



Pubic osteotomy with 2-curved blunt Hohmann retractors placed subperiosteally to protect the obturator nerve and vessels against the penetrating osteotome.

rotated and adducted to release tension from the medial soft tissue, as this keeps the soft-tissue flap, including the psoas tendon, medially.

(3) To protect the sciatic nerve during performance of the blind ischial cut, we directed the osteotome toward the contralateral shoulder to help avoid lateral perforation, which is controlled by palpating the infracotyloid groove and inferior acetabular lip with the osteotome under fluoroscopy, the hip extended and abducted and the knee flexed to increase sciatic nerve relaxation (Fig. 3).

(4) To protect the obturator nerve, we put two-curved blunt Hohmann retractors subperiosteally around the pubis just medial to the iliopectineal eminence. Thus, the obturator nerve and vessels were protected against the penetrating osteotome during cutting of the contralateral cortex of the pubic bone (Figs 4).

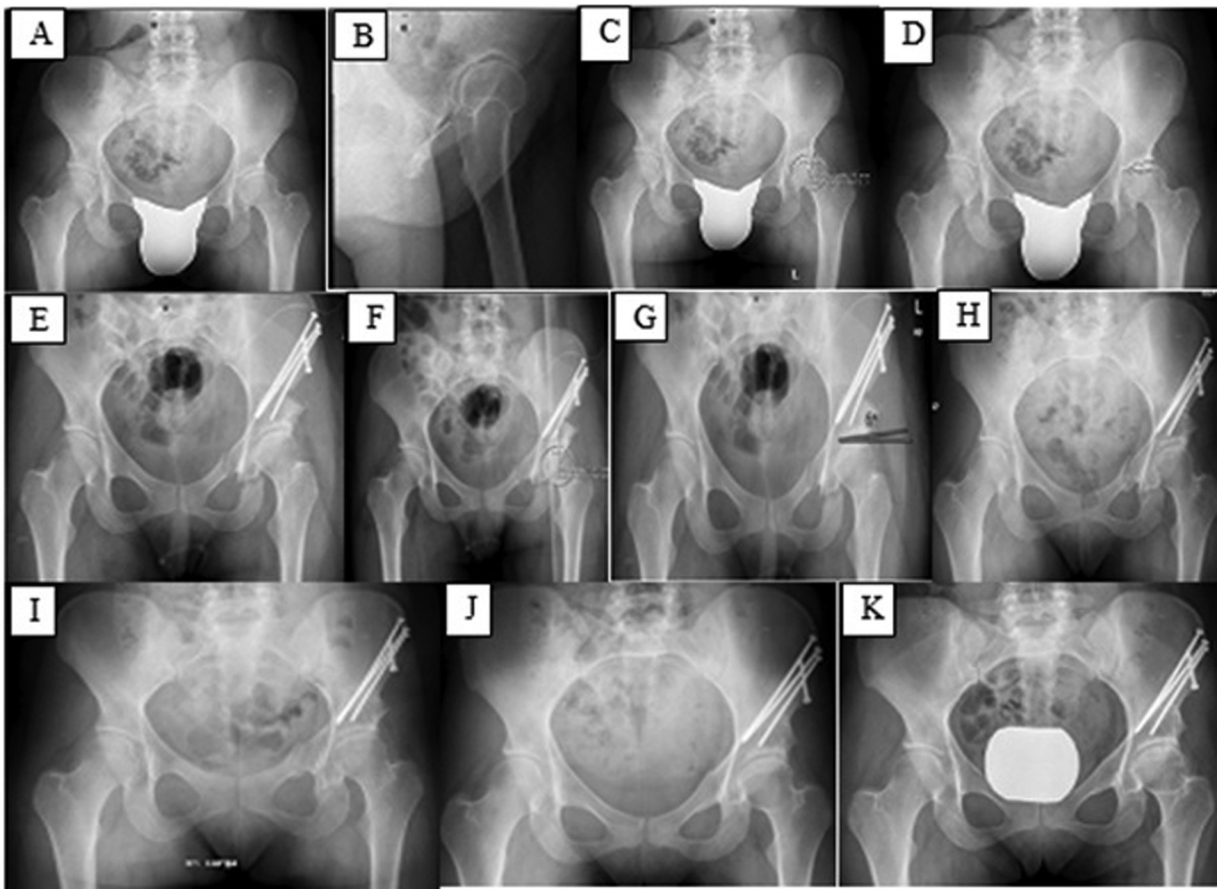
After confirmation that the Acetabular fragment is completely free and mobile. Correction was done under c-arm was done and temporarily fixation was done with kirschner wires to confirm adequate correction of acetabular index, coverage of femoral head, Intact shenton line and correction of retroversion if present.

