Developmental Dysplasia and Dislocation of the Hip in Adults

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In memory of Professor Han-Ting Chen
(1924–1983)
The pioneer and great educator who introduced modern orthopedics, pediatric orthopedics, and joint reconstruction to Taiwan.

Foreword

Despite the advancement and the many improvements in the modern medical care of infants and young children, dysplastic hip problems that inevitably lead to osteoarthritis remain. Advancing the effectiveness and quality of treatments, in order to reach optimal outcomes, continues to be the main goal for orthopedic surgeons, so that patients may grow to enjoy active lives free of pain.

Doctors Kuo-An Lai, Pang-Hsin Hsieh, and Chun-Hsiung Shih are well-respected hip surgeons, who have treated a myriad of different hip diseases. Drawing from their experiences, they have also developed several different types of surgical techniques for the treatment of hip dysplasia.

In this book, they address a variety of different options for the treatment of varying degrees of dysplastic hip problems. They have collected a number of different anecdotes from many renowned orthopedic hip surgeons, allowing the reader to explore how different approaches may affect the eventual outcome of each treatment. They provide several detailed algorithms to guide surgeons in their management of cases, such as when to perform osteotomies, when and how to use the autologous bone grafts to create the acetabulum, when hip replacement surgery will require particular preparation, and the types of surgery that are best suited to the different types of patients.

With the improvement of neonatal and postnatal care, the number of cases of moderate to high degree hip dysplasia should decrease. For those patients who continue to suffer from hip dysplasia, a broad review of numerous collected outcome studies will lead to the determination of the best treatment options and management plans. As a result, this book will be an excellent resource and become one of best guides for many young surgeons who are interested in hip surgeries.

I take my hat off to Professor Kuo-An Lai for his dedication and hard work in writing and publishing this important book.

Congratulations on a job well done!

Gwo-Jaw Wang
University of Virginia, Charlottesville, VA, USA
National Cheng Kung University, Tainan, Taiwan
Kaohsiung Medical University, Kaohsiung, Taiwan
National Ciao Tung University, Hsinchu, Taiwan

Preface

Developmental dysplasia of the hip (DDH) in adulthood includes a wide range of deformities from a mildly shallow acetabulum without symptoms to a complete high dislocation. Although early detection and early treatment of DDH in infancy or early childhood are the golden rule for managing this problem, many DDH patients in the world were not treated early on in their life due to poor accessibility to modern medical care or obscured symptoms. An untreated or not adequately treated DDH may progress to arthritis in adulthood.

Taiwan was an underdeveloped country before 1980. The National Health Insurance of Taiwan was initiated in 1995, and it was able to include nearly all of the population under the insurance. A lot of people with DDH or even high dislocation of the hip, previously called congenital dislocation of the hip (CDH), were not adequately treated before the coverage of the insurance. These patients became a great challenge to orthopedic surgeons when they grew to adulthood.

Technology for treating adult DDH/CDH has improved continuously over the past decades and experience of treatment was accumulated. The editors invited several surgeons, who are reputed for treating adult DDH with joint salvage and joint replacement, to write chapters for this book. Of course, this book may not cover all the aspects about DDH such as embryology, natural history, diagnosis and treatment in infancy and childhood, and so on. This book would rather concentrate on the specificity of the patients and the technology applied by these authors for treating these problems.

This book describes periacetabular and salvage osteotomies of the acetabulum for joint conservation in young adults with less severe deformities and joint replacement for more severe deformities. Corrective osteotomy of the femur may be useful for children with DDH and can be applied with a pelvic osteotomy to obtain a better congruity of the joint, but its sole application for adult patients may have limited value and may make joint replacement more difficult when it becomes necessary. Joint replacement is indicated for a DDH patient with advanced arthritis or unilateral high dislocation with severe leg length discrepancy and following problems of scoliosis and the knee deformity of the better leg. Resurfacing arthroplasty using the right implant and meticulous technique may be a reasonable choice for a carefully selected young patient with less severe deformity. Total hip arthroplasty (THA) for DDH patients, especially those with the most severe form (Crowe IV), is very challenging. The chapter on THA for DDH/CDH patients proposes a protocol of treatment options for achieving symmetry of the lower limbs. Because the DDH patients undergoing THA are usually young, female dominant, with small acetabular components, wearing off of the polyethylene liner and loosening of the components are more common than THA in other patients.

Additional surgeries and revisions may be necessary for the patients with residual leg length discrepancy, poor position of the implants, wearing, loosening, and other problems such as dislocation, periprosthetic fracture, and infection. Revision surgery for these patients often encounters severe defects of the acetabulum. A chapter is included to discuss reconstruction of the deficient acetabulum.

The editor sincerely thanks all the contributors for their effort to write the chapters and sharing their experiences with the readers.

Tainan, Taiwan Kuo-An Lai

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1 Developmental Dysplasia of the Hip in Adults: An Overview

Chun-Hsiung Shih and Kuo-An Lai

Abstract

Due to not treated in the early life for some reasons, developmental dysplasia and dislocation of the hip (DDH/CDH) remain a problem in the adults and contain a wide range of deformities from a symptomless dysplasia to a complete dislocation with severe anatomic anomaly. Crowe's or Hartofilakidis' classifications are commonly applied for grading the deformities of adult DDH/CDH. Conservative treatment includes observation for the hip without intolerable pain and shoe lift for the shorter limb. For young patients, periacetabular osteotomy can be applied for a dysplastic but relatively congruent hip, and salvage pelvic osteotomies with or without a proximal femoral osteotomy can be considered for an incongruent hip. For a patient over age of 40 with degenerative arthritis, replacement arthroplasty can be considered. Although total hip is the main trend, surface replacement conserves more bone stock and has good results if the patient and prosthesis are well-selected and the surgery done with a meticulously technique.

Keywords

Developmental dysplasia of the hip · Crowe's classification · Hartofilakidis' classification · Treatment options

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Developmental dysplasia of the hip (DDH) is one of the most common anomalies among children. DDH can be diagnosed by routine, clinical, and sonographic evaluations soon after birth for laxity, instability, and dislocation of the joint. The incidence rate is around 1.4–35 per 1000 depending on the method and criteria of diagnosis. Age at diagnosis, ethnic group, and the culture of caring for their infants may also influence the incidence [1–3]. The risk factors include breech presentation, family history, gender (female), presence of torticollis or foot deformities, ligament laxity, abnormal collagen metabolism, etc. [4–6].

Early diagnosis of DDH in infancy and early childhood can be easily treated with concentric reduction and protection for the hip to develop normally. But there are still many patients in the world, for whom early detection and adequate treatment were not available. Patients with obscured symptoms were not diagnosed and treated early in their life [7, 8]. About 20–40% of osteoarthritis of the hip is related to DDH [9, 10]. Sequels of treatments in early life might also remain as problems in adulthood. These patients form the group of DDH in adults.

Pain and limp are the most common clinical presentations of DDH in adults.

Diagnosis of DDH in adults is based on the radiological image of the coronal plane to find sub-optimal coverage of the femoral head by the acetabulum. A three-dimensional image may also find incongruity and impingement on other planes [11–13].

Pathological Anatomy and Biomechanics

DDH in adults varies widely from only a smaller than normal center-edge angle without symptoms to a secondary osteoarthritis and a complete high dislocation.

Crowe's or Hartofilakidis' classification is commonly applied for the classification of dysplasia and dislocation in adult patients.

Crowe's classification [14] uses the height of the true acetabulum as the reference. In cases of an underdeveloped acetabulum, the height for reference is the second fifth from the bottom of the height of the innominate bone. Subluxation under 50% of the true acetabular height is classified as **type I**, 50 to 75% as **type II**, 75 to 100% as **type III**, and over 100% as **type IV** (Fig. 1.1).

Hartofilakidis' classification [15] classified them as **dysplasia (type A)**, femoral head within the acetabulum despite some subluxation, segmental deficiency of the superior wall, and inadequate depth of the true acetabulum; **low dislocation (type B)**, femoral head creates a false acetabulum superior to the true acetabulum and there is complete absence of the superior wall and inadequate depth of the true acetabulum; **and high dislocation (type C)**, femoral head is completely uncovered by the true acetabulum and has migrated supero-posteriorly; there is a complete deficiency of the acetabulum and excessive anteversion of the true acetabulum (Fig. 1.2).

