Evolution of Technique and Indications for the Bernese Periacetabular Osteotomy

Michael Leunig, M.D., and Reinhold Ganz, M.D.

Abstract
Acetabular dysplasia is among the most frequent causes of secondary osteoarthritis (OA) of the hip. While hip arthroplasty is a valid option in elderly patients, young and active patients are likely to outlive their implants and therefore may require a different approach. During the last 20 years, the emphasis of these osteotomies shifted from the femoral to the acetabular side, with the Bernese periacetabular osteotomy being one of the most frequently and successfully used techniques today. The procedure combines a polygonal juxta-articular osteotomy using a modified Smith-Peterson approach. During refinement of the technique, the principle osteotomy steps remained unchanged, while the soft-tissue dissection has been modified, in that the abductors are not detached from the iliac wing. Due to a better appreciation of hip deformities, other indications for this technique have continuously evolved over time.

Residual acetabular dysplasia is considered to be the most frequent cause of degeneration of the hip, leading to end-stage osteoarthritis (OA) in 25% to 50% of cases by the age of 50 years.1 Arthroplasty, being the treatment of choice in the aged population, is a less attractive solution in young, active patients. For these patients, joint-preserving surgery addressing the morphological deformity is preferred, with the intention of preventing or at least delaying the development of severe osteoarthritis.

Technique
For the first few years, the abductor musculature was detached from the ilium for execution of the chevron-type osteotomy of the ilium1; now all osteotomies are executed from the inside of the pelvis.10-12 The following will briefly describe the different steps. As part of the modified Smith-Petersen approach, the anterosuperior iliac spine is osteotomized and reflected medially together with the origin of the sartorius muscle. After preparation of the space between the anteroinferior capsule and the psoas tendon, the ischium is approached proximal to the obturator externus muscle. This is important because the medial femoral circumflex artery runs distal to this muscle.13 Starting at the infracotyloid groove (posterior inferior rim of the acetabulum), the first, incomplete osteotomy of the ischium is approached proximal to the obturator externus muscle. This is important because the medial femoral circumflex artery runs distal to this muscle.13 Starting at the infracotyloid groove (posterior inferior rim of the acetabulum), the first, incomplete osteotomy of the ischium is executed with a special chisel and is normally 2 to 2.5 centimeters deep. It is recommended to perform this osteotomy using palpable landmarks; however, many surgeons prefer to control this step with fluoroscopy. The second osteotomy is the complete separation of the pubic bone medial to the iliopectineal...
eminence; during this osteotomy, the obturator nerve and vessels have to be protected with blunt retractors. The third osteotomy has two branches: the supra-acetabular osteotomy, performed with an oscillating saw, and the retro-acetabular osteotomy, performed with chisels. The last osteotomy connects the first incomplete cut of the ischium with the retroacetabular osteotomy and is performed from inside the pelvis with a special chisel. Using a Schanz screw inserted at the anteroinferior iliac spine and a spreader, the acetabular fragment is mobilized to allow spatial orientation. It is preferable to start the correction with anterior rotation of the fragment; this movement normally produces additional lateral coverage that is often sufficient. If more lateral coverage is needed, it is now easier to correct this with the use of a second Schanz screw. Starting the correction with improvement of the lateral coverage first leads to earlier and higher friction between the fragment and its osseous bed, especially at the pubis osteotomy, and makes the other corrections more laborious. Adjustment of version is always the last correction. One to several orthograde plain films of the pelvis allow for optimal spatial control of the acetabular correction before the position of the fragment is definitively fixed, using three 3.5 mm screws.

The osteotomies are normally consolidated after 6 to 8 weeks, mostly dependent on the amount of correction. Thereafter, increased loading of the hip is allowed and muscle strengthening and range-of-motion training is initiated. The operated hip is normally ready for standard use 3 to 4 weeks after controlled weightbearing was permitted.

