Treatment of Adolescents with a Periacetabular Osteotomy After Previous Pelvic Surgery

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Abstract

Background Although the success of the Bernese periacetabular osteotomy (PAO) has been reported for primary dysplasia, there is no study analyzing the radiographic, functional, and gait results of the PAO to correct residual hip dysplasia after previous pelvic surgery.

Questions/purposes We assessed (1) radiographic and (2) functional and gait outcomes of patients treated with a PAO after previous pelvic surgery (PPSx) and compared their results with results of patients with no previous surgery (NPSx) to determine whether the PAO was equally effective in patients with revision pelvic surgery.

Methods Twenty-nine dysplastic hips in 26 patients (average age, 16.3 years) were included: 13 in the PPSx group and 13 in the NPSx group. Radiographic parameters included the lateral center-edge angle, acetabular index, and femoral head extrusion index measured preoperatively and at 6 months and 1 year. We assessed preoperative and

postoperative function using the Harris hip score (HHS). Preoperative and postoperative gait analysis included the hip abductor impulse.

Results Improvements in groups were seen from preoperatively to 1 year postoperatively for the lateral center-edge angle, acetabular index, and femoral head extrusion index without differences between groups. The modified HHSs improved at 6 months and were maintained at 1 year for patients in both groups without differences between groups. The hip abductor impulse returned to preoperative values at 6 months in the NPSx group but not until 1 year in the PPSx group.

Conclusions The Bernese PAO is effective in providing similar final radiographic and functional results, however, a trend toward decreased hip flexion and abduction power at 1 year was seen with previous pelvic surgery.

Level of Evidence Level II, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Residual hip dysplasia in adolescents and young adults who have failed treatment for developmental dysplasia of the hip (DDH) can result in early osteoarthritis and may limit the biomechanical function of the hip [21, 25, 28, 45]. Various surgical procedures, including the Salter, Pemberton, Steel, and Tönnis osteotomies and shelf acetabuloplasty, have addressed the different pathologic components of the dysplastic hip. However, their success rates based on radiographs and self-reported patient outcomes have been variable [8, 16, 26, 32, 33, 39, 43, 44, 46] and the choice for the optimal surgical procedure to correct acetabular dysplasia continues to be controversial.

The Bernese PAO was first described by Ganz et al. [11] in 1988 for treatment of acetabular dysplasia and hip subluxation and has since been established as an effective reconstructive procedure for correcting hip dysplasia of varying etiologies [4, 5, 15, 18, 27, 29, 40, 41]. The advantages of this technically demanding surgery include preservation of the posterior column allowing immediate postoperative mobilization, the ability to medially translate the joint center, and preservation of the size and shape of the true pelvis [3, 11, 40–42]. Although the technical demands of the PAO, including its substantial learning curve, its requirement for precise three-dimensional planning, and its potential for a high rate of complications, have been described [2, 7, 14, 29, 31, 35, 37], surgical outcome after previous pelvic osteotomy has not been thoroughly studied. To our knowledge, there were two studies of adult patients who have undergone a PAO after a previous pelvic osteotomy [6, 23]; however, there are no published reports that have evaluated the effects of previous pelvic surgery in adolescents or that have included gait analysis.

As residual dysplasia in patients previously treated with pelvic osteotomies for DDH may result in decreased function and make revision surgery challenging, it is important to specifically study the biomechanical properties of the hip. Gait analysis in adult patients with dysplasia has shown the decreased acetabular weightbearing zone and the lateralized joint center affect the joint contact pressures [1, 10, 24, 27, 28, 30]. There are no studies, however, that have specifically assessed the kinematics and kinetics of the hip in adolescent and young adult patients undergoing a PAO who have been treated with a previous pelvic osteotomy.

We therefore assessed (1) radiographic, (2) functional, and (3) gait outcomes of patients treated with a PAO after previous pelvic surgery and compared their results with those of patients who had no previous surgery. Our hypothesis is that the PAO is equally effective in correcting hip dysplasia and improving patient outcomes in patients who have undergone a previous pelvic osteotomy.

