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Diagnosis and Management of Developmental Dysplasia of the Hip from Triradiate Closure Through Young Adulthood

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Management of the Acetabular Side

Closure of the triradiate cartilage may occur as early as eight to ten years of age¹. Thus, typically the pelvis of a very young teenager already is amenable to different kinds of juxta-acetabular osteotomies for the treatment of hip disorders. Treatment options for the dysplastic acetabulum can be divided into (1) augmentation and (2) reorientation procedures. Augmentation procedures include a Chiari osteotomy² or different techniques of shelf procedures³, based on the principle of load reduction by distributing load through a larger surface area. However, the potentially damaged labrum and articular cartilage at the abnormally loaded acetabular rim⁴ remain within the main weight-bearing zone with both of these surgical procedures. This may be one main cause of inferior results reported with Chiari osteotomies in adolescents who are more than fourteen years old⁵ or in patients with a torn labrum⁶. Augmentation procedures are not commonly indicated in adolescents and young

adults currently, but may be considered in acetabula with a very short roof or in hips in which the acetabular radius is smaller than the radius of the femoral head.

Three types of juxta-acetabular osteotomies for acetabular reorientation are currently in wider use. These osteotomies include (1) a spherical or rotational osteotomy, (2) a triple osteotomy, and (3) the Bernese periacetabular osteotomy. The principle of the spherical or rotational osteotomy was described by Wagner⁷ in Europe and by Ninomiya and Tagawa⁸ in Japan. The osteotomy is performed with a curved chisel close to the subchondral bone. The advantage is that it provides a mobile fragment. However, this osteotomy lacks the potential for medialization of the hip center⁹ and may become intra-articular in the caudal portion of the acetabulum¹⁰. Tönnis et al.¹¹ popularized a triple osteotomy with complete osteotomies of the iliac, ischial, and pubic bone. Initial fixation included osteosynthesis of the iliac and pubic bone. The recommended

postoperative treatment was immobilization in a spica cast for several weeks. With the current technique, the ischial spine with the attached sacrospinal ligament remains attached to the pelvic segment, and fixation of the acetabular fragment has become easier without the need for postoperative cast immobilization. The Bernese periacetabular osteotomy was popularized in 1988 by Ganz et al.¹² and was first performed in 1984. This osteotomy has the advantage of creating a polygonal acetabular fragment while leaving the posterior column intact, by an incomplete osteotomy of the ischium. There is immediate postoperative stability since the pelvic ring is not disrupted. There is no deformity of the true pelvis in young female patients, allowing for childbirth through vaginal delivery after surgical correction¹³. The mobile acetabular fragment allows adequate corrections, even for severe deformities, and has the potential for an optimal medialization of the acetabular center of rotation. Fixation of the

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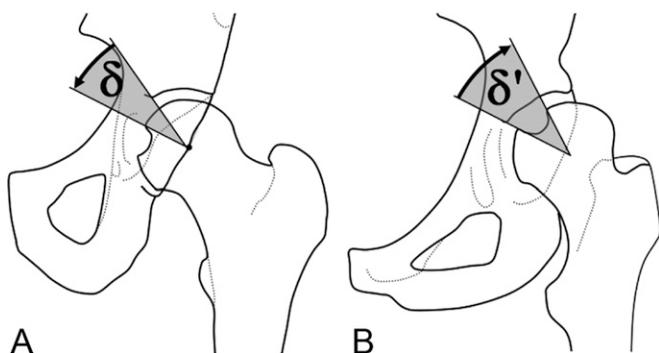


Fig. 1

Fig. 1-A In a normal hip, the fovea capitis femoris is caudal to the weight-bearing area of the acetabulum. **Fig. 1-B** In dysplastic hips, because of the extreme valgus, the fovea can extend into the weight-bearing area, reducing the loaded articular cartilage surface. The fovea-acetabular angle is defined as the angle formed by a line from the femoral head center to the medial edge of the weight-bearing zone of the acetabulum (reference line) and a line from the femoral head center to the superior edge of the fovea capitis femoris. The value of the fovea-acetabular angle is positive if the superior edge of the fovea capitis femoris lies caudal to the medial edge of the weight-bearing zone of the acetabulum (**Fig. 1-A**). It becomes negative if the superior edge of the fovea capitis femoris lies cranial to the medial edge of the weight-bearing zone of the acetabulum (**Fig. 1-B**).

osteotomized fragment can be done typically with screws only in the acetabular fragment, and postoperative care requires only partial weight-bearing on crutches without the need for a cast. Thus, the Bernese periacetabular osteotomy has become our preferred treatment for correction of acetabular dysplasia in hips with a closed triradiate growth plate.

