Periacetabular osteotomy: a review of swiss experience

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Abstract Symptomatic dysplasia of the hip and acetabular retroversion are possible causes of osteoarthritis in the young adult. Surgical management with reorientation of the acetabulum allows causal therapy of the deformity and preservation of the native hip joint. The Ganz' periacetabular osteotomy permits a free 3-dimensional reorientation of the acetabulum and respects the blood supply of the acetabular fragment. The posterior column remains intact with a stable fixation of the acetabular fragment and a preserved shape of the true pelvis. There is a significant learning curve with severe complications in up to 30 % of cases. Good results can be expected in the long-term follow-up if performed with correct indication at young age in hips with preserved joint cartilage and proper reorientation of the acetabular fragment. Overall survivorship is superior to the natural course of hip dysplasia with a preserved hip joint in 61 % after 20 years.

Keywords Hip · Periacetabular osteotomy · PAO · Dysplasia · Retroversion

Introduction

Acetabular dysplasia is one of the most common causes of secondary arthritis of the hip joint in young adults [1–4]. Forty percent to 50 % of patients with residual hip dysplasia without subluxation suffer of advanced osteoarthritis at the age of 50

[5–7]. In cases with instability and subluxation of the hip, end stage osteoarthritis develops in nearly 100 % of all cases [2, 8, 9]. The surface area of the lunate surface is smaller than the one of a normal hip and the inclination of the sourcil is increased. The transarticular load is increased and causes overload of the acetabular rim and damage to the acetabular cartilage and labrum (“acetabular rim syndrome”) [10]. The aim of surgical intervention is to relieve symptoms and prevent or slow the progression of osteoarthritis of the hip. A variety of pelvic osteotomies are currently used and can be divided into augmentation and reorientation procedures. Augmentation procedures include Chiari osteotomy [11] or various shelf procedures [12, 13] and are intended to stabilize the femoral head by increasing the lateral surface of the acetabulum and reducing the acetabular index. However, the extra-articular buttress is not fully congruent and the interposed joint capsule transforms into fibrocartilage. In patients with very poor acetabular formation and complete dislocation of the femoral head, a capsular arthroplasty was first described by Codivilla in 1901 and Colonna in 1932 [14, 15]. Initially, these procedures were associated with a high rate of complications. Modified as a 1-stage procedure with surgical hip dislocation, this procedure has become more popular in recent years with good long-term results [16]. Reorientation procedures consist of spherical, triple, or periacetabular osteotomies and intend to correct femoral head coverage by rotating the entire acetabulum over the femoral head. Periacetabular spherical osteotomies were first performed by Ninomiya [17] in Japan and were later independently popularized in Europe by Wagner [18]. Good long-term results are reported [19]. To prevent necrosis of the acetabular fragment its thickness should not be less than 1.5 cm and a capsulotomy should be avoided [20]. A disadvantage is that the fragment cannot be medialized. Good corrections can be achieved using the triple osteotomies such as the one popularized by Tönnis [21]. The cuts do not cross the growth plate and can be performed in

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children. Because of the complete osteotomy of the posterior column, the sacrospinal ligament can hinder the free reorientation of the fragment and the ischial spine may protrude in the true pelvis and prevent natural birth. The Bernese periacetabular osteotomy (PAO) according to Ganz et al [22] is a powerful and versatile technique for reorientation of the acetabulum after closure of the growth plate. A large, entirely mobile acetabular fragment is created [23] while preserving the blood supply [24]. The incomplete osteotomy of the ischium leaves the posterior column intact. The acetabular fragment is easily fixed with cortical screws and early partial weight bearing is possible. The shape of the true pelvis is not altered and a vaginal birth is possible [23, 25]. The PAO has reportedly led to good to excellent results with survivorship of the affected hip up to 61 % at 20 years [26•].