Patients and Methods

This is an institutional review board-approved prospective analysis of adolescent patients treated with a PAO for hip dysplasia at one institution. All PAOs reported in this study were performed by the two senior authors (DJS, DAP) from 1999 to 2008. All patients who were included were treated for idiopathic hip dysplasia with radiographically closed triradiate cartilage and had a minimum of 1-year radiographic, functional, and gait followup (mean, 1.1 years; range, 0.9–1.9 years). We excluded from the study any patients with an underlying syndrome,

insufficient radiographic and gait followup, and who were nonambulatory at the time of preoperative assessment. A total of 26 patients (22 females, four males) with 29 hips (15 right, 14 left) (average age, 16.3 years; range, 11.5–25.1 years) were included in the analysis. Patients were divided into one of two groups based on whether they were treated with a previous pelvic osteotomy for hip dysplasia. Thirteen patients were included in the PPSx group and 13 were included in the NPSx group. Fifteen prior procedures had been performed in the 13 patients in the PPSx group and included 10 Salter osteotomies, two Chiari osteotomies, and one varus proximal femoral osteotomy. One patient was treated with a previous shelf acetabuloplasty and one patient underwent an indeterminate pelvic osteotomy at an outside facility. All patients underwent a PAO as described by Ganz et al. [11] using a modified Smith-Petersen approach [13]. In all cases, the indications for surgery were hip pain, radiographic dysplasia, and a concentric reduction of the femoral head as observed on an abduction/internal-rotation radiograph of the affected hip in a skeletally mature patient.

Radiographic evaluations were completed with a standing AP view of the pelvis and a false-profile view of Lequesne and de Seze [17] on the affected hip. Dysplasia was quantified by measuring the lateral center-edge angle (LCEA) of Wiberg [45], the acetabular index of the weightbearing zone (AI) [21], the ventral center-edge angle (VCEA) [17], and the femoral head extrusion index (FHEI) [12, 25] before surgery and 6 months and 1 year postoperative. The VCEA [17] was quantified preoperatively and postoperatively at one time. Of the patients included in the study, 24 had a false-profile view at 1 year postoperatively, three at 6 months postoperatively, and two did not have a postoperative false-profile radiograph. For all patients, the preoperative and 1-year postoperative AP pelvic radiographs were used to calculate the medial translation of the hip center [3]. Self-reported hip function was assessed in 24 of 26 patients at the respective times using the modified Harris hip score (HHS) with a maximum score of 89.

All subjects underwent instrumented motion analysis with a modified Helen Hayes marker set for lower-extremity kinematics, and data were collected using a VICON motion capture system (VICON, Denver, CO, USA). Kinetic data were acquired using two force platforms (AMTI, Newton, MA, USA). Lower-extremity kinematics and kinetics were determined using the Plug-in-Gait model in the VICON software. The timing and magnitude of the maxima and minima and mean over stance phase and/or the gait cycle were determined for each joint angle and plane. The hip abductor moment impulse was calculated as the area under the coronal plane hip abductor moment during single-limb stance. Isokinetic hip abduction and hip flexion strength were assessed using a Biodex

System 3 Isokinetic Dynamometer (Biodex Medical Systems Inc, Shirley, NY, USA) preoperatively and postoperatively in 19 patients. Strength values (torques) were normalized to body weight and multiplied by 100 (% Nm/kg). We analyzed the differences between the radiographic and gait parameters and the functional hip score at the preoperative and followup evaluations with Student's *t*-tests. Significance was determined to be *p* less than 0.05. When accounting for Bonferroni correction for multiple comparison, *p* values less than 0.013 were considered statistically significant.

Results

There were no differences in surgical times (201 versus 230 minutes) and blood loss (569 versus 981 mL) between the PPSx group and the NPSx group. One patient included in the PPSx group had a transient partial sciatic nerve palsy with foot drop develop after the PAO requiring an ankle-foot orthosis for 6 weeks. No complications were noted in any of the patients in the NPSx group.

