(iii) Bernese periacetabular osteotomy

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Summary
The Bernese Periacetabular Osteotomy (PAO) is a reorientation procedure of the dysplastic acetabulum and was first executed in 1984 after extensive feasibility studies in the anatomy lab including injection studies of the blood supply of the periacetabular bone. Dissatisfaction with available techniques led to the new procedure with its power of correction and intracapsular access, avoiding the danger of avascular necrosis. It should not interfere with the natural birth canal. The approach was chosen to produce little morbidity and reduced care in the postoperative period. The resulting procedure using a Smith–Peterson approach evolved to one of the most frequently executed reorientations of today, although the execution is technically rather demanding. Reorientation of the acetabulum became the most successful operation in our armamentarium to preserve the natural joint. Addressing the tendency to produce acetabular retroversion and an eventually insufficient head–neck offset has helped to avoid impingement after reorientation and has further improved the results.

Combined pathology of acetabulum and proximal femur is not treatable via a Smith–Peterson approach so a feasibility study on cadavers was undertaken to achieve acetabular and femoral correction using one posterolateral approach. Again, injection studies have shown how interference with the periacetabular bone perfusion can be avoided, even when performing a large capsulotomy with dislocation of the femoral head. The technique has been tested successfully clinically, although the number of cases is still small.

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Introduction
Osteoarthritis of the hip is frequently caused by mechanical abnormalities including residual deformity from developmental hip disease such as acetabular dysplasia.\textsuperscript{1} Untreated acetabular dysplasia (Fig. 1) is the most common cause of secondary osteoarthritis\textsuperscript{2,3} arising from pathological joint-loading forces.\textsuperscript{4}

Pelvic osteotomies for residual acetabular dysplasia attempt to increase coverage of the femoral head in order to reduce the joint-loading forces that otherwise exceed the tolerance level of the articular cartilage.\textsuperscript{5} There are two
ways to achieve this goal, one is by augmentation of the roof, the other is by spatial reorientation of the entire acetabulum. Augmentation procedures are the different types of the shelf procedures and the Chiari pelvic osteotomy. With both operations the intact capsule is interposed, undergoing metaplastic transformation to fibrocartilage. However, fibrocartilage has inferior mechanical characteristics when compared to hyaline cartilage and optimal coverage of the acetabulum is difficult to achieve. Moreover, the interposed labrum may continue to create pain when it is avulsed and subjected to shear forces during motion.

Reorientation procedures provide more physiological coverage by tilting the acetabular hyaline cartilage over the head (Fig. 2a and b). In classic dysplasia there is usually sufficient articular surface available in the postero-inferior area of the socket so that hyaline cartilage supported by subchondral bone offers optimal mechanical properties for load transmission and motion. Reorientation procedures include single, double and triple osteotomies as well as spherical and periacetabular osteotomies. This paper focuses on the Bernese Periacetabular Osteotomy (PAO).

Rationale for the Bernese PAO

One of the most frequently performed reorientation procedures is Salter’s single innominate osteotomy. Its world-wide acceptance reflects its ease of execution; however, it is a correction hinged at the symphysis pubis, the weakest structure of the pelvic ring. The supraacetabular bone distal to the osteotomy is pulled anteriorly and laterally, moving the centre of rotation laterally and distally. The desired increase in anterior coverage results in a decrease of posterior coverage producing retroversion. Hips after a Salter osteotomy in childhood may fail later from impingement.

To overcome the adverse aspects of the Salter osteotomy and to increase the amount of correction, a number of double and triple osteotomies of the pelvis have been proposed. Hopf was the first to describe a double osteotomy which was designed for hips with a subluxing femoral head. Besides the innominate osteotomy, he performed a second cut through the empty inferior socket. The technique did not receive wide popularity, mainly because it risked vascular disturbance of the acetabular fragment. In the other double osteotomy, proposed by Sutherland and Greenfield, the second cut was near the symphysis. Again, this osteotomy was abandoned because of poor lower fragment correction. LeCoeur was the first to perform a triple osteotomy and he did it long before he published the technique. Like the osteotomy later described by Steel it was a triple osteotomy distant to the acetabulum, correction being limited by the intact sacro-pelvic ligaments.