In a patient with Crowe I or Hartofilakidis type A dysplasia, the acetabulum is shallow, and the coverage of the femoral head is poorer than a normal subject. The

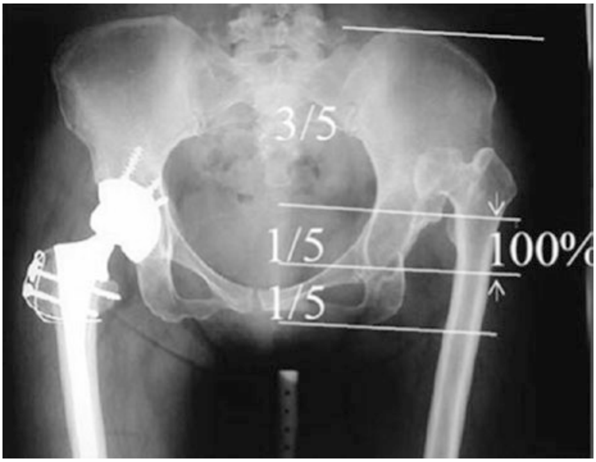

Fig. 1.1 Crowe's classification of adult DDH (application of this X-ray picture was agreed by the patient)

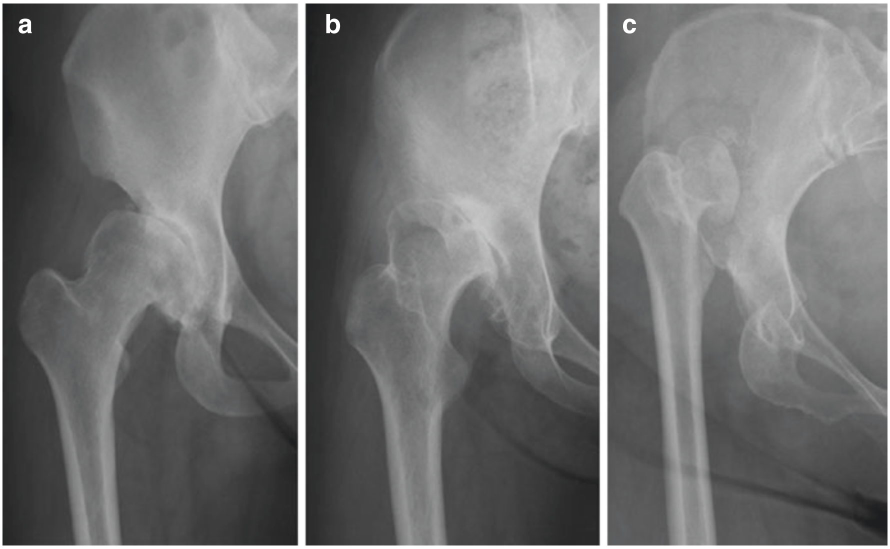

Fig. 1.2 Hartofilakidis' classification of adult DDH. (**a**) Dysplasia, (**b**) low dislocation, (**c**) high dislocation (the X-ray pictures were agreed by the patients for publication)

femoral head is less spherical, and the femoral neck is more anteverted and valgus in orientation than that of a normal subject. It is easy to understand that forces are loaded on a smaller area of the joint surface and the stresses are higher on this area under loading. Joint cartilage degeneration occurs earlier than a normal subject. The labrum consists mainly of cartilage and has to share more loads in the dysplastic hip than the normal subjects. The labrum is usually hypertrophic and easily injured with secondary degenerative changes that may count for the pain and limited motion (Fig. 1.3).

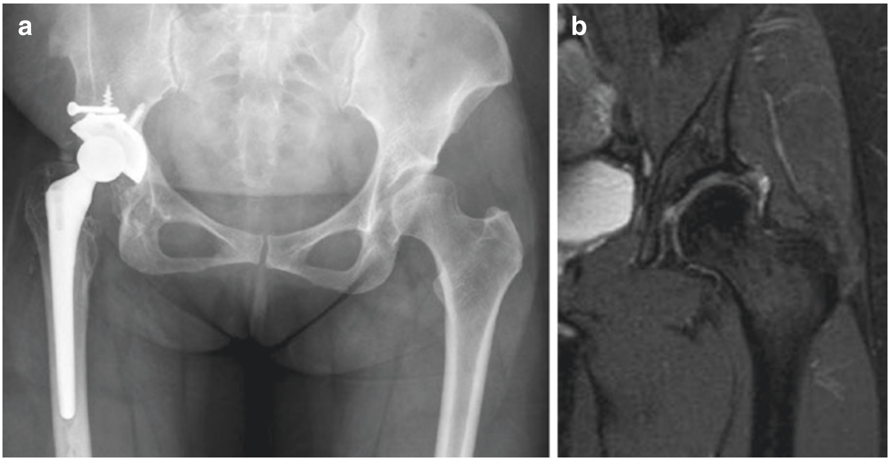

Fig. 1.3 (**a**) A 43-year-old female patient with right total hip arthroplasty for Crowe IV high dislocation that was done 12 years previously. She suffered severe left hip pain. The anterior-posterior view sowed Crowe I dysplasia without narrowing of the joint space (Tonnis grade 0 [16]). (**b**) The T2 magnetic resonance image revealed a tear of the labrum with a cyst formation (these pictures were agreed by the patient for publication)

In a more severe form of dysplasia such as Crowe type II and III or Hartofilakidis low dislocation, the femoral head migrates out of the center of the joint but remains in contact with the acetabulum. The anatomical anomalies are similar to but are more severe than that of the less severe type. Cartilage damage and degenerative changes of the joint are more common and severe than the less severe type of dysplasia.

The true acetabulum of the untreated Crowe type IV or Hartofilakidis type C (high dislocation) in adulthood is undeveloped, shallow, small, and lower than the sound side. It is also obstructed by osteophytes, joint capsule, and fat.

In patients with a false joint, the anatomical anomaly of the proximal femur is usually mild. The femoral head and neck have slightly more anteversion and valgus angle than that of a normal subject.

In patients without a false joint, the hip is highly dislocated. Overgrowth of the greater trochanter, extreme anteversion of the neck, an extra-small head, and straight, small caliber of the proximal femur are the common findings.

The joint capsule is redundant and hypertrophic, and the orientation of the abductor muscle becomes anterior-posterior orientated rather than a normal proximal-distal orientation. The adductors, psoas tendon, iliotibial band, femoral nerve, and sciatic nerve are usually tight and make distal transfer of the femur difficult and hazardous.

Patients with unilateral high dislocation commonly have prominent leg length discrepancy. Asymmetrical gait, pelvic tilting, scoliosis, and abnormal load patterns of the knees were observed [17]. The patients with bilateral high dislocation have the typical “waddling gait” with slower walking speed and shorter stride length.

Sequels of Treatments in Infancy and Childhood

Although early diagnosis and treatment restored a normal hip for the majority of patients with DDH, sequels or even failure of treatments can continue to be problems in adulthood. Besides osteoarthrosis, the common problems are osteonecrosis of the femoral head, insufficient coverage of the femoral head, and bizarre-shaped proximal femur following a proximal femoral osteotomy.

Treatment Options

Nonsurgical Treatments

An adult patient with a less severe type of DDH without symptoms can be regularly observed without surgical intervention. An untreated unilateral Crowe IV patient with leg length discrepancy can be treated with a shoe lift for the shorter leg [18]. An adult patient with untreated bilateral high dislocation can be observed if there is no untolerable pain.

Periacetabular Corrective Osteotomy, Salvage Pelvic Osteotomy, and Proximal Femoral Osteotomy

For an adult DDH patient with pain and early arthritis symptoms, periacetabular corrective osteotomy provides a better coverage of the femoral head and decreases stress concentration of the joint that might deter the progress of arthritis. A wide range of periacetabular and salvage osteotomy procedures have been reported [19–22].

Proximal femoral osteotomy combined with pelvic osteotomy may improve the congruity of the joint. The benefit of an isolated proximal femur osteotomy for an adult DDH patient is limited and may increase the difficulty of joint replacement when it becomes necessary.

Joint Replacement

Joint replacement surgery may be indicated for the DDH patients with advanced arthritis of the true or false joint for pain relief and functional improvement. Patients with unilateral Crowe IV high dislocation may suffer from problems with leg length discrepancy and can benefit from hip replacement surgery and restoration of the leg length to within a reasonable range [23, 24]. Although total hip arthroplasty is the traditional choice for these patients, surface replacement may preserve more bone stock for young patients if the patients and implants are well selected [25, 26].

Surgeons performing hip replacement surgery for DDH patients often encounter patients of a young age, deficient bone stocks, and small-sized acetabulum and proximal femur. It is technically more demanding and more prone to an early failure due to wearing, loosening, dislocation, and infection than a usual hip replacement [27–30]. The newly developed bearing surfaces such as highly cross-linked polyethylene and ceramics can be useful to reduce wearing of the implant and osteolysis, which may improve long-term survival of the implants.

THA for a highly dislocated hip may be associated with more complications for its difficulty. It is better to avoid these complications than to treat them.

Adult DDH patients are more often young and female. Many of them have to face the problems of marriage, pregnancy, and childbirth. The impact of hip replacements on these patients was not well understood.

Revision surgery for THA of a DDH patient may encounter compromised cup positioning and severe bone defects at the acetabulum. Meticulous preoperative planning of reconstruction procedures is necessary for revision surgeries.

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Suggested Readings

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2 Pelvic Osteotomy for Adult Patients with Hip Dysplasia

Szu-Yuan Chen, Pang-Hsin Hsieh, Wen-E Yang, and Ting-Ming Wang

Abstract

For a DDH patient under age of 40 or an older patient without advanced degenerative arthritis, pelvic osteotomies may be a better choice than a hip replacement. Periacetabular osteotomy (PAO) is indicated for a patient with a relatively congruent hip. Hsieh's periacetabular osteotomy is modified from Ninomiya rotational osteotomy and Ganz Bernese PAO. Trochanter osteotomy provides a better vision to the surgical field and capsulotomy can be done for assessment and debridement for the intra-articular lesions. Round-shaped osteotomy makes rotation of the segment easier and changes the shape of pelvic cavity less than a diagonal osteotomy. Salvage osteotomies with or without a proximal femoral osteotomy are indicated for a patient with an incongruent joint which is not to be restored by a PAO. Chiari osteotomy osteotomizes the pelvis above the acetabulum, medializes the distal fragment, and uses the joint capsule for interposition between the head and the proximal fragment for a better coverage. Shelf acetabuloplasty creates a slot at the pelvis above the femoral head and uses a bone graft to cover the femoral head. Chiari osteotomy has the advantage of a better coverage of the femoral head and better abduction of the hip, while shelf acetabuloplasty is easier to perform and may have fewer complications.