Radiographic outcomes showed improvement ($p < 0.001$) in both groups at both postoperative evaluations when compared with preoperatively for the LCEA, AI, VCEA, and FHEI (Table 1). At followup, there were no differences between groups in the LCEA, AI, and FHEI;

however, there was less ($p = 0.049$) anterior coverage in the PPSx group with a VCEA of 20.3° compared with the NPSx group (28.9°). There was medialization of the hip center in both groups without a difference ($p = 0.564$) between the PPSx group (5.9 mm) and the NPSx group (4.8 mm). The AP standing radiographs showed similar postoperative improvement in all parameters, especially when comparing patients who had similar preoperative severity of hip dysplasia (Fig. 1).

Both groups had similar modified HHSs and showed similar improvement with time (Table 2). The scores improved at 6 months and were maintained at the 1-year postoperative evaluation for patients in both groups. The increase in the hip scores for the patients in both groups was significant between the preoperative and 1-year postoperative periods. There were no difference in HHS pain scores (maximum of 44 = no pain) between groups preoperatively (25.4 ± 8.8 versus 25.7 ± 8.5 ; $p = 0.922$), at the 6-month evaluation (37.8 ± 10.2 versus 36.0 ± 8.3 ; $p = 0.672$), and at the 1-year evaluation (37.1 ± 10.5 versus 34.0 ± 9.4 ; $p = 0.430$) for the PPSx group and NPSx group, respectively. A subanalysis specifically evaluating pain showed improvement in pain from preoperatively to postoperatively for the PPSx group ($p = 0.006$) and the NPSx group ($p = 0.012$) (Table 2).

Gait analysis showed no statistical difference between groups for hip abductor impulse, however, there was a

Table 1. Radiographic correction in the PPSx and NPSx groups.

Parameter/group	Preoperatively	6 months postoperatively	1 year postoperatively	<i>p</i> value*
LCEA ($^\circ$)				
PPSx	1.9 ± 7.4	25.1 ± 11.5	26.2 ± 7.0	$< 0.001^{\ddagger,\S}$
NPSx	1.7 ± 13.8	25.9 ± 8.3	28.6 ± 9.6	$< 0.001^{\ddagger,\S}$
			($p = 0.459^\dagger$)	
VCEA ($^\circ$)				
PPSx	-3.0 ± 14.3	20.3 ± 12.1		$< 0.001^\S$
NPSx	-2.3 ± 14.6	28.9 ± 9.7		$< 0.001^\S$
		($p = 0.049^\dagger$)		
AI ($^\circ$)				
PPSx	25.3 ± 6.1	9.4 ± 7.8	10.1 ± 7.9	$< 0.001^{\ddagger,\S}$
NPSx	27.1 ± 11.8	5.3 ± 4.6	6.3 ± 5.8	$< 0.001^{\ddagger,\S}$
			($p = 0.145^\dagger$)	
FHEI (%)				
PPSx	39.4 ± 10.0	12.9 ± 10.8	9.2 ± 9.4	$< 0.001^{\ddagger,\S}$
NPSx	39.5 ± 10.1	9.7 ± 8.6	8.6 ± 8.0	$< 0.001^{\ddagger,\S}$
			($p = 0.856^\dagger$)	

Values are expressed as mean $\pm$ SD; * difference between times in each group; † difference between each group at each time; ‡ preoperatively different from 6 months postoperatively; § preoperatively different from 1 year postoperatively; PPSx = previous pelvic surgery; NPSx = no previous pelvic surgery; LCEA = lateral center-edge angle; VCEA = ventral center-edge angle; AI = acetabular index; FHEI = femoral head extrusion index.

Fig. 1 A–D (A) Preoperative and (C) 1-year postoperative AP radiographs show the hips of a 14-year-old boy with hip dysplasia and no previous surgery (NPSx). (B) Preoperative and (D) postoperative radiographs show the hips of an 18-year-old woman with DDH and previous Chiari osteotomy (PPSx). Both had improved head coverage and congruency and decreased medial translation and acetabular inclination with good clinical results.

