

# Complications Associated with the Bernese Periacetabular Osteotomy for Hip Dysplasia in Adolescents

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**Background:** The Bernese (Ganz) periacetabular osteotomy is an effective surgical procedure to reorient the acetabulum, allowing restoration of anatomic femoral head coverage and medial translation of the hip in adults with hip dysplasia. However, it is a challenging surgical procedure, and we know of no study that has specifically analyzed the complications and associated factors seen with this procedure in adolescent patients.

**Methods:** A retrospective clinical and radiographic review of a consecutive series of adolescent patients who underwent a Bernese periacetabular osteotomy for hip dysplasia was conducted.

**Results:** Eighty-three osteotomies were performed in seventy-six patients with an average age (and standard deviation) of  $15.6 \pm 2.4$  years. Significant improvement from the preoperative to the two-year follow-up evaluation was seen radiographically with regard to the lateral center-edge angle ( $-0.14^\circ$  to  $35.5^\circ$ ), the ventral center-edge angle ( $-5.13^\circ$  to  $31.3^\circ$ ), and the femoral head extrusion index (38.4% to 7.7%) ( $p < 0.0001$  for all). There were three major complications, including excessive arterial bleeding requiring embolization in a patient with a prior acetabuloplasty, osteonecrosis of the acetabular fragment in a patient with severe dysplasia and subluxation of the hip, and osteonecrosis of the femoral head following combined periacetabular and femoral osteotomies in a patient with Charcot-Marie-Tooth disease. Eighteen hips (22%) had minor complications, including nonunion of the superior pubic ramus osteotomy (five hips), a superficial stitch abscess (four), and transient lateral femoral cutaneous nerve palsy (four). Nine hips (11%) underwent removal of symptomatic screws, and two required a second operation to reposition the acetabular fragment. An underlying diagnosis other than developmental dysplasia increased the prevalence of minor complications ( $p = 0.0017$ ), while a major complication was more likely with longer surgery time, greater blood loss, and proximal femoral osteotomy.

**Conclusions:** The Bernese periacetabular osteotomy is a joint-preserving procedure that very effectively corrects acetabular dysplasia in adolescent patients, providing improved radiographic results and a low rate of complications. Although the rate of minor complications is increased when there is an underlying diagnosis other than developmental dysplasia, no other predictors were identified. However, a major complication is more likely with a longer duration of surgery and with a concomitant femoral varus osteotomy.

**Level of Evidence:** Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

The treatment of hip dysplasia changed substantially after the introduction of the Bernese periacetabular osteotomy by Ganz et al.<sup>1</sup>. The power of this osteotomy to reorient the acetabulum has led to successful treatment of patients with aspherical femoral head deformities<sup>2</sup> and patients with severe acetabular dysplasia<sup>3</sup>. The advantages of the Bernese periacetabular osteotomy are a single surgical approach<sup>1,4</sup>, extensive acetabular reorientation because of the proximity of

cuts to the acetabulum<sup>5-7</sup>, immediate postoperative mobilization because of the intact posterior column<sup>1,5</sup>, the ability to medially translate the hip joint center<sup>8</sup>, preservation of the acetabular blood supply<sup>9,10</sup>, and the preservation of the shape and size of the true pelvis to allow normal child delivery in female patients<sup>11</sup>. Excellent radiographic and clinical results have been demonstrated in short-term, mid-term, and long-term follow-up from various centers<sup>1,10-16</sup>.

**Disclosure:** The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity.

Although the Bernese periacetabular osteotomy provides excellent radiographic and clinical results, it is a technically demanding procedure with a distinct learning curve<sup>1,5,12-14</sup>, it requires careful three-dimensional planning<sup>7</sup>, and, above all, it carries a high rate of potential complications<sup>13</sup>. All of the studies that have reviewed complications with the procedure have involved adult patients<sup>13,15-19</sup>. It can be hypothesized that patients who present with symptoms earlier, during the adolescent period, have more severe dysplasia and have more often had previous surgery than do those who present later as adults with mild hip dysplasia. The purpose of the present study was to report the complications associated with the Bernese periacetabular osteotomy and the outcomes of a large series of adolescent patients treated for acetabular dysplasia.