Treatment of the Abnormal Femoral Side

Developmental dysplasia of the hip also affects the femoral head side. There is a wide range of deformities of the proximal part of the femur from a subtle oval-shaped deformity of the femoral head to aberrant torsion or orientation of the femoral neck, to more severe abnormalities of the entire proximal part of the femur¹⁴⁻¹⁶.

Additional Intertrochanteric Osteotomy

Generally, a concomitant intertrochanteric osteotomy is only indicated in approximately 10% of all patients undergoing periacetabular osteotomy¹⁷. The most common indications for an additional intertrochanteric osteotomy are (1) an extreme valgus angulation of the femoral neck with a fovea alta, (2) joint incongruency following acetabular reorientation (typically seen with more severe

femoral head deformities), and (3) restoration of a normal femoral neck-shaft angle after a previous varus osteotomy of the proximal part of the femur.

Extreme Valgus with Fovea Alta

In dysplastic hips, an abnormal valgus femoral neck configuration may be associated with a fovea alta¹⁸, with the fovea capitis femoris more cranial than in a normal hip joint and the ligamentum capitis femoris articulating with the

weight-bearing area of the acetabular cartilage (Figs. 1-A and 1-B). A fovea alta further reduces the weight-bearing zone between the cartilaginous joint surfaces of the femoral head and the acetabulum, aggravating the underlying dysplastic pathomorphology¹⁸.

Joint Incongruency After Periacetabular Osteotomy

Primary or secondary deformity of the femoral head leads to numerous instantaneous centers of rotation that depend on the actual surface under stress, which varies with the relative position of the acetabulum and femur¹⁷. This can be seen on an abduction radiograph made either preoperatively or intraoperatively after periacetabular osteotomy. If the abduction radiograph shows improved hip congruency, a varus osteotomy should be considered (Figs. 2-A, 2-B, and 2-C)¹⁷.

Femoral Neck-Shaft Realignment After a Previous Proximal Femoral Varus Osteotomy

If residual hip dysplasia after a previous proximal femoral varus osteotomy needs acetabular correction, a periacetabular osteotomy may lead to restricted hip abduction, flexion, and internal rotation. A corrective rotational valgus intertrochanteric osteotomy can then minimize anterolateral

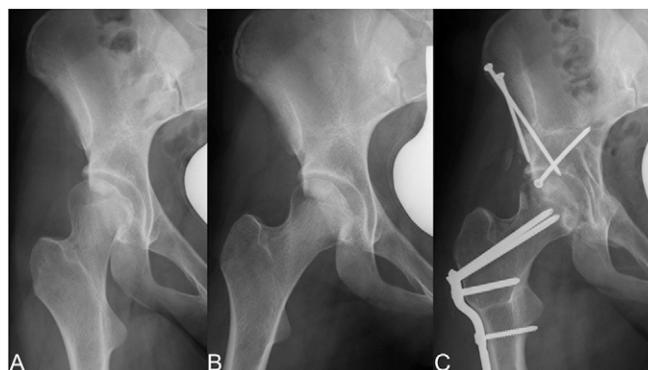


Fig. 2

Figs. 2-A, 2-B, and 2-C A nineteen-year-old woman who presented with acetabular dysplasia, coxa valga, and a high fovea capitis femoris in the right hip. **Fig. 2-A** Anteroposterior radiograph made at the time of presentation. **Fig. 2-B** The preoperative radiograph showed slight incongruency of the joint that resolved in the abduction view. **Fig. 2-C** Radiograph made after a periacetabular osteotomy with an intertrochanteric varus femoral osteotomy.



