Other Pelvic Osteotomies

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Key Learning Points

- Triple osteotomy offers an acetabular correction option in immature triradiate cartilage.
- Improvements in technique increased fragment mobility and fixation, diminishing surgical trauma.
- Chiari osteotomy is a unique salvage pelvic osteotomy.
- Optimized technique with surgical hip dislocation improves access and lowers abductor muscle trauma.
- Shelf acetabuloplasty as stand-alone or augmentation procedure increases hip coverage.

Introduction

Numerous variations of pelvic osteotomies have been described over the years. They can be divided into two main types: reconstructive procedures and augmentation (salvage) procedures. The idea behind the reconstructive procedures is to realign the joint surface to increase the surface area for load transmission while restoring the stability. This creates near normal joint loading and delays or prevents secondary osteoarthritis by reorientation of acetabular hyaline cartilage and its subchondral bone over the femoral head. Augmentation procedures aim to create a fibrocartilaginous surface after a metaplastic adaptation of the new cover created over the femoral head which is provided either by the joint capsule or a bone graft. Studies have shown that shelf and Chiari osteotomies did not lead to a higher perioperative complication rate, higher revision rate, or shortened survivorship of subsequent total hip arthroplasty (THA) in developmental dysplasia of the hip. On the contrary, such procedures can improve acetabular bone stock and facilitate subsequent THA. However, rotational acetabular osteotomy (RAO) may render conversion to THA more difficult. The operative time was significantly longer, and a significantly more acetabular bulk bone augmentation was required in the RAO due to posterior wall defects created after anterior and lateral rotation acetabular fragment [1–3]. However, the need for an extensive

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surgical dissection, disruption of the acetabular anatomy making THA more challenging, and less than excellent results of THA have limited the indications of some of those reconstructive procedures.

Reconstructive Procedures

Triple Pelvic Osteotomy

Historical Background

The first triple pelvic osteotomy (TPO) was described by Le Cœur in 1965 and offered better rotation of the acetabular fragment and correction capacity in patients with immature triradiate cartilage. In the initial technique, the osteotomies of the pubic and ischial rami were performed close to the symphysis in the medial aspect of the obturator foramen. Steel's modification of the technique was published in 1973 and included two separate incisions to perform the osteotomies. The ischial cut was performed through a buttock incision, while the pubic and ilium cuts were performed through the classic approach for the Salter innominate osteotomy. This technique allowed greater freedom of movement for the correction of the acetabulum, although still limited by the sacrospinous ligament.

In 1981, Tönnis published a variation of the triple pelvic osteotomy in which the ischial cut was performed proximal to the ischial spine and much closer to the joint, thus allowing a greater correction of the acetabulum and a greater bone contact for healing [4]. Subsequently, it was demonstrated that the Tönnis triple osteotomy provides a range of correction similar to the Ganz osteotomy [5]. The drawbacks of the triple osteotomy technique include a discontinuity of the anterior and posterior columns, rendering the acetabular fragment unstable in the post-operative period.

Many alterations of this technique have since been described in the literature. Birmingham Interlocking Pelvic Osteotomy (BIPO) is a technique which uses angulated cut edges in the ilium at predetermined angles to allow interlocking of the acetabular fragment with the ilium and thus provide an immediate stable construct [6, 7]. Various surgical techniques have been described using single or two incisions in a minimally invasive surgery (MIS) fashion [8, 9]. Others resect a triangular wedge of bone from the proximal ilium, thus creating a slot in which the distal segment of the posterior ilium will interlock and stabilize after it is rotated [10].

Clinical Indications

The generally accepted surgical indication for TPO is acetabular dysplasia with clinically important pain that interferes with normal activities. The patient is typically between 5 and 10 years old with open triradiate cartilage. Acetabular dysplasia is radiographically defined as a center-edge angle (CEA) <20 ° and acetabular Sharp's angle >40 °. The prerequisites to perform a TPO include a preserved range of motion of the hip joint with 20 ° of abduction, 90 ° of flexion, and 10 ° of internal rotation. Failure to respect these criteria results in an externally rotated hip with limited flexion, thus making normal walking impossible [11]. In addition, the femoral head must be spherical and reducible, although this criterion can be partially ignored in young adults [11]. The contraindications to performing TPO include incongruity of the hip joint due to femoral head or acetabular deformity resulting from a previous hip disease, degenerative arthritis of the hip, severe contractures of the hip, and inability to reduce the femoral head within the acetabulum [10].

The second indication for TPO includes Legg-Calvé-Perthes (LCP) disease. The primary goal of the management of LCP disease is to prevent deformation of the femoral head by its containment during the healing phase of the disease to promote spherical remodelling during growth [12]. Recent studies have demonstrated that surgical containment procedures produce better results than non-surgical treatment in the lateral pillar B and B-C border groups [13]. Recent data also show that TPO produces better radiological and clinical outcomes than Chiari osteotomy [14]. Although it has been demonstrated that proximal femoral varus osteotomy yields favourable results when performed before late fragmentation [15], TPO alone may produce favourable results even in severe cases without altering proximal femoral anatomy [16].

Advantages of TPO

- Easier learning curve
- Independent of triradiate cartilage maturity
- Low risk of osteonecrosis of the acetabulum
- Low risk of major vessel complications

Disadvantages of TPO

- Risk of non-union
- Limited weight bearing in the post-operative period
- Limited acetabular correction
- Morphological deformity of the birth canal

Surgical Technique

Steel's Modification

Steel's TPO technique involves two incisions while the patient is placed supine on the operating table. With the hip flexed at 90 °, the first incision is horizontal, 1 cm proximal to the gluteal crease and perpendicular to the long axis of the femur. The gluteus maximus is retracted laterally and the biceps femoris is then elevated off the ischium. A curved forcep is placed around the ischium between the origin of the semi-membranous and semi-tendinous muscles. An osteotome is used to complete the osteotomy obliquely from lateral to medial. The incision is then closed.

A second incision is then performed using the standard iliofemoral approach. The iliacus and gluteal muscles are reflected off the iliac wing in a subperiosteal fashion. The sartorius and the origin of the inguinal ligament are detached and reflected medially. The pectineal muscle is detached from the superior pubic rami. An osteotome is then used to cut the superior pubic rami approximately 1 cm medial to the pectineal tubercule while protecting the obturator neurovascular bundle with forceps. The iliac osteotomy is then completed according to the Salter technique. A Gigli saw is introduced subperiosteally in the sciatic notch and carried anteriorly to a mid-point between the antero-superior and antero-inferior iliac spine.