### Materials and Methods

We conducted an institutional review board-approved retrospective review of 112 consecutive dysplastic hips in 102 adolescent patients who underwent a Bernese periacetabular osteotomy over a ten-year period at a single institution. Twenty-six hips were excluded as they were in patients with an underlying diagnosis of cerebral palsy, and three hips were excluded as they were in patients who were over the age of twenty-one. The remaining eighty-three hips in seventy-six adolescent patients were analyzed for the present study.

Radiographic evaluations were performed on a standing anteroposterior pelvic radiograph and a false-profile view described by Lequesne and de Seze<sup>20</sup>. Radiographic measurements were made by one of the authors (D.T.), and each measurement line was confirmed visually by one of the two senior authors (D.J.S.) on the saved digital image. The author (D.J.S.) then performed the radiographic measurements on a random sample of patients, and the interobserver reliability was determined. Dysplasia was quantified by the lateral center-edge angle (normal,  $>20^\circ$ ) of Wiberg<sup>21</sup>, the ventral center-edge angle (normal,  $>25^\circ$ ) as described by Lequesne and de Seze<sup>20</sup>, the acetabular index of the weight-bearing zone (normal,  $<10^\circ$ )<sup>21</sup>, and the femoral head extrusion index (normal,  $>70^\circ$ ) described by Heyman and Herndon<sup>22</sup>. The distance from the medial edge of the femoral head to the midpoint of the line joining the coccyx to the pubic symphysis on an anteroposterior pelvic radiograph was measured to assess medialization of the hip. Osteoarthritis of the hip was graded according to the Tönnis criteria<sup>23</sup>, with grade 0 indicating a normal hip; grade 1, increased sclerosis, minimal osteophytes, and slight decrease in joint space; grade 2, moderate loss of joint space and the presence of cysts; and grade 3, severe loss of joint space and large cysts. Heterotopic ossification was graded according to the classification described by Brooker et al.<sup>24</sup>. All measurements were performed preoperatively, immediately postoperatively, and at a minimum of two years of follow-up. All radiographic measurements were compared at each time point with the preoperative parameters.

Operative and clinical records were reviewed for documentation of intraoperative and immediate postoperative complications. Complications were defined as minor and major.

Minor complications were those that did not alter the clinical condition of the patient and/or required no treatment or were an incidental radiographic finding. Symptoms related to implants were also considered to be a minor complication. Major complications included those that required immediate intervention or had a potential for substantial morbidity.

Clinical and surgical records were carefully reviewed to collect the following data: patient demographics, previous surgical and nonsurgical treatments, procedures performed concomitantly with the periacetabular osteotomy, and any procedures performed subsequent to the periacetabular osteotomy.

### Surgical Technique

The indication for performing the periacetabular osteotomy was symptomatic acetabular dysplasia with a closed triradiate cartilage and concentric reduction of the femoral head on an abduction-internal rotation radiograph of the affected hip. A magnetic resonance arthrogram was used to assess the condition of the labrum in patients with a positive anterior impingement sign (sharp groin pain with hip flexion to  $90^\circ$  and concomitant hip adduction and with internal rotation). All patients underwent a periacetabular osteotomy as described by Ganz et al.<sup>1</sup>, with use of a modified, abductor-sparing Smith-Petersen approach and under fluoroscopic guidance<sup>4,5</sup>. Definitive fixation was achieved with three or four 3.5-mm-diameter fully threaded cortical screws placed through the iliac wing in addition to a screw placed from the superior aspect of the acetabular fragment into the ilium. A hip arthrotomy was performed if the patient had a positive impingement test preoperatively or a labral tear was documented on the preoperative magnetic resonance arthrogram. A proximal femoral osteotomy was performed simultaneously to optimize joint congruity for the hips with severe subluxation associated with an abnormal neck-shaft angle. Postoperatively, all patients were allowed 20 to 30 lb (9 to 13.6 kg) of weight-bearing on the operatively treated limb for six weeks or until healing of the osteotomy was deemed adequate to allow full weight-bearing. In general, prophylaxis against deep-vein thrombosis was not used. Clinical and radiographic follow-up was performed at six weeks, twelve weeks, six months, twelve months, and then yearly.