Experience
One of our earlier findings was the variety of acetabular rim pathologies. It was known that the labrum may be avulsed in hip dysplasia. However, the incidence was seen much more frequently using routine magnetic resonance (MR) arthrography and was often accompanied by other rim pathologies, such as ganglion formation within and outside the capsule. Rim fracture in the presence of acetabular dysplasia could be identified as a special type of a labrum rupture. Using magnetic resonance imaging (MRI), one could also see that some labral tears showed the disconnection deep within the acetabular cartilage, indicating an unfavorable prognosis when compared with a labrum that was avulsed at its connection to the acetabular cartilage. Also, our 10-year results showed that hips with an intact labrum at the time of surgery do better compared to hips with a labral rupture. The observation that the labrum in acetabular dysplasia is hypertrophic added a new criterion in borderline morphologies, where symptoms may be related more to an impingement and less to the dysplasia.

Over the years, we learned that acetabular dysplasia is not a uniform anterolateral deficiency of femoral head coverage but is a diversity of pure or combined anterior, lateral, and posterior coverage problems; the most important being retroversion of the acetabulum as seen in one out of six dysplastic hips. Marked retroversion has been observed in hip dysplasia with proximal femoral focal deficiency (PFFD), in posttraumatic dysplasias, and more importantly after reorientation procedures, such as Salter osteotomies in childhood. If a retroverted dysplastic acetabulum is redirected in the same way as an antero-laterally dysplastic acetabulum, the problems in such a hip may be increased, and more difficult revision surgery may become inevitable.

Our first 75 PAOs with a minimum follow-up of 10 years showed good-to-excellent results in 88%, when only hips without radiographic signs of osteoarthritis were considered; with all hips included, the success rate dropped to 73%. At a minimum follow-up of 20 years, the same group of patients had a success rate of 75% and 60%, respectively (Fig. 1), indicating that the PAO can be a successful treatment concept and revealing long-term results that are clearly superior to femoral corrections in hip dysplasia.

As reported for femoral osteotomies for hip dysplasia, the failure rate is high in hips with grade III osteoarthritis, an observation that led to exclude most of such hips from the indications for PAO. However, an anteroposterior radiograph

Figure 1 A. Preoperative pelvic anteroposterior radiograph of a 17-year-old female with bilateral symptomatic anterolateral acetabular dysplasia, without signs of radiographic osteoarthritis. B. Twenty years after PAO, the joint space was still preserved, and the patient was doing well clinically.
alone may be misleading, since anterolateral subluxation of the femoral head may mimic arthritic joint space narrowing; if the joint space becomes clearly wider with abduction and slight flexion, such a hip can still be an acceptable indication for PAO with a good prognosis for several years.

The 10-year follow-up study yielded unexpected findings, with close to 30% of the patients developing impingement symptoms over time, even with an acetabulum considered to be perfectly oriented. Further studies revealed that the anterior head-neck junction in acetabular dysplasia frequently has no waisting contour, eventually leading to impingement after the acetabulum is corrected.34 As a consequence, a routine capsulotomy is performed to check motion, especially for internal rotation and to perform an osteochondroplasty when needed to normalize the waist of the anterolateral head-neck contour. A recently completed 10-year follow-up study compared a series without routine capsulotomy and eventual femoral osteochondroplasty with a newer series with such additional steps, but also including special efforts made for an optimal correction of acetabular version. Further optimization of results may be possible by combining acetabular and femoral corrections in dysplastic hips with complex acetabular and femoral deformities, although the number of such combined surgeries has been small.25,26

