Not All Hip Dysplasias are the Same: Preoperative CT Version Study and the Need for Reverse Bernese Periacetabular Osteotomy

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Background: Dysplastic hip may present with acetabular retroversion with or without femoral retroversion. This retroversion, if not accounted for when performing a periacetabular osteotomy (PAO), will lead to anterior hip pain and early osteoarthritis. A reverse PAO involves anteverting the acetabulum while still obtaining lateral coverage. The purpose of this study was to investigate the relationship between rotational malalignment of acetabulum and femur on 2-dimensional computed tomographic (CT) scans of hips that underwent Bernese PAO and its role in the surgical decision making.

Methods: This retrospective, case-control study examined and compared preoperative 2-dimensional CT scans of hips that underwent reverse PAO to the hips that underwent traditional PAO.

Results: Twelve hips underwent reverse PAO from 2005 to 2010. Twelve hips were randomly selected from a cohort of 52 hips that underwent traditional PAO during same time period. Hips that underwent reverse PAO showed crossover sign on preoperative radiographs, but not on postoperative radiographs. Crossover sign was negative preoperatively and postoperatively on hips that underwent traditional PAO. The 2 groups were similar in regards to preoperative lateral center-edge angle, acetabular index, and anterior center-edge angle on plain radiographs and showed significant improvement after surgery. On preoperative CT scans both acetabulae and femurs were retroverted in reverse PAO group. Comparison of the 2 groups demonstrated that acetabular version (16.5 ± 4.9 degrees vs. 25.3 ± 5.6 degrees, $P = 0.001$), femoral version (12.8 ± 10.4 degrees vs. 31.9 ± 8 degrees, $P < 0.001$), and McKibbins Instability Index (29.3 ± 11.9 degrees vs. 57.1 ± 9.8 degrees, $P < 0.001$) were significantly lower for the reverse PAO than the traditional PAO group. Anterior Acetabular Sector Angle (determines anterior coverage) was significantly higher in reverse PAO group, 53.1 ± 13.7 degrees versus 39.7 ± 10.4 degrees ($P = 0.013$).

Conclusions: Retroverted acetabulae seem to be associated with reduced femoral version. Given that retroverted acetabulum and retroverted femur have additive effect and increase chances of anterior hip pain, preoperative identification of correct acetabular, and femoral version by CT scan or MRI is necessary to determine which hip need reverse PAO as opposed to traditional PAO.

Level of Evidence: Level III—Therapeutic.

Key Words: reverse periacetabular osteotomy, Bernese periacetabular osteotomy, acetabular anteversion, acetabular retroversion, femoral anteversion, reverse PAO, Ganz osteotomy, Bernese osteotomy, pelvic osteotomy, PAO

(*J Pediatr Orthop* 2015;00:000–000)

Recent literature has concentrated on the abnormal morphology of hip joint that is responsible for femoroacetabular impingement, labral tear, abnormal joint stresses, cartilage damage, and therefore, early osteoarthritis (OA) of the hip joint.[1–3] Rotational abnormalities of the hip are, however, underreported in the literature. In general, most dysplastic hips have anteverted acetabulum. Improved radiographic assessment of hip anatomy revealed that up to 15% to 20% of dysplastic hips have retroverted acetabulum, which may be coming either from a hypoplastic posterior acetabular wall, prominent anterior acetabular wall, or pure rotational abnormality of the acetabulum.[4,5] Studies also have found a higher incidence of anterior hip pain and early OA with retroverted acetabulum due to the abnormal abutment of the anterior femoral neck on the anterior edge of the acetabulum.[3–8] Tönnis and Heinecke[9] reported that acetabular retroversion and associated femoral retroversion have an additive effect and this is a major cause of hip pain and OA. Therefore, recognition of rotational malalignment of both the acetabulum and femur is important when performing any corrective rotational osteotomy around the hip joint. Despite this, no studies have examined the role of femoral version (FV) in rotational pelvic osteotomy.