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Keywords
Developmental dysplasia of the hip · Periacetabular osteotomy (PAO) · Hsieh's modification of PAO · Chiari osteotomy · Shelf acetabuloplasty

Developmental dysplasia is a common cause of osteoarthritis (OA) of the hip [1–3]. Although good long-term results have been recorded following total hip replacement in patients below the age of 50 years [4, 5], disappointing long-term results have been described in patients under 40 years of age [5, 6]. The rationale for performing a pelvic osteotomy in the treatment of adult hip dysplasia is to reposition the dysplastic acetabulum into a more anatomically correct orientation, to provide a better coverage of the femoral head, and thus prevent or deter the need for total hip arthroplasty in these relatively young patients.

Periacetabular Osteotomy (PAO)

PAO was developed to reduce the consequences of hip dysplasia by surgical reorientation of the acetabulum. Growing evidence suggests that timely correction of the deformity may prevent progressive destruction of the hip [7–11]. However, a periacetabular osteotomy is technically demanding, and patients require a long period of rehabilitation.

Evolution of PAO

The Bernese PAO has become popular since it was first described by Ganz et al. [8] in 1988, and several authors have reported encouraging results [12–15]. The Bernese PAO is a major progression from previously described triple innominate osteotomies (TIO). The TIO was originally described by Le Coeur [16] in 1965. In his technique, the pubis and ischium are osteotomized through a single incision near the symphysis. The ilium is then osteotomized just above the sourcil through a Smith-Petersen approach. In 1973, Steel described his technique for the TIO, in which an incision is made just proximal to the gluteal crease and the ischium is divided at the tubercle [17]. In 1981, Tonnis modified Steel's TIO by changing the location of the ischial cut so that it runs immediately inferior to the acetabulum and ends proximally to the sacrotuberous and sacrospinous ligaments, thereby improving acetabular mobility [18]. The ischial osteotomy is performed in the prone position, requiring an intraoperative flip to the supine position, where the pubic and iliac osteotomies are performed in a manner similar to those described by Steel. In 1982, Carlioz introduced a modification to Steel's technique in which the ischial osteotomy starts just below the acetabulum and runs horizontally, ending between the sacrospinous and sacrotuberous ligaments, leaving the sacrospinous ligaments attached to the mobile fragment and sacrotuberous ligament attached to stable fragment. The benefit of the Carlioz technique is that it does not require an intraoperative flip [19].

PAO is a general term that describes a series of bony cuts involved in mobilizing the acetabulum from the surrounding innominate bone to allow reorientation, but it is often used eponymously in reference to the Ganz technique for Bernese PAO. In 1975, Eppright described a barrel-shaped PAO oriented along the anteroposterior axis [20]. This osteotomy allows for increased lateral coverage, but limits the amount of achievable anterior coverage. In 1976, Wagner described three separated types of PAO [21]. In a type I PAO, a hemispherical cut is made around the acetabulum down to the obturator foramen using a specifically designed chisel. The loosened acetabular fragment is then redirected to allow anterolateral coverage of the femoral head. In a type II PAO, a cut is made similar to the cut made in a type I PAO and an autologous bone graft is inserted between the ilium and the acetabular osseous fragment to distalize the acetabular fragment. Type III PAO combines a type I osteotomy with a Chiari-like innominate osteotomy to allow realignment and medialization. In 1984, Ninomiya and Tagawa reported their experience with rotational acetabular osteotomy in skeletally mature patients with symptomatic hip dysplasia [22]. Their procedure was a modification of the circumacetabular osteotomies described by Eppright [20] and Wagner [23]. While the results reported by Ninomiya and Tagawa were satisfactory, the design of the osteotomy tended to leave the teardrop in its original position and technical errors, such as intra-articular penetration or osteonecrosis of the acetabular fragment, have raised concerns about the difficulty of performing this procedure well and in a consistent manner [24].

The Bernese PAO, originally described by Ganz, uses four or five straight osteotomies to separate the acetabulum from the surrounding innominate bone [8]. It has a number of benefits over other techniques. For example, it can be performed through a single incision in the supine position. The posterior column of the innominate bone remains intact, greatly improving stability and allowing for immediate postoperative mobilization without protection by a cast or brace. The bone cuts are performed close to the acetabular center of rotation, thereby facilitating correction of the acetabular fragment. The Bernese PAO reliably results in medialization of the acetabular center, which improves the biomechanics when compared with previously described techniques. The vascularity of the acetabular fragment is preserved via the inferior gluteal artery, which allows simultaneous hip arthrotomy without concern of devascularing the mobile fragment.

Surgical Anatomy

The hip differs from most other joints in the body in that it is deep and nonpalpable from the surface. This highlights the importance of understanding surface anatomy when planning the surgical intervention. During childhood, the articular cartilage of the acetabulum is continuous medially with the triradiate cartilage, lying between the ilium (superiorly), ischium (inferiorly), and pubis (anteriorly) [25]. Closure of the triradiate cartilage occurs at the halfway point of the ascending limb of the pubertal growth curve, corresponding to an approximate bone age of 12 years for girls and 14 years for boys [26]. The hip joint is a highly constrained and inherently stable ball and socket synovial joint formed by the confluence of the acetabulum with the femoral head.

The articular capsule consists of strong and dense collagen fibers arranged in a cylindrical sleeve, connecting the margins of the acetabulum to the proximal femur [27]. Distinct thickening of the articular capsule forms four reinforcing ligaments. The iliofemoral ligament, also known as the Y-ligament or the ligament of Bigelow, lies anteriorly and has an inverted Y shape. The lateral limb restricts internal and external rotation in extension. The medial limb restricts external rotation in extension. The pubofemoral ligament resembles a sling covering the inferior and medial aspect of the hip joint capsule and tightens with hip extension and abduction. The pubofemoral ligament's main restriction is external rotation in extension. The ischiofemoral ligament lies posteriorly. Its two horizontal bands spiral upward to blend with the zona orbicularis. The ischiofemoral ligament's major contribution to the stability of the hip is internal rotation. The zona orbicularis is a circumferential ligament surrounding the femoral neck at the lateral edge of the capsule. The fibers of the zona orbicularis are most abundant at the inferoposterior aspect of the capsule and anteriorly blend with the deep surface of iliofemoral ligament. The zona orbicularis contributes to stability in distraction.

The hip joint is surrounded by 23 muscles divided into five groups based on function: the flexors (iliacus, psoas, iliocapsularis, pecteneus, rectus femoris, and sartorius muscles), the extensors (gluteus maximus, semimembranosus, semitendinosus, biceps femoris long head, and posterior part of the adductor magnus muscles), the abductors (gluteus medius, gluteus minimus, and tensor fascia lata muscles), the adductors (adductor brevis, adductor longus, gracilis, and posterior part of the adductor magnus muscles), and external rotators (piriformis, quadratus femoris, superior gemellus, inferior gemellus, obturator internus, and obturator externus muscles).

The acetabulum receives its blood supply from the superior gluteal, inferior gluteal, and obturator arteries [28]. The obturator artery, a branch of the internal iliac artery, passes anteroinferiorly across the inner table of the pelvis, where pubic branches supply the quadrilateral plate. After exiting through the upper border of the obturator foramen, the artery splits into anterior and posterior branches. The posterior branch gives off an acetabular branch, which supplies the acetabulum ascending through the cotyloid fossa. The largest branch of the internal iliac artery, the superior gluteal artery, heads posteriorly between the lumbosacral trunk and the first sacral nerve before passing above the superior edge of the piriformis as it exits the greater sciatic notch and then dividing into superior and deep branches. The deep branches descend to supply the superior rim of the acetabulum. The inferior gluteal artery descends on the sacral plexus before passing below the inferior border of the piriformis, exiting the inferior portion of the greater sciatic notch. Outside the pelvis, a transverse branch runs inferiorly to supply the inferior and posterior region of the acetabulum. The corona mortis, an anastomosis between the obturator and external iliac vascular system traversing cranial to the superior ramus, is present in 83–84% of patients with a hemipelvis, according to two cadaveric studies [29, 30]. The anastomosis is found, on average, 6.5 cm lateral to the symphysis (range, 3.0–9.0 cm). Thirty-four to 36% of patients with a hemipelvis have an arterial connection, whereas 60–70% of such patients have a venous connection and 20–27.5% have both.