The power of correction has substantially increased with juxta-articular triple osteotomies. While the proposed operation of Carlioz only separates the sacrotuberal ligament from the acetabular fragment, the Tönnis osteotomy isolates the fragment from both ligaments allowing a large amount of spatial correction. To do this, three incisions and introperative reprinting of the patient is necessary. Both types interrupt the pelvic ring and therefore require careful stabilization. Nishio, Eppright, Wagner and Ninomiya and Tagawa described so-called dial or spherical osteotomies very close to the joint. While the Eppright osteotomy has some limitations for anterior correction, the more spherical osteotomies are limited with regard to correction of version and medialization. The Wagner osteotomy in particular may become intra-articular at the level of the tear drop. In addition, spherical osteotomies may produce acetabular avascular necrosis, especially when attempting a simultaneous capsulotomy.
In view of these limitations, the Bernese PAO was developed in 1983 after cadaveric feasibility studies including the vascular supply to the periacetabular bone. The polygonal juxtaarticular osteotomy not only respects the blood supply but also facilitates extensive acutarial reorientation including correction of version and mediolateral displacement. The posterior column remains mechanically intact, protecting the sciatic nerve and enabling minimal internal fixation together with easy postoperative mobilization. The dimensions of the true pelvic cavity remain unchanged with this osteotomy permitting unimpaired vaginal delivery, even when performed bilaterally. This is an important aspect since the majority of patients are female and in their reproductive period.23

All osteotomy cuts are performed through a modified (abductor sparing) Smith-Peterson incision, while the deeper dissections expose the anterior and medial aspects of the periacetabular bone. The approach allows a large anterior capsulotomy for the treatment of intra-articular pathology, ensuring impingement-free motion, especially anterior capsulotomy for the treatment of intra-articular pathology. Since the Bernese PAO crosses the posterior line of the triradiate cartilage, a sufficient space for placement of the mould-arthroplasty was restricted to the outside of the periacetabular bone, the different osteotomy steps of the periacetabular osteotomy have been performed medial to the pelvic ring since 1993, avoiding elevation of the abductors. Access to the pubic bone and the anterior approach to the ischium can be achieved medial (direct anterior approach25) or lateral to the rectus muscle as described in the original article.26 With the direct anterior approach the straight head of the rectus muscle does not need to be sectioned but there is a risk of stretching the femoral nerve. The PAO can also be executed via an ilioinguinal approach.27,28 The dissection takes longer but the exposure for the pubic and ischial cuts is easier and the scarring of the skin incision becomes more acceptable compared with the laterally curved Smith-Peterson incision. However, the ilioinguinal approach may produce thrombosis of the femoral vessels.

After the curved skin incision over the anterior–superior iliac spine (Fig. 3a) the fascia is incised over the tensor muscle to avoid injury to the lateral femoral cutaneous nerve, running in a layer of fatty tissue between the sartorius and tensor muscles. The anterior–superior iliac spine is then osteotomized and mobilized medially together with the origin of the sartorius muscle and the inguinal ligament (Fig. 3b). Proximally for a distance of about 10 cm, the abdominal obliquus externus and the iliacus muscles are dissected from the iliac crest and inner surface together with the periosteum. This step is facilitated by placing the hip in about 45° flexion to release muscular tension. Deep between the rectus and tensor muscles both heads of the rectus femoris muscle are identified. The reflected head is tenotomized and the direct head is separated from the anterior–inferior iliac spine to allow medial mobilization together with the iliacus muscle covering the anterior surface of the joint capsule (Fig. 3c). The next structure medially and distally is the iliopsoas bursa which may be partially obliterated or may represent a large cavity through which the tendon of the psoas muscle takes its course (Fig. 3d). Further distal continuation of the dissection of the iliacus muscle from the capsule allows access to the gap between capsule and psoas tendon and more posteriorly between capsule and the obturator externus muscle (Fig. 3d). This allows access to the infracotyloid groove of the ischial bone. The abductor musculature is elevated from the outside of the ilium only at the level of the horizontal cut of the supra-acetabular osteotomy allowing the insertion of a blunt retractor into this tunnel, reaching the greater sciatic notch with its tip. Medially, the strong periosteum covering the quadrilateral surface of the acetabular bone is elevated allowing a second blunt retractor to be placed on the base of the ischial spine. The obturator neurovascular bundle is protected by two curved retractors around the proximal and distal contours of the base of the pubic bone, which is further exposed by a sharp retractor hooked into the pubic bone about 1.5 cm medial to the iliopsoas eminence.

The routine execution of the different osteotomy steps is performed without the assistance of fluoroscopy, depending upon the three-dimensional understanding of this procedure. Nevertheless, fluoroscopy is widely used by those who claim this makes the PAO more accurate and safe.