The Bernese periacetabular osteotomy (PAO) is a powerful rotational osteotomy providing maximum freedom of rotation to the acetabular fragment compared with other pelvic osteotomies.[10,11] In addition, PAO carries numerous advantages such as, single incision, early patient mobility due to intact posterior column, medialization of hip joint, and unaltered true pelvis.[11] Steppacher et al[12] reported a 60% survival rate of hips at 20 years follow-up after PAO. Traditionally the Bernese

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There was no external funding for this study related with this study.
The authors declare no conflicts of interest.

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PAO has improved anterior and lateral coverage of the femoral head in dysplastic hips by producing internal rotation, forward tilt (or extension), and medialization of the acetabulum.[13] This challenging step of repositioning of the acetabulum may sometimes lead to excessive anterior coverage or frank retroversion. Many investigators have found high incidences of acetabular retroversion after traditional PAO and could be the reason for anterior hip pain after the surgery. None of these studies objectively assessed the status of their acetabular version (AV) preoperatively.[2,14–17] Nonetheless, a hip with a preoperatively retroverted acetabulum is not considered an ideal candidate for a traditional PAO. Professor Ganz et al[18] used the term reverse Bernese PAO for the pelvic osteotomy in which they treated underlying retroverted acetabulum by creating anteversion.[7] A detailed description of the surgical technique of the reverse Bernese PAO was reported by Sierra.[19] The current study carries the same meaning of the reverse Bernese PAO as has been described by these authors in the past. The reverse Bernese PAO involves rotating the retroverted acetabulum to reduce retroversion or produce anteversion while simultaneously achieving lateral coverage.[7,18,19]

We routinely obtain 2-dimensional (2-D) computed tomographic (CT) version studies of hips before a PAO. Our hypothesis is that dysplastic hips have rotational malalignment of both the femur and the acetabulum. Therefore, in addition to AV we take FV into account in surgical planning. In this study, we sought to investigate the relationship between rotational malalignment of acetabulum and femur on 2-D CT scans of hips that underwent PAO at our institution and its influence on the surgical decision making. We understand that the average age of patients at the time of surgery in our study does not belong to pediatric age group and this is a pediatric-oriented orthopaedic journal. However, because of several reasons we have strong feeling that this manuscript is worth publication in the *Journal of Pediatric Orthopaedics*. First, there are several adolescent patients in this study; second, hip dysplasia is more commonly treated in pediatric age group; third, overall pelvic osteotomies are more commonly performed in pediatric age group; and fourth, recent trend shows that Bernese PAO is getting more popular in adolescent patients with hip dysplasia in North America. In addition, given that the purpose of this study is to make surgeons aware about the importance of surgical planning of the pelvic osteotomies we feel pediatric orthopaedic surgeons will be at advantage with this knowledge by publication in *Journal of Pediatric Orthopaedics*.

METHODS

After obtaining institutional review board approval we conducted this retrospective case-control study on hips that underwent a PAO from 2005 to 2010. Operative notes of all hips were carefully reviewed to distinguish between hips that underwent a reverse PAO and a traditional PAO. Preoperative CT scans of hips that underwent a reverse PAO were analyzed for this study and were then compared with a matched control group obtained by random computer-generated selection of hips that underwent a traditional PAO.

Radiographic parameters were measured on plain anteroposterior pelvis and false-profile radiographs preoperatively and postoperatively and compared for the 2 groups. To minimize interobserver variation a single fellowship trained orthopaedic surgeon performed all measurements. Measurements were repeated at 6 to 8 weeks to determine intraobserver reliability. During the second round of measurements the observer was blinded regarding the group assignment of the hips. Dysplasia was quantified by the lateral center-edge angle (LCE, normal > 25 degrees) of Wiberg,[20] the anterior center-edge angle (ACE, normal > 25 degrees) as described by Lequesne and de Seze,[21] and the acetabular index (AI) of the weight-bearing zone (normal < 10 degrees).[20] Migration index (MI) was calculated as the part of the femoral head outside the vertical line drawn at the outer edge of acetabulum, on the plain AP radiographs, divided by the total width of the femoral head multiplied by 100. The acetabulum was considered retroverted on plain radiographs if the crossover sign was positive. Posterior wall coverage was evaluated by the posterior wall sign, which was considered positive if the posterior wall was medial to the center of femoral head, indicating deficient posterior coverage.[8]