After satisfaction with correction, the acetabular fragment was fixed with long 3.5 mm cortical screws. A hip arthrotomy and osteochondroplasty was performed if the patient had positive impingement postoperatively. Blood loss, length of time of surgery and intraoperative complications were recorded.

Postoperative outcomes

The patients had intravenous antibiotics for 48 h and received thromboprophylaxis. The patient was mobilized 2 days postoperatively and maintained partial-weight bearing for 6 weeks with crutches. Full-weight bearing was advised after complete healing of the osteotomy site was detected radiologically at follow-up. All postoperative complications were documented.

Figure 5



Radiograph in a 21-year-old woman with left acetabular dysplasia (case number 22): (a) preoperative anteroposterior (AP) pelvis, (b) preoperative false profile view of the left hip, (c) preoperative measurement of lateral central edge angle, (d) preoperative measurement of acetabular index, (e) immediate postoperative AP view, (f) postoperative measurement of lateral central-edge angle, (g) postoperative measurement of acetabular index, (h) 3-month postoperative AP view, (i) 6-month postoperative AP view, (j) 12-month postoperative AP view and (k) 18-month postoperative AP view.

Results

The mean operative time was 173.07±25.38 min. Intraoperative blood loss was estimated and it ranged from 400 to 700 ml with an average of 540 ml; 16 of our patients needed intraoperative or postoperative blood transfusion.

As regards the intraoperative problems, one patient had severe intraoperative bleeding during fixation of the periacetabular fragment, and the bleeding was controlled by compression, injection of a haemostatic agent, blood transfusion and exploration of the site of bleeding by the vascular surgeon. Another patient had a fractured inferior pubic ramus, and it completely healed 6 weeks after the operation.

As regards the combined procedure at the same session with PAO, there were three patients who underwent proximal femoral varus osteotomy for correction of severe coxa valga, which was performed immediately before PAO, and two patients underwent arthrotomy and osteochondroplasty after PAO, because they had positive impingement after fixation of the acetabular fragment.

In this study, the mean postoperative LCEA was 31.96°±4.42° with a mean correction of 21.38° ($P>0.0001$). The mean postoperative acetabular index was 7.57°±1.81°, with a mean correction of 15.34° ($P>0.0001$; Table 1).

As regards postoperative range of motion, the mean postoperative flexion was 116.9°±6.79°, the mean postoperative internal rotation (IR) in 90° flexion was 32.11°±6.50° and the mean postoperative external rotation (ER) in 90° flexion was 30°±6.85°.

As regards postoperative complication, in the majority of cases (73%), no major postoperative complication occurred. Two (8%) patients developed a superficial wound infection. One (4%) case developed postoperative avascular necrosis (AVN), detected 3 months after operation and had total hip replacement 1 year after PAO. Three (3%) cases

Table 1 Comparison of preoperative and postoperative radiological parameters

Angle	Preoperative		Postoperative		Correction mean	*P* value (significance)
	Mean	SD	Mean	SD		
LCEA (25°–39°)	10.57	11.61	31.96	4.42	21.38	<0.0001 (ES)
ACEA (<25°)	11.26	7.88	30.96	3.49	19.69	0.0001 (ES)
AI (0°–13°)	22.92	6.75	7.57	1.81	–15.34	>0.0001 (ES)
EI% (17°–27°)	44.11	19.94	21.61	6.40	–22.50	>0.0001 (ES)
Sharps angle (33°–38°)	52.23	1.50	36.69	5.25	–15.53	>0.0001 (ES)

ACEA, anterior central edge angle; AI, acetabular index; EI, extrusion index; ES, extremely significant; LCEA, lateral central edge angle.