### Statistical Analysis

Continuous variables are given as the mean and the standard deviation. Categorical variables are presented as the number of events and the percentage of the total. Continuous variables were compared at different times by repeated-measures analysis of variance. Spearman nonparametric correlation and the Fisher exact test were used to determine whether any of the preoperative or intraoperative variables influenced the likelihood of having a complication. The Spearman correlation was chosen to provide a quantitative measure of the association between the occurrence of a complication and continuous variables, in part, because of the presence of some extreme values. Ordinary kappa statistics were used to measure interobserver agreement for categorical variables. Significance was achieved with a  $p$  value of  $<0.05$ .

**TABLE I** Distribution of the Underlying Diagnosis and the Prevalence of Complications (Major and Minor) for Each Diagnosis

Diagnosis	No. of Hips	Complications (no. of hips)	
		Major	Minor
Developmental dysplasia-acetabular dysplasia	63	2	8
Charcot-Marie-Tooth disease	6	1	5
Legg-Calvé-Perthes disease	4	0	2
Unknown chromosomal translocation	4	0	1
Arthrogryposis	2	0	1
Spina bifida	1	0	1
Congenital short femur	1	0	0
Multiple epiphyseal dysplasia	1	0	0
Posttraumatic physeal bar arrest	1	0	0
Total	83	3 (4%)	18 (22%)

### Source of Funding

There was no external funding for this study.

### Results

There were eighty-three hips (thirty-six right and forty-seven left hips) in seventy-six patients (sixty-nine with unilateral and seven with bilateral involvement), including fourteen male patients (fifteen hips) and sixty-two female patients (sixty-eight hips). The average age at the time of surgery was  $15.6 \pm 2.4$  years, and the average body-mass index was  $23.9 \pm 4.9$  kg/m<sup>2</sup> (with an average height of  $158.2 \pm 10.5$  cm and average weight of  $60.2 \pm 16.3$  kg). The youngest patient in this series was eleven years old, and the oldest was twenty-one years. The osteotomies were performed by the two senior authors (D.J.S. and D.A.P.). Our previous experience with the Bernese periacetabular osteotomy consisted of learning the procedure during residency and scrubbing as the first assistant on a number of these procedures during that time. Both authors then trained with Professor Reinhold Ganz in Switzerland prior to performing the osteotomy independently.

Twenty hips had an underlying diagnosis, including Charcot-Marie-Tooth disease, Legg-Calvé-Perthes disease, arthrogryposis, or chromosomal abnormalities (Table I). The majority of patients in this series had previous surgical treatment, with forty-eight hips (58%) that had a variety of procedures, including a previous acetabular procedure (thirty-one hips) (Table II). The average surgical time for the periacetabular osteotomy was  $241.8 \pm 83.5$  minutes (range, 135 to 630 minutes), and the estimated blood loss was an average of  $760.2 \pm 508.6$  mL. These results include total surgical time and estimated blood loss for surgical procedures performed in combination with the periacetabular osteotomy (Table III).

Thirty hips (36%) underwent a concomitant open arthrotomy through the same surgical approach to evaluate and address intra-articular pathology. Three hips required labral repair, and thirteen underwent labral debridement. Osteochondroplasty (recreation of the femoral head-neck offset)

was performed in five hips. Three additional patients underwent a combined surgical hip dislocation at the time of the Bernese periacetabular osteotomy because of a large labral tear that required repair. Table III lists the other procedures performed at the time of the periacetabular osteotomy. The average duration of the hospital stay was  $5.1 \pm 1.3$  days.