Preoperative 2-D axial CT scans were used to measure AV, anterior and posterior coverage of the femoral head, and FV using the standardized technique described by Anda et al.[22] Acetabular measurements were performed using a transaxial slice through the center of both femoral heads (Fig. 1). The angle formed by a reference line perpendicular to the line joining the posterior edge of the 2 ischium and a line connecting the posterior and anterior edges of the acetabulum, represents AV (normal 21 degrees). The angle formed between a line connecting the 2 femoral heads and an oblique line connecting the center of the femoral head to the anterior edge of the acetabulum represents the anterior acetabular sector angle (AASA, normal 63 degrees in males and 64 degrees in females),

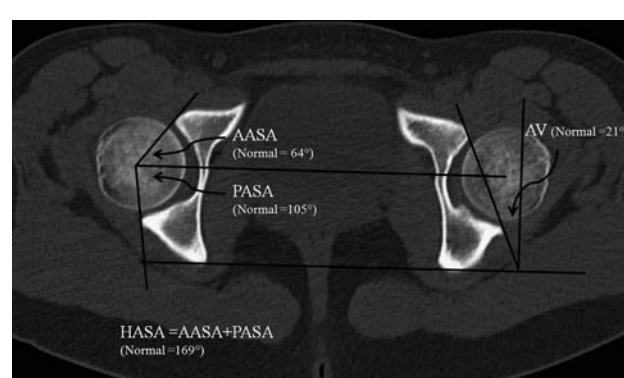

FIGURE 1. Two dimensional transaxial computed tomographic scan shows measurements: anterior acetabular sector angle (AASA), posterior acetabular sector angle (PASA), horizontal acetabular sector angle (HASA), and acetabular version (AV).

which determines the anterior coverage of the femoral head. Similarly, the angle formed between a line connecting the 2 femoral heads and an oblique line connecting the center of the femoral head to the posterior edge of the acetabulum represents the posterior acetabular sector angle (PASA, normal 105 degrees), which determines posterior coverage of the femoral head. Global coverage was assessed by using the horizontal acetabular sector angle (HASA, normal 169 degrees; HASA = AASA + PASA). FV (normal 15 degrees) was calculated as the angulation between the projected head-neck angle and the posterior condylar tangent. McKibbins Instability Index (MII, normal 30 to 40 degrees) is the sum of acetabular and FV.[9]

STATISTICAL METHODS

Intraclass correlation coefficient (ICC) was calculated to assess intraobserver reliability of CT scan measurements. ICC values were interpreted as per recommendations by Fleiss.[23] The frequency of positive/negative crossover and posterior wall signs was determined on preoperative and postoperative plain radiographs for the reverse and traditional PAO groups. The t test for independent samples was used to compare the 2 groups for LCE, AI, MI, and ACE from preoperative and postoperative plain radiographs and AV, FV, AASA, PASA, HASA, and MII from preoperative CT scans. The t test for related samples was used to compare preoperative and postoperative LCE, AI, MI, and ACE from plain radiographs for the reverse PAO group and for the traditional PAO group. Pearson Product Correlation Coefficient (r) was determined to assess the correlation between AV and FV. For all analyses, $P < 0.05$ was considered significant.