Fig. 3

Figs. 3-A, 3-B, and 3-C A twenty-four-year-old man with residual dysplasia after previous shelf acetabuloplasty and varus femoral osteotomy of the right hip. **Fig. 3-A** Preoperative anteroposterior radiograph. **Fig. 3-B** Anteroposterior radiograph made after a periacetabular osteotomy was performed with resection of the shelf acetabuloplasty and a concomitant intertrochanteric valgus femoral osteotomy. **Fig. 3-C** Radiograph of the hip made ten years postoperatively showing an excellent clinical result.

impingement and improve clinical abduction by advancing the greater trochanter distally and laterally (Figs. 3-A, 3-B, and 3-C).

Substantial (Perthes-Like) Femoral Head Deformities

Surgical correction of acetabular abnormalities associated with major femoral head deformities is complex. It is conceivable that hips with major femoral head deformities, such as Legg-Calvé-Perthes disease or slipped capital femoral epiphysis, should be treated with additional correction of the deformity of the proximal part of the femur. In severely deformed femoral heads, the femoral side needs to be addressed prior to the periacetabular osteotomy, at times with the technique of a surgical hip dislocation with or without an extended retinacular soft-tissue flap¹⁹. Surgical correction includes osteoplasty of the severely deformed femoral head, trimming of the greater trochanter, and relative lengthening of the femoral neck with distalization of the greater trochanter (see Appendix). In some patients, intertrochanteric flexion or extension osteotomies can be performed.

Prevention of Femoroacetabular Impingement

Hips with developmental dysplasia often have a decreased femoral head-neck offset¹⁴. With the acetabular reorientation typically anterosuperior, head coverage will be increased, which potentially initiates painful femoroacetab-

ular impingement against the proximal part of the femur with reduced femoral head-neck offset (Fig. 4). Therefore, in hips with limited internal rotation ($<30^\circ$), the joint should be opened, visually inspected, and analyzed for impingement with the hip flexed and internally rotated²⁰. The arthrotomy allows for inspection of the acetabular labrum as well as the assessment of the anatomy of the femoral head-neck junction. An osteochondroplasty with removal of the aspherical portion of the femoral head-neck junction should be done (Fig. 4 and Appendix). To provide a rough guideline for the amount of

bone to be resected, the goal of internal rotation of 30° in 90° of flexion seems appropriate²¹. Optionally, major unstable labral tears can be debrided or repaired with suture anchors¹⁵.

Surgical Considerations and Our Preferred Technique

The patient is placed in a supine position with the hemipelvis and leg of the affected side sterilely prepared and draped. The skin incision is a shortened ilioinguinal incision. The incision starts laterally at the intersection between the medial and middle third of the iliac wing and extends about 5 cm medial to the anterior superior iliac spine. The incision is placed about 2 cm distal to the iliac crest (Fig. 5-A). This type of incision is cosmetically superior to the modified Smith-Petersen incision. The sartorius muscle (medial) is separated from the tensor fascia lata muscle (lateral), exposing the direct origin of the rectus femoris muscle from the anterior inferior iliac spine. The abdominal wall muscles are sharply dissected off the iliac crest, and the iliac muscle is mobilized from the iliac wing. The origin of the sartorius muscle together with the inguinal ligament is sharply dissected, mobilized, and medially retracted from the anterior superior iliac spine with the