### Radiographic Results

The kappa values for the comparison of the original measurements made by one author (D.T.) and those made by one of the two senior authors (D.J.S.) were 0.65 for the lateral

**TABLE II** Prevalence and Type of Previous Hip Surgery Prior to the Bernese Periacetabular Osteotomy in Eighty-three Hips

	No. (%) of Hips
No previous surgery	35 (42)
Open reduction with or without capsulorrhaphy	27 (33)
Pelvic procedure	31 (37)
Salter osteotomy	21
Shelf acetabuloplasty	2
Chiari osteotomy	2
Pemberton osteotomy	2
Triple innominate osteotomy	2
Dega osteotomy	1
Unknown pelvic osteotomy	1
Femoral osteotomy	30 (36)
Femoral shortening	14
Femoral varus	13
Femoral derotation	3
Miscellaneous hip procedures	11 (13)
Closed reduction	10
Hip arthroscopy	1

**TABLE III Associated Procedures Performed at the Same Time as the Bernese Periacetabular Osteotomy**

Associated Procedure	No. of Hips
Open arthrotomy	30
Labral debridement	13
Capsulorrhaphy	9
Osteochondroplasty	5
Proximal femoral varus osteotomy	4
Surgical hip dislocation	3
Labral repair	3
Implant removal	3
Greater trochanteric advancement	3
Proximal femoral valgus osteotomy	1
Adductor tenotomy or release	1
Periacetabular cyst debridement	1
Repair of osteochondral defect	1

center-edge angle, 0.72 for the ventral center-edge angle, and 0.76 for the acetabular index of the weight-bearing zone. These values fall into the category indicating substantial agreement (0.61 to 0.80). Significant radiographic improvement from the preoperative to the two-year follow-up evaluations was seen in all hip dysplasia parameters: lateral center-edge angle ( $-0.14^{\circ}$  to  $35.5^{\circ}$ ), ventral center-edge angle ( $-5.13^{\circ}$  to  $31.3^{\circ}$ ), acetabular index of the weight-bearing zone ( $27.8^{\circ}$  to  $7.7^{\circ}$ ), and femoral head extrusion index ( $38.4\%$  to  $7.7\%$ ) ( $p < 0.0001$  for all) (Table IV). The hips were medialized by an average of 8.7 mm.

Preoperatively, nine hips (11%) had no signs of osteoarthritis (grade 0 according to the Tönnis classification), while sixty-six hips (80%) demonstrated early joint space narrowing or early osteophyte formation (grade 1), eight (10%) had moderate joint space narrowing and moderate loss of head sphericity (grade 2), and no hip had complete loss of articular

cartilage (grade 3). At the time of the final follow-up, the number of Tönnis grade-0 hips increased to thirty-four (41%) ( $p < 0.0001$ ), which may represent the reorientation of thicker cartilage into the weight-bearing zone. At the time of the final follow-up, thirty-nine hips were Tönnis grade 1, nine were grade 2, and one was grade 3.

We separately analyzed outcomes of eight hips (10%) that had preoperative Tönnis grade-2 osteoarthritis. One underwent total hip arthroplasty two years following the periacetabular osteotomy because of progressive pain. This patient was 12.5 years old and was previously treated for developmental dysplasia of the hip with two open reductions of the hip through a Smith-Petersen approach and simultaneously two femoral varus and shortening osteotomies. Preoperatively, the patient had Tönnis grade-2 osteoarthritis, with a severely dysplastic acetabulum and hip subluxation. A magnetic resonance arthrogram revealed grade-3 to grade-4 cartilage thinning of the femoral head and acetabulum with associated labral intrasubstance degeneration. In light of the extensive changes in the femoral head and acetabulum, the family was warned of the high risk of failure of the periacetabular osteotomy. However, given the young age and high physical activity level of the patient, a collective decision was made to proceed with the Bernese periacetabular osteotomy in an attempt to delay the need for joint arthroplasty.

One hip progressed to Tönnis grade 3, while one had improved to grade 1 at the time of the two-year follow-up. Again, this apparent improvement is believed to be a result of reorientation of thicker cartilage into the weight-bearing zone as well as improvement in the anterior coverage, which prevents anterior subluxation of the hip, creating apparent joint space changes on the anteroposterior radiograph. The remaining six hips with preoperative Tönnis grade-2 osteoarthritis were still grade 2 at two years following the periacetabular osteotomy.