RESULTS

Sixty-four hips underwent a PAO from 2005 to 2010. Twelve hips in 10 patients underwent a reverse PAO, at a mean age of 22.3 (± 9.7) years, and constituted our study group. They were compared with a computer-generated randomly selected control group, matching the basic preoperative variables between the groups. Hence, the control group comprised 12 hips, 10 patients, mean age 33.8 (± 12.3) years, from the remaining cohort of 52 hips that underwent a traditional PAO. The reverse PAO (or retroverted acetabulum) and the traditional PAO groups (or anteverted acetabulum) were not significantly different ($P > 0.05$) in regards to LCE, AI, MI, and ACE preoperatively and postoperatively (Table 1). Both groups showed significant improvement in all of these parameters from preoperative to postoperative values (Table 2).

Acetabular and FV

Preoperative radiographs of the hips that underwent reverse PAO showed a positive crossover sign on 10 hips but none on postoperative radiographs. Two hips with unacceptable pelvic tilt on preoperative radiographs were excluded for the assessment of crossover sign. This was in contrast to the hips from the control group that showed a negative crossover sign on both preoperative and postoperative radiographs.

On axial CT scans, the hips that underwent reverse PAO were retroverted with AV significantly lower than those that underwent traditional PAO, 16.5 ± 4.9 degrees versus 25.3 ± 5.6 degrees ($P = 0.001$). The mean FV in the reverse PAO group was significantly lower than the traditional PAO group, 12.8 ± 10.4 degrees versus 31.9 ± 8 degrees ($P < 0.001$). Seven of 12 femurs (58.3%) were retroverted in reverse PAO group (< 15 degrees). All 12 hips in traditional PAO group showed increased femoral anteversion (> 15 degrees). A moderate correlation ($r = 0.50$) was found between AV and FV ($P < 0.013$) (Fig. 2). The hips in the reverse PAO group having low values of AV (or acetabular retroversion) associated with low values of FV (or femoral retroversion). The McKibbins Instability Index was significantly lower in hips that underwent a reverse PAO as compared with the traditional PAO, 29.3 ± 11.9 degrees versus 57.1 ± 9.8 degrees ($P < 0.001$) (Table 3).

TABLE 1. Comparison of Reverse and Traditional PAO Groups for Plain Radiographs

	Reverse PAO [Mean (SD)]	Traditional PAO [Mean (SD)]	*P*
AP view			
Lateral center-edge angle (deg.)			
Preop	10.9 (± 7.9)	11.0 (± 5.4)	0.976
Postop	31.1 (± 7.0)	26.5 (± 5.5)	0.100
Acetabular index (deg.)			
Preop	14.5 (± 6.2)	20.8 (± 9.1)	0.061
Postop	3.6 (± 4.3)	6.8 (± 6.3)	0.159
Migration index (%)			
Preop	34.1 (± 8.0)	37.0 (± 11.5)	0.469
Postop	15.3 (± 5.4)	17.7 (± 3.1)	0.219
False-positive view			
Anterior center-edge angle (deg.)			
Preop	14.4 (± 11.4)	9.6 (± 11.2)	0.386
Postop	34.5 (± 11.3)	28.9 (± 9.7)	0.223

AP indicates anteroposterior; PAO, periacetabular osteotomy; Preop, preoperative; Postop, postoperative.

TABLE 2. Comparison of Preoperative and Postoperative Results for Plain Radiographs

	Preoperative X-ray [Mean (SD)]	Postoperative X-ray [Mean (SD)]	*P*
Reverse PAO			
Lateral center-edge angle (deg.)	10.9 (± 7.9)	31.1 (± 7.0)	< 0.001
Acetabular index (deg.)	14.5 (± 6.2)	3.6 (± 4.3)	< 0.001
Migration index (%)	34.1 (± 8.0)	15.3 (± 5.4)	< 0.001
Anterior center-edge angle (deg.)	14.4 (± 11.4)	34.5 (± 11.3)	< 0.001
Traditional PAO			
Lateral center-edge angle (deg.)	11.0 (± 5.4)	26.5 (± 5.5)	< 0.001
Acetabular index (deg.)	20.8 (± 9.1)	6.8 (± 6.3)	< 0.001
Migration index (%)	37.0 (± 11.5)	17.7 (± 3.1)	< 0.001
Anterior center-edge angle (deg.)	9.6 (± 11.2)	28.9 (± 9.7)	0.002

PAO indicates periacetabular osteotomy.