A towel clip gripping the AIIS is then used to correct the acetabulum in the desired position. The acetabular fragment is then stabilized using a bone graft obtained from the superior iliac wing and transfixed with two extra-articular pins just penetrating the inner table of the ilium to prevent superior migration of the pins during healing. The wound is closed in layers, and a Spica cast is applied.

Tönnis' Modification

Tönnis' technique originally involved three incisions and two different positions, although subsequent publications have recommended a single patient position and incision [17]. The patient is first placed prone on the operating table. A first incision is made in the gluteal region, from the ischial spine to the ischial tuberosity. The gluteus maximus is dissected bluntly to expose the ischial spine and the fascia covering the external rotators. The external rotators are then divided between the internal obturator and gemelli, sparing the sacrotuberous ligament. Retractors are then placed within the obturator foramen and the sciatic notch. The first osteotomy is performed, begins just cephalad to the ischial spine and ends in the obturator foramen. The incision is then closed and the patient placed supine on the radiolucent table.

A second incision is made in the pubic area. The femoral neurovascular bundle is retracted laterally. Dissection is carried up to the pubis rami. Subperiosteal dissection is carried laterally up the pubic rami to the lateral border of the obturator foramen. The second osteotomy is performed parallel and close to the teardrop. A third incision is then performed in order to expose the region above the roof of the acetabulum. The incision extends from the iliac crest to the inguinal region, similar to that described in Salter

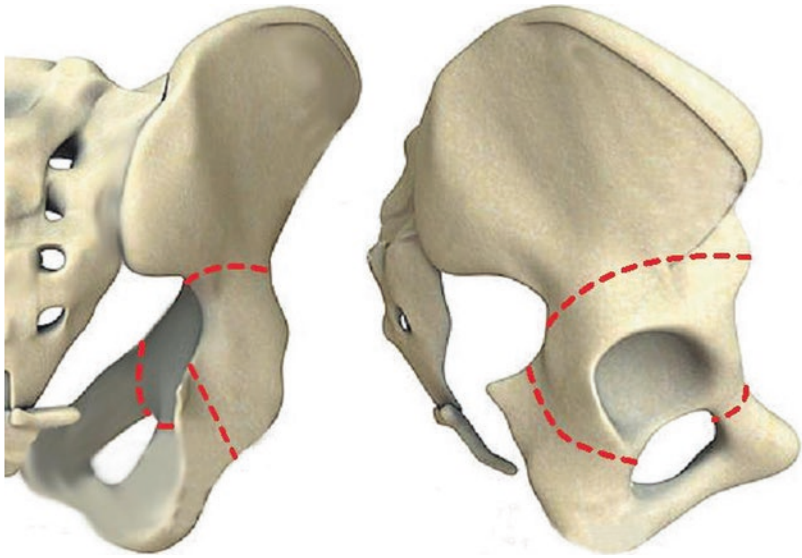

Fig. 13.1 Illustration of Tönnis osteotomy

osteotomy. Subperiosteal dissection is performed on the outer and inner tables of the ilium. Retractors are placed on either side of the ilium into the sciatic notch. When adequate exposure has been obtained, a Steinmann pin is inserted just above the acetabular roof and aimed in a medial and caudal direction, parallel to the planned osteotomy. The third osteotomy is then performed 2–3 cm above the acetabular roof laterally towards the sciatic notch in a posteromedial descending direction (Fig. 13.1).

The Steinmann pin can then be used to joystick the fragment into the desired position. Once the desired femoral head coverage has been obtained, a bone wedge taken from the iliac crest is inserted into the osteotomy cleft. Four non-threaded 2–2.5 mm K-wires are inserted via the iliac crest and stabilize the osteotomy site.

Post-operative immobilization is done with a Spica cast for 6 weeks. Full weight bearing is allowed once sufficient radiologic consolidation is present. The K-wires are typically removed after 4 months.

O'Hara's Modification

In 2002, O'Hara and colleagues proposed the Birmingham Interlocking Pelvic (Triple) Osteotomy (BIPO) that facilitates the reduction manoeuvre and provides greater fragment stability, which allows immediate post-operative weight bearing [6]. The technique involves two skin incisions and two different positions. The patient is first placed in a lateral decubitus position on the operating table. An oblique skin incision is performed between the greater trochanter and the ischium. The gluteus maximus is bluntly dissected in line with its fibres. The sciatic nerve is mobilized over a distance of 8–10 cm and retracted laterally. The external rotators are elevated to allow access to the ischium. A straight Lexer 2 × 2 cm osteotome is used to perform the ischial cut, starting slightly proximal to the ischial spine and aiming at the obturator foramen in an oblique fashion. The depth of the osteotome prevents medial penetration during the cuts and subsequent damage to the pudendal structures. Once the osteotomy is complete, the wound is closed and the patient is placed supine on the table.

A Salter-type incision is then performed to access the pubic and ilium cuts. The superior pubis ramus is dissected in a subperiosteal manner, and the cut is performed just medial to the teardrop with a concave-ended angled Lexer osteotome. Dissection of the inner table of the ilium is then continued past the iliopectineal line into the quadrilateral plate until the sciatic notch is visualized. The iliac osteotomy is then performed using three linked cuts. The two angles formed between these osteotomies must be equal to allow accurate bony apposition and interlocking of the construct. The resulted angle between the cuts must be templated preoperatively since it determines the extent of lateral coverage. The first pin is inserted above the triradiate cartilage in the true sagittal/axial plane, whereas the second is inserted parallel to the acetabular dome. An external fixator link bar can be used to joystick and to rotate the central acetabular fragment laterally. The acetabular fragment is then fixed using two 4.5 mm screws either in a parallel or in a converging configuration. Early weight bearing is permitted in the post-operative period.

Surgical Complications

Non-union

Recent literature describes the TPO non-union rates varying between 1% and 14.5% [7, 11, 16, 18–25]. A review of non-union cases following TPO suggested several recommendations to decrease the incidence, notably achieving adequate bony contact on all osteotomy sites, using strong screws to stabilize the iliac cut, using a long mediolateral screw to stabilize the pubic osteotomy until union and avoidance of sitting on the ipsilateral ischial tuberosity for 6 weeks following the surgery [26].

Nerve Injury

The most frequent nerve injuries reported are lateral femoral cutaneous nerve (LFCN), sciatic nerve (SN), and femoral nerve (FN) palsies [6, 7, 11, 18, 19, 21–23, 25, 27–29]. Some series have reported permanent LFCN injuries in up to 9% of patients [11] and others transient SN palsies in up to 7.1% of patients [21].