### Complications

Major complications occurred in three hips (4%); minor complications, in eighteen (22%); and removals of symptomatic

**TABLE IV Radiographic Parameters Preoperatively, Postoperatively, and at the Time of Final Follow-up**

Variable	Preop.	Postop.	Final Follow-up	P Value†
Lateral center-edge angle* (deg)	$-0.14 \pm 10.6$	$34.6 \pm 12.1$	$35.5 \pm 14.3$	$<0.0001$
Ventral center-edge angle* (deg)	$-5.13 \pm 15.2$	$32.3 \pm 13.5$	$31.3 \pm 14.0$	$<0.0001$
Acetabular index of weight-bearing zone* (deg)	$27.8 \pm 8.0$	$8.5 \pm 5.5$	$7.7 \pm 6.1$	$<0.0001$
Extrusion index* (%)	$38.4 \pm 12.4$	$7.9 \pm 10.6$	$7.7 \pm 11.3$	$<0.0001$
Tönnis grade (no. of hips)				$<0.0001$
0	9	14	34	
1	66	61	39	
2	8	8	9	
3	0	0	1	

\*The values are given as the mean and the standard deviation. †The p values are for the comparison of the preoperative and final follow-up results.

screws, in nine hips (11%). One hip had both a major and a minor complication. In addition, two hips had two minor complications each. Thus, twenty-seven hips (33%) presented with a complication or symptoms related to implants, whereas fifty-six hips (67%) did not have any postoperative clinical or radiographic issues. To evaluate the learning curve, we assessed the complication rate, comparing the initial forty-two periacetabular osteotomies with the later forty-one periacetabular osteotomies. There was no difference in the rate of major or minor complications between these two groups. One major and ten minor complications occurred in the initial set of forty-two periacetabular osteotomies, and, similarly, two major and eight minor complications occurred in the later group of forty-one osteotomies.

### Major Complications

The single intraoperative complication was an episode of major arterial bleeding that began after elevating the periosteum on the medial aspect of the iliac wing toward the sciatic notch. The bleeding could not be controlled by standard intraoperative techniques, and the patient underwent an urgent embolization of an aberrant artery, not the superior gluteal artery, which was intact on the arteriogram, performed by an interventional radiologist. The patient was not hemodynamically unstable at any point during the periacetabular osteotomy or at the time of embolization. The patient had undergone a Dega-type pelvic osteotomy five years prior to the periacetabular osteotomy, which may have played a role in the development of neovascularization. The periacetabular osteotomy was completed twelve days later, and the patient had an otherwise uncomplicated recovery with alleviation of the symptoms.

Two hips developed osteonecrosis, which involved the femoral head in one and the acetabulum in the other. Femoral head osteonecrosis occurred in a teenaged boy with Charcot-Marie-Tooth disease who had a combined Bernese periacetabular osteotomy and varus proximal femoral osteotomy as well as an arthrotomy to debride a peripheral labral tear. The osteonecrosis was treated with a hinged external fixator with traction across the hip for a three-month period. At three years after the original surgery, the patient was able to walk with a moderate limp, had minimal symptoms, and had not required further surgery. The diagnosis of partial osteonecrosis of the acetabulum was made on the basis of increased radiographic density of the acetabular fragment in a thirteen-year-old girl with severe hip dysplasia. Preoperatively, she had a lateral center-edge angle of  $-25^\circ$  and a ventral center-edge angle of  $-33^\circ$ , with substantial radiographic improvement postoperatively to  $28^\circ$  and  $34^\circ$ , respectively. Preoperatively, there were no signs of early osteoarthritis, but Tönnis grade-1 arthritic changes were seen radiographically at five years after surgery. At the time of the final follow-up, the patient was doing well clinically with only occasional discomfort.