Indications for surgery

Joint preserving reorientation procedures are indicated in symptomatic, active patients with preserved joint cartilage and a malorientation of the acetabulum that causes dysfunction or pain of the hip. An upper age limit does not exist, but in patients older than 30–40 years with advanced osteoarthritis (Tönnis Grade 2 or more) or a reduced functional score, results are less favorable [26•, 27], and a conservative treatment with possible later THR is indicated. Indications for PAO include symptomatic residual dysplasia of the hip after closure of the growth plates [23], acetabular retroversion [28], and acetabular protrusion [29]. In residual Legg-Calvé-Perthes disease with subluxation of the femoral head, a PAO can be performed [30] in addition to the head reshaping procedures with surgical hip dislocation and/or intertrochanteric femoral osteotomy.

A high dislocation of the hip or the presence of a secondary acetabulum with fibrous cartilage are considered relative contraindications of PAO, as they are generally associated with poorer outcomes. However, Clohisy et al [31] showed that even in hips with severe acetabular dysplasia with subluxated hips or a false acetabulum a good or excellent clinical result could be achieved in 14 of 16 hips at 4 years follow-up. Optimal reconstruction may require additional femoral osteotomy in hips with severe femoral deformities and articular mismatch to optimize congruency and joint stability [32].

Radiological examinations

Radiological evaluation includes a standardized anteroposterior (AP) view of the pelvis, an axial view (cross table lateral image) [33] and a false profile view.

Correct patient positioning and position of the center beam is important, as variations greatly influence the measured parameters [34]. To simulate the hip joint congruency after reorientation, an abduction/internal rotation view of both legs is required. The following radiographic parameters are measured: Tönnis grade osteoarthritis [35], lateral center edge angle (LCE) of Wiberg [36], the Acetabular Index [37–39], crossover sign, posterior wall sign [40], and ischial spine sign [41]. To assess the anterior and posterior femoral head coverage the acetabular wall index is calculated [42]. As a sign of subluxation of the head the Shenton line [43] is measured. On the lateral view the alpha angle [44] is measured and the antetorsion of the femoral neck is estimated. The anterior center-edge angle of Lequesne and de Sèze [45] is determined on the false profile radiograph.

Additional radiographic examinations include a radially reconstructed magnetic resonance arthrography of the hip joint to evaluate chondrolabral damage. Secondary signs for an instable hip are a hypertrophied labrum, an increased thickness of the iliocapsularis muscle [46] and subluxation of the femoral head with a crescent of contrast medial-caudal to the femoral head. In addition, the femoral neck torsion is measured and the exact location of a cam deformity defined. In cases with severe abnormalities, animated 3D computed tomography reconstruction or 3D print can provide valuable additional information for preoperative planning.

Technique of PAO

In general, the PAO is still performed according the original technique described by Ganz [22]. The patient is positioned in a supine position on a radiolucent table under general anesthesia with full muscle relaxation. Perioperative antibiotics and a cell saver are used. The freely mobile leg is draped up to the costal margin to allow manipulation of the leg during surgery.

The procedure is performed through a modified Smith-Petersen approach [47]. The skin incision starts at the iliac crest about 5–7 cm proximal of the anterior superior iliac spine (ASIS). Staying lateral to the ASIS, the lateral femoral cutaneous nerve is protected. With the hip in extension and slight abduction, the fascia of the Tensor Fascia Lata is incised and the Tensor pulled laterally, developing the interval between the Sartorius and Tensor. The back of the fascial envelope is then incised over the reflected part of the Rectus Femoris. The ascending branch of the lateral circumflex femoral artery is preserved. Proximally, the abdominal muscles are detached from the iliac crest and the Iliacus is elevated subperiostally from the iliac wing to the level of the pelvic brim. The 2 parts of the approach are now connected with