The major pelvis innervation of the lumbar plexus originates from the L1, L2, L3, and L4 roots. The femoral nerve (L2–L4) courses through the psoas and emerges on the inferolateral aspect of the psoas. It then travels between the psoas and iliacus, behind the iliac fascia until it passes under the inguinal ligament, before bifurcating into anterior and posterior branches. The lateral femoral cutaneous nerve (LCFN) (L2–L3) emerges from the lateral border of the psoas major and crosses the iliacus toward the antero-superior iliac spine (ASIS). It then passes under the inguinal ligament medial to the ASIS and over the sartorius in the thigh, where it divides into an anterior and a posterior branch. In two cadaveric studies of a total of 63 limbs, the LCFN was always found to be medial to the ASIS and deep to the inguinal ligament [31, 32]. On average, the LCFN was 3.25 cm medial to the ASIS (range, 0.6–9.2 cm). The obturator nerve (L2–L4) pierces the psoas major, emerging from its medial border near the brim of the true pelvis. It travels posteriorly to the common iliac artery before it descends laterally to the internal iliac artery and ureter. It then travels along the lateral wall of the lesser pelvis and superoanterior to the obturator artery, before exiting through the superior edge of the obturator foramen. Major pelvic innervation of the lumbosacral plexus originates from the L4, L5, S1, S2, and S3 roots. The sciatic nerve (L4–S3) exits the greater sciatic foramen and most commonly courses anteriorly (deep) to the piriformis before crossing posteriorly (superficial) to the superior gemellus, inferior gemellus, and obturator internus. It then travels down the posterior thigh, crossing below the long head of biceps femoris. The superior gluteal nerve leaves the pelvis through the greater sciatic notch above the piriformis, accompanied by the superior gluteal artery and the superior gluteal vein. The superior gluteal nerve provides innervation to the gluteus medius, gluteus minimus, and tensor fascia lata muscles. The inferior gluteal nerve exits through the greater sciatic notch below the piriformis accompanied by the inferior gluteal artery and the inferior gluteal vein. Then, the inferior gluteal nerve provides innervation to the gluteus maximus.

Surgical Indications and Approaches

Indications for the performance of a PAO include closed triradiate cartilage and symptomatic acetabular dysplasia without preexisting arthrosis. Although there is an apparent association between dysplasia and secondary arthritis, there is potential, but no strong evidence, that the correction of dysplasia will decrease the development of future arthritis [8–10]. Thus, a PAO should be a pain-relieving surgery first and a joint-preserving surgery second, not vice versa. Although the lower age limit for a PAO is dictated by the closure of the triradiate cartilage, the upper age limit is more ambiguous. Any patient with dysplasia without arthritis may be considered, but in North America, most patients are younger than the age of 40–45 years, as those with significant dysplasia will often show signs of significant arthritis by the fifth or sixth decade and may be better served by a total hip arthroplasty. However, Hsieh et al. found that a PAO could provide a favorable clinical outcome comparable to that of a total hip arthroplasty in the matched-pair analysis in young active patients [33]. Despite its increased surgical difficulty and longer recovery time, more patients preferred the outcome of the PAO to that of the THR at 2 to 10 years after surgery.

Several types of PAO have been developed in the past decades, and most are considered technically demanding [8, 10, 22]. Difficulties arise not only from the complex anatomical structures of the pelvis but also from the limited visualization provided by various surgical approaches in which some of the bony cuts have to be performed beyond the surgeon's field of view [10]. Opening of the joint offers an opportunity to directly assess intra-articular pathology. However, with a thin fragment created in the rotational acetabular osteotomy [22], capsulotomy is contraindicated because this may alter blood supply to the osteotomized fragment and lead to osteonecrosis. The design of the modified PAO proposed by Hsieh et al. creates a thick fragment with its vascular supply from the inner side of the pelvis; thus, the performance of a capsulotomy is permissible [10].

The PAO procedure can be undertaken through various approaches, including the Smith-Petersen, ilioinguinal, direct anterior, two-incision, and transtrochanteric methods. The classic Smith-Petersen exposure originally used by Ganz et al. carries a high risk of postoperative abductor weakness [34]. Although the use of the modified Smith-Petersen exposure, the ilioinguinal exposure, and recently, the direct anterior exposure to spare abductor dissection have been proposed, we believe that these approaches are still difficult and that surgical exposure can be improved with an alternative approach [24]. A high rate of damaging the lateral femoral cutaneous nerve and a cosmetically unacceptable scar are common problems with the Smith-Petersen approach [34]. Alternatively, the ilioinguinal exposure has been used to decrease abductor morbidity. However, this exposure is associated with other problems (e.g., it makes the assessment of intra-articular disease difficult, increases the likelihood of vascular injury, requires a longer operative time, and makes manipulation of the fragment difficult). The direct anterior exposure advocated by Murphy and Millis is also an abductor-sparing approach [35]. The main concern, however, is the vulnerability of the femoral nerve when dissection proceeds medially to the iliopsoas muscle. In one report two out of five patients, with whom the direct anterior exposure was used, sustained femoral nerve palsies [34]. Importantly, these surgical exposures were all anterior approaches so that the ischial osteotomy had to be performed blindly with special osteotomies, thereby requiring extensive anatomic knowledge and experience [35].

Hsieh's Modification of PAO

To improve exposure, Hsieh et al. [10] modified the techniques described by Ninomiya and Tagawa [22] and Ganz et al. [8]. The use of the transtrochanteric approach provides a sufficiently wide exposure to the osteotomy sites, and it is also a familiar approach used by most orthopedic surgeons.

Surgical Technique

After general anesthesia, the patient is placed in the lateral decubitus position. The leg involved is prepared and draped for easy mobilization during the procedure. A lateral skin incision is made 10 cm proximally to the tip of the greater trochanter and is carried distally along the longitudinal axis of the femur, ending at the base of the greater trochanter. After dividing the fascia lata using a straight midlateral line along the entire length of the skin incision, the anterior and posterior borders of the gluteus medius are identified at its insertion into the greater trochanter. A periosteal elevator is placed between the gluteus medius, minimus muscles, and the joint capsule to allow extracapsular dissection. The greater trochanter is osteotomized with the use of a Gigli saw and is reflected upward with the attached gluteus medius and minimus muscles. The osteotomy should end 0.5 cm proximal to the vastus lateralis ridge so that detachment of the vastus muscle is not required.

To free the joint capsule from the osteotomized trochanter, the piriformis and the proximal part of the conjoined tendon of the short external rotators are divided. Only the proximal part of the short external rotators should be dissected to prevent injury to the medial femoral circumflex artery, which is the main blood supply to the femoral head. The anterior, superior, and posterosuperior aspects of the capsule are then visualized. At this time, a T-shaped capsulotomy can be made, first, by a longitudinal incision to the anterolateral aspect of the joint capsule and, second, by a transverse incision along the acetabular rim. The flaps are retracted for direct inspection of the joint.

To proceed with the anterior exposure, the reflected head of the rectus femoris muscle is detached form the joint capsule to expose the anterior rim of the acetabulum. Through the plane between the iliocapsularis muscle, which is adherent to the anterior part of the capsule, and the psoas muscle, one can palpate bone medially and distally to the level of the base of the superior pubic ramus. Blunt dissection is performed deep to the rectus femoris and iliopsoas muscles to avoid injury to the neurovascular bundle that lies anterior to the iliopsoas. This dissection is made easier if the hip is flexed.

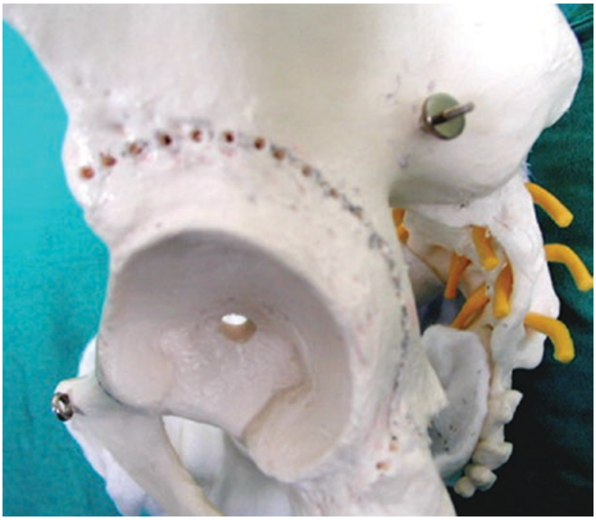

Fig. 2.1 The osteotomy is spherical in shape around the circumference of the acetabulum and is approximately 1.5 cm from the acetabular ridge

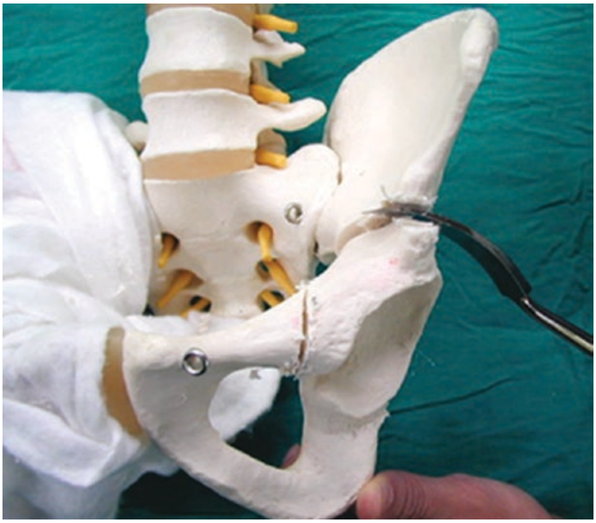

Fig. 2.2 The osteotomy penetrates the inner pelvic table rather than the medial part of the acetabular wall. Thus, the risk of creating an intra-articular osteotomy is minimized

With the use of a curved osteotome, the osteotomy is begun at the superolateral portion of the ilium, 1.5 cm from the acetabular ridge. We extend the osteotomy anteriorly and posteriorly around the circumference of the acetabulum (Fig. 2.1). Our method differs from the rotational acetabular osteotomy described by Ninomiya and Tagawa [22], in that it penetrates the inner pelvic table rather than the medial part of the acetabular wall (Fig. 2.2). Thus, the risk of creating an intra-articular osteotomy is virtually eliminated. In addition, we create a larger acetabular

Figs. 2.3 and 2.4 The correction is made by anterior and lateral rotation of the fragment. Because the fragment is smooth and round, the displacement is usually obtained without creating large gaps at the osteotomy site

fragment that includes the inner pelvic table, decreasing the potential complications of osteonecrosis.

