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Research article

Outcomes of periacetabular osteotomy for borderline hip dysplasia in adolescent patients

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ABSTRACT

Treatment of borderline acetabular dysplasia (lateral center edge angle ≥18°) remains controversial, and there is a paucity of literature focusing on outcomes in adolescent patients. The purpose of this study was to evaluate the outcomes of a periacetabular osteotomy (PAO) as surgical management of borderline acetabular dysplasia in adolescent patients. We performed a retrospective review of prospectively collected data and included patients ≤ 21 years of age that underwent PAO for borderline acetabular dysplasia. All patients had a minimum of 1-year follow-up. Outcomes were assessed using modified Harris Hip Scores (mHHS), Hip Outcome Scores (HOS) and international Hip Outcome Tool (iHOT-33). Descriptive and univariate statistical analyses were performed. This study included 33 adolescent patients (35 hips) with symptomatic, borderline acetabular dysplasia. The majority of patients was female (32 patients, 97%); half of all patients reported a history of hip pain for over 1 year; and seven patients had previous hip arthroscopy. In addition to PAO, seven hips (20%) underwent a concurrent hip arthroscopy at the time of surgery. There were significant improvements in mean mHHS, HOS-activities of daily living (ADL), HOS-Sport and iHOT-33 scores after surgery ($P < 0.01$). Minimal clinically important difference in outcome scores was achieved for over 90% of patients at a minimum of 1-year follow-up. Borderline acetabular dysplasia is a major cause of hip pain in adolescent patients. Patients with symptomatic borderline acetabular dysplasia report a significant benefit after a PAO to correct structural hip instability.

INTRODUCTION

Hip dysplasia describes a deficiency in the bony coverage of the femoral head by the acetabulum. This deficiency results in increased stress on the acetabular cartilage, labrum and surrounding soft-tissue stabilizers of the hip. The increased force may subsequently cause hip pain, functional limitations and future joint degeneration [1–10]. The severity of dysplasia is commonly referred to in the literature as severe, moderate and mild or borderline. This classification is subjective in nature and not predicated on natural history studies. The severity is determined by using the lateral center edge angle (LCEA) of Wiberg [11], although there are many other radiographic criteria that should be considered in the diagnosis. Hip dysplasia is a well-recognized risk factor for osteoarthritis, and even borderline hip dysplasia is associated with the development of hip osteoarthritis [12].

Hip dysplasia can be surgically managed with the Bernese periacetabular osteotomy (PAO) [13]. This procedure reorients the acetabulum while preserving posterior column continuity, retaining the shape of the true pelvis and addressing the acetabular deficiency in multiple planes [13]. A recent prospective cohort study showed an improvement in pain, function, quality of life, overall health and activity level after PAO for symptomatic hip dysplasia [14]. In some cases, arthroscopic or open hip preservation procedures are required in addition to PAO in order to address intra-articular pathology, such as labral tears or impingement lesions.

The surgical management of radiographically mild or borderline hip dysplasia (LCEA ≥ 18°) remains

controversial. There are recent studies indicating good outcomes of hip arthroscopy in this cohort but there is limited follow-up and hip arthroscopy does not change the acetabular bony coverage. Historically, there are several reports of iatrogenic instability as well as poor outcomes and reoperation specifically in patients with concomitant acetabular dysplasia [1, 15–27]. Hip arthroscopy in isolation may not be adequate in the setting of hip dysplasia since it does not address the underlying structural abnormality of the acetabulum, which is contributing to the patient's symptoms and intra-articular pathology [28]. In these cases, a PAO may be beneficial to address the underlying pathoanatomy and structural abnormality, and it is now being offered to patients with borderline and moderate hip dysplasia. However, the use of PAO in these patients remains controversial given its perceived invasive nature and risk of perioperative complications [29].