Evolution of Indications
Retroversion is not only seen together with acetabular dysplasia, but found even more frequently in non-dysplastic hips where it is considered to be more a torsional problem of the hemipelvis than of the acetabulum.27,28 Isolated impingement due to retroversion is a linear contact between the rim area of the anterior over-coverage and the head-neck junction. However, many hips with normal coverage in the frontal plane and retroversion have an additional abnormality of the proximal femur, which is mainly a nonspherical extension of the femoral head.29 In young patients without major damage to the rim cartilage and with a posterior acetabular border clearly medial to the center of rotation, the retroversion can be treated with a reversed periacetabular osteotomy, which re-establishes anteversion by internal rotation of the acetabular fragment.30 The risk of posterior impingement increases with higher corrections; furthermore, larger malformations of the proximal femur may not be sufficiently correctable by an anterior arthrotomy. In such instances, one may decide to start with a lateral approach to shape the proximal femur first. Depending on the local situation, surgery may continue with additional trimming of the acetabular rim or with periacetabular osteotomy by this approach.31 When the lateral execution of the PAO is combined with a large capsulotomy, the dissection must include preservation of the blood supply to the acetabular bone.32

A further possibility is to execute only the first and more difficult ischial cut of the PAO by the lateral approach and to continue with the remaining periacetabular cuts, using the Smith-Petersen approach after repositioning of the patient into a supine decubitus position. This is a safe procedure and the subsequent execution of the PAO is less time-consuming. Together with an inguinal extension of the Smith-Petersen approach, it has been successfully applied for complex protrusio hips or for posttraumatic intra-pelvic displacement of the acetabulum in young patients.26

Discussion
The surgical technique of the Bernese periacetabular osteotomy was subjected to some modifications over time; however, the principle osteotomy steps did not undergo substantial changes. Soon after inauguration of the technique, it became obvious that for the supracaetal osteotomy complete stripping of the abductor musculature from the ilium was not necessary and that all cuts could be performed easily from the inside of the pelvis. An early adaptation to increased knowledge of the periacetabular vascularity placed the supra-acetabular osteotomy more cephalad, immediately distal to the anterior superior iliac spine. The advantages of this were two-fold: first, the vascular supply from the superior gluteal artery to the supra-acetabular bone could be protected more efficiently, and second, the purchase of the Schanz screw, inserted into the anterior inferior iliac spine for manipulation of the acetabular fragment, was clearly increased. After recognition of the diversity of intra-articular pathology,3,24 the arthrotomy for treating such pathology during execution of the osteotomies became a routine aspect of the procedure. Meanwhile, this has been shown to lead to substantial improvement of the long-term results, although the diversity the patho-morphologies and the varying degrees of degeneration before surgery will always play an important role for the outcome.9 Viewing the spectrum of our surgical procedures to preserve the natural hip joint, periacetabular osteotomy for acetabular dysplasia is the procedure that leads to the most predictable results. However, the technical execution, and even more so, the spatial orientation of the acetabulum remains challenging.

In the future, efforts have to be concentrated on better preoperative evaluation. New parameters for grading of the cartilage damage before surgery and a stratification of the series into morphological categories is necessary to assess and eventually achieve more meaningful results. Improvement of the technical execution of this demanding surgery is certainly desirable. Computer navigation for osteotomies and correction have been tested; however, so far, it has not become routine practice.34 One obstacle is the need for pre-operative computer tomography, an aspect of some importance for these predominantly female patients in their reproductive age; however, computer navigation may have a place in phantom surgery, with the goal to shorten the learning curve. Recently, mini-invasive surgery for PAO has been discussed35 and may be justifiable for small deformities; however, for more severe dysplasias,
especially when version has to be corrected, a perfectly mobile acetabular fragment is needed to allow for optimal spatial orientation of the acetabulum. During the more recent years of experience with periacetabular osteotomy, other pathologies have become conditions of interest for correction using this technique. Retroverted hips are sometimes indicated. The execution of the osteotomy steps is identical; however, the manipulations for optimal positioning without adverse side corrections are different. For other pathologies, such as protrusio acetabuli and posttraumatic deformities, the PAO remains a technical possibility; however, the maneuvers needed for adequate correction of the complex deformity in an individual situation should not be underestimated.

**Disclosure Statement**
None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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