Vascular Injury

Although rare, vascular injuries are a dangerous potential complication of the TPO. Liddell et al. and Hailer et al. have reported major bleeding from the internal iliac artery [27, 28].

Infection

Reported infection rates in the literature vary between 1.7% and 6.5% [6, 19, 20, 23, 25, 27, 29, 30]. Although most infections are superficial and treated with antibiotics, Hailer et al. reported two cases of infection requiring revision surgery [27].

Other Complications

Eceviz et al. reported a case of intra-articular fracture during the TPO [20]. Three case series have reported deep vein thrombosis, with rates varying between 0.5% and 1.7% [7, 18, 20]. Hailer et al. reported two cases of fatal pulmonary embolism (3.2%) [27]. Other reported complications include chondrolysis of the joint [6, 20], heterotopic ossification in up to 4.7% of patients [21, 27], gluteal muscle insufficiency, and femoral head necrosis [27].

Clinical Results

Functional and Clinical Outcomes

Many studies have considered conversion to total hip arthroplasty as the end-point survival of the TPO (Table 13.1). The longest follow-up

Table 13.1 TPO survivorship in the literature

Author	Year of publication	Hips (patients)	Follow-up mean years (range)	Age at surgery years (range)	Survival as conversion to THA
Eceviz [20]	2017	58 (50)	8.8 (1.5–15.9)	23.3 (14–47)	At 8.8 years: 98%
Mei-Dan [7]	2017	116 (100)	17.5 (13.8–21.5)	31 (7–57)	At 10 years: 76%, At 17 years: 57%
Van Stralen [23]	2013	51 (43)	25 (23–29)	28 (14–48)	At 10 years 83%, At 15 years: 80.3%, At 25 years: 68.6%
Janssen [18]	2009	177	11.5 (11–12.2)	38.6 (23.9–57)	At 11.5 years: 85.3%
van Hellemondt [19]	2005	51 (43)	15 (13–20)	28 (14–46)	At 15 years: 88%
Hailer [27]	2005	61 (51)	6 (2–16.9)	23 (8–44)	At 6 years: 87%

published has demonstrated 68.6% survival rate at 25 years using the Tönnis technique [23]. This same series demonstrated 83% survival at 10 years and 80.3% at 15 years. Other series using the Tönnis osteotomy have demonstrated survival rates ranging from 97.4% at 3.5 years to 85.3% at 11.5 years [18, 27]. Mei-Dan et al. published their results using the BIPO technique, with survival rates of 76% at 10 years and 57% at 17 years [7]. Functional outcomes have also been reported in these series using several scores, notably the Harris Hip Score (HHS), the Oxford Hip Score (OHS), the UCLA activity score, and the Merle d'Aubigné score (MAP). Most reported outcomes demonstrate lasting improvements in pain and function scores, with good or excellent outcomes present in >90% of patients with follow-up of 10 or more years. Janssen et al. published results on TPO in 32 patients with grade 2 osteoarthritis and concluded that it was a viable alternative in delaying THA, with a 85.3% survival at 11.5 years [18]. He also reported poor outcomes with preoperative HHS score <70 and BMI >25.

Radiological Outcomes

Radiological outcomes have also been reported in many series in an attempt to better understand the amount of correction obtained with the osteotomy. The most frequent radiological measurements included were center-edge angle (CEA), acetabular index (AI), and anterior center-edge angle (ACEA).

Among the studies, the average increase in CEA varies between 5.9° and 30.7° when comparing preoperative with post-operative values at the final follow-up [7, 14, 17, 18, 20–22, 28, 30]. Meanwhile, an average decrease in the AI varies between 2° and 28° when comparing these same studies (Fig. 13.2). The average increase in ACEA varies between 22° and 26°. Several authors have warned about the dangers of overcorrection, i.e. acetabular retroversion, which may lead to an iatrogenic femoroacetabular impingement (FAI).

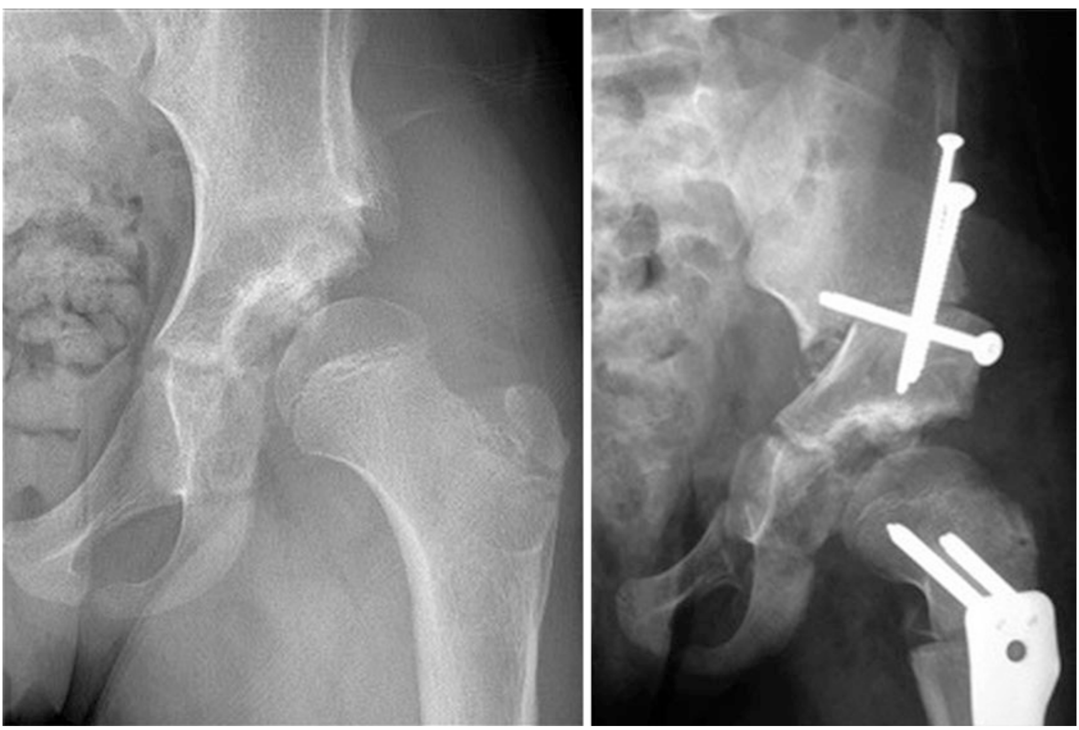

Fig. 13.2 Radiological demonstration of a triple osteotomy: in a 13 year old girl presenting with residual dysplasia after an open reduction at age 18 months; pre, and 6-month post-operative radiograph

Pearls and Pitfalls

- More rigid fixation allows shorter Spica immobilization if any.
- An anterior approach to complete the ischium cut with a curved osteotome using the Ganz technique avoids a second patient positioning [17].
- The pubic ramus osteotomy is performed as lateral as possible to maximize acetabular fragment mobility.
- Upon acetabular fragment positioning, the centre of the acetabulum is medially displaced to reduce Shenton's line.
- Range of motion of the hip is tested after final acetabular fragment fixation to avoid acetabular retroversion/FAI.