Previous studies on outcomes of PAO have often excluded patients with mild acetabular deformity. A recent study compared outcomes after PAO between patients with radiographically borderline and severe hip dysplasia, but this study included patients of all ages [30]. To our knowledge, there are no studies focusing on outcomes after PAO for symptomatic borderline hip dysplasia in adolescent patients. The purpose of this study is to describe the presentation and evaluation of adolescent patients with symptomatic, borderline hip dysplasia and to analyze the patient-reported outcomes (PROs) after PAO. We hypothesize that adolescent patients with symptomatic borderline hip dysplasia will report significant improvement after PAO.

MATERIALS AND METHODS

We performed a retrospective review of prospectively collected data from our institutional hip preservation registry. The institution hip preservation registry is a repository of pre-operative, operative and post-operative data for patients, and the primary surgeon and patients who complete PROs provide the data. This study focused on patients that underwent a primary PAO or PAO following hip arthroscopy with a minimum of 1-year follow-up. We included patients aged 21 or younger at time of PAO with an LCEA $\geq 18^\circ$ and $\leq 25^\circ$. Patients undergoing bilateral PAO were included in this study if their outcomes were at least 12 months from the second sided surgery. We excluded patients that had missing baseline or 1-year follow-up data as well as patients that underwent anteverting PAO. This study was approved by our institutional review board.

Indication, surgery and follow-up

A single, high-volume surgeon evaluated and indicated all of the patients in this study. Many of the patients were also evaluated by hip arthroscopic surgeons and referred for a PAO. Indications for PAO were symptomatic acetabular dysplasia (LCEA $> 18^\circ$), which was characterized by hip pain that had been recalcitrant to extensive non-operative management, and patients with symptoms suggestive of hip instability. PAOs were not performed for a primary diagnosis of femoroacetabular impingement (FAI). Additionally, PAOs were performed after confirmation of joint congruency on von Rosen view and in the setting of minimal radiographic osteoarthritis (Tonnis Grade 0 or 1). Pre-operative evaluation consisted of an extensive history, gait observation and supine and prone hip range of motion and provocative maneuvers. Radiographic evaluation was comprised of standing AP pelvis, lateral of the proximal femur, 45° Dunn view and false profile view. Advanced imaging was obtained for surgical patients, specifically magnetic resonance imaging (MRI) to evaluate for chondral and labral pathology and computed tomography (CT) to better evaluate acetabular deficiency and for pre-operative planning. Acetabular and femoral version, as well as femoral head coverage, was evaluated on three-dimensional CT scan.

A single surgeon performed the Bernese PAO. The procedure was performed following the technique described by Ganz *et al.* [13]. Notable modifications to the original technique included a rectus sparing approach, which allowed an accelerated post-operative rehabilitation protocol [31, 32]. Abnormalities associated with FAI were addressed with an arthrotomy. This additional step was performed in patients with evidence of limited internal rotation after acetabular correction or head–neck offset abnormality on pre-operative CT scans. A capsular repair was performed whenever an arthrotomy was needed.

Post-operatively, patients were 20% weight bearing for 4 weeks after which they were allowed to be weight bearing as tolerated with crutches. After 6-week radiographs, patients could wean off their crutches and physical therapy was commenced at 6 weeks as well. Patients were evaluated at 6 weeks, 3 months, 6 months and 1 year. Post-operative physical therapy advances from a period of 6 weeks until 6 months when the protocol is directed to allow the patients to return to all activities.

Data collection and outcomes

All patients >11 years of age are included into the hip preservation registry upon initial consultation. Patients with borderline dysplasia were identified from the institutional hip preservation registry and data extraction was

performed. We collected basic demographic data, details from the pre-operative evaluation, intra-operative data, radiographic and imaging data and the incidence of peri-operative complications. Demographic data included patient age, gender, BMI and laterality. Pre-operative history data included chief complaint, diagnosis, location of pain, duration of symptoms, previous treatments and pertinent medical and surgical history. Physical examination data included range of motion and provocative maneuvers, such as impingement signs. Intra-operative data included primary and associated procedures, and if applicable, labral tear location. Imaging data were based on pre-operative radiographs, MRI and CT scans. Radiographic measures of interest included LCEA, anterior center edge angle (ACEA), Tonnis grade and acetabular depth. CT measurements included femoral and acetabular version, alpha angle and neck-shaft angle. MRIs were reviewed to determine the presence of labral tear or chondral wear and defects. Last, intra- and post-operative complications were recorded and classified by the Dindo–Clavien classification.