### Minor Complications

The most common minor complication was nonunion at an osteotomy site. Five hips (6%) had a nonunion of the superior

pubic ramus. Four patients were completely asymptomatic, and one continued to have mild symptoms and underwent autologous bone-grafting and plate fixation of the nonunion twelve months after the index procedure, with complete resolution of symptoms. At the time of the revision surgery, it was noted that the psoas tendon had been displaced into the superior ramus osteotomy, which may have promoted development of the nonunion. One patient developed an asymptomatic ischial nonunion. Other minor complications included a superficial stitch abscess in four hips (5%), transient lateral femoral cutaneous nerve numbness in four (5%), and stress fracture of the inferior pubic ramus found incidentally on a routine follow-up examination in four patients (5%), all of whom were asymptomatic and did not require further intervention.

### Subsequent Surgeries

Fifteen patients required subsequent surgical procedures, which included removal of symptomatic screws in nine patients (11%), with three patients who had removal of the anterior superior iliac spine screw at an average of twenty-two months postoperatively and six patients who had all screws removed at an average of twenty-two months postoperatively.

Six patients had various subsequent procedures. One patient, as noted above, had subsequent surgery because of a superior ramus nonunion. One patient with Legg-Calvé-Perthes disease and a dysmorphic femoral head had a surgical hip dislocation to treat combined cam and pincer femoroacetabular impingement and a labral tear sixty-three months following the periacetabular osteotomy. One patient with Legg-Calvé-Perthes disease who had multiple previous surgeries had a substantial leg-length discrepancy prior to the periacetabular osteotomy and had closed femoral shortening of the contralateral femur eighteen months following the periacetabular osteotomy. One patient previously treated for developmental dysplasia of the hip with bilateral periacetabular osteotomies had a varus proximal femoral osteotomy at thirty-six months to treat insufficient radiographic femoral head coverage without symptoms. Two hips, with excessive anterior coverage demonstrated postoperatively on the false-profile radiographs, were revised surgically within ten days of the index surgery.

### *Assessment of Factors Associated with the Occurrence of Complications*

#### Demographics

No significant association was seen between the occurrence of a major or a minor complication and any of the demographic parameters (age, sex, height, weight, body mass index, side, and bilaterality).

#### Underlying Diagnosis

For statistical analysis, hips were divided into two groups on the basis of the primary diagnosis, with sixty-three in the group that had developmental dysplasia of the hip and twenty in the group that had other diagnoses. The group with developmental dysplasia of the hip had a significantly lower rate of



minor complications (eight patients; 12.7%) than the group with other diagnoses (ten patients; 50%) ( $p = 0.0017$ ). We did not identify a significant difference between the groups with respect to the rate of major complications.

#### Prior Treatment

With the numbers studied, we were not able to identify a significant correlation between major or minor complications and prior surgeries or prior acetabular procedures. Major complications occurred in two (6%) of thirty-five hips with no prior surgery and in one (2%) of forty-eight hips with prior surgery. Minor complications occurred in eight (23%) of thirty-five hips with no prior surgery and in ten (21%) of forty-eight hips with prior surgery. Similarly, thirty-one hips had various pelvic osteotomies done prior to the index Bernese periacetabular osteotomy. These included a Salter osteotomy (twenty-one hips), Pemberton osteotomy (two), triple innominate osteotomy (two), shelf acetabuloplasty (two), Chiari osteotomy (two), Dega osteotomy (one), and unspecified pelvic osteotomies (one). A major complication occurred in one hip (3%), and minor complications occurred in nine (29%) of the thirty-one hips with a previous procedure, whereas two (4%) of the remaining fifty-two hips with no prior pelvic procedure had a major complication and nine (17%) had minor complications.

#### Intraoperative Variables

Spearman nonparametric correlation values demonstrated a modest but significant association between the occurrence of a major complication and surgical duration ( $\rho = 0.26$ ,  $p < 0.02$ ), estimated blood loss ( $\rho = 0.25$ ,  $p = 0.02$ ), and a concomitant varus femoral osteotomy ( $\rho = 0.25$ ,  $p < 0.01$ ).

#### Radiographic Variables

The Spearman nonparametric correlations demonstrated no significant correlation between the occurrence of complications and any of the preoperative radiographic values.