Augmentation (Salvage) Procedures

Chiari Pelvic Osteotomy

Historical Background

The surgical technique for this salvage pelvic osteotomy was introduced for the first time, in Vienna, by Karl Chiari in the 1950s [31]. The original indications for this technique included congenital hip dysplasia with or without subluxation for all age groups. Later, children under 6 years were excluded, when reorientation osteotomies and acetabuloplasties offered an improved head coverage by virtue of healthy cartilage [32]. Currently, the indications for the Chiari osteotomy have become more limited since the introduction of modern periacetabular reorientation osteotomies and improvements in total hip arthroplasty (THA) wear properties. Therefore, careful patient selection as well as proper management of patient expectations is crucial for a successful result.

The biomechanical rationale for the Chiari osteotomy is to increase the acetabular coverage by creating a superolateral roof. The overload of the hip intra-articular cartilage is decreased by medial displacement of the femoral head, which in turn reduces the joint loading and abductor lever arm (Fig. 13.3). Displacing the hip centre closer to the midline can also improve the Trendelenburg limp [33]. As a result, the hip joint capsule is interposed between the superolateral roof created by the laterally displaced iliac bone

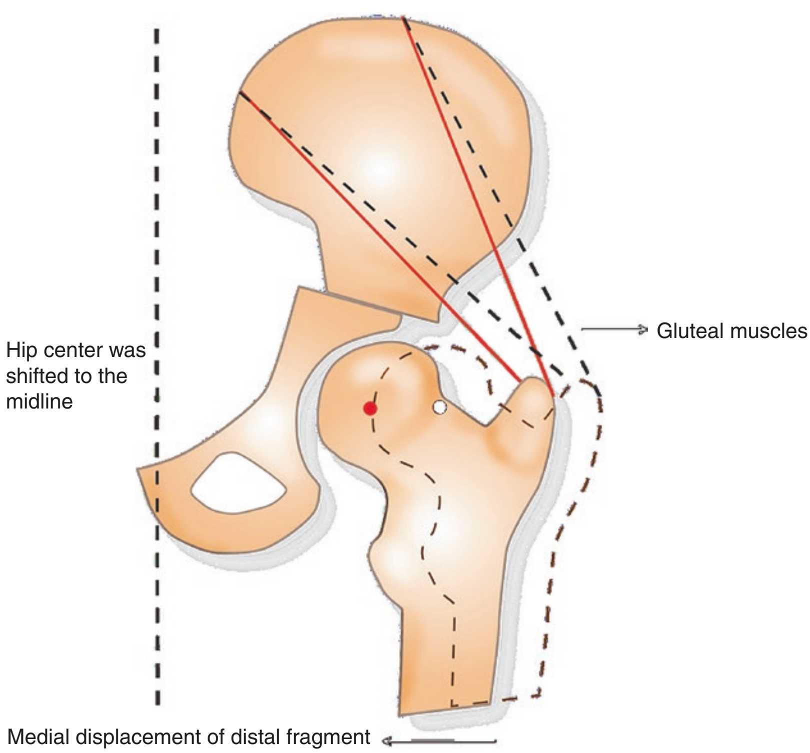

Fig. 13.3 Demonstration of the biomechanical effects of the Chiari medialization

and inferiorly by the medially displaced femoral head. This part of the capsule undergoes metaplastic change to fibrocartilaginous tissue after 6 months [31, 34].

Clinical Indications

The classical indication for the Chiari osteotomy was described in congenital dysplasia of the hip with femoral head subluxation and closed triradiate cartilage. The early description of the femoral head coverage included congruent hip joint once the reduction was obtained. More contemporary indications for this osteotomy focus on adolescents and young adults presenting with incongruent dysplastic hip with mild to moderate arthritic changes [32, 35]. The medial displacement of the femoral head centre has been useful in severe dysplasia or subluxated hips with inadequate femoral head coverage and where the shallow acetabulum cannot provide sufficient bone stock to be mobilized to the weight-bearing area by reorientation osteotomies and/or femoral osteotomy alone [36]. Coxa magna as an acquired sequelae of Legg-Calvé-Perthes disease represents an excellent indication [37].

Contraindications for performing a Chiari pelvic osteotomy include advanced arthritic changes, severe dysplasia associated with a highly dislocated hip that prevents an adequate slope of the osteotomy towards the top of the greater sciatic notch above the hip joint sourcil [38], and patients with hip flexion of 90 ° or less. Relative contraindications may include patients over 40 years of age for whom a THA would provide good to excellent results. Recent recommendations debate whether to avoid Chiari osteotomy in the hips with labral tears or address these tears arthroscopically before the osteotomy for optimized results [39, 40].

Advantages

- Medialization of the acetabulum leads to the improvement of the abductor lever arm, the reduction of the body weight moment arm, and the decrease in the hip reaction forces (20% decrease with 15 mm of medialization).
- Offers an immediate roof coverage allowing early weight bearing.
- Creates a deeper and larger acetabular cavity for future THA.

Disadvantages

- Technically demanding with regard to the level and angle of the osteotomy.
- The hyaline cartilage covered weight-bearing area cannot be increased.
- Lower limb length adjustment is not possible.
- Pelvic ring is deformed with large medial displacement.
- Risk of sciatic nerve injury.

Surgical Technique

The patient is typically in the supine position on a fracture table with an image intensifier available during the duration of the procedure. Classical teaching favours the *Smith-Petersen approach* using an anterolateral bikini-like incision 10- to 12-cm long lateral and slightly distal to the iliac crest. The iliac crest is first exposed subperiosteally. The inner table is exposed by subperiosteal elevation to the greater sciatic notch. The sciatic nerve is protected by a blunt flexible retractor, positioned deep into the greater sciatic notch. The hip joint capsule is exposed by blunt dissection and elevation of tensor fasciae latae, the anterior part of the gluteus medius and the gluteus minimus. Gluteal vessels and nerves are protected at the sciatic notch by another retractor laterally. Dissection of the tendon of the reflected head of rectus femoris muscle from the joint capsule is performed to expose the ilium and the osteotomy site [41]. In order to gain proper lateral access, it may be necessary to further elevate the fasciae latae subperiosteally from anterior to posterior.