the osteotomy of the ASIS, which is gradually mobilized medially. The hip is now flexed and the femur positioned on a support for the remaining surgery. The reflected head of the rectus femoris is incised and the direct head is detached from the anterior inferior iliac spine and mobilized medially together with the iliocapsularis from the hip capsule. The iliopectineal bursa is identified and a pointed Hohmann retractor positioned medial to the iliopectineal eminence. The joint capsule is now exposed and followed by blunt dissection with a large, slightly curved scissors. The scissors are advanced posteriorly until the ischial ramus is palpated, identifying the medial border (obturator foramen). Laterally, the tendons of the hamstrings prevent lateral manipulation, protecting the sciatic nerve. Cranially, the infracotyloid groove of the os ischium is identified. Osteotomy of ischium cannot be visually checked and is performed blind or under control of image intensifier. The first, partial osteotomy is performed just distal to the joint capsule within the infracotyloid groove. To protect the ischial nerve the hip is flexed and abducted. A specially designed curved chisel with 30° angulation and a notched 15 mm blade is used. The blade is perpendicular to the ischium and the shaft of the osteotome vertical. Driving the blade about 10–20 mm into the medial cortex, the shaft of the osteotome is gradually lowered to follow the angulation. Depending on the size of the ischium, the chisel is moved medially to osteotomize the entire width of the ischium at the level of the infracotyloid notch. The lateral cortex is left in place to protect the sciatic nerve. It will later brake easily. If performed correctly, the obturator and medial circumflex artery are not in danger. The complete osteotomy of the superior pubic ramus is performed medial to the iliopectineal eminence acetabulum with a straight osteotome pointed 45° medially. The femoral neurovascular structures are retracted medially and protected with the pointed Hohmann retractor about 1 cm medial to the iliopectineal eminence. The obturator artery and nerve are protected with 2 blunt retractors around the pubic ramus at the place of the osteotomy. Next, the obturator internus is elevated from the quadrilateral plate and a reversed Hohmann retractor is placed on the ischial spine. The abductors are tunneled at the level of the ASIS and a reversed Hohmann retractor is introduced into the superior sciatic foramen to protect the sciatic nerve during the execution of the following osteotomies. To preserve the blood supply of the acetabular fragment from the ramus supraacetabularis of the superior gluteal artery, the osteotomy of the ilium is performed as high as possible just distal to the ASIS. The first cut is performed with an oscillating saw, aiming straight about 1 cm lateral to the pelvic brim. From this point the osteotomy is continued with a curved chisel,

aiming 110°–120° toward the ischial spine with 2 cm distance to the greater sciatic notch. This leaves the posterior column intact. Ideally, this last osteotomy meets with the first, incomplete osteotomy of the ischium. If this is not the case, the osteotomy is completed with a large 30° angled chisel.

To mobilize the acetabular fragment, a 5 mm Shanz screw is inserted in the supraacetabular bone and the remaining osseous connection toward the ischial spine is broken in a controlled form with the help of a lamina spreader placed in the retroacetabular osteotomy. The acetabular fragment can now be freely moved and reoriented according to the desired correction. The fragment is provisionally stabilized with two 2.5 mm threaded Kirschner wires. The correction of acetabular retroversion is more difficult than for dysplasia. Correction usually involves internal rotation and extension of the acetabular fragment. This often leads to bony contact at the pubic osteotomy and supraacetabular osteotomy. Therefore, it is sometimes necessary to shorten the pubic ramus and to remove a wedge from the ilium at the supraacetabular osteotomy to achieve the desired correction.

A correct intraoperative pelvic radiograph is taken to check the position of fragment.

Intraoperative assessment

The repositioned acetabular fragment should show the following radiological parameters [48, 49•, 50]: LCE angle, acetabular index, medialization of the fragment, acetabular version, and continuity of the Shenton line. The LCE angle is corrected to between 25°–30°, depending on the size of the acetabulum and the inclination of the sourcil. The acetabular index angle should remain positive. The acetabulum should have normal anteversion with the anterior and posterior rim both meeting at the lateral end of the sourcil. The medial aspect of the femoral head should lie approximately 10 mm lateral to the ilioischial line. The continuity of Shenton's line is observed, but often cannot be normalized in situations of high dislocations.

If necessary, the position of the fragment is corrected and the x-ray is repeated. Overcorrection with excessive lateral cover or acetabular retroversion should be avoided as this may lead to a pincer type FAI. The range of motion of the hip is tested. An internal rotation of 30° in 90° flexion should be possible [51, 52••]. If necessary, the joint capsule is opened to assess the labrum and head-neck junction to treat impending CAM type FAI. Degenerative labral tears or unstable flaps are debrided or reattached. Finally, the acetabular fragment is fixed with three 3.5 mm cortical screws (Fig. 1). If an excessive correction of the acetabular fragment was necessary, a plate can be placed on the inner aspect of the ilium to increase stability. If opened, the joint capsule is closed. The origins of the Rectus Femoris are reinserted with transosseous suture.