The Bernese PAO consists of five steps. The first step is the incomplete osteotomy of the ischium (Fig. 4a). With the hip in flexion using a leg holder, a specially curved chisel is introduced in the gap between the antero-inferior capsule and the psoas tendon, and at a deeper plane, the obturator externus muscle. After contact with the bone,
Figure 3  Sequence of soft tissue approach to perform the osteotomy cuts. (a) 1, Sartorius muscle; 2, ASIS; and 3, tensor fascia lata muscle. (b) 1, Direct head of rectus femoris muscle; 2, osteotomized ASIS; and 3, rectus femoris muscle. (c) 1, Sartorius muscle; 2, psoas muscle; 3 released rectus femoris muscle; and 4, ilio capsularis muscle. (d) 1, Iliopectineal eminence; 2, released rectus femoris muscle; 3, released ilio capsularis muscle; and 4, joint capsule. (e) 1, Iliopectineal eminence; 2, obturator externus muscle; and 3, joint capsule.
Figure 4: (a) "Blind" incomplete ischial osteotomy; (b) pubic osteotomy; (c) supraacetabular osteotomy; (d) retroacetabular osteotomy; and (e) controlled fracture of the acetabular fragment.
the infracotyloid groove (with the postero-inferior acetabular tip as its most proximal extension) is probed. Strong hammer blows are exerted only after good contact of the chisel against the bone is secured by gentle taps. Supported by raising the handle of the chisel, the course of the osteotomy becomes slightly curved and ends at a depth of about 2.5 cm. This depth can be estimated more easily while slowly pulling back the chisel to the starting position than during its forward movement. The quality of the resistance while sideward wiggling of the chisel gives information whether it is in the middle of the bone or overlapping the medial or lateral border. It is important to cut the medial cortex of the ischium. The lateral cortex in close vicinity to the sciatic nerve is thin and can be broken easily during the final manual manoeuvre to free the fragment completely. Care must be taken not to cut distal to the obturator externus muscle where the medial femoral circumflex artery runs parallel to the muscle belly. If performed correctly, bleeding from this area is minimal and only of venous origin.

The second step is the complete osteotomy of the pubis (Fig. 4b). It is best performed at its largest diameter close to the joint. Slight adduction in the flexed hip improves the exposure. The two subperiosteal retractors are directed to protect the neurovascular bundle at the level where the tip of the chisel penetrates out of the opposite cortex. With a narrow double osteotomy splintering of the bone during deeper penetration of the chisel can be avoided. The osteotomy starts immediately medial to the iliopectineal eminence and is 45° centrally inclined to avoid penetration into the joint. Completion of the osteotomy is controlled by a spreading manoeuvre with the chisel.

The third step is the chevron-shaped supra- and retroacetabular osteotomy (Fig. 4c). Currently the anterior cut is performed more proximally than was described in the original paper. It starts at the inferior border of the osteotomized anterior-superior spine and is directed transversely, ending 1–2 cm before it reaches the iliopectineal line. It is performed with an oscillating saw, the abductor musculature being protected by the blunt retractor described earlier. The second cut of the osteotomy is performed with straight and curved chisels. A straight chisel is directed towards the ischial spine at an angle of about 110° to 120° to the first leg. However, only the inner cortex is cut to a distance of about 2 cm posterior to the iliopectineal line. A 1-cm bone bridge is controlled with finger palpation between this cut and the border of the sciatic notch. Thereafter a curved chisel is placed into the most proximal part of this cut and directed under visual control towards the lateral cortex superior to the joint. As soon as the lateral cortex of the supra-retroacetabular bone is separated, a distinct warping of the first osteotomy cut becomes visible, indicating that with leverage by a large chisel placed in the corner of both osteotomy segments the cuts will propagate as a controlled fracture further towards the sciatic spine. A 5-mm Schanz screw is inserted into the anterior inferior iliac spine, directed towards the osteotomy corner and parallel to the inner cortex. It provides a good handle for further mobilization of the acetabular fragment, while the retroacetabular osteotomy gap is further opened with a laminar spreader. Occasionally gentle blows on a chisel are necessary to promote this propagation.