An alternative option would propose a *trans-trochanteric approach* [42, 43]. It allows better exposure of the supra-acetabular region by lifting the abductors after the greater trochanteric osteotomy. It avoids dissection of the gluteal muscles from the outer table of the ilium. It can also be decided to distally transfer the greater trochanter to improve the abductor lever arm and consequently the Trendelenburg gait [38].

The level and angle of the iliac bone osteotomy is of the utmost importance to allow the sliding motion between cut surfaces. The iliac bone is osteotomized just above the acetabulum and below the AIIS. The exact location of the osteotomy line starts between the capsular attachment to the iliac bone and reflected head of rectus femoris. Most surgeons will use image intensifier guidance for orientation of the bony cut. The osteotomy ascends towards the sciatic notch at an angle of 7–10 ° medially and proximally in a curved fashion above the insertion of the sacrospinous ligament (Fig. 13.4). Classically, the lateral table is opened first along this line from anterior to posterior. Afterwards, the osteotomy is completed through the medial cortex. The acetabulum is medialized by forced abduction in neutral rotation after release of the traction or direct leg manipulation [44–47]. The amount of correction via translation can be evaluated by a full pelvis antero-posterior view on the image intensifier during surgery. While the amount of coverage of the femoral head should be aimed to obtain a lateral center-edge angle around 25°, **the lateral translation** remains limited by the amount of bone medially to keep enough bone contact for fixation and healing

Although Chiari's original technique involved no fixation or immobilization during the postoperative period, current recommendations include fixation with K-wires or cannulated short threaded screws to secure and maintain adequate displacement (Fig. 13.5) [47, 48].

Surgical Complications

- Incomplete medialization
- Decreased hip range of motion
- Sciatic nerve palsy
- Non-union
- Heterotopic ossification
- Difficult dislocation of femoral head during THA conversion

Clinical Results

Functional and Clinical Outcomes

Clinical outcome is related to the stage of the disease at surgery. Yanagimoto et al. compared surgical technique parameters (osteotomy height, osteotomy angle, displacement ratio) between an improved patient group (66 hips) and a poor

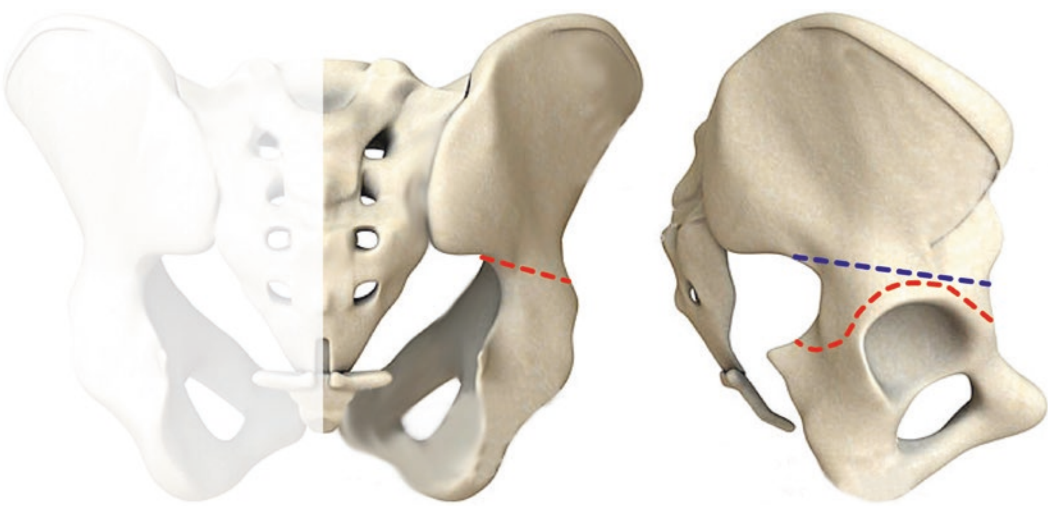

Fig. 13.4 Representation of the Chiari position of the osteotomy. The dashed red line demonstrates a contemporary modification of the classical (blue dashed line) osteotomy