Fig. 1 The osteotomies, reorientation, and fixation of the PAO are shown. **A**, AP view: an osteotomy of the anterior superior iliac spine was performed to mobilize the inguinal ligament and sartorius muscle. With 4 periacetabular osteotomies and a controlled fracture, the acetabulum is completely mobilized from the innominate bone. In this model, the

acetabular fragment was anteverted for treatment of acetabular retroversion. **B**, Medial view: the posterior column of the pelvis remains intact, preserving the stability of the pelvic ring and not altering the size and shape of the true pelvis. **C**, Lateral view: for fixation of the reoriented fragment, 3 cortical screws are used

The osteotomized ASIS with the inguinal ligament and origin of the Sartorius are reattached to the ASIS.

Modification of original technique

Over time, several modifications of the original technique were developed.

Approach

Initially, the abductors were detached from the outside of the ilium. Since 1993, an abductor sparing direct anterior approach is generally used. The abductors on the lateral iliac crest are left attached. A narrow subgluteal window is elevated with a blunt distractor placed in the sciatic notch to protect the abductors and sciatic nerve from the oscillating saw during osteotomy of the supraacetabular ilium. Because of the limited overview, the incidence of sciatic nerve injuries has increased compared with the initial technique [53]. The originally used modified Smith-Petersen incision often shows unsatisfactory scar formation in the distal part of the incision and there is a risk of injury to the lateral femoral cutaneous nerve. A shortened ilioinguinal incision [54] partly overcome these complications. The incision starts at the anterior third of the iliac wing and extends slightly medial to the ASIS. As an alternative, a Bikini type incision in the skinfold of the groin can be used in slim patients. The scar is more cosmetic, but the incision is not extensible and access can be very difficult in large or muscular patients. Minimally invasive techniques include 2 incisions [55] and transsartorial approaches [56]. Even though the results are reportedly good, the overview is very limited and the osteotomies have to be performed under fluoroscopic guidance. Alternatively to the osteotomy of the ASIS, the ilioinguinal ligament together with Sartorius can be

detached sharply from the ASIS or together with a small piece of bone that can be reattached with sutures. As an alternative of the deep dissection, the 2 origins of the Rectus Femoris are left intact. The muscle is retracted laterally with a blunt retractor and the ischial osteotomy is performed using the sheet of the psoas tendon as guide to the ischium.

Offset correction

Capsulotomy and offset correction during PAO in hips with a CAM type deformity is an important step to prevent secondary femoroacetabular impingement [26•, 52••]. Not performing an offset correction increases the adjusted hazard ratio by 2.8 for an unsatisfactory result [52••]. There is, however, a limited access to the labrum and intraarticular cartilage. Hip arthroscopy before or after PAO allows observation of the joint, treatment of labral or chondral injuries and offset correction on the femoral neck. There is very limited data on the benefit of this procedure with no long-term results [57].

Navigation

Computer aided navigation with real-time image guidance for PAO is feasible. However, the necessary preoperative computed tomography scan of the pelvis results in a significant radiation exposure in the mostly young female patients and navigation offers little additional benefit when an experienced surgeon performs the surgery [58].

Postoperative care

Continuous passive motion therapy is initiated on the day after surgery to prevent intraarticular adhesions. After removal of the drainage, the patient is mobilized on crutches with

restricted weight bearing of 15 kg on the operated side for 8 weeks. Active flexion of the straight leg should be avoided for 6 weeks to protect the Rectus and Sartorius. Increased weight bearing under physiotherapeutic guidance is allowed if radiologic signs of osseous consolidations are seen at 8 weeks follow-up.