Table 2 Comparison of preoperative and postoperative Harris hip score

Harris hip score	Range	Mean	SD	Improvement mean	*P* value (significance)
Preoperative	38–75	62.5	8.20	29.08	>0.001 (ES)
Postoperative	89–96	91.36	4.14		

ES, extremely significant.

developed immediate postoperative LFCN injury: one of them recovered 8 weeks postoperatively and the remaining two had permanent damage. Four cases required removal of the screws: three of them had them removed 15 months postoperatively, and the remaining one was removed 18 months postoperatively. As regards the mean postoperative HHS in our series, it was 91.36±4.14, and the mean improvement was 29.08 points (Table 2).

Discussion

The PAO has been established as a safe and effective procedure for treating acetabular dysplasia with excellent reported outcomes in established acetabular units performing the procedures [14,17–23].

The operation succeeded to provide 'a biological solution for the mechanical problem' that presents in a dysplastic hip. The main objective of this procedure is to improve joint congruency and increase the contact area at the articular surface, thus decreasing the overall articular overload. This has been shown to stop the process of joint destruction and, sometimes, reverse it [24].

It has also been demonstrated that proper performance of the procedure, individualized to correct the specific deficiency, may result in periarticular bone regeneration and apparent joint space preservation. In practical terms, the enhanced biomechanical function of the hip joint translates into superior radiographic and functional outcome [24].

In this study, we reviewed 26 PAOs performed in 22 patients, 19 female individuals and three male individuals, with a mean age of 23.76 years (range: 13–40 years), with a mean follow-up of 15.5 months (range: 6–24 months); five patients underwent PAO associated with other procedures at the same session, and the remaining underwent only PAO.

The patients in this series presented with varying conditions; however, the majority of surgeries were performed for classical hip dysplasia. The severity of dysplasia ranged from deficits of the anterior acetabular coverage with a stable femoral head to complete loss of the superior acetabular roof and chronic subluxation of the hip.

The clinical outcome in this study showed pain relief and improvement in hip function in the majority of patients at short-term of follow-up. The extent of acetabular correction we achieved by this procedure was assessed by comparing preoperative and postoperative radiographs. Comparing our result with other studies published in the literature about the PAO, Ganz *et al.* [14], Trousdale *et al.* [22], Trumble *et al.* [23], Clohisy *et al.* [17], Clohisy *et al.* [25], Park *et al.* [26], Chen *et al.* [27] and Sierra *et al.* [28] reported a gross match, and there was a satisfactory correlation between it and our result (Table 3).

In this study, the HHS was used for evaluation of functional improvement of the patient after PAO, and this score was mostly used for evaluation of other patients in similar studies. We have reported an average improvement in HHS of 29.08 points from an average of 62.5 points preoperatively to 91.36 points postoperatively. In the study by Trousdale *et al.* [22], the HHS improved from an average of 62 points (range: 33–95 points) preoperatively to an average of 86 points (range: 29–100 points) postoperatively ($P<0.0001$). In the study by Trumble *et al.* [23], the average HHS increased from 65 points preoperatively

Table 3 Surgical techniques and outcomes reported from studies evaluating periacetabular osteotomy

References	Hip/patients	PAO isolated	PAO with other	Clinical outcome score	Number of clinically good or excellent outcomes	Change in hip score points
Ganz *et al*. [14]	75	NA	NA	HHS	NA	NA
Trousdale *et al*. [22]	42/42	32 (76%) hips	10 (24%) hips	HHS	32 (97%) hips	24 (62–86)
Trumble *et al*. [23]	123/115	90 (73%) hips	33 (27%) hips	HHS	102 (83%) hips	24 (64–87)
Clohisy *et al*. [17]	16/13	10 (62%) hips	6 (38%) hips	HHS	14 (88%) hips	17.9 (73.4–91.3)
Clohisy *et al*. [25]	24/20	9 (37%) hips	15 (63%) hips	HHS	19 (79%) hips	22.5 (68.8–91.3)
Park *et al*. [26]	20/19	NA	NA	HHS	NA	59.6–96.4
Chen *et al*. (2013)	41	30	11	HHS	40 hips	63.7–88.4
Sierra *et al*. [28]	MHD: 19SHD: 163	NA	NA	HHS	MHD: 17 (89.5%) hipSHD: 148 (90.8%) hip	(52–92)(66–89)
This study	26/22	21	5	HHS	25	29 (62–91)