After the osteotomy of the ilium and the ischium is completed, the fragment is connected to the pelvis only at the pubis. The osteotomy at the base of the superior pubic ramus is made easier with the leg flexed. It is safe to perform the pubic osteotomy through the plane between the flexor muscles and the joint capsule, and the location and the direction of the pubic osteotomy can be confirmed with an intraoperative anteroposterior radiograph.

When the osteotomy is completed, the surgeon controls the fragment with a bone hook to redirect the acetabulum. The main corrective displacement is by anterior and lateral rotation, but the fragment can also be shifted more medially. Because the fragment is smooth and round, the correction is usually obtained without creating gaps at the osteotomy site (Figs. 2.3 and 2.4).

After temporary fixation of the osteotomy with two Kirschner wires, the range of motion of the hip is tested. A radiograph is performed to confirm the amount of correction. The fragment is fixed to the ilium with three or four 3.5 mm cortical screws. The freed greater trochanter is then reduced and stabilized with two 6.5 mm cancellous screws. The joint capsule, the origin of the rectus femoris muscle, and short external rotators are repaired. Suction drains are placed anterior and posterior to the capsule.

Postoperative Care

No cast is required. Early active range of motion is encouraged. The patient is instructed to walk with crutches and partial weight bearing after the pain has subsided, usually on the fourth or fifth postoperative day. After 6 weeks, the patient is allowed to walk with one cane. The cane is usually discarded 3 months postoperatively when osseous healing is evident radiographically (Fig. 2.5a–f). We do not prescribe indomethacin for prophylaxis against heterotopic bone formation nor pharmaceutical prophylaxis for deep vein thrombosis because these complications are rare in our population.

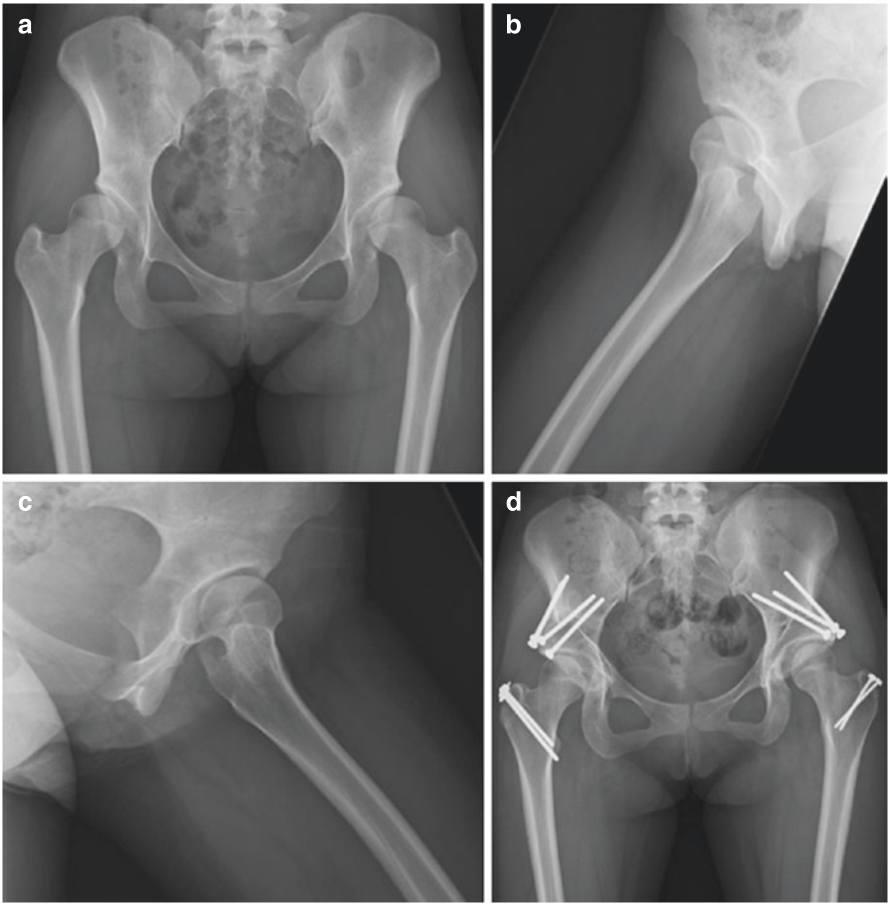

Fig. 2.5 The radiographs of a 19-year-old girl who had bilateral hip dysplasia. Anteroposterior (**a**) and lateral (**b** and **c**) views show the deformity before surgery. Five years after bilateral periacetabular osteotomy, the radiographs show good correction, healed osteotomy, and adequate joint spaces (**d**–**f**) (These pictures were agreed by the patient for publication)

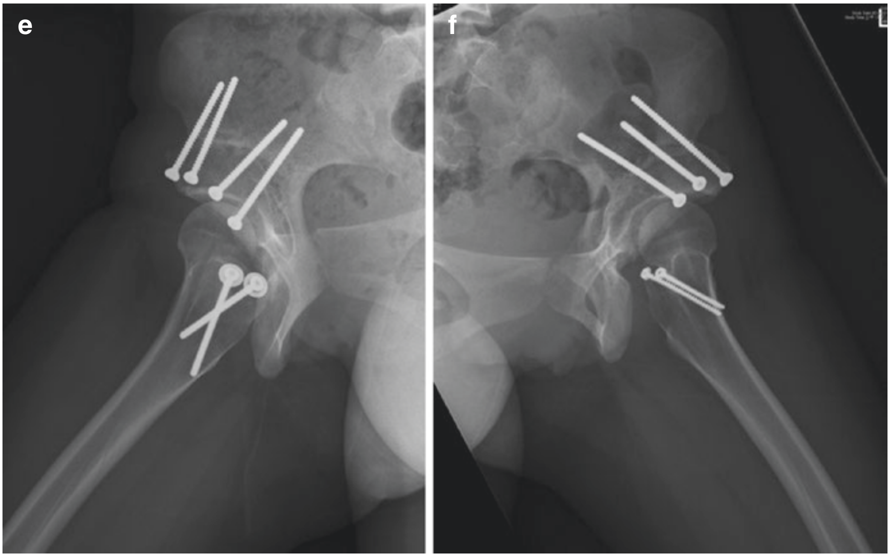

Fig. 2.5 (continued)

Outcomes of PAO

Management of young active patients with symptomatic OA secondary to hip dysplasia is a major challenge. PAO is usually considered for early OA (Tonnis grade 0–2) to arrest or delay its progression [8–10], and total hip arthroplasty is often required for advanced changes (Tonnis grade 3). Hsieh et al. found that, at the time of a follow-up at 2 to 10 years postoperatively, PAO led to similar functional results as did a total hip arthroplasty. Both groups of patients showed marked improvement in the Merle d'Aubigne and Postel hip scores, and most patients had high WOMAC scores in both hips. More patients preferred the outcome in the hips treated with a PAO to those treated with a total hip arthroplasty. Joint-preserving PAO can provide favorable clinical outcomes comparable to that of a total hip arthroplasty in the matched-pair analysis in young active patients (Fig. 2.6a–f). Despite its increased surgical difficulty and longer recovery time, more patients preferred the outcomes of a PAO to that of a total hip arthroplasty at 2 to 10 years after surgery. In the treatment of young adults with symptomatic developmental dysplasia of the hip, these findings should be considered during clinical decision-making.