Complications

Most major complications are associated with the learning curve and occur in the first 20–50 procedures [22, 50, 59–61, 62•]. In a systematic literature review of studies with at least 2 years' follow-up, Clohisy et al [61] found major complications in 6 %–37 % of cases. Hussell and Ganz [62•] published technical complications in the first 508 consecutive PAO performed. Major complications were transient femoral and sciatic nerve palsies in 0.6 % and 1 %, respectively. Intra-articular osteotomies occurred in 2.5 % and osteotomy or fracture of the posterior column in 1.2 %. Loss of fixation or nonunions occurred in 2.2 %. Symptomatic ectopic bone formation occurred in 5.3 %, most commonly at the origin of the rectus femoris and had to be removed if hip flexion was restricted. In primary PAO and if the osteotomies are performed correctly, necrosis of the acetabular fragment is extremely rare [50, 62•]. Minor complications include hematomas, symptomatically prominent screws, cosmetically unsatisfactory scar inferior to the ASIS, and damage to the lateral femoral cutaneous nerve in up to 30 % of cases [62•].

Review of the literature

Various authors have published short- to medium-term results after PAO with comparable results. Studies with a follow-up of at least 5 years are summarized in Table 1. Patients without preoperative degenerative changes of the hip seem to have significantly better outcomes than patients with signs of osteoarthritis [26•, 63, 64, 65•]. Other factors that led to significantly poorer outcomes were preoperative advanced age, lower functional score, limp, and a positive impingement test [26•]. Siebenrock et al [50] investigated the course of the first 63 patients (75 hips), which had been operated between 1984–1987 with a PAO. After a mean follow-up of 11.3 years, the hip was preserved in 82 % of patients, with good to very good functional outcomes in 73 %. Steppacher et al [26•] studied the same patient population 10 years later. The remaining 68 hips showed a preserved hip joint in 61 % after 20 years with good to very good functional result in 60 %. Proper acetabular reorientation and postoperative impingement free range of motion is an important factor for good outcome. Albers et al [52••] found a faster progression of OA in hips with suboptimal acetabular reorientation and/or signs of persisting Cam

Table 1 Results after PAO with a follow-up of at least 5 years

Study	Study design; level of evidence [48]	Follow-up (y)	Percent follow-up	Hips/ patients	Age at surgery	Previous surgery	Survival rate
Siebenrock et al [50] (1999)	Retrospective case series; IV	11.3 (10–13.8)	100 %	75/63	29 (13–56)	23 (31 %)	82 % at 10 years
Kralj et al [66] (2005)	Retrospective case series; IV	12 (7–15)	100 %	26/26	34 (18–50)	NA	85 %
Steppacher et al [26•] (2008)	Prognostic; III	20.4 (19–23)	91 %	75/63	29.3 (13–56)	23 (31 %)	61 % at 20 years
Troelsen et al [67] (2009)	Prognostic; II	6.8 (5.2–9.2)	81 %	116/96	29.9 (14.1–57.0)	14 (12 %)	82 % at 9 years
Matheney et al [65•] (2009)	Prognostic; II	9±2.2	85 %	135/109	26.7±9	27(20 %)	84 % at 10 years
Ito et al [68] (2011)	Therapeutic; IV	11 (5–20)	95 %	166/146	32 (12–56)	NA	96 %
Albers et al [52••] (2013)	Therapeutic; III	11 (10–14)	97.5 %	165/147	Group I: 29 (12–55) Group II: 28 (13–44)	36 (22 %)	Group I: 90 % at 10 years Group II: 78 % at 10 years

impingement. A summary of studies with follow-up of at least 5 years is presented in Table 1.

Conclusions/outlook

The first PAO was performed by Ganz in April 1984. In the 30 years of use, this technique has become a powerful tool in hip preserving surgery and has especially revolutionized the treatment of residual dysplasia of the hip in adult patients. The PAO is increasingly performed in many centers all over the world. A thorough understanding of the underlying pathology is required and the operation is technically demanding with a significant learning curve. The long-term results are promising with a survivorship of the operated hips of 90 % after 10 years and 60 % after 20 years. The operation technique is still in the process of being refined, with focus on improvement and minimization of the approach and better understanding of correct indications to prevent unsatisfactory outcomes.

Compliance with Ethics Guidelines

Conflict of Interest Lorenz Büchler and Martin Beck declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with animal subjects performed by any of the authors. With regard to the authors' research cited in this paper, all procedures were followed in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

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