Table 2. Modified HHS outcomes in the PPSx and NPSx groups.

Parameter/group	Preoperatively	6 months postoperatively	1 year postoperatively	p value*
Total HHS (maximum score: 89 points)				
PPSx	65.9 ± 12.1	77.0 ± 13.4	78.5 ± 10.4	0.024 [§]
NPSx	65.6 ± 9.5	76.6 ± 10.1	75.6 ± 12.3	0.022 ^{‡,§}
HHS-pain score (maximum score: 44 points = no pain)				
PPSx	25.4 ± 8.8	37.8 ± 10.2	37.1 ± 10.5	0.006 [§]
NPSx	25.7 ± 8.5	36.0 ± 8.3	34.0 ± 9.4	0.012 ^{‡,§}
	(p = 0.922 [†])	(p = 0.672 [†])	(p = 0.430 [†])	

Values are expressed as mean ± SD; * difference between times in each group; † difference between each group at each time; ‡ preoperative different from 6 months postoperative; § preoperative different than 1 year postoperative; HHS = Harris hip score; PPSx = previous pelvic surgery; NPSx = no previous pelvic surgery.

trend toward decreased hip flexion strength before surgery and 1 year postoperative in the PPSx group and for abductor strength at 1 year postoperative. At 6 months postoperatively the hip abductor impulse tended to decrease for patients in the PPSx group, which returned to baseline values at 1 year (Table 3). In contrast, the NPSx group maintained preoperative hip abductor impulse values at 6 months and showed slight improvement at 1 year.

Changes across time, however, were not different in the PPSx and NPSx groups with respect to hip flexion or hip abductor strength. Owing to high variability across individuals in each group, these changes with time approached, but did not reach statistical significance. Patients in the PPSx group also did have lower hip extension during midstance compared with control subjects ($p < 0.001$) and the NPSx group ($p = 0.003$).

Table 3. Kinematic and kinetic results in the PPSx, NPSx, and control groups.

Parameter/group	PPSx	NPSx	p value	Interpretation
Hip abductor impulse (Nm/kg)				
Preoperative	0.250 ± 0.072	0.273 ± 0.086	0.456	
6 months	0.218 ± 0.078	0.271 ± 0.061	0.093	Trend toward decreased impulse in the PPSx group at 6 months
1 year	0.266 ± 0.073	0.280 ± 0.103	0.687	
Hip abduction strength (% Nm/kg)				
Preoperative	56.4 ± 19.3	70.5 ± 26.1	0.188	
6 months	41.9 ± 23.8	68.0 ± 34.0	0.086	
1 year	48.3 ± 25.3	80.9 ± 35.4	0.030	Trend toward decreased abduction strength in the PPSx group at 1 year
Maximum hip extension midstance (°)				
Preoperative	1.8 ± 7.2	-5.6 ± 4.9	0.003	PPSx less than NPSx
6 months	0.5 ± 8.9	-1.2 ± 6.9	0.617	
1 year	0.2 ± 9.8	-5.2 ± 8.8	.0161	
Hip flexion strength (% Nm/kg)				
Preoperative	62.2 ± 22.1	92.7 ± 33.9	0.030	Trend toward decreased flexion strength before surgery in PPSx group
6 months	42.6 ± 27.6	61.1 ± 23.8	0.147	
1 year	52.9 ± 25.0	86.2 ± 35.8	0.028	Trend toward decreased flexion strength at 1 year in the PPSx group

When using Bonferroni correction for multiple comparisons, p values less than 0.013 were considered statistically significant; values are expressed as mean ± SD; there were no differences in the parameters between the PPSx and NPSx groups at any time, except for maximum hip extension preoperatively; PPSx = previous pelvic surgery; NPSx = no previous pelvic surgery.