#### Discussion

This study is the first, as far as we know, to describe complications associated with the Bernese periacetabular osteotomy in adolescent patients. The initial description of the Bernese osteotomy and the vast majority of subsequent studies have described its use in the treatment of adult hip dysplasia, in which it has been very effective in improving radiographic parameters, symptoms, and functional outcomes. Our study focuses on the prevalence and type of complications as well as the risk factors for the development of those complications in adolescent patients. An adult patient who presents with pain for the first time is more likely to have less severe dysplasia than is a patient who presents at a younger age with severe dysplasia and often has had previous surgery to treat the dysplasia. Ganz et al., in the initial description of the Bernese periacetabular osteotomy, reported on seventy-five hips with a preoperative lateral center-edge angle of  $6^\circ$  and a ventral center-edge angle of  $4^\circ$  in patients who were an average age of twenty-nine years<sup>1</sup>.

Others have reported a similar degree of preoperative acetabular dysplasia predominantly in adult patients. Weighted means of various preoperative radiographic parameters from previously published studies<sup>1,2,8,12,15,16,18,19,25-31</sup> on periacetabular osteotomy in adults showed that the patients, with an average age of 30.3 years at the time of surgery, had a lateral center-edge angle of  $5.09^\circ$ , a ventral center-edge angle of  $4.99^\circ$ , and an acetabular index of the weight-bearing zone of  $20.32^\circ$ .

In the present study, we report on seventy-six patients with an average age of 15.6 years who had an average preoperative lateral center-edge angle of  $-0.14^\circ$ , a ventral center-edge angle of  $-5.13^\circ$ , and an acetabular index of the weight-bearing zone of  $27.8^\circ$ , indicating severe acetabular deformity. In addition to the severity of acetabular dysplasia, previous hip surgery would seem to make the surgical procedure more challenging. In the literature, the highest rate of previous surgery was reported in the original series by Ganz et al.<sup>1</sup>, in which 30.7% of the patients had previous surgery, with the remaining studies having rates between 5.1% and 21%<sup>12,18,19,30</sup>. The current series of patients had the highest rate of previous hip surgery (58% of hips) prior to the Bernese periacetabular osteotomy. It can be hypothesized that the severity of hip dysplasia and the high rate of previous surgery make the treatment of these adolescent patients challenging, especially compared with adult patients. Clohisy et al. reported on a series of sixteen patients who underwent the Bernese periacetabular osteotomy for the treatment of severe acetabular dysplasia at an average age of 17.6 years<sup>3</sup>. They noted outstanding radiographic improvement for all standard parameters and significant improvement in the mean Harris hip scores from 73 points preoperatively to 91 points at the time of follow-up. Two of the sixteen patients had a major complication—loss of fixation in one and excessive medial translation of the acetabulum with associated ischial nonunion in another.

Two previous studies have specifically analyzed complications during or following the Bernese periacetabular osteotomy. Davey and Santore reviewed the initial experience of the senior author with the osteotomy and demonstrated a significant decrease in the rate of complications from 17% in the initial thirty-five procedures to a rate of 2.9% in the second thirty-five procedures<sup>13</sup>. Overall, they reported a 10% rate of complications, including excessive bleeding in two patients; reflex sympathetic dystrophy in two patients; and sciatic nerve palsy with residual deficit, deep vein thrombosis, and a nonunion that required a revision in one patient each. We report a smaller 3.6% rate of major complications, but we could not demonstrate a learning curve phenomenon, in which the rate of complications decreased with time. In the second study, Hussell et al. reviewed over 500 Bernese periacetabular osteotomies performed by Ganz and provide an ideal benchmark with which to compare one's experience<sup>32</sup>. They reported a learning curve phenomenon in which 85% of the technical complications occurred during the initial fifty procedures. Complication rates were 2.2% for intra-articular extension of the osteotomy, 0.79% for insufficient or excessive coverage,

0.6% for femoral nerve palsy, 1.0% for sciatic nerve palsy, 1.2% for posterior column discontinuity, 0.8% for acetabular fragment migration, 3% for symptoms related to screws, 0.6% for acetabular osteonecrosis, and 0.2% for femoral head osteonecrosis. The two other major complications in our study were symptomatic osteonecrosis of the femoral head and osteonecrosis of the acetabular fragment. The latter complication has been reported previously by Hussell et al. who noted a 0.6% rate of acetabular osteonecrosis<sup>32</sup>.