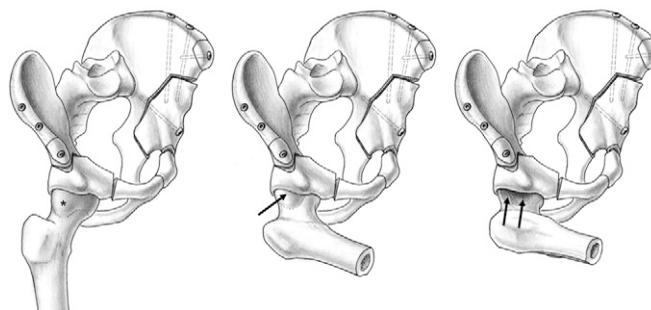
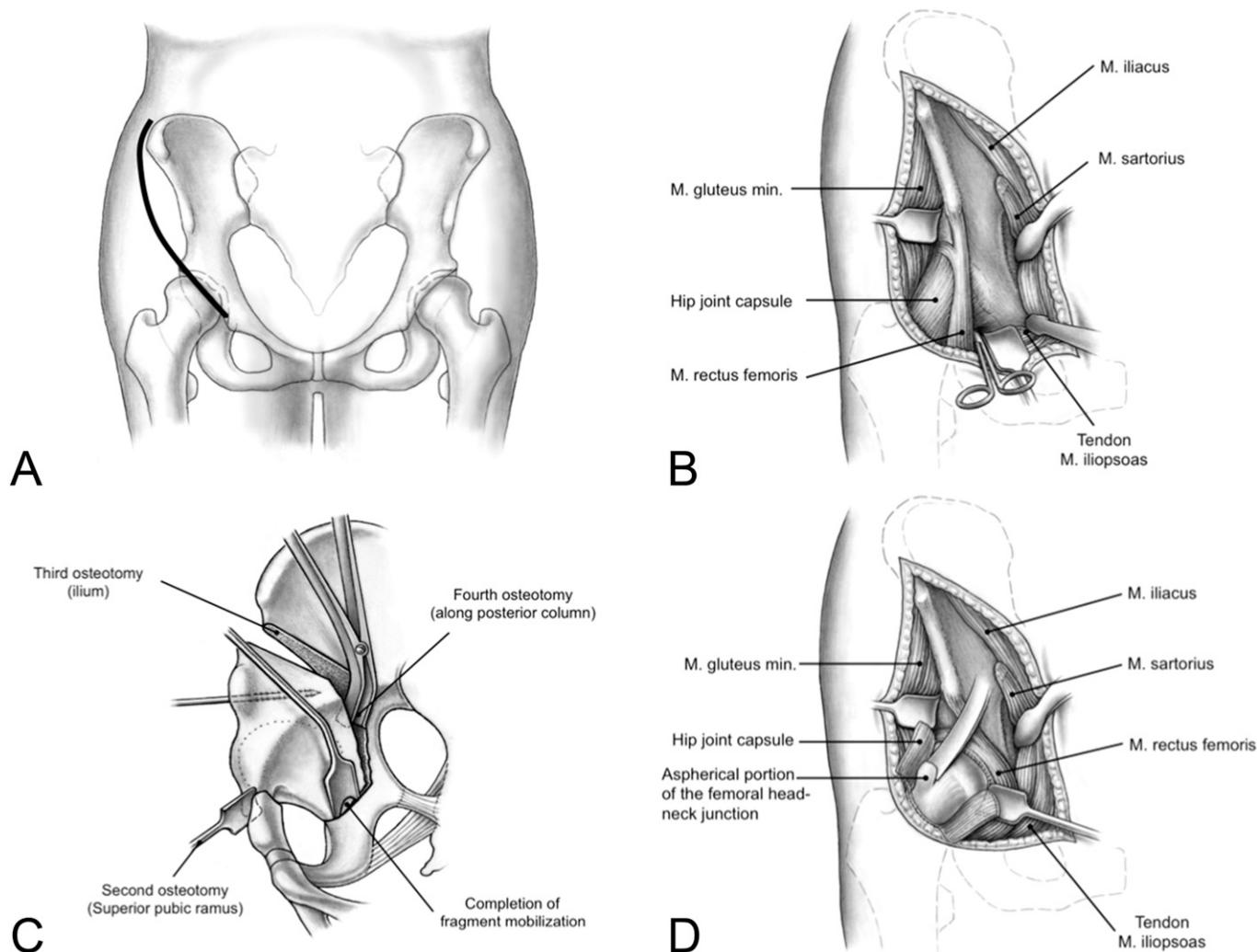