Discussion

The Bernese PAO has become one of the most popular and successful procedures for treating hip dysplasia in adults; however, reports on its ability to successfully treat hip dysplasia in younger patients are limited [36, 37]. Although the versatility of the PAO to correct even the most severe dysplastic hips in the adult population is well documented [4, 5, 22, 34, 37], the limitations of the PAO are not well defined for either the adult or adolescent patient populations. Surgical planning and performance of the PAO for a patient who has had a previous pelvic osteotomy can be hypothesized to be more difficult and challenging because of scarring from the initial surgery, diminished muscle function surrounding the hip, and the distorted anatomy of the pelvis, including a wider and shortened iliac crest. We therefore evaluated the radiographic and functional outcomes of adolescent patients treated with a PAO after previous treatment with a pelvic osteotomy and compared their results with those of a group of patients treated with a PAO with no previous surgery.

Our study has some limitations. First the study population is small; however, this was attributable to the strict inclusion criteria for the study to complete a postoperative gait analysis. Second, patient followup was limited to 1 year instead of 2 years. The goals of hip preservation

surgery in the young patient using the PAO for hip dysplasia are to improve pain, return normal function, and ultimately improve the natural history of the hip to avoid or limit total hip arthroplasty. The first two goals are best assessed at a time when return to activities has been resumed and in our experience this occurs at 6 months to 1 year after surgery. A 1-year period has been used to assess functional recovery in adult patients with hip fractures [20], after patellar tendon repair in active-duty military personnel [9], and after a PAO in adolescents [38]. The third goal of prolonging the natural history of the hip is best studied with greater than 2 years followup and is not the objective of this study.

There are two studies that have specifically reviewed the outcomes of patients treated with a PAO with previous pelvic osteotomies, however, both studies involved adult patients. Czubak et al. [6] reported radiographic improvement of the LCEA and the VCEA after a PAO (from -14° to 34° and from -10° to 35°, respectively) in a group of young adults with previous surgery about the hip. Their study, however, included patients who had been treated previously with a combination of pelvic and soft tissue procedures, including open reduction (10 hips), derotational varus osteotomy (14 hips), pelvic osteotomy (eight hips), combined open reduction/pelvic osteotomy/derotational varus osteotomy (10 hips), bone lengthening (four

hips), and acetabular cyst removal (one hip) [6]. As the results were not stratified for patients specifically treated with pelvic osteotomy, an accurate assessment of the influence of pelvic surgery before a PAO on patient outcomes could not be completed. Additionally, the reports described radiographic correction alone and did not include any reference to patient outcome scores or gait [6, 23]. Mayo et al. [23] studied the radiographic and functional outcomes of 18 adult patients with an average age of 30.9 years who underwent 19 PAOs for treatment of residual dysplasia. Although that study included 10 patients with previous pelvic osteotomies (seven Salter, two Chiari, and two shelf acetabuloplasties), the remaining eight patients had isolated proximal femoral osteotomies without a procedure performed on the pelvis. The patients with previous pelvic surgery showed improvement in the LCEA (from 5° to 29°), VCEA (from 3° to 24°), and AI (from 24° to 6°), which were not different from those of the patients without previous pelvic surgery [23]. Our study showed similar improvement in these radiographic parameters in the PPSx and NPSx groups without differences between the groups. Although patients in the PPSx and NPSx groups had an average improvement in anterior coverage that was greater than 20°, the difference in postoperative improvement in the VCEA was marginally significant between the groups, with the NPSx group achieving a greater VCEA than the PPSx group. Our experience in performing PAOs in patients with complex hip dysplasia, including patients with previous surgery, has assisted us in achieving similar radiographic correction for patients having PAOs as achieved by patients without previous surgery. There are some differences between performing a PAO in a virgin hip and one performed in a hip that has had previous surgery. First, the pelvic wing is usually very thick and the morphologic features of the anterior-superior iliac spine often are distorted secondary to previous surgery; second, scar tissue in and around the muscles and the pelvis makes mobility of the acetabular fragment somewhat limited; third, the version of the acetabulum may be affected by the previous pelvic surgery and restoration of normal version can be complicated. We have kept these differences in mind when performing a PAO in a hip that has had previous surgery and have taken great care to address these three differences by, first, understanding the osseous anatomy at the time of surgery to ensure that the appropriate dissection preserves the soft tissue attachments to the anterior-superior spine before creating the osteotomy; second, to be more aggressive in creating the osteotomies especially the posterior column osteotomy to prevent hinging at the time of attempted mobilization of the fragment as this requires some propagation through the lateral cortex during fragment correction; and finally, repositioning of the fragment requires careful evaluation of