Acetabular Coverage of the Femoral Head

Preoperatively all hips in both groups were dysplastic, evident on both plain radiographs and CT scans (Tables 1, 3). On plain AP pelvis radiographs the posterior wall sign was positive in 11 of 12 hips in the reverse PAO group while it was positive in 5 of 12 hips in the control group. This demonstrates that posterior wall deficiency was present in majority of retroverted hips but only less than half of the anteverted hips.

CT measurements showed deficient global coverage of 83.1% and 77.3% of normal predicted values of HASA, respectively, in reverse and traditional PAO groups. Furthermore, anterior coverage was significantly higher in retroverted acetabulae, that is, in reverse PAO group versus traditional PAO group, 53.1 ± 13.7 degrees versus 39.7 ± 10.4 degrees ($P = 0.013$). A trend toward reduced posterior coverage in retroverted acetabulae was found but measurements were not significantly different between the 2 groups, PASA was 87.3 ± 6.2 degrees versus 90.9 ± 7.7 degrees ($P = 0.22$). Ratio of percentage of acetabulum utilized in anterior coverage to percentage for posterior coverage revealed 60.8% in retroverted group and 43.6% in anteverted group ($P = 0.005$) (Table 3). Intraobserver reliability of CT scan measurements was excellent with ICC ranging between 0.78 and 0.93.

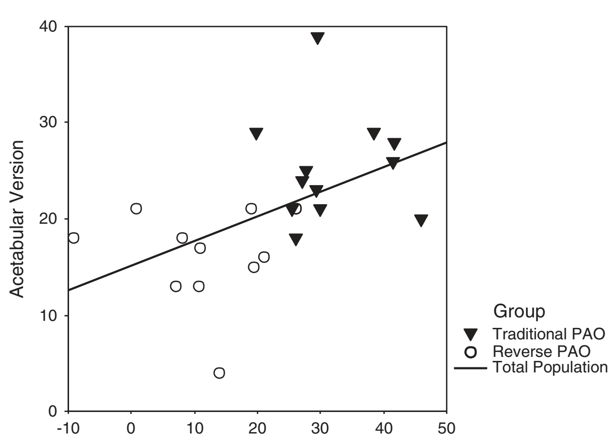

FIGURE 2. Association between acetabular version and femoral version for reverse periacetabular osteotomy (PAO) and traditional PAO hips.

DISCUSSION

This study demonstrates that preoperative version studies of both the acetabulum and femur are useful in planning the Bernese PAO. Combined preoperative assessment of acetabular and FV determines how the acetabulum should be repositioned during the PAO. We found a higher incidence of retroverted femurs in hips having acetabular retroversion therefore, creating a larger amount of exposed femoral head posteriorly.

Various authors recognized a strong correlation between acetabular retroversion and early OA of the hip.[3–8,24,25] Fujii and colleagues found hips with acetabular retroversion had a 3.8-fold higher risk of onset of hip pain than those with anteverted acetabulum. They also found that patients with retroverted acetabulum have onset of hip pain at a significantly younger age than those with anteverted acetabulae.[5] Tönnis and Heinecke[9] studied 254 hips for the combined effect of femoral and acetabular rotational deformities on hip pain and early OA. They were able to divide the hips into groups depending on various combinations of femoral and AV. They found that 41% had a combination of various degrees of retroverted acetabulum and retroverted femurs, 9% hips had retroverted acetabulum with increased femoral anteversion, 21% had increased acetabular anteversion in combination with femoral retroversion, and 8% had both increased acetabular and femoral anteversion. Their observations suggested that retroverted acetabulae and retroverted femurs have an additive effect and are a major cause of hip pain and early OA.[9] In our study we found a positive linear relationship between retroverted acetabulae and retroverted femurs (Fig. 2). Seven of 12 (58.2%) retroverted acetabulae had retroverted femur. In contrast, none of the anteverted acetabulae in our study had retroverted femurs. Preoperative precise determination of these retroverted acetabulae guided us to perform reverse PAO instead of traditional PAO.