HHS, Harris hip score; MHD, mild hip dysplasia; PAO, periacetabular osteotomy; SHD, severe hip dysplasia.

to 89 points at the latest follow-up. In the study by Clohisy *et al*. [17], the average HHS improved from 73.4 points preoperatively to 91.3 points at the time of the latest follow-up. In the study by Clohisy *et al*. [25], the mean HHS increased from 68.8 points preoperatively to 91.3 points at the time of the most recent follow-up ($P<0.0001$). In the study by Park *et al*. [26], the mean HHS improved from 59.6 to 96.4 points. In the study by Chen *et al*. [27], one hip had total hip replacement (THR) at the last follow-up. In the study by Sierra *et al*. [28], the HHS improved significantly in both groups [mild hip dysplasia (MHD): 52–92 and severe hip dysplasia (SHD): 66–89] (Table 3).

In this study, we reported an average improvement of 21.38° (from 10.57° to 31.96°) in the lateral center-edge angle of Wiberg, an average improvement of 19.69° (from 11.26° to 30.96°) in the anterior center-edge angle of Lequesne and an average improvement of 15.34° (from 22.92° to 7.57°) in acetabular roof obliquity. In the study by Ganz *et al*. [14], the corrections were 31° for the vertical center-edge angle of Wiberg and 26° for the corresponding angle of Lequesne. In the study by Trousdale *et al*. [22], there was an average improvement of 28° in the lateral center-edge angle of Wiberg, an average improvement of 26° in the anterior center-edge angle of Lequesne and an average improvement of 20° in acetabular roof obliquity. In the study carried out by Trumble *et al*. [23], there was an average improvement of 23° in the lateral center-edge angle of Wiberg, an average improvement of 25° in the anterior center-edge angle of Lequesne and an average improvement of 17° in acetabular roof obliquity. In the study by Clohisy *et al*. [17], there was an average improvement of 44.6° in the lateral center-edge angle of Wiberg, an average improvement of 51° in the anterior center-edge angle of Lequesne and an average improvement of 25.9° in acetabular roof obliquity. In the study by Clohisy *et al*. [25], there was an average improvement of 27.6° in the lateral center-edge angle of Wiberg, an average improvement of 33.1° in the anterior center-edge angle of Lequesne and an average improvement of 16.5° in acetabular roof obliquity. In the study by Park *et al*. [26], the mean acetabular angle improved from 47.9° to 26.4°. The mean center-edge angle increased from 14.2° to 41°. The acetabular depth increased from 176 to 242.7. The mean femoral head coverage increased from 63.3 to 95.4%. In the study by Chen *et al*. [27], radiographic parameters postoperatively improved into the normal range, with an average improvement of 29.1° in the lateral center-edge angle of Wiberg and an average improvement of 27.4° in the anterior center-edge angle of Lequesne, whereas no progression was found from preoperative Tonnis osteoarthritis score. In the study by Sierra *et al*. [28], there was an average improvement of 31° in MHD, 23° in SHD in the lateral center-edge angle of Wiberg, an average improvement of 42° in MHD, 28° in SHD in the anterior center-edge angle of Lequesne and an average improvement of 5° in MHD, and an improvement of 12° in SHD in acetabular roof obliquity (Table 4).