The fourth step is the distal retroacetabular osteotomy (Fig. 4d) which combines the former cut with the first incomplete ischial osteotomy. It is performed under tension with the spreader to promote a controlled fracture after osteotomizing the inner cortex only. A special chisel is used, allowing the execution of the osteotomy 4 cm posterior to the iliopectineal line at an angle of about 50° towards the quadrilateral surface. Injection studies of the proximal femur and of the periacetabular bone have shown good perfusion of the acetabular fragment with this arrangement of osteotomies. The acetabular fragment can now be broken completely free by levering it against the surrounding pelvic bone with the simultaneous use of the spreader and the Schanz screw (Fig. 4e).

The precise positioning of the mobile acetabular fragment is as demanding as the execution of the osteotomies. The most important correction is anterior rotation of the fragment, which is accompanied by a simultaneous increase of lateral coverage. If there is retroversion the fragment is additionally rotated inwards. After preliminary fixation using K-wires, an anteroposterior radiograph of the entire pelvis affords accurate portrayal of the correct spatial orientation of the acetabular fragment. Redirecting the fragment position as frequently as necessary and repeated radiographic control ensure an optimal spatial position of the acetabulum. Fluoroscopy for control of the fragment orientation gives little information on rotation and tilt of the pelvis, while the projected picture also differs by 4° compared with a pelvic radiograph. Orientation of the acetabular roof, the position of the head relative to the ilioschial line, the position of the radiographic teardrop, the posterior and the anterior acetabular rims, the inferior border of the acetabulum relative to the inferior border of the femoral head and Shenton’s arc are all evaluated. While radiographs are processed, an anterior capsulotomy allows inspection of the joint for intraarticular pathology and eventual treatment. In particular, labral instability (tears) and an insufficient anterolateral femoral head/neck offset are addressed.

After the reorientation is interpreted as radiologically correct, the capsule is closed with a running suture. The acetabular fragment is routinely fixed by means of three, 3.5 mm AO screws, a fixation which is sufficient because of the polygonal shape of the osteotomy and the intact posterior column. The direct head of the rectus is refixed with a non-resorbable suture and the bony fragment of the sartorius origin is fixed back using one 2.7-mm screw. Suction drainage is unnecessary and 80% of the patients do not need blood transfusion; however, a cell saver system is used routinely and autologous blood donation is recommended for young females. Prophylaxis against deep venous thrombosis is routinely ensured for 6 weeks.

By the second day after surgery the patient is allowed to walk with crutches. For about 8 weeks, loading of the hip joint is restricted to touch weight bearing. Active flexion of the hip is prohibited for 6 weeks and prophylaxis against heterotopic ossification is only used in patients with a predisposition. At 8 weeks, union of the osteotomies is normally sufficient for full weight bearing and physiotherapy may be started.
Results with the Bernese PAO

The first periacetabular osteotomy was performed in April 1984; almost 1500 hips have been operated since by the senior author. In 1999, the minimum 10-year results of the first 75 osteotomies performed between 1984 and 1987 in 63 patients were published. The average age at surgery was 29.3 years and the male:female ratio was 1:3.4; 31% of the operated hips had undergone previous surgery. According to the classification of Severin, 49% were in group III preoperatively and 44% in group IV, 5% in group V and only 1% in group II. Restriction of walking ability was present in 73%. A total of 71 hips (95%) with adequate documentation were included in the follow-up study at 11.3 years (10–13.8 years). One patient with two PAO hips died 6 years after the second periacetabular osteotomy and two patients (hips) were lost to follow up.

In all hips the radiographic parameters were improved significantly and Shenton’s line was restored in 62%. The hip joint was preserved in 58 (82%) of the 71 cases; 13 hips were revised by THR at an average of 1.1 years (1–13.2 years). Clinically, the average Merle d’Aubigné score for the 58 hips increased from 14.6 points (7–17 points) to 16.4 points (12–18 points) at the time of the last follow-up. In all, 52 (73%) of the 71 preserved hips had a good or excellent result (Fig. 5a and b). Only 27 hips had no signs of osteoarthritis at the time of surgery (49%). This number increased to 44 hips (80%) at the last follow-up. Six of the 13 non-preserved hips had preoperative, secondary osteoarthritis and five had a primary osteoarthritis (Fig. 6a and b). The two hips with tertiary osteoarthritis were preserved at follow-up. Two non-preserved hips did not have sufficient radiographic documentation. Arthroscopy was not routinely performed. However, in 15 hips a labral lesion was detected at surgery; these hips had a significantly worse outcome. Overall, older age, presence and grade of OA and the presence of a labral lesion were predictors for a negative outcome.