The MII is based on the assumption that the effects of femoral and acetabular anteversion may be additive or may offset each other. The index is calculated by the sum of femoral and acetabular anteversions. Normal values

TABLE 3. Comparison Between Reverse PAO and Traditional PAO for Preoperative CT Scans

	Reverse PAO [Mean (SD)]	Traditional PAO [Mean (SD)]	*P*
Acetabular version (deg.)	16.5 ± 4.9	25.3 ± 5.6	0.001
Femoral version (deg.)	12.8 ± 10.4	31.9 ± 8	< 0.001
McKibbins Instability Index (N = 30-40 deg.)	29.3 ± 11.9	57.1 ± 9.8	< 0.001
AASA (N = 63 deg. M, 64 deg. F) (percentage of entire acetabulum)	53.1 ± 13.7 (37.8)	39.7 ± 10.4 (30.4)	0.013
PASA (N = 105 deg.) (percentage of entire acetabulum)	87.3 ± 6.2 (62.1)	90.9 ± 7.7 (69.6)	0.222
AASA/PASA % ratio	60.8 ± 15.1	43.6 ± 11	0.005
HASA (N = 169 deg.) (percentage of normal expected value)	140.4 ± 16.4 (83.1 ± 9.7)	130.6 ± 13.9 (77.3 ± 8.2)	0.127

AASA indicates anterior acetabular sector angle; CT, computed tomography; F, female; HASA, horizontal acetabular sector angle; M, male; N, normal; PAO, periacetabular osteotomy; PASA, posterior acetabular sector angle.

of MII range between 30 and 40 degrees. Tönnis and Heinecke[9] found that MII value < 20 degrees is a cause of altered rotation of the hip, pain and early OA. Higher values are suggestive of hip instability, with > 60 denoting severe instability. Preoperative MII in our reverse PAO group was < 30 degrees. Any further reduction in AV by traditional PAO in these hips would have further reduced MII and adversely affected the hip joint by producing anterior hip pain and early OA. On the contrary, preoperative MII of hips that underwent traditional PAO was almost 60 degrees. These hips needed reduction of their AV or FV to bring the MII within the normal range. We performed the traditional PAO in these hips, reducing acetabular anteversion and obtaining lateral coverage at the same time. Therefore, while performing any reorientation osteotomy of either the acetabulum or femur, consideration should be given to the version of the other component and all attempts should be made to bring the MII within normal range.

Studies analyzing acetabular retroversion after PAO have reported its incidence between 25% and 62%.[2,12,14–16] Similarly, the rate of anterior hip pain after PAO has been shown to be up to 56%.[2,12,14] Xie et al[16] demonstrated significant reduction in free flexion in hips with retroversion after PAO. In addition, they found a 1-grade progression in Tönnis hip OA scale in most hips with retroversion after PAO.[16] Myers et al[15] recommended doing routine hip arthrotomy during PAO to visualize any abnormal femoral and acetabular abutment and to do an osteochondroplasty if necessary to prevent anterior femoroacetabular impingement. None of these studies objectively assessed preoperative AV and none of them took FV in account while performing a PAO. This raises the question whether all of their hips were real candidates for traditional PAO or some were the candidates for reverse PAO and doing that could have reduced such a high incidence of postoperative anterior hip pain in their population.