With the osteotomy proposed by Hsieh et al. [10], the osseous cuts are near the acetabulum so that a large correction in the acetabular orientation is achieved

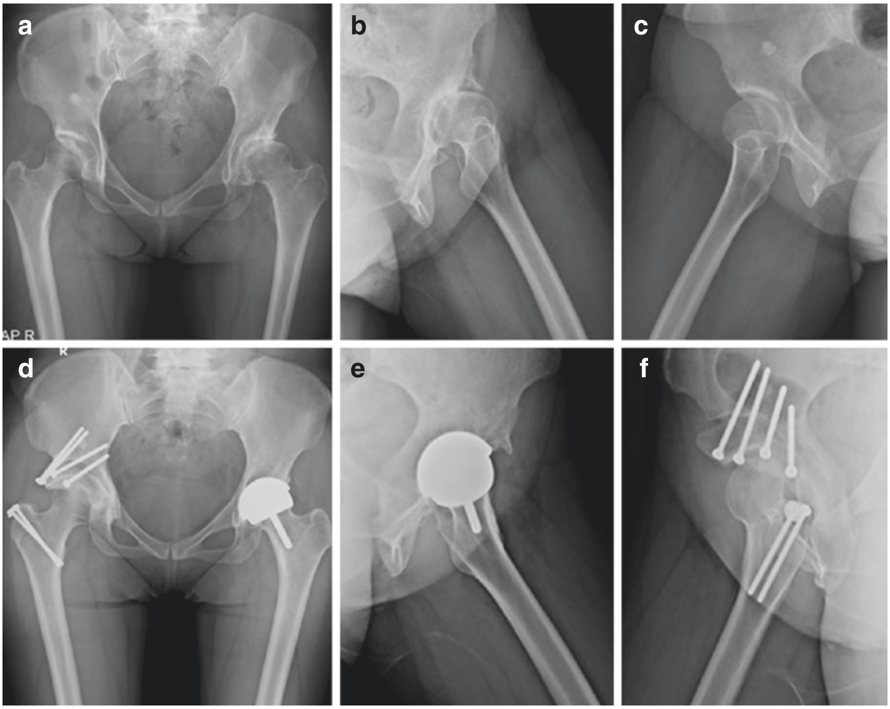

Fig. 2.6 The radiographs of a 35-year-old woman with bilateral dysplastic hips. Preoperative anteroposterior (**a**) and lateral (**b** and **c**) radiographs show advanced osteoarthritic changes in the left hip and mild osteoarthritis in the right hip. The postoperative radiographs (**d**–**f**), performed 9 years after resurfacing hip arthroplasty and 6 years after PAO, show well-fixed prosthesis in the left hip and solid bony union with good joint congruity in the right hip (These pictures were agreed by the patient for publication)

without altering the shape of the true pelvis, a benefit that allows young female patients to give birth naturally. In addition, maintaining the continuity of the posterior column offers the reliable stability of the pelvis for fixation of the fragment. Therefore, early postoperative mobilization is allowed without adverse effects on the osseous union.

Our osteotomy is spherical in shape, which is similar to the design of the rotational acetabular osteotomy [22]. The smooth, rounded surface allows easy mobilization of the fragment in all directions without impingement, and it provides a large area of contact, which results in rapid and predictable bone healing. In contrast, the polygonal shape of the Bernese osteotomy can result in large gaps, especially when a large corrective displacement is required. Furthermore, nonunion or delayed unions have been reported in other studies involving the Bernese osteotomy [8, 13, 34, 35].

The transtrochanteric approach through a single lateral incision has several advantages. Firstly, it is a familiar technique for most orthopedic surgeons and provides sufficient exposure, including the posterior column of the hemipelvis.

Secondly, the PAO can be performed outside the pelvis with minimal dissection of important structures. Thirdly, there is no change in the length of the abductors, and the abductor mechanism can be securely restored by bone-to-bone healing. Finally, this approach allows a surgeon to perform arthrotomy of the hip joint to directly assess intra-articular disease, which has been considered an important cause of residual symptoms [36].

Complications of trochanteric osteotomy include increased operative trauma, blood loss, and bursitis, with the most commonly noted serious complication being nonunion [37–39]. This complication is frequently seen in patients following a total hip replacement when the blood supply in the trochanteric area has been altered by the insertion of a femoral stem and the osteotomized trochanter can only be fixed by cables or wires [40]. In the series proposed by Hsieh et al., however, fixation was performed with two cancellous screws and bone healing was uneventful in all cases [10].

Computer-Assisted PAO

Computer-assisted image-guided surgeries, also called navigation surgeries, have recently been introduced to improve the accuracy and safety of hip, knee, and spine surgeries [41]. These technologies provide real-time, three-dimensional images of the position and orientation of surgical instruments with respect to the patient's anatomy. Hsieh et al. compared computer-assisted navigation and conventional techniques for PAO and found that the CT-based navigation effectively reduced the need for intraoperative radiographs and surgical time by a surgeon experienced with PAO surgery, although no differences with regard to the operative blood loss, transfusion requirement, radiographic correction of the deformity, and the functional outcomes between the groups were found [42]. A surgeon less experienced with PAO may benefit from application of the computer-assisted system more than an experienced surgeon.

In conclusion, an ideal technique of PAO for the treatment of hip dysplasia in adults should be safe and easy to perform and provide reliable stability and predictable correction with minimal use of postoperative external support. In addition, it should also allow the surgeon to address the intra-articular abnormality and have a low prevalence of complications.

Salvage Osteotomy of the Pelvis

Because the application of a PAO restores a nearly normal anatomy for most adult dysplastic hips, other pelvic osteotomies have been performed less often recently. However, some of the osteotomies may still be useful when PAO is not expected to be successful. These osteotomies that aim at providing a better coverage of the femoral head instead of restoring the congruity are referred to as "salvage" osteotomies. Among them, the most often mentioned are Chiari osteotomy [43–49] and shelf acetabuloplasty [49–54].

Indications for Salvage Osteotomy

Young patients with dysplasia of the hip and poor congruity between the femoral head and the acetabulum can be considered for salvage pelvic osteotomy, because a PAO cannot restore the congruity and an arthroplasty at a very young age is known to have poor long-term results.

The differences between Chiari osteotomy and shelf acetabuloplasty are that the Chiari osteotomy osteotomizes the pelvis above the acetabulum, medializes the distal fragment, and uses the joint capsule for interposition between the head and the proximal fragment for a better coverage, while shelf acetabuloplasty only creates a slot at the pelvis above the femoral head and uses a bone graft to cover the femoral head. Chiari osteotomy has the advantage of a better coverage of the femoral head and better abduction of the hip, while shelf acetabuloplasty is easier to perform and may have fewer complications.

The Chiari Osteotomy

The level and angle of the osteotomy is very important for the success of the surgery. The patient is placed supine on a radiolucent operation table to allow for the usage of an image intensifier during surgery. An anterior approach, usually the Smith-Petersen approach, is applied to expose the joint capsule, outer and inner tables of the pelvis, and the sciatic notch. A greater trochanter osteotomy may improve the exposure. The pelvic osteotomy is guided by an image intensifier, started at the brim of the acetabular insertion of the joint capsule, slightly curved to contain the joint capsule, and aimed at about 10° superiorly toward the inner table. After completion of the osteotomy, the distal fragment is translated medially until the joint capsule and the femoral head is well covered by the proximal fragment. The proximal and distal fragments are then fixed with screws or threaded pins (Fig. 2.7a–c).

Partial weight bearing can be allowed if the fixation is stable. Full weight bearing is allowed after the union of the osteotomy, and muscle strengthening exercise is started.

Although the Chiari osteotomy is referred to as a salvage surgery, it is technically demanding. If the osteotomy level is too low, the pressure on the medialized joint capsule might be too large and could cause necrosis of the joint capsule and prevent its metaplastic change into fibrocartilage. If the osteotomy level is too high, the transfer of the load for coverage of the femoral head is not achieved. The angle of the osteotomy and displacement of the distal fragment must be done meticulously to prevent damaging the sciatic nerve and poor coverage or impingement of the fragments.

Reported results of Chiari osteotomies varied widely because they usually contained mixed patient selection [47–49]. Major complications such as sciatic nerve palsy, nonunion and ectopic ossification were reported. Conversion to a surface replacement arthroplasty may be difficult due to difficult dislocation of

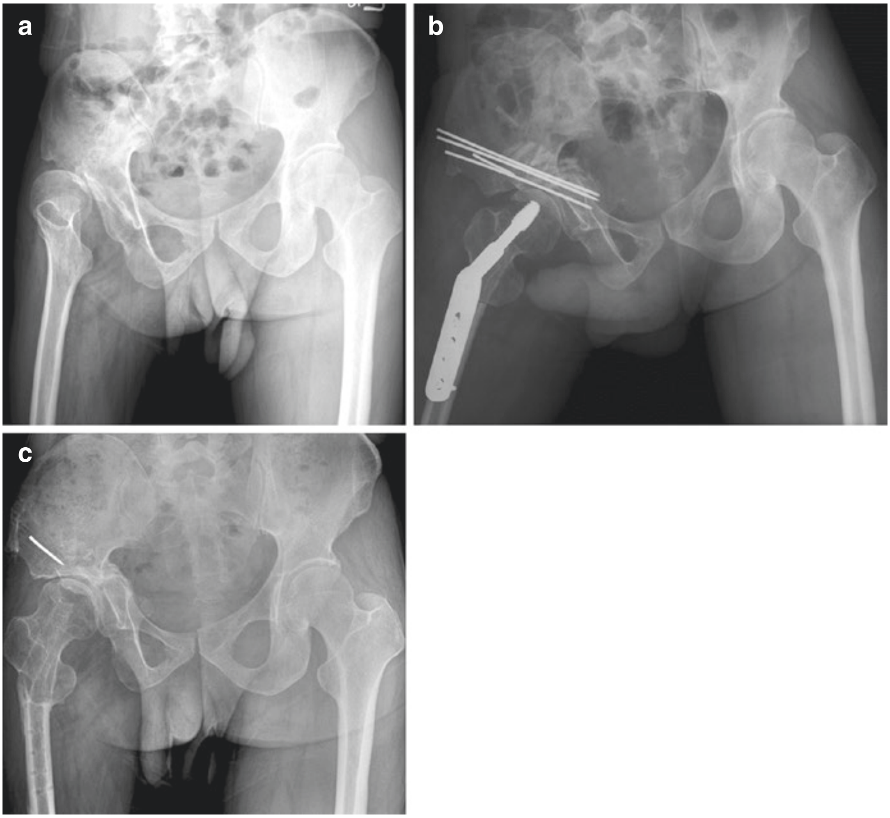

Fig. 2.7 (**a**) The anteroposterior X-ray of a 53-year-old male patient showing dysplasia and Hartofilakidis' low dislocation of the right hip. (**b**) A Chiari pelvic osteotomy with shortening-derotation osteotomy of the proximal femur was done. (**c**) After the removal of the fixation devices, acceptable coverage of the femoral head was observed 6 years after surgery (These pictures were agreed by the patient for publication)

the femoral head. However, conversion to total hip may be benefited by a deeper and larger acetabulum [50].