Patient function and outcomes were assessed using the modified Harris Hip score (mHHS), Hip Outcome Score (HOS) and international Hip Outcome Tool 33 (i-HOT33). These surveys were administered at the patient's pre-operative visit and subsequent post-operative visits. Although we did not specifically assess improvement in pain, this outcome is likely associated with other measures included in this study [33]. Minimal clinically important difference (MCID) was defined as mHHS of $\geq$8, improvement in HOS-ADL $\geq$5, improvement in HOS-Sport $\geq$6 and improvement in iHOT $\geq$ 10 [34]. All data were extracted from the registry and missing data were obtained by chart review. Our primary outcomes of interest included the mHHS, HOS and i-HOT33 scores. Secondary outcomes included pre-operative patient symptoms, physical examination and the presence of intra- and post-operative complications.

Statistical analysis

Continuous variables are summarized as means with SDs or medians with first and third quartiles (Q1 and Q3, respectively), depending upon the distribution of the data. Categorical variables are summarized as frequencies and percentages. The generalized estimating equations (GEEs) method was used to compare pre- versus post-operative imaging and PRO measures. GEE was used to account for the correlation between repeated measurements on the same patient (i.e. multiple hips or time-points). All statistical hypothesis tests were two-sided. Statistical analyses were performed with SAS Version 9.4 (SAS Institute, Cary, NC, USA).

RESULTS

This study included 33 adolescent patients (35 hips) with symptomatic borderline hip dysplasia (Table I). The mean age at time of surgery was 17 years (range 12–21 years), and the majority of patients was female (32 patients, 97%). Approximately, one-half of all patients reported a history of hip pain for over 1 year; and the pain was localized to the anterior hip (26 patients, 79%) or medial groin (seven patients, 21%) in most patients. The majority of patients had no medical problems (22 patients, 67%), and three patients had a history of anxiety or depression. In total, seven patients had previously undergone a hip arthroscopy and no patients had undergone a previous PAO on the hip of interest. On physical exam, apprehension and impingement were common findings (Table II); however, not all patients with symptomatic borderline hip dysplasia exhibited apprehension on exam. Pre-operative MRI revealed labral pathology in the majority of hips (28 hips, 85%; Table III). However, few patients reported mechanical symptoms at presentation. The mean (range) pre-operative BMI was 21.2 (12.8–29.5; $n = 30$ patients).

All patients were managed with a PAO after failure of extensive non-operative treatment which included at least 3–6 months of physical therapy and intra-articular injections. In total, 31 patients underwent a unilateral PAO, and two patients had a bilateral PAO that were at a minimum 1 year apart (range 1–3 years). Seven hips (20%) underwent a concurrent hip arthroscopy at the time of the PAO for mechanical symptoms and a detached labrum on MRI in addition to pain. Arthroscopic labral repair was performed in five cases, labral debridement in one case and removal of loose body in one case. In addition, open CAM

Table I. Demographic data for adolescent patients with mild hip dysplasia

Female, n *(%)*	*32 (97)*
Age at first PAO (years), mean ± SD	16.9 ± 2.2
BMI, mean ± SD	21.2 ± 4
Surgical side, *n* (%)	
Right	19 (58)
Left	12 (36)
Bilateral	2 (6)
Any prior hip surgery, *n* (%)	10 (30)

Table II. History and physical examination findings

	Number of patients or hips	n (%)
Primary location of pain, *n* (%)	33	
Anterior		26 (79)
Lateral		10 (30)
Medial/groin		7 (21)
Pre-operative ROM, mean ± SD (°)		
Hip flexion	34	107.1 ± 10.8
Internal rotation at 90° of hip flexion	35	37.1 ± 10.9
External rotation at 90° of hip flexion	35	52.3 ± 17.2
Hip abduction	35	33.9 ± 5.3
Provocative tests, *n* (%)		
Impingement	34	28 (82)
Instability	27	13 (48)