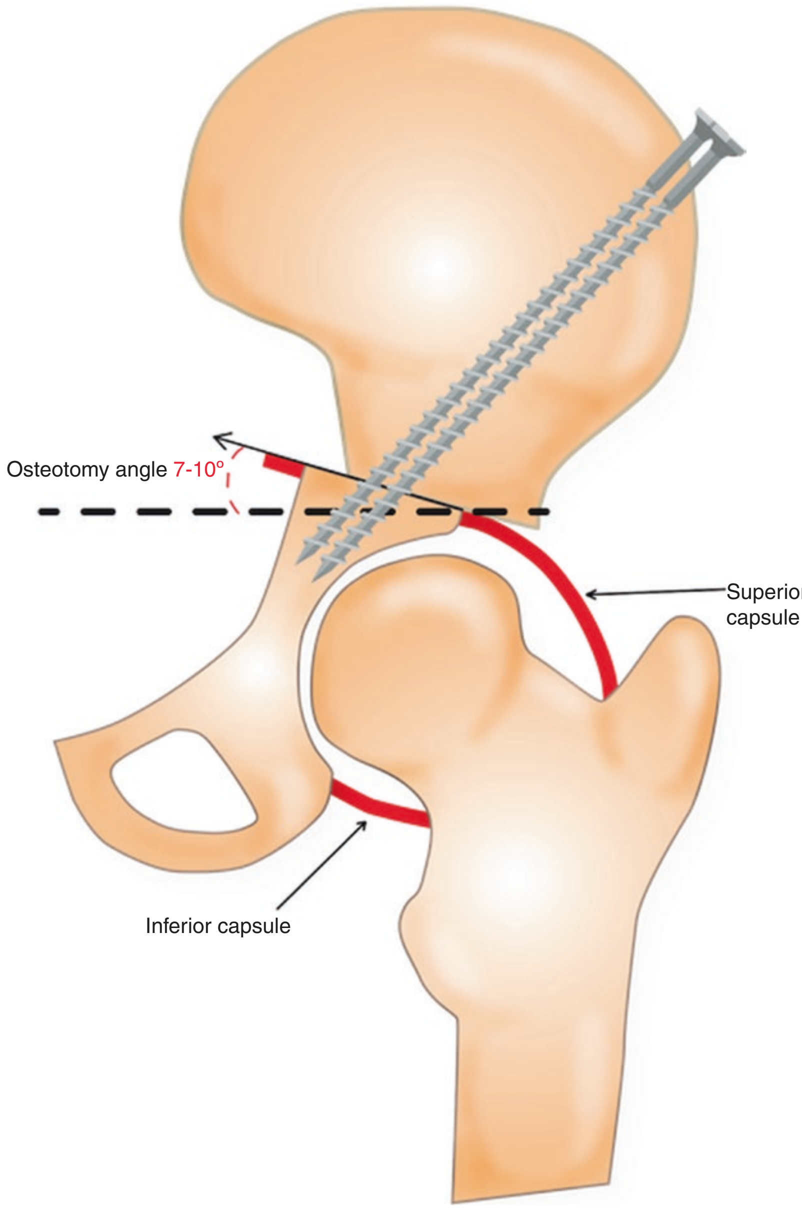

Fig. 13.5 Illustration of the Chiari osteotomy fixation method with screws

outcome patient group (7 hips) to identify factors affecting the final outcome [49]. Authors found no statistically significant differences between the two groups for these three surgical technique parameters. Early Tönnis grade 1 dysplasia is a good indication for Chiari, while the combination of advanced Tönnis grade dysplasia may show early progression to osteoarthritis [49]. Lack et al. and Windhager et al. have reported long-term outcome of Chiari osteotomy performed by Chiari himself (82 patients, age ≥30 years, average follow-up of 15.5 years and 236 patients, follow-up >20 years, respectively). While effective in treating pain, the osteotomy tended to decrease hip range of motion and is therefore contraindicated in hips with flexion of 90° or less [35, 50]. Authors have reported high statistically significant improvements in patient-reported outcome scores [8, 43, 46–48, 51]. Leg length discrepancies remained unchanged, and

Table 13.2 Chiari survivorship in the literature

Author	Year of publication	Hips	Follow-up mean years (range)	Age at surgery years (range)	Survival as conversion to THA
Ito et al. [52]	2011	173	30.2 (10–32.5)	29 (9–54)	28% had fair or poor result 30-year survival rate of 85.9%
Vukasinovic et al. [43]	2011	86	7.2 (4–12.5)	15.6 (10–19)	100% at 4 years 16.2% had early degenerative changes
Kotz et al. [47]	2009	80	32 (27–48)	29.7 (12–54)	40% underwent THR
Migaud et al. [40]	2004	89	18 (6–25)	33 (17–56)	68% at 18 years
Macnicol et al. [53]	2004	215	18 (5–30)	15.9 (9.5)	85.5% 30-year survival rate
Rozkydal et al. [54]	2003	130	22.3 (15–30)	29 (15–52)	38% underwent THR
Ohashi et al. [45]	2000	103	17.1 (4–37)	18.2 (6–48)	Advanced degenerative change developed in 33.7%
Windhager et al. [50]	1991	236	24.8 (20–34)	22.3 (10.7–28.3)	9% needed reoperation

the Trendelenburg positive gait was not improved after a Chiari osteotomy. Many studies have considered conversion to total hip arthroplasty as the endpoint survival of the Chiari osteotomy as shown in Table 13.2.

Radiological Outcomes

Radiological measures have also been reported in many series in an attempt to better understand the amount of femoral head coverage obtained with the osteotomy (Fig. 13.6). Vukasinovic et al. reported an increase in the CE angle by 28.76° ($p < 0.01$) and a decrease in the uncoverage of the femoral head by 51.51% ($p < 0.01$) [43]. Similarly, others have reported improvements in all radiologic parameters of the hip joint (Sharp angle, CE angle, and coverage of the femoral head) [48]. In the study conducted by Ito et al., all radiologic parameters improved with a mean CE angle increase from −2.3° (−27–16 °) preoperatively to 39.1° (18–72 °) post-operatively ($p < 0.001$) [52].

Pearls and Pitfalls

- The reflected head of the rectus femoris is an important surgical landmark. It should be clearly identified and followed posterolaterally to the true acetabulum.
- The level of the osteotomy will remain to be a key element in the clinical outcome. A low osteotomy starting point can lead to an injury of the hip joint capsule [32, 55]. A high osteotomy starting point can lead to later subluxation of the femoral head and injury to the inferior end of the sacroiliac joint [43, 55].
- Draw/guide your osteotomy line to match the femoral head deformity and to finally achieve a congruent incongruity, i.e. a matching between the deformed femoral head and the new acetabular roof.
- Capsule should be kept intact and attached to the distal acetabular fragment.
- Do not use Gigli saw as it is difficult to guide it from posteriorly to produce such a curved and ascending osteotomy orientation.
- Horizontal or downward sloping osteotomies should be avoided as they will block the medial displacement of the distal fragment.

Shelf Acetabuloplasty

Historical Background

The shelf acetabuloplasty was first described by König in 1891 and subsequently modified by Gill and Spitzy [56], Wiberg [57], Staheli [58], and Chiron [59], and Uchida [60] later improved

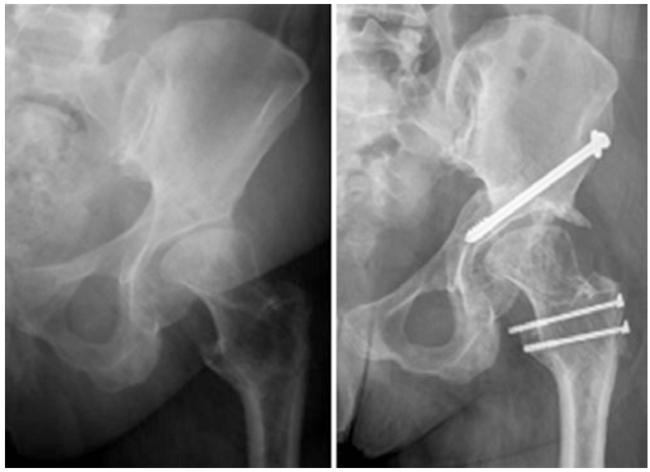

Fig. 13.6 Radiological demonstration of a Chiari osteotomy in a 21 year old Down's syndrome woman presenting with early OA in a dysplastic hip previously treated with a proximal varus and subsequent valgus ITO; pre, and 5-year post-operative radiographs

the technique. The original technique was described in children and adolescents, but there are a few authors who have used the shelf procedures in the skeletally mature adults [40, 61–63]. The main goal of this procedure is to increase the femoral head coverage laterally over the existing hip joint capsule using bone autograft from the ipsilateral ilium. The extra-articular superolateral buttress widens the bearing surface and reduces the shear force applied to the acetabular cartilage complex. Thus, the shelf will provide superior and posterior or anterior support to the subluxated femoral head by bone graft and eventual fibrocartilaginous metaplasia of the joint capsule [64]. Technical differences focus on surgical approach, peri-capsular and abductor muscles dissection as well as the method of bone graft fixation.