Fig. 4

The current technique of periacetabular osteotomy is shown. Typically, dysplastic hips present with an aspherical femoral head (asterisk) (left). Before periacetabular osteotomy, this decreased head-neck offset is compensated for by the diminished anterior acetabular coverage. After proper reorientation, femoroacetabular impingement may become apparent in deep flexion and internal rotation (arrow) (center). Iatrogenic acetabular overcoverage can worsen this impingement. Through an intraoperative arthrotomy, the femoroacetabular impingement can be assessed (right). If necessary, a concomitant osteochondroplasty of the femoral neck can be performed (arrows). (Reproduced, with modification, from Springer Science+Business Media: Albers CE, Steppacher SD, Ganz R, Tannast M, Siebenrock KA. Impingement adversely affects 10-year survivorship after periacetabular osteotomy for DDH. Clin Orthop Relat Res. 2013 Jan 25. [Epub ahead of print]. Reproduced with permission.)



Figs. 5

Figs. 5-A through 5-D Our preferred technique of periacetabular osteotomy is shown. **Fig. 5-A** An ilioinguinal incision is performed. **Fig. 5-B** Intraoperative view after mobilization of the iliopsoas and the sartorius muscles. The first cut of the ischium is performed through the interval between the joint capsule and the rectus femoris muscle. **Fig. 5-C** The four periacetabular osteotomies are shown. **Fig. 5-D** Offset creation is performed with the rectus femoris muscle retracted medially through an H-shaped capsulotomy.

iliacus and psoas muscles (Fig. 5-B). As a further modification from the previously used technique, the two origins of the rectus femoris muscle are left intact and the interval between the rectus muscle (lateral) and the iliopsoas muscle (medial) is dissected and bluntly opened with scissors. The iliocapsularis muscle²² is sharply separated from the capsule laterally and mobilized medially, together with the iliopsoas muscle. A Hohmann retractor is placed into the superior pubic ramus 2 to 3 cm medial to the pubic eminence. With use of scissors, the infra-articular space is spread open strictly following the con-

tour of the calcar directly on the intact capsule (Fig. 5-B). With the tip of the scissors, the ischial bone can be palpated beneath the posterior horn. With a specially designed curved chisel, the first ischial osteotomy is done. The osteotomy of approximately 4 to 5 cm is an incomplete cut of the ischium. Next, two blunt retractors are placed around the superior aspect of the pubic bone to protect the soft tissues and perform the pubic osteotomy (Fig. 5-C). At the level of the anterior superior iliac spine, partial elevation of the abductor muscles from the outside of the iliac wing is done to place a blunt retractor for protection

of the abductor muscles. The periosteum and obturator internus muscles are bluntly dissected off the quadrilateral plate, and another blunt curved retractor is placed on the quadrilateral surface close to the ischial spine to further retract the soft tissues medially. With use of an oscillating saw, an oblique iliac osteotomy is performed at the level of the anterior superior iliac spine (Fig. 5-C). This osteotomy ends 1 to 2 cm lateral to the pelvic rim. From there, an osteotomy angled approximately 110° distally in regard to the previous horizontal cut of the ilium. This osteotomy is performed with a

TABLE 1 Minimum Ten-Year Survivorship of the Hip After Surgical Treatment of Developmental Dysplasia with Conversion to Total Hip Arthroplasty as the End Point