Table III. CT and MRI Findings

	Number of hips	
Pre-operative CT measurements, mean ± SD (°)		
Acetabular version	24	21 ± 11
Acetabular version at 1 o'clock	22	9 ± 6
Acetabular version at 2 o'clock	22	15 ± 7
Acetabular version at 3 o'clock	22	18 ± 4
Alpha angle	25	60 ± 15
Neck-shaft angle	20	131 ± 7
Pre-operative MRI findings, *n* (%)		
Labral tear	33	25 (76)
Labral degeneration without tear	33	3 (9.4)
Chondral wear (MRI)	28	14 (50)

decompression was performed in one case and open decompression of the anterior inferior iliac spine in one case.

The mean ± SD LCEA improved from 22 ± 3° pre-operatively to 36 ± 4° post-operatively ($P < 0.001$). Similarly, the mean ACEA improved from 24 ± 7° pre-operatively to 38 ± 7° post-operatively ($P < 0.001$). There were significant improvements in mean mHHS, HOS-ADL, HOS-Sport and iHOT-33 scores at a minimum of 1 year after surgery ($P < 0.001$; Table IV). Minimally important change (MIC) for mHHS was achieved for 94% of patients at their recent follow-up. Similarly, MIC for HOS-ADL was achieved for 94% of patients; MIC for HOOS-Sport was achieved for 91% of patients; and MIC for iHOT-33 was achieved for 94% of patients. We assessed minor and major complications in this cohort, and no intra- or post-operative complications were noted in these patients.

DISCUSSION

Hip dysplasia is an anatomic abnormality where the femoral head is not adequately covered by the acetabulum. This causes increased stress on the surrounding soft-tissue stabilizers of the hip, labrum and cartilage [1–10]. Even though the benefits of a PAO are well established in the setting of severe hip dysplasia, the surgical management of borderline hip dysplasia remains controversial. The majority of patients in our study had long-standing hip pain affecting their quality of life that was refractory to non-operative treatment. Extensive pre-operative workup included history, exam, radiographs, MRI and CT scan that proved evidence of borderline hip dysplasia in addition to concurrent impingement, and in some cases, intra-articular pathology. The cases are commonly evaluated and referred by hip arthroscopic surgeons and deemed to be inappropriate for arthroscopic management. We managed these cases with a PAO, and when indicated, we addressed symptomatic labral tears and FAI concurrently. In this cohort of patients with borderline hip dysplasia, we found that a PAO resulted in a significant improvement in radiographic parameters and patient outcomes.

Hip arthroscopy may be chosen as the treatment by surgeons and patients due to a concern that the PAO is a relatively invasive procedure for a patient with 'borderline dysplasia.' There have been reports of hip arthroscopy for borderline dysplasia; however, this approach may prove to be inadequate as evidenced by several reports of iatrogenic instability, poor outcomes and high rates of reoperation after isolated hip arthroscopy in the setting of acetabular dysplasia [1, 15–27]. Additionally, a recent study concluded that even if labral pathology is present on MRI, it may not explain the pain seen in patients with concomitant borderline dysplasia [35]. Structural deformity of the hip is a well-known risk factor for failure after hip arthroscopy [19]. Parvizi *et al.* [16] reported that the majority of patients with hip dysplasia and labral pathology did not

Table IV.Mean outcome scores for adolescent patients with mild hip dysplasia

	Pre-operative	*Post-operative*[a]	*Difference from baseline*[a]	*Achieved MCID (%)*	P-*value*
mHHS (SD)	50 (15)	88 (12)	38 (21)	94	<0.01
HOS-ADL (SD)	57 (15)	92 (10)	35 (19)	94	<0.01
HOS-Sport (SD)	31 (20)	81 (22)	50 (29)	91	<0.01
iHOT-33 (SD)	27 (12)	81 (18)	54 (21)	94	<0.01