Clinical Indications

The contemporary indication for the shelf acetabuloplasty is residual hip dysplasia that cannot be corrected by redirectional pelvic osteotomies. Early degenerative changes in young adults may now represent the patient population most likely to benefit from this procedure. Other surgeons recommend this easier procedure in patients with acetabular dysplasia with a lateral center-edge angle between 5° and 20° [40, 63, 64]. Subluxated femoral head secondary to Legg-Calvé-Perthes disease seems to be particularly well fitted for this augmentation procedure as the femoral head size and acetabular volume are often mismatched. The acetabular shelf procedure can also be indicated as a complementary salvage procedure after a previous pelvic osteotomy has failed to provide adequate femoral head coverage. Dysplastic hip with spherical congruity that can be corrected by redirectional osteotomy is an absolute contraindication to this procedure. Advanced degenerative changes of the hip are also contraindications to shelf acetabuloplasty, since better outcome is obtained after THA.

Advantages

- Simple surgical technique
- Less invasive procedure that can postpone the progression of osteoarthritis in young adults
- Can optimize acetabular bone stock before conversion to THA
- No risk of nerve injury
- Non-union often asymptomatic

Disadvantages

- Hip centre remains lateral, thus providing no improvement in hip abduction or Trendelenburg gait.
- Protected weight bearing is required if no graft fixation is used.
- Optimal graft position is difficult to obtain.
- Poor midterm hip joint survivorship.

Surgical Technique

Numerous surgical procedures have been described to create superolateral coverage. The most commonly used is the slotted acetabular augmentation described by Staheli [58]. The patient is positioned supine on a radiolucent table with an image intensifier available during the duration of the procedure. A *Smith-Petersen approach*, with a bikini incision, has been recommended as it allows ease of bone graft positioning. Alternatively, some authors have used the Hueter approach which is now commonly used for total hip replacement as the anterior approach [65]. The hip joint capsule is exposed and the tendon of the reflected head of rectus femoris is divided in line with the direct head of the tendon. The reflected head is lifted off the hip capsule from anterior to posterior. The most important step is to create a slot in the superior acetabular region that serves as a bone bed where the graft is going to be inserted. Its position needs to be as close to the level of the hip capsule superior origin in order to obtain load transfer once positioned. The graft slot is created using a drill to form a series of trough holes and an osteotome to connect them just above the capsular reflection and extends through to the inner table without piercing it.

A uni- or bicortical bone block is harvested from the iliac crest and prepared to fit the created slot without the need for internal fixation to achieve stability. The size of the shelf is calculated by measuring the width of augmentation (WA) that is equal to the sum of the graft size and slot depth in order to achieve a lateral coverage angle of 35° after correction (Fig. 13.7). Some authors used the inner table of the ilium as graft harvest site that has the advantages of being concave in shape, often matching the acetabular margin of the patient. The graft could be extended anteriorly or posteriorly to provide sufficient coverage whenever needed. It is secured to the underlying capsule with two holding sutures [58]. Others have preferred using cannulated screws [59] or small volar plate and screws [40] to secure the bone graft.

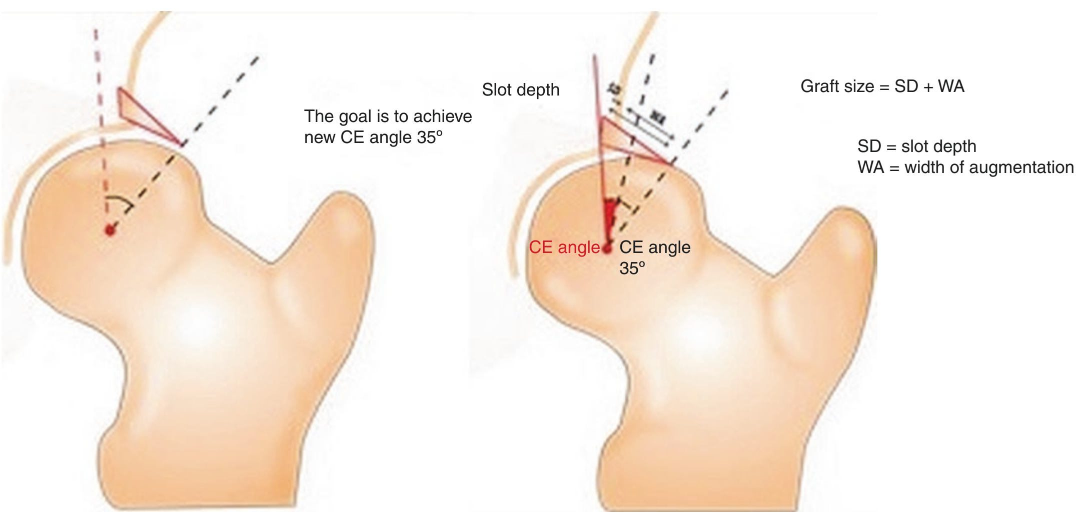

Fig. 13.7 Illustration of the surgical plan for a shelf acetabuloplasty

Table 13.3 Shelf survivorship in the literature

Author	Year of publication	Hips	Follow-up mean years	Age at surgery years (range)	Survival
Iida et al. [69]	2018	47	17	33 (16–56)	97.8% at 10 years and 78% at 20 years
Hirose et al. [70]	2011	28	25	34 (17–54)	100% at 10 years, 93% at 20 years, and 71% at 32 years
Fawzy et al. [64]	2005	76	11	33 (17–60)	86% at 5 years and 46% at 10 years
Nishimatsu et al. [63]	1975	119	23.8	Two groups > 25 and < 25	93% at 10 years and 80% at 15 years (< 25) 68% at 10 years and 60% at 15 years (> 25)