Study	Technique	Duration of Follow-up* (yr)	No. of Hips	Age* (yr)	Survival Rate (%)
Siebenrock et al. ¹⁰ (1999)	Periacetabular	11.3 (10-14)	75	29 (13-56)	82
Kralj et al. ²⁷ (2005)	Periacetabular	12 (7-15)	26	34 (18-50)	85
Flecher et al. ²⁸ (2008)	Periacetabular	12 (2-19)	33	32 (18-47)	74
Steppacher et al. ²⁶ (2008)	Periacetabular	20.4 (19-23)	75	29.3 (13-56)	61
Matheney et al. ⁴⁰ (2009)	Periacetabular	9 ± 2.2	135	23 (10-44)	84
Ito et al. ⁴⁶ (2011)	Periacetabular	11 (5-20)	158	32 (12-56)	96
Nakamura et al. ³⁴ (1998)	Rotational	13 (10-23)	145	28 (11-52)	95
Takatori et al. ⁴⁷ (2000)	Rotational	13 (10-18)	28	33 (19-40)	96
Takatori et al. ³⁰ (2001)	Rotational	19.8 (15-22)	15	24.3 (20-28)	100
Nozawa et al. ⁴⁸ (2002)	Rotational	11.4 (10-15)	50	31.8 (13-53)	98
Yasunaga et al. ³⁹ (2004)	Rotational	11 (8-15)	61	35 (13-58)	100
Guille et al. ³¹ (1992)	Triple	12 (10-16)	11	14 (11-16)	91
van Hellemond et al. ³⁵ (2005)	Triple	15 (13-20)	51	28 (14-46)	88
Janssen et al. ³⁶ (2009)	Triple	12 (11-12)	35	39 (24-57)	85
Schramm et al. ⁹ (2003)	Wagner spherical	23.9 (20-29)	22	24.4 ± 9.7	68
Zagra et al. ²⁹ (2007)	Wagner spherical	23.1 (21-27)	10	19.3 (17-27)	100

*Continuous data are expressed as the mean, with the range in parentheses if available, or the standard deviation.

straight and a curved chisel and is directed to the ischial spine. A Schanz screw is inserted at the level of the anterior inferior iliac spine to do a controlled fracture of the remaining bone (Fig. 5-C). A spreader inserted in the osteotomy gap of the iliac bone assists this maneuver. The controlled fracture can be aided by an additional cut with the specially designed curved chisel from the inside of the quadrilateral surface. Once the fragment is completely free, the acetabulum is oriented with the Schanz screw and Hohmann retractors. Preliminary fixation of the bone is done with use of 2.5-mm partially threaded pins.

An intraoperative radiograph is made with a radiographic plate slid underneath the patient, using a specially designed "sandwich" table, which eliminates the need to move the patient or the drapes. The evaluation criteria for an optimal correction are described in more detail in the following section. The intraoperative decision for the need of an additional osteotomy on the femoral side may require additional abduction or adduction radiographs. Three 3.5-mm cortical screws are typically used to

definitively fix the acetabular fragment. Internal rotation is evaluated with the hip flexed 90°. If there is <30° of internal rotation in the presence of decreased femoral head-neck offset on a lateral radiograph, an H-shaped capsulotomy is performed (Fig. 5-D).

The rectus femoris muscle is retracted medially for the capsulotomy. The osseous contour of the anterosuperior femoral head-neck contour²⁰ is trimmed (a so-called offset correction) with a curved chisel and/or a high-speed burr (Fig. 5-D)²⁰. This is best performed with the lower limb in 10° of flexion and various positions of rotation. The incision is closed with absorbable sutures, and a running suture is placed along the iliac crest to reattach the muscle sleeve and the inguinal ligament to the outer fascia of the pelvis and thigh. Postoperatively, a continuous passive motion machine is used and partial weight-bearing of 15 to 20 kg is recommended for six to eight weeks after surgery.

Intraoperative Evaluation

Intraoperative evaluation can most accurately and efficiently be done by examining an anteroposterior pelvic

radiograph. The tube-to-film distance is approximately 1.2 m in our department. Recommendations for defining the so-called ideal correction parameters can only be given in ranges and not to the exact degree. The parameters and recommended goals are (1) a lateral center-edge angle between 20° and 35°, preferably between 25° and 30°; (2) an anterior center-edge angle between 0° and 10°, preferably in the upper range; (3) head medialization with a distance between the medial aspect of the femoral head and the iliioischial line of <10 mm; (4) restoration of the Shenton line; (5) a weight-bearing dome centered over the head; (6) anteversion of the acetabulum as defined by the absence of a cross-over sign and the outlines of the anterior and posterior rim meeting at the lateral acetabular edge; and (7) restoration of hip joint congruency²³.