As regards the incidence of complications, it was low in our study; we reported one patient who had an AVN, three had LFCN injury, two had superficial wound infection, and one had a fracture of the inferior pubic ramus. In the study by Ganz *et al*. [14], the complications included two intra-articular osteotomies, a femoral nerve palsy that resolved, one

Table 4 Radiographic outcomes reported from studies evaluating the periacetabular osteotomy

References	Mean change in acetabular inclination	Mean anterior center-edge angle correction	Mean lateral center-edge angle correction
Ganz *et al*. [14]	NA	26	31
Trousdale *et al*. [22]	20	26	28
Trumble *et al*. [23]	17	25	23
Clohisy *et al*. [17]	25.9	51.0	44.6
Clohisy *et al*. [25]	16.5	33.1	27.6
Park *et al*. [26]	NA	NA	26.4
Chen *et al*. (2013)	NA	27.4	29.1
Sierra *et al*. [28]	MHD: 5SHD: 12	MHD: 42SHD: 28	MHD: 31SHD:23
This study	15.34	19.69	21.38

MHD, mild hip dysplasia, SHD, severe hip dysplasia.

Table 5 Complications reported from studies evaluating the periacetabular osteotomy

References	Major complications	Moderate complications	Minor complications
Ganz *et al*. [14]	2 intra-articular osteotomies1 femoral nerve palsy (resolved)1 nonunion4 ectopic bone formation	13 required screw removal	NA
Trousdale *et al*. [22]	2 (5%) DVT1 (2%) symptomatic heterotopic ossification1 (2%) LFCN dysesthesias	9 (21%) symptomatic hardware	13 (31%) asymptomaticHeterotopic ossification2 (5%) pubic nonunion
Trumble *et al*. [23]	3 (3%) arterial thrombosis2 (2%) DVT2 (2%) wound infections1 (1%) loss of fixation after PFO1 (1%) pubic nonunion and intermittent entrapment of iliopsoas muscle1 (1%) impending iliac nonunion5 (4%) hematomas1 (1%) femoral vein laceration1 (1%) heterotopic ossification (excised)	31 (25%) symptomatic hardware	20 (16%) heterotopic ossification (Brooker I–II, not excised)
Clohisy *et al*. [17]	1 (6%) loss of fixation (required ORIF)	1 (6%) asymptomatic ischial nonunion	2 (12%) pubic nonunions
Clohisy *et al*. [25]	1 (4%) peroneal nerve dysfunction1 (4%) femoral nerve dysfunction1 (4%) symptomatic pubic nonunion	NA	1 (4%) asymptomatic pubic nonunion1 (4%) asymptomatic heterotopic ossification
Park *et al*. [26]	Temporary lateral femoral cutaneous nerve palsy in three cases	NA	Hematoma in two cases, superficial wound infection in one case
Chen *et al*. (2013)	1 THR	NA	NA
Sierra *et al*. [28]	MHD: 2 hips THRSHD: 15 hips THR	NA	NA
This study	1 (4%) AVN3 (11%) cases of LFCN injury	1 (4%) fracture of the inferior pubic ramus	2 (8%) superficial wound infections

AVN, avascular necrosis; DVT, deep venous thrombosis; LFCN, lateral femoral cutaneous nerve; MHD, mild hip dysplasia; NA, not available, ORIF, open reduction internal fixation; PFO, proximal femoral osteotomy; SHD, severe hip dysplasia, THR, total hip replacement.

nonunion, and ectopic bone formation in four patients before the prophylactic use of indomethacin. Thirteen patients required screw removal. In the study by Trousdale *et al*. [22], complications reported were two DVTs, one symptomatic heterotopic ossification, one LFCN dysesthesias (requiring neurolysis), nine symptomatic hardware, 13 asymptomatic heterotopic ossifications, and two pubic nonunions (no surgery). In the study by Trumble *et al*. [23], there were three arterial thromboses, two DVTs, two wound infections (required surgery), one loss of fixation after proximal femoral osteotomy (PFO), one pubic nonunion and intermittent entrapment of iliopsoas muscle, one impending iliac nonunion (bone grafting), five hematomas, one femoral vein laceration, one heterotopic ossification (excised), 31 symptomatic hardware, and 20 heterotopic ossifications (Brooker I–II, not excised). In the study by Clohisy *et al*. [17], there was one loss of fixation [required open reduction internal fixation (ORIF)], one asymptomatic ischial nonunion, and two pubic nonunions. In the study by Clohisy *et al*. [25], there was one peroneal nerve dysfunction, one femoral nerve dysfunction, one symptomatic pubic nonunion, one asymptomatic

pubic nonunion, and one asymptomatic heterotopic ossification. In the study by Park *et al*. [26], there was a hematoma in two cases, temporary lateral femoral cutaneous nerve palsy in three cases, and superficial wound infection in one case. In the study by Chen *et al*. [27], there was one hip that had THR at the last follow-up. In the study by Sierra *et al*. [28], two hips in the MHD group and 15 hips in the SHD group underwent future total hip arthroplasty (THA) (Table 5).