[a]Outcome score at most recent follow-up (minimum of 1-year post-operative follow-up).

benefit from hip arthroscopy, and they cautioned that hip arthroscopy may be ineffective as well as accelerate the process of arthritis in these patients. The ANCHOR study investigators subsequently reported that failure of hip arthroscopy and need for PAO is commonly noted in young female patients with mild to moderate dysplasia [26]. In a recent study by Larson *et al.* [23], patients with mild to moderate acetabular dysplasia had inferior outcomes after hip arthroscopy compared with patients with FAI, and almost a third of patients with dysplasia had low outcome scores or required a subsequent osteotomy or arthroplasty. Similar results were reported by Matsuda *et al.* [27], who found that patients with borderline dysplasia and FAI had worse outcomes compared with patients with only FAI after hip arthroscopy.

In contrast, Fukui *et al.* [24] found that a subset of patients with mild to moderate dysplasia and FAI may benefit from hip arthroscopy, but this study was limited by its small sample size and lack of a comparison group. Evidence also suggests that patients who fail hip arthroscopy and require a PAO have worse outcomes compared with non-arthroscopy patients [21]. Kirsch *et al.* [28] concluded in a recent review that hip arthroscopy may be effective in patients with borderline dysplasia without frank instability, but the assessment of instability is subjective and there is a significant risk of failure in dysplastic patients with symptomatic hips, which should be discussed with patients prior to hip arthroscopy. Furthermore, surgeons should consider the results of a recent study that reported inferior outcomes in patients that undergo PAO after failed hip arthroscopy compared with patients did not undergo a previous hip arthroscopy.

Given the potential of failure and reoperation after hip arthroscopy in young patients with borderline dysplasia [36], compounded with the potential catastrophic outcome of progression of arthritis and instability, addressing the structural deformity of the hip with a PAO is a prudent approach in adolescent patients with symptomatic borderline hip dysplasia. In addition, the improved structural orientation of the hip likely complements concurrent procedures to address symptomatic intra-articular pathology and impingement. However, additional studies are needed to determine whether improved structural orientation contributes to lower risks of recurrence and reoperation in these patients. In our study, the overwhelming majority of patients had clinically significant improvements at a minimum of 1 year after PAO and no patients required a reoperation during the study period. Our results are comparable to older cohorts [30], but there is no comparative data in adolescent patients with borderline dysplasia. In our practice, a concurrent hip arthroscopy is recommended for patients with labral symptoms and evidence of a labral detachment on MRI.

The limitations of our study include our sample size and length of follow-up. However, to our knowledge, this is the largest reported series in the literature of adolescent patients treated with PAO for symptomatic borderline hip dysplasia. In addition, we did not have a comparison group in this study and we are likely underpowered to assess differences between subgroups. Previous studies have shown that addressing the structural abnormality in patients with dysplasia is paramount, but additional comparative studies are needed. Furthermore, we have presented a range of clinical and radiographic data; however, we do not have additional data such as femoral version, acetabular inclination, acetabular depth and Beighton score. Last, all procedures were performed by a single high-volume hip preservation surgeon, and the results of this study may not be generalizable to all settings.

In conclusion, symptomatic borderline hip dysplasia in adolescent patients is a challenging issue. Patient evaluation and diagnosis are based on a careful review of the history, physical exam, radiographs, and in some cases, advanced imaging. Adolescent patients that present with a long-standing history of anterior or medial hip pain, evidence of hip instability on exam and radiographic evidence of dysplasia will likely benefit from a PAO after exhausting non-operative management. Mechanical symptoms and

impingement may be addressed concurrently with open or arthroscopic procedures. The PAO is a reliable procedure for symptomatic borderline hip dysplasia in adolescent patients with significant improvements in radiographic measures and PROs.

CONFLICT OF INTEREST STATEMENT

None declared.

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