the radiographs at completion of the procedure to ensure that normal restoration of version is achieved, by observing the anterior and posterior walls as they converge laterally [35].

All patients included in our study also completed a modified HHS and underwent gait analysis to better understand the overall function of the hip and outcome of the hip after the PAO. The HHS preoperative values were similar between the PPSx group (65.9) and the NPSx group (65.6) and also improved to a similar level after surgery to 78.5 and 75.6, respectively. These results are similar to those reported by Mayo et al. [23] for adult patients with previous pelvic osteotomy, with an average increase from 60 to 90. However, these outcome scores were representative of the entire group of patients who had been treated with prior hip surgery and were not limited to only patients with prior pelvic osteotomies. The slight variability in the scores between the adolescent patients in our study and the adults also might be attributed to the different point scales studied as we used the modified HHS with a maximum score of 89 compared with the original HHS with a maximum score of 100 points.

Previous reports have noted patients with hip dysplasia have increased flexion and reduced hip flexor moment [10, 19, 28, 30]. Pedersen et al. [27] initially reported this finding in a group of adult women with hip dysplasia after treatment with a PAO. They reported hip extensor moment decreased after surgery and all subjects walked with increased extension of the knee during the stance phase when compared with control subjects [27]. In our study, the PPSx group showed decreased hip extension during mid-stance preoperatively compared with the NPSx group. With respect to the hip abductor impulse, the PPSx group showed a trend toward a decrease from preoperatively to 6 months postoperatively but improved to baseline values at 1 year. The NPSx group did not change significantly with time. Although there were no statistically significant differences between the two groups at any of the times, the NPSx group tended to have a slightly greater hip impulse value than the PPSx group at all periods. The hip abductor strength tended to be lower in the PPSx group preoperatively, diminished at 6 months, but returned to baseline values 1 year after surgery while the NPSx group tended to show slight improvement 1 year. It has been our anecdotal experience that some patients seem to have a more difficult time regaining hip abductor and hip flexion strength when a previous pelvic procedure has been performed, however, this study did not show this in a group of patients using objective strength data and comparisons between the two groups using statistical analysis. This lack of improvement in hip abductor impulse and strength in the PPSx group may be attributed to abductor muscle stripping off the lateral iliac crest at the time of the initial pelvic surgery.

This may lead to scarring with decreased muscle function. During the Bernese PAO, we performed an abductor muscle-sparing approach with the exception of a small window to complete the partial innominate osteotomy just below the anterior-superior iliac spine. This small window does not seem to produce a detrimental effect on the abductor muscle function when there has been no previous surgery although it does when there has been previous surgery. This seems to be the primary reason as medialization of the hip center was similar between groups and the postoperative protocol in all of these patients was the same. Our clinical experience has showed that patients return to their baseline gait pattern within 1 year of surgery without significant differences in their gait and supports the data reported in this study. There are no major differences between patients when it comes to an abductor lurch or walking speed. However, clinically patients with previous pelvic surgery tended to be weaker in abductor and flexion strength at 1 year after a Ganz PAO.

Our results showed that at 1 year after surgery in this adolescent population with hip dysplasia, the Ganz PAO provided radiographic, gait, and functional results when previous pelvic surgery has been performed similar to those when it has not been performed. Abduction and flexion strength tended to be lower at last followup in the patients with previous pelvic surgery. Although this procedure may be more technically demanding in this group of patients, after early and preliminary followup it has provided excellent deformity correction and good clinical results.

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