The results of this study showed that the treatment of symptomatic hip dysplasia in adolescent and young adult patients by PAO is an effective way of preservation of the natural hip joint, as it improves the joint function clinically and radiographically, as it relieves the pain, prevents further overload on the labrum, cartilage, and soft tissue, and it helps in delaying or preventing the development of osteoarthritis; moreover, it is being performed safely with effective outcomes in comparison with other institutions.

The strength and limitations

The strength of this study is that we used the same parameters of other institutions performing the PAO for evaluation of the results of our patients postoperatively (LCEA, acetabular index and HHS). Hence, we can easily compare our results on mid-term and long-term follow-up with them.

In contrast, this study has some limitations, like any single-cohort study; there was a lack of comparison or control group in this case series' study. Without a truly randomized long-term study about the results of PAO in hip dysplasia, it would be difficult to compare outcomes of this technique with other various surgical techniques such as triple osteotomy (steel) or a rotational osteotomy.

Another limitation in this study is the lack of long-term follow-up in comparison with other studies. This was due to the late application of this technique in our institution in 2016, while, in other studies, they started very early in 1988 [14], 1995 [22], 1999 [23], and 2005 [17].

Case presentation

Figure 5 including the photos.

Conclusion

The PAO is the recommended way for treatment of symptomatic hip dysplasia in adolescent and young adult patients in our institution, but the patients should have the recommended criteria for PAO to gain a good result and achieve joint improvement after the operation. Moreover, the PAO is a challenging procedure that has a learning curve, and the initial surgical experience can be enhanced by proper mentorship by an experienced surgeon, or by training in a specialized center performing the technique, which will produce overall satisfactory results.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Dezateux C, Rosendahl K. Developmental dysplasia of the hip. *Lancet* 2007; **369**:1541–1552.

2 Pun S. Hip dysplasia in the young adult caused by residual childhood and adolescent-onset dysplasia. *Curr Rev Musculoskelet Med* 2016; **9**:427–434.

3 Engesæter IØ, Laborie LB, Lehmann TG, Fevang JM, Lie SA, Engesæter LB, Rosendahl K. Prevalence of radiographic findings associated with hip dysplasia in a population based cohort of2081 19-year-old Norwegians. *Bone Joint J* 2013; **95-B**:279-285.

4 Duncan ST, Bogunovic L, Baca G, Schoenecker PL, Clohisy JC. Are there sex-dependent differences in acetabular dysplasia characteristics? *Clin Orthop Relat Res* 2015; **473**:1432–1439.

5 Luca G, Clohisy JC, Beaule PE. Hip dysplasia in the young adult. *J Bone Joint Surg Am* 2016; **98**: 63–73.

6 Lee CB, Mata-Fink A, Millis MB, Kim YJ. Demographic differences in adolescent-diagnosed and adult-diagnosed acetabular dysplasia compared with infantile developmental dysplasia of the hip. *J Pediatr Orthop*. 2013; **33**:107–111.

7 Clohisy JC, Dobson MA, Robison JF, Warth LC, Zheng J, Liu SS, *et al.* Radiographic structural abnormalities associated with premature, natural hip-joint failure. *J Bone Joint Surg Am* 2011; **93**(Suppl 2):3–9.

8 Nunley RM, Prather H, Hunt D, Schoenecker PL, Clohisy JC. Clinical presentation of symptomatic acetabular dysplasia in skeletally mature patients. *J Bone Joint Surg Am* 2011; **93**(Suppl 2):17–21.