Complications

For the first group of 75 hips all major complications occurred in the first 18 hips, although the technique was started clinically only after extensive cadaver work. Hussell et al. have collected the complications of 508 consecutive hips including the first 75 osteotomies.

Intra-articular osteotomy occurred in 13 hips. Eleven times it was in the inferior intra-articular extension of the ischial osteotomy. All 11 hips had major supra-lateral femoral head migration, leaving an empty inferior capsule. There were no clinical sequelae directly associated with this type of intra-articular osteotomy. In two hips the posterior leg of the supra-acetabular osteotomy extended into the joint, leading to incongruency following correction of the anterosuperior part of the acetabulum. The salvage procedure for both hips was total hip replacement. In four hips substantial undercorrection and in six hips major overcorrection occurred; in three of these patients inadequate intraoperative radiography could be identified to be at least partially responsible for the poor correction. Early reoperation is the best way to treat this type of complication. In three out of four hips, femoral varus osteotomy led to a symptomatic resolution of the subluxation; in the fourth case a shelf graft for a postero-superior subluxation was followed by a full relief of symptoms, now continuing for 22 years. The other possible cause of resubluxation is coxa magna. In the one case in this series the problem was solved with intetrochanteric osteotomy combined with a shelf procedure.

Femoral nerve palsies occurred in three patients. One hip had extensive anterior scarring. The other two cases occurred in two of five hips that were exposed through a direct anterior approach. All palsies resolved within 3–6 months. Sciatic nerve palsy occurred in five patients; all recovered slowly with no major late deficit. In one case a bone spike was diagnosed using CT and revision surgery with excision of the spike led to a relief of the causalgia.

No vascular complication occurred in this series. However, thrombosis of the femoral artery has been reported when using an ilio-inguinal approach.

Osteonecrosis of the reoriented acetabulum has been observed in three hips. The first occurred in 1984, when soft
tissue stripping was excessive and the inferior cut of the ischium penetrated the inferior acetabulum, interrupting the acetabular artery. Two later cases occurred in patients undergoing revision pelvic osteotomy where the previous surgery had stripped the soft tissue extensively from the bone. All three hips required total hip replacement. Today extensive soft tissue dissection from the external ilium is avoided.

Isolated delayed unions of the ilium, ischium or pubis were seen with significant gaps due to large corrections. Only two supra-acetabular non-unions needed revision. Posterior column discontinuity was seen in six patients where the osteotomy line extended into the greater sciatic notch. Prolonged protection from weight bearing led to healing in all cases.

Lessons learned

Peri-acetabular osteotomy is a demanding procedure which needs accurate knowledge of the anatomy, especially the vascular anatomy of the hip. After successful execution of the osteotomies, precise, spatial positioning of the acetabulum is of paramount importance.

The acetabular rim may fail with different pathologies before the cartilage itself becomes affected. With the routine use of MR arthograms, especially with the technique of radial arthro MR arthography, an increased number of labral ruptures with acetabular dysplasia were appreciated. Some disruptions occur deep in the substance of the acetabular cartilage, adversely affecting outcome after a reorientation procedure. Since hypertrophy of the labrum seems to be a constant finding in acetabular dysplasia, it may be an additional factor indicating surgery for a symptomatic hip with borderline dysplasia.

We further learned that acetabular dysplasia is not uniformly an anterolateral insufficiency of femoral head cover. Although the classic anterolateral dysplasia is the most common morphology, one out of six or even one out of three acetabula is retroverted. All post-traumatic dysplasias and all functional PFFH-hips are retroverted. Posterior insufficiency of coverage or anterior overcoverage is also very frequent after Salter- and triple-osteotomies in dysplasias and all functional PFFD-hips are retroverted. However, the posterior wall should be clearly medial to the centre of the femoral head. Otherwise the rotatory correction will increase posterior coverage and may lead to posterior impingement.

A further limitation of the procedure for retroversion is the quality of the acetabular cartilage in the area of the anterior overhang. Preoperative MR arthrography should show normal cartilage in this area before considering a reversed peri-acetabular osteotomy.

In summary, the Bernese PAO is potent means of redirecting the acetabulum. For acetabular dysplasia it is a successful but risky operation. The goal of this osteotomy is precise, spatial re-orientation of the acetabulum. Over-correction is as adverse as undercorrection and false correction. Anteversion or retroversion should be included in the list of corrective details and one has to take into consideration that the orientation of the proximal femur may be pathological as well.

References