Shelf Acetabuloplasty

Shelf acetabuloplasty provides acetabular augmentation and extends acetabular size for aspheric congruity. It is a capsular arthroplasty based on the transformation of a fibrous capsule into fibrous cartilage.

The shelf procedure was first described by Konig [51] in 1891, and many modifications have been reported since. It can be used alone or in combination with other reconstructive procedures. Staheli's modification [52] of the shelf procedure—the slotted acetabular augmentation (SAA)—is done usually with the anterior approach

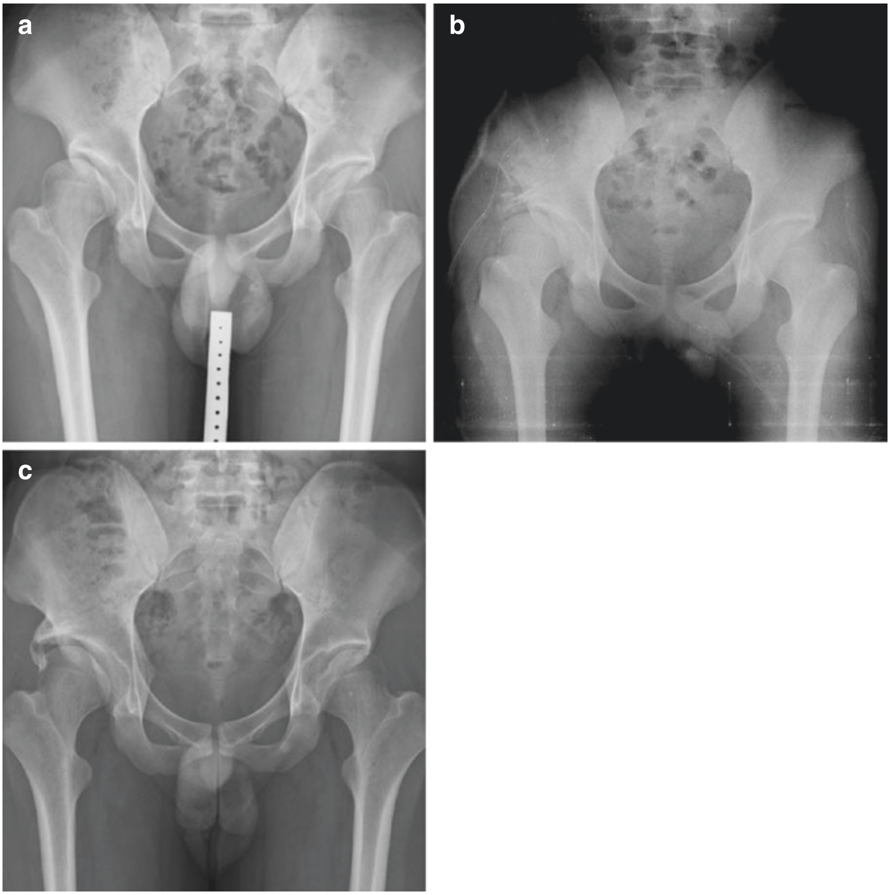

Fig. 2.8 (**a**) An anteroposterior X-ray of a 16-year-old boy shows the right hip dysplasia with an aspherical femoral head. (**b**) A shelf acetabuloplasty with SAA modification was performed. (**c**) Acetabular new saucer formation with acceptable coverage of the femoral head was observed 4 years after the operation (These pictures were agreed by the patient for publication)

of the hip. After lifting the rectus femoris tendon, a row of holes is drilled along the edge of the acetabulum. A slot is created along the holes. Strips of corticocancellous bone are harvested from the outer table of the ilium and inserted into the slot. The second layer of bone strips is paved. The reflected rectus tendon is sutured and more bone graft is added (Fig. 2.8a–c).

Partial weight bearing and external protection are necessary before consolidation of the bone graft.

The main complication of the SAA is the absorption of bone graft if it is placed too high from the joint. Other minor complications such as fracture and lateral femoral cutaneous nerve dysesthesia are reported.

Compared with other pelvic osteotomies, the shelf procedure is simpler and safer; there's no need for internal fixation, no interfering with the birth canal, and no risk of sciatic nerve injury; and it can be performed in both hips at one stage. The disadvantages are that the hip is not medialized and that it needs a long period of protection.

The long-term survival of the shelf procedure was around 60% at 15 years and 40% at 20 years [53, 54]. It also provides a better socket for total hip replacement when it becomes necessary.

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Resurfacing Hip Arthroplasty for Developmental Dysplasia

3

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Abstract

There have been many reports of increasing numbers of resurfacing hip arthroplasty revisions because of unexplained pain and adverse local tissue reactions, especially with the Articular Surface Replacement system. Thus, the use of many resurfacing hip replacements has been declining. In contrast, the Birmingham Hip Resurfacing system has shown excellent long-term survivorship compared with other resurfacing prostheses, especially for young and active patients with osteoarthritis. Some reports on primary total resurfacing hip arthroplasty for developmental dysplasia of the hip (DDH) showed a higher rate of revision than primary osteoarthritis, but it is controversial whether a diagnosis of DDH itself is an independent risk factor for failure of hip resurfacing or it is related to its characteristics of female dominant gender and smaller component size. With most resurfacing prostheses, small components have a small coverage arc, indicating that small acetabular components have a narrower safe zone for the alignment against edge loading. Thus, strict control of acetabular component alignment is essential to prevent adverse wear for patients with DDH. It also requires surgical skill to fix an acetabular component using the press-fit technique alone. With a severely deformed femoral head, it is technically demanding to determine the proper insertion position and alignment of the guidewire while avoiding notch formation and preparing a healthy host bone with sufficient stability for the femoral components. Sufficient surgical experience, a properly designed prosthesis, and dedicated alignment control via intraoperative radiographic checks and/or computer technology (e.g., navigation or a patient-specific surgical guidance) would be required to improve implant survival

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of hip resurfacing for patients with DDH. We believe that DDH itself is not a contraindication for primary total hip resurfacing arthroplasty.

Keywords
Developmental dysplasia of the hip · Resurfacing hip arthroplasty · Adverse local tissue reaction · Press-fit cup fixation · Birmingham Hip Resurfacing

Current Status of Hip Resurfacing

Hip resurfacing has been expected to be a successful alternative to conventional total hip arthroplasty, especially in young and active patients, because it has several advantages regarding bone preservation [1, 2] and a lower risk of dislocation [3]. It also permits high activity [4] and provides a good gait pattern by restoring the proximal femoral anatomy [5]. However, there have been many reports of an increasing number of revisions because of unexplained pain and adverse local tissue reactions, especially regarding particularly designed hip resurfacing arthroplasty [6, 7]. The DePuy Articular Surface Replacement (ASR) device was withdrawn after unacceptably high revision rates were reported. A recent 10-year cumulative percent revision of ASR was 27.05% [95% confidence interval (CI) 25.30–28.89] in the United Kingdom [8] and 30.1% (95%CI 27.4–33.1) in Australia [9].

These high revision rates are mainly because of adverse wear on the metal-on-metal bearing due to a flawed design including lower clearance and a small coverage arc (Table 3.1). As a result of press-fit fixation with 1–2 mm underreaming, a one-piece metal-on-metal acetabular cup could deform as much as 60–100 μm at

Table 3.1 Comparison of three design types of hip resurfacing

Design parameter	ASR	BHR	C+
Subtended articular surface angle (°)	144–160[a]	158–166[a]	162–165
Mean diametric clearance (μm)	100	200	160
Wall thickness at rim (mm)	3.1	3.6/4.6	3.8
Manufacturing method of the head	As cast	As cast	HIP/SA
Manufacturing method and treatment of component	HIP/SA	As cast	HIP/SA
Surface roughness (μm)	0.025	0.029	0.020
Deviation of roundness of the head (μm)	3.4	0.9	3.2
Deviation of roundness component (μm)	3.8	0.9	1.8
Carbon content[b]	High	High	High

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ASR Articular Surface Replacement, *BHR* Birmingham Hip Resurfacing, *C+* Conserve Plus, *HIP/SA* cast process and heat treatment by hot isostatic pressure/surface annealed

[a]Subtended articular surface angles increase with increasing component diameter

[b]High carbon content is defined as ≥0.2%

the rim diameter [10]. It should be considered that effective clearance of the metal-on-metal bearing could be reduced by press-fit cup fixation. According to the 13th Annual Report of the National Joint Registry for England, Wales, Northern Ireland, and the Isle of Man (NJR), the proportion of metal-on-metal resurfacing implants have decreased from a peak of 10.8% in 2006 to only 0.9% (801 hips) of all implants in 2015 [8]. According to the annual report of the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR), the use of total resurfacing hip replacement in Australia has been declining since 2005 [9]. The number of total resurfacing procedures was 80.3% less in 2015 than in 2005. Total resurfacing hip replacement thus represents 0.8% (361 hips) of all hip replacements performed in 2015.