Persistent joint incongruity after acetabular reorientation requires intraoperative functional radiographs made with the hip in abduction or adduction to decide whether an intertrochanteric osteotomy is necessary. After obtaining a satisfactory correction, we judge the hip

motion, especially flexion and internal rotation. Although there is no agreement regarding the definition of decreased internal rotation, internal rotation that is only between 15° and 30° should lead one to further search for its cause. Exclusion of intra-articular femoroacetabular impingement or extra-articular impingement against the anterior inferior iliac spine is recommended²⁴. In a recent series of ninety patients, a femoral head-neck offset correction was performed in 57% of the hips after acetabular reorientation through a periacetabular osteotomy²⁵.

Review of the Literature

There is evidence that acetabular reorientation can decelerate joint degeneration²⁶. The long-term results (ten to almost thirty years) for all three types of juxta-acetabular osteotomies are summarized in Table I. The survivorship of the hip has been reproducibly shown to be approximately 90% after ten years and 60% to 70% after twenty years, independent of the reorientation technique. The long-term reports of the early series typically involved heterogeneous patient cohorts²⁶⁻²⁸, including patients with advanced age and/or joint degeneration. In a follow-up study with a more homogeneous patient cohort at our institution, a good clinical result without progression of osteoarthritis was achieved in 90% of the patients at a minimum ten-year follow-up interval²⁵. Follow-up studies that have shown survivorship of up to 100% typically have involved a nonconsecutive series of patients²⁹, exclusive of patients with previous surgical procedures on the hip³⁰, low numbers of patients²⁹⁻³¹, or a substantial percentage of patients lost to follow-up³⁰. The natural history of hip dysplasia is not as good³².

Several common negative predictors influencing the long-term outcome after acetabular reorientation for devel-

opmental dysplasia of the hip were identified. These include mainly demographic or independent preoperative factors such as advanced age^{27,33,34}, low preoperative functional hip scores^{26,35}, a body mass index of >25 (kg/m²)³⁶, preexisting early osteoarthritis^{26,37-41}, a preoperative limp²⁶, evidence of a labral tear⁴² with pain in flexion and internal rotation²⁶, and preoperative femoral head subluxation^{25,41}.

Postoperative lateral acetabular undercoverage^{25,43} and excessive acetabular anteversion²⁵ can lead to persistent static overload of the lateral and/or the anterior acetabular rim with subsequent degeneration. Postoperative lateral overcoverage^{20,25} and acetabular retroversion^{25,44} have been associated with decreased hip survivorship because of iatrogenic postoperative femoroacetabular impingement between the overcorrected acetabulum and the proximal part of the femur. A previous femoral head-neck offset correction or, if necessary, an intraoperative offset correction in hips with an aspherical head-neck junction improves the ten-year survivorship^{25,45}. In conclusion, improper acetabular reorientation, specifically incorrect acetabular version and a concomitant persistence of an aspherical femoral head-neck junction, needs to be included as a risk factor for a less favorable outcome²⁵.

Overview

The appropriate surgical treatment of hip dysplasia after closure of the tri-radiate cartilage is a reorientation of the entire acetabulum. Among the different surgical techniques for acetabular reorientation, periacetabular osteotomy has become the gold standard. It provides the largest reorientation potential with inherent stability because of its polygonal shape without changing the dimensions of the birth canal. There is increasing evidence that the natural

degeneration in dysplastic hips can be decelerated by periacetabular osteotomy. The survival rate of the hip after acetabular reorientation is approximately 90% after ten years and 60% to 70% after twenty years. Careful patient selection, an optimal acetabular reorientation, and a concomitant osteochondroplasty of an aspherical femoral head-neck junction may lead to improved long-term results.

Appendix

eA Figures showing radiographs of a twenty-five-year-old woman with residual deformity from Legg-Calvé-Perthes disease who had an excellent result after a periacetabular osteotomy, surgical hip dislocation with trimming of the femoral head-neck junction, and lengthening of the femoral neck as well as radiographs of a female patient with developmental dysplasia of the hip who had correction of a decreased femoral head-neck offset with an arthrotomy are available with the online version of this article as a data supplement at jbjs.org.

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