Many surgeons have learned from the finer technical points taught by Ganz to limit some of the complications. For example, he encountered intra-articular extension of the osteotomy<sup>1,32</sup>, which was not seen in our series and may be a reflection, in part, on the use of image intensification, especially to confirm the trajectory of the osteotomy of the infra-acetabular ischial cut and the posterior column final cut.

Ganz et al. also reported femoral nerve palsy as a major complication in their series<sup>1</sup>. Major nerve injury has been reported to occur in 1% to 10% of the patients in the literature<sup>1,2,6,12,13,15,16,26,30-32</sup>. The risk of injury to the sciatic nerve is small because the posterior column remains intact, thus protecting the nerve when the posterior column osteotomy is performed; however, nerve stretch still can occur during soft-tissue retraction during this osteotomy. The obturator nerve is in danger at the time of the pubic ramus osteotomy as it travels on the inferior aspect of the ramus immediately adjacent to the bone at the level of the osteotomy. Careful subperiosteal dissection and the use of blunt, reverse Hohmann retractors on either side of the pubic ramus during the pubic osteotomy are important. The only neurological complication in our series was transient numbness in the distribution of the lateral femoral cutaneous nerve (four hips; 5%), most likely because of stretching of the nerve during retraction. In comparison, studies on adults have described a rate of lateral femoral cutaneous nerve palsy ranging from 1.5% to 38%<sup>1,13,15,16,27,28,31</sup>. Our low rate of lateral femoral cutaneous nerve palsy may be, in part, a reflection of the retrospective nature of the study, as we relied on specific reporting of this occurrence by the patient.

Optimal reorientation of the acetabular fragment is facilitated by its extreme mobility following the Bernese osteotomy; however, this may result in overcorrection of the fragment leading to femoroacetabular impingement. The learning curve for positioning of the fragment seems to be very steep, and it may be accentuated when severe deformity is present. The use of image intensification and plain radiographs intraoperatively prior to final screw fixation<sup>14</sup> to assist in positioning the fragment has proven to be useful and was utilized

in all of the patients in this series. Two (2%) of eighty-three hips in our study underwent revision of the acetabular fragment reduction within two weeks of the index procedure because of overcorrection with excessive anterior coverage and retroversion of the acetabulum.

Five hips with nonunion of the superior pubic ramus and one hip with nonunion of the ischium were diagnosed radiographically in our series, and one hip that had a symptomatic nonunion of the superior ramus required surgical treatment. All were asymptomatic at the time of most recent follow-up. Studies on periacetabular osteotomy in adults have described nonunion rates ranging from 1% to 16%<sup>1,2,12,13,15,16,28,30-33</sup>. These nonunions are frequently symptomatic and often require operative intervention<sup>1,2,6,12,19,31,32</sup>.

The only complication found in these adolescent patients that has not been previously described is a stress fracture of the inferior pubic ramus. Four patients demonstrated this incidental radiographic finding approximately one year following the periacetabular osteotomy. The superior pubic ramus osteotomy site was united in all of these patients. None of the patients were symptomatic or underwent treatment for the stress fracture.

In the original description of the procedure, Ganz et al. noted that sixteen (21%) of seventy-five hips had a combined intertrochanteric osteotomy<sup>1</sup>. Hersche et al. studied the indications for performing an intertrochanteric osteotomy following a periacetabular osteotomy in adult patients<sup>34</sup>, and the indications continue to evolve. Our current indications are individualized for each patient; however, in general, we perform an intertrochanteric osteotomy in patients with a neck-shaft angle of >145°, those with a false acetabulum, or those with severe hip dysplasia with lateral subluxation to such a degree that there is no or minimal coverage by the acetabulum preoperatively.

In conclusion, the Bernese periacetabular osteotomy is a joint-preserving procedure that very effectively corrects acetabular dysplasia in adolescent patients and has a low rate of major complications. ■

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