Clinical recognition of FV is not easy to assess in the adult population. Several factors should be considered: adult patients have different body habitus and amount of anterior or posterior hip pain. Retroverted acetabulae in these patients are often a reason for anterior hip pain making flexion and rotation difficult to examine. In addition, patients with exposed posterior femoral head (retroverted acetabulum) may also have posterior femoral head or acetabular cartilage lesion (coup-countercoup lesion) resulting in painful rotational motion even in the prone position. Preoperative CT version studies of the acetabulum and femur in our study show significant linear association between acetabular retroversion and femoral retroversion similar to that reported by Tönnis and Heinecke.[9] At this point it is difficult to say that CT is absolutely necessary because of limited power in the study. However, we found CT very helpful in our practice in the preoperative planning.

Preoperatively, plain radiographs and CT evaluation of the hips in the present study demonstrated that all hips irrespective of their group were globally dysplastic. Global coverage (HASA) was not significantly different between the groups. Similarly, posterior coverage (PASA) was also not significantly different between the groups on CT scans. However, anterior coverage (AASA) was significantly higher in retroverted acetabulae. The ratio of percentage of coverage of the femoral head anteriorly/posteriorly was also higher in the retroverted hips than anteverted hips. This demonstrates that acetabular retroversion in patients with hip dysplasia results more from relative excessive anterior coverage than posterior insufficiency. This finding is different from that of Dandachli's study, which showed that retroverted acetabulae are more covered anteriorly and are also deficient posteriorly.[3] This is one of the reasons that we feel more confident and comfortable obtaining a CT scan for precise assessment of coverage and planning the surgery because 3-D assessment of the deficiency of the acetabulum is very important to recognize before we reposition the acetabulum during a PAO.

The placement of the acetabular fragment during surgery is the most challenging step of the PAO. Diagnosis of acetabular retroversion on plain radiographs is difficult, because it is determined by the relationship of anterior and posterior walls of acetabulum, which is influenced by the quality of radiograph and pelvic tilt. Moreover, there is no objective way to quantify the amount of retroversion on plain radiographs. Underlying rotational malalignment of the femur also influences outcomes of rotational pelvic osteotomies. As experience with PAO is increasing we give extra care not to produce any untoward retroversion during the surgery especially in hips with preoperative retroverted acetabulae or retroverted femurs. Preoperative CT version studies help to objectively assess the version of the acetabulum and femur, and therefore, assist in planning of the crucial intraoperative step of optimal placement of acetabulum more precisely. We routinely introduce 2 Schanz pins in the proximal portion of the acetabulum after completing all osteotomy cuts. These pins are inserted perpendicular to each other and provide better control over 3-D mobilization of the acetabulum. We then reposition the acetabulum as per preoperative planning from CT scans. In general for retroverted acetabulum, reorientation is achieved by combined flexion and internal rotation of the acetabular fragment.[7,19] The goal is to eliminate the crossover sign and allow sufficient impingement-free flexion and internal rotation. Anterior and posterior rims of acetabulum are carefully checked under image guidance before final fixation to avoid any excessive posterior coverage.

This is the first study in English literature determining the role of FV in PAO. The most important findings are the higher association between retroverted acetabulae and retroverted femurs, and the role of 2-D CT scans to objectively define these deformities and therefore assist in the surgical decision making. We assume that consideration of this crucial information in surgical planning of a joint preservation surgery like the PAO will positively impact the outcome by reducing anterior hip pain and may improve future survival rate of hips after the surgery. There are certain limitations to our study. This includes the lack of postoperative CT scans to determine the extent of improvement after the PAO and the long-term clinical and functional outcome data. However, we believe that this preliminary study on this topic will actuate future prospective studies to substantiate our findings.

In summary, Bernese PAO is a powerful technique to reorient dysplastic and maloriented acetabulum. Retroverted acetabulae seem to have a higher association with retroverted femurs. Identification of this rotational malalignment of acetabulum and femur is necessary as retroverted hips require reverse Bernese PAO to improve their AV as opposed to traditional PAO. Therefore, we recommend a 2-D axial CT version study or MRI as part of routine preoperative planning to objectively determine the correct version of the hip (both acetabulum and femur) and distinctly identify those requiring reverse PAO.

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