Surgical Complications

- Graft resorption
- Hip impingement
- Hip ankylosis
- Femoral head subluxation

Clinical Results

Functional and Clinical Outcomes

In the study conducted by Fawzy et al., 76 hip acetabular shelf augmentations were followed for a mean period of 11 years [64]. Pain improvement was observed in 90% of hips 6 months after surgery. However, pain had returned in 14% of hips, at a mean of 5 years post-operatively, and 30% of hips required THA at a mean of 7.5 years (2–14) after index procedure [64]. At 10 years of follow-up, 46% of patients still reported pain relief. Trendelenburg gait improved from being positive in 43% of hips preoperatively to 14% post-operatively [64]. In the study conducted by Nishimatsu, there were statistical differences in the survivorship and outcomes between patients younger than 25 years and those over 25 years [63]. In the younger group, 72% had good results despite having advanced osteoarthritis, but in the older group, only 40% of such patients had a good result. Nishimatsu submitted the proposal that the younger a patient is at the time of surgery, the longer a good result should be maintained [63]. However, Yamamuro et al. objected to this statement by publishing unsatisfactory long-term results when the osteotomy was performed in early childhood between the age of 1 and 6 years, due to graft resorption and disturbance of acetabular growth [66]. Thus, the shelf acetabuloplasty should not be recommended for patients aged less than 6 years. Table 13.3 demonstrates the survival rate of shelf acetabuloplasty by different authors. Currently, some authors suggest endoscopic shelf acetabuloplasty in the young and active adults with evidence of a labral tear and positive anterior and posterior impingement tests. The outcomes have shown that patients might benefit from the advantages of minimally invasive surgery. However, prolonged surgical time is still a major disadvantage of an endoscopic technique with risk of intra-abdominal fluid extravasation [67, 68].

Radiological Outcomes

Fawzy et al. demonstrated an improvement of the mean CE angle from 11° (−20° to +17°) preoperatively to 50° post-operatively (30°–70°) and the mean acetabular angle of Sharp from 52° (46°–64°) preoperatively to 32° (18°–57°) post-operatively [64] (Fig. 13.8). In the study conducted by Nishimatsu looking at shelves in two age groups (>25 and <25), there were improvements in the Sharp angle, the CE angle, and the angle of the roof post-operatively in all patients [64]. However, the position of the shelf with respect to the hip capsule was significantly lower in patients younger than 25 than in patients more than 25 years of age.

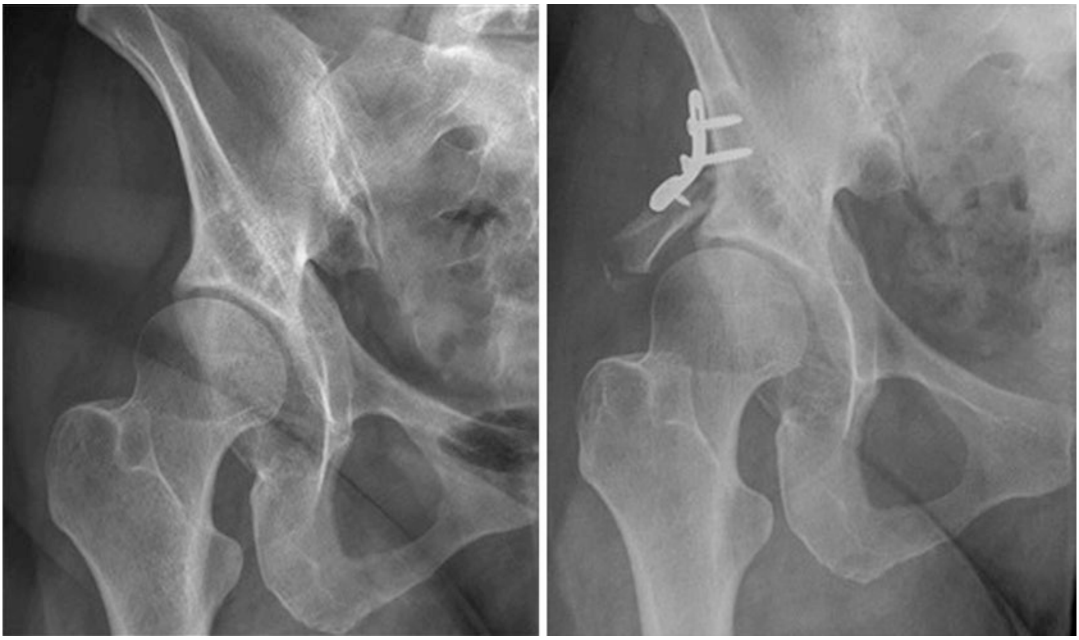

Fig. 13.8 Radiological demonstration of a shelf acetabuloplasty using a tricortical iliac autograft: in a 45 year old women with mild dysplasia and labral tear; pre, and 1-year post-operative radiographs

Pearls and Pitfalls

- Knowing the morphology of the dysplastic acetabulum is the cornerstone for shelf acetabuloplasty. It is essential to plan for shelf level of positioning and the size of the graft.
- Complete exposure of the capsule intraoperatively is the key to find the tendon of indirect head the rectus femoris.
- The level of the graft is very crucial. A supra-acetabular slot is made to avoid hip joint penetration.
- Hip range of motion should be tested intraoperatively to confirm that there is no impingement by the femoral neck or the greater trochanter.
- Bone graft should not be harvested near the slot. Otherwise, there will not be enough bone to support the shelf.
- A rib binder could be used to reshape the graft in a curved fashion.
- Reflected head of the rectus is put back over the graft and sutured at its original position to secure the graft.
- Augmentation is thickened by adding morselized bone graft above the shelf after decortication of the outer surface of the supra-acetabular area.

Conclusion

Although it is clear that the current gold standard for the surgical treatment of the congruent dysplastic hip in young adults remains the Bernese periacetabular osteotomy, it is important to recognize viable surgical alternatives in the subset of patients with incongruent hips or with morphological abnormalities preventing the successful use of reorientation osteotomies.

The contemporary TPO provides a good range of correction and is particularly useful in hips with an open triradiate cartilage. It is mostly used in skeletally immature patients with DDH and can be combined with femoral osteotomy as needed. Current literature boasts good long-term results in terms of hip scores and conversion to THA.

Salvage procedures are particularly helpful in cases where reorientation osteotomy procedures cannot provide sufficient bone stock to the weight-bearing area of a shallow acetabulum. These procedures help increase the lateral coverage and promote the formation of fibrocartilage. Current indications for the Chiari osteotomy include young adults with incongruent dysplastic hip as well as *coxa magna* as an acquired sequelae of LCP disease. The shelf osteotomy remains particularly useful in cases of volume mismatch between the head and acetabulum following LCP disease. The shelf can also serve as a complementary salvage procedure after a previous pelvic osteotomy has failed to provide adequate head coverage. Congruent dysplastic hips which can be corrected using a redirectional osteotomy are an absolute contraindication to salvage procedures. Advanced degenerative changes in a dysplastic hip are best treated with THA since modern techniques and implants have been proven to provide superior long-term results.

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