9 Clohisy JC, Carlisle JC, Beaulé PE, Kim YJ, Trousdale RT, Sierra RJ, *et al.* A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am* 2008; **90**(Suppl 4):47–66.

10 Salter RB. Innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip. *J Bone Joint Surg* 1961; **43B**:S18

11 LeCoeur P. Corrections of the orientation of the joint coxo-femoral by osteotomy of the iliac isthmus. *Rev Chir Orthop*. 1965;**51**:21.

12 Tönnis D. Pelvic operations for dysplasia of the hip. In: Tönnis D, editor. *Congenital dysplasia and dislocation of the hip in children and adults*. Berlin, Heidelberg: Springer-Verlag 1987. pp. 370-387.

13 Ninomiya S, Tagawa H. Rotational acetabular osteotomy for the dysplastic hip. *J Bone Joint Surg* 1984; **66A**:430.

14 Ganz R, Klaue K, Vinh TS, Mast JW. A new periacetabular osteotomy for the treatment of hip dysplasias: technique and preliminary results. *Clin Orthop Relat Res* 1988; **232**:26–36.

15 Perry KI, Trousdale RT, Sierra RJ. Joint preservation: avoiding arthroplasty, hip dysplasia in the young adult: an osteotomy solution. *Bone Joint J* 2013; **95-B**(Suppl A):21–25.

16 Kalhor M, Gharehdaghi J, Schoeniger R, Ganz R. Reducing the risk of nerve injury during Bernese periacetabular osteotomy: a cadaveric study. *Bone Joint J* 2015; **97-B**:636–641.

17 Clohisy JC, Barrett SE, Gordon JE, Delgado ED, Schoenecker PL. Periacetabular osteotomy for the treatment of severe acetabular dysplasia. *J Bone Joint Surg* 2005; **87-A**:254–259.

18 Davey JP, Santore RF. Complications of periacetabular osteotomy. *Clin Orthop Relat Res* 1999; **363**:33–37.

19 Matta JM, Stover MD, Siebenrock K. Periacetabular osteotomy through the Smith-Petersen approach. *Clin Orthop Relat Res* 1999; **363**:21–32.

20 Murphy SB, Millis MB. Periacetabular osteotomy without abductor dissection using direct anterior exposure. *Clin Orthop Relat Res* 1999; **364**:92–98.

21 Siebenrock KA, Scholl E, Lottenbach M, Ganz R. Bernese periacetabular osteotomy. *Clin Orthop Relat Res* 1999; **363**:9–20.

22 Trousdale RT, Ekkernkamp A, Ganz R, Wallrichs SL. Periacetabular and intertrochanteric osteotomy for the treatment of osteoarthrosis in dysplastic hips. *J Bone Joint Surg* 1995; **77-A**:73–85.

23 Trumble SJ, Mayo KA, Mast JW. The periacetabular osteotomy. Minimum 2-year follow up in more than 100 hips. *Clin Orthop Relat Res* 1999; **363**:54–63.

24 Burke NG, Devitt BM, Baker JF, Butler JS, Cousins G, McCormack D, O'Byrne JM. Outcome of periacetabular osteotomy for the management of acetabular dysplasia: experience in an academic centre. *Acta Orthopaedic Belgica* 2011; **77**:33–40.

25 Clohisy JC, Nunley RM, Curry MC, Schoenecker PL. Periacetabular osteotomy for the treatment of acetabular dysplasia associated with major aspherical femoral head deformities. *J Bone Joint Surg Am* 2007; **89**:1417–1423.

26 Park YS, Moon YW, Lim SJ, Park JC, Son MS. Short-term follow-up results of periacetabular osteotomy for hip dysplasia. *J Korean Hip Soc* 2009; **21**:156–161.

27 Chen X, Zhu J, Cui Y, Shen C, Cai G. Mid-term results of Bernese periacetabular osteotomy for developmental dysplasia of hip in middle aged patients. *Int Orthop* 2013; **37**:589–594.

28 Sierra RJ, Potter GD, Novais EN, Trousdale RT. Successful outcomes at midterm follow-up of periacetabular osteotomy done for mild hip dysplasia. *J Hip Surg* 2017; **1**:167–172.