In contrast, Smith and Nephews' Birmingham Hip Resurfacing (BHR) system has shown lower revision rates because of its design, which includes a higher clearance, a larger arc of coverage, and a high carbide volume fraction without heat treatment. This design was developed based on evidence derived from successful cases of ring metal-on-metal total hip prostheses [11]. According to the AOANJRR 2016 report, the 10-year cumulative percent revision of BHRs was 6.9% (95%CI 6.4–7.5), and the 15-year cumulative revision rate was 10.1% (95%CI 9.1–11.3). According to the 13th NJR report, the 10-year cumulative percent revision for BHR was 8.39% (95%CI 7.93–8.88), and the 12-year cumulative rate was 9.91% (95%CI 9.29–10.57). In 2015 in the United Kingdom, five types of resurfacing prosthesis were used, with the BHR system accounting for 84% of the procedures. That same year in Australia, the BHR and the Adept were the only prostheses used, with the Adept being used in 54.0% of the procedures.

Risk Factors for Revision of Hip Resurfacing

Other than the implant design, several risk factors for hip resurfacing revision have been reported, including older age, small femoral head size, female sex, higher inclination, excessive anteversion, and hip dysplasia [12]. A small component is more likely to suffer from adverse wear due to edge loading because the coverage arc is smaller by design [13]. Based on the results of several studies with the DePuy ASR implant, Langton et al. [7] found that the risk of adverse wear failure correlated strongly with higher inclination and excessive anteversion. They also found that the component design and size determined the extent of the safe zone of acetabular component alignment. Liu and Gross [14] performed whole blood measurements of metallic ions for 761 hips (613 patients) and determined possible risk factors for elevated metallic ion levels. They evaluated the Corin Cormet 2000 and Biomet Recap-Magnum implants after a minimum 2-year follow-up. They defined a safe zone that could prevent metal ion levels >10 μg/L with a 99% confidence interval. The acceptable acetabular inclination angle decreased with the implant bearing size (Table 3.2). Their results confirmed that small implants, which are shallower by design, must be placed more horizontally to avoid edge loading. The safe zone of these smaller acetabular components is

Table 3.2 Relative acetabular inclination angle reference table for correct acetabular placement to avoid high metallic ion levels due to edge loading

Femoral component size (mm)	Coverage arc (°)	Cup inclination angle (°)
40	155.8	32
42	156.9	35
44	157.9	36
46	158.8	40
48	159.6	43
50	160.4	46
52	161.1	48
54	161.8	51
56	162.4	54
58	163.0	56
60	163.6	59

(Reproduced with permission from BMC Musculoskeletal Disorders [24])

narrower, which could cause the relatively high failure rates of hip resurfacing in patients with DDH.

Is DDH a Contraindication for Resurfacing Arthroplasty?

Whether DDH itself is an independent risk factor for failed hip resurfacing in women or those needing a small component size is controversial. This might be due to the effect of confounding, as it is also unknown whether female sex itself is a risk factor for failed hip resurfacing. At the Advanced Hip Resurfacing Course in Ghent, Belgium, in 2014, the opinions of an international faculty of highly experienced hip replacement and hip resurfacing surgeons and researchers (118 participants) gathered to reach a consensus opinion on the status of hip resurfacing arthroplasty [15]. Voting showed that 60% of participants considered sex not to be the issue. The issue was size. We consider that the same is true for DDH (Fig. 3.1). In most resurfacing prostheses, small components have a small coverage arc [13], inferring that small acetabular components have a narrower safe zone in their alignment against edge loading. Thus, stricter control of acetabular component alignment is essential to prevent adverse wear, especially in patients with DDH. It also requires surgical skill and experience to fix an acetabular component using the press-fit technique alone. For the severely deformed small femoral head, it is also technically demanding to determine the proper insertion position and alignment of the guidewire while avoiding notch formation and still preparing a healthy host bone to ensure sufficient stability of the femoral component.

Daniel et al. [16] reported a 12- to 15-year implant survival assessment of 1000 consecutive BHR revisions with no exclusions. With "revision for any reason" as the end point, the Kaplan-Meier analysis showed a 10-year survival of 97.4% (95%CI 96.9–97.9) and a 15-year survival of 95.8% (95%CI 96.9–97.9). Significant

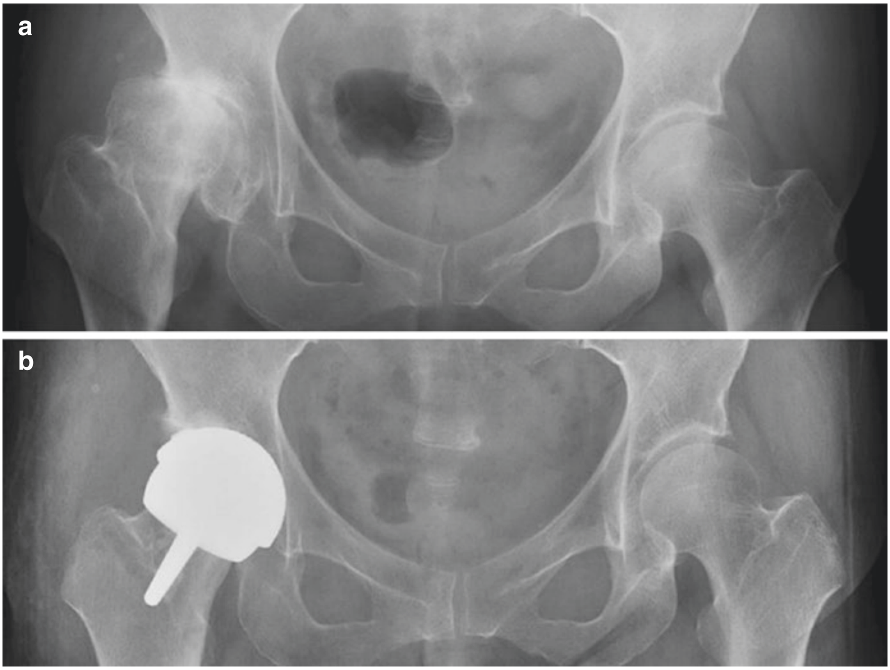

Fig. 3.1 Anteroposterior radiographs of the hip before (**a**) and after (**b**) primary total hip resurfacing. A 62-year-old woman with Crowe I developmental dysplasia of the hip (DDH) had total primary hip resurfacing using Birmingham Hip Resurfacing. A 52-mm acetabular cup and a 46-mm femoral component were implanted (these X-ray pictures were agreed by the patients for publication)

negative factors for implant survival included a diagnosis of hip dysplasia and femoral head osteonecrosis, whereas age at operation, sex, American Society of Anesthesiologists grade, head size, or whether unilateral or bilateral were not implicated. Male patients younger than 50 years of age with osteoarthritis fared best [99.4% (95%CI 98.8–100) at 15 years], although there were no failures in any of the men in this group. For women with DDH, implant survival was 96% (95%CI 93.8–98.2) at 5 years, 91% (95%CI 87.7–94.3) at 10 years, and 85% (95%CI 80.2–89.8) at 15 years. Several authors have reported similar survivorship of hip resurfacing for patients with DDH [17–24](Table 3.3).

Fixing an acetabular component to dysplastic acetabulum by using the press-fit technique alone is a technically demanding procedure. Gross and Liu [25] analyzed 1092 resurfacing arthroplasties, including 134 patients with DDH, after an average 5-year follow-up. They reported that DDH was the only significant risk factor independent of small femoral component size and female sex. Among DDH patients, 70% of failures were due to acetabular problems—50% of which were due to failure of fixation and 20% to adverse wear. Thereafter, they improved acetabular component fixation by using a cup with three spikes in high-risk patients (those with the largest deformities) [24]. To avoid adverse wear, they determined the target

Table 3.3 Study results after primary total hip resurfacing arthroplasty for patients with DDH

Study	Publication year	*N* (hips)	Prosthesis	Data range	Crowe classification	Female ratio (%)	Mean age (y)	Mean follow-up (y)	Mean femoral component size (mm)	Survivorship rate[a]
Nishii [17]	2007	50 (DDH 37)	BHR	1998–2000	I 78%, II 16%, III 6%	53[b]	51[b]	5.6[b]	Male 50, female 43[b]	96% at 5 y[b]
Amstutz [18]	2007	59	Conserve Plus	1996–2002	I 88%, II 12%	82	43.7	6	NA	Revision rate 10%
Amstutz [19]	2008	103	Conserve Plus	1996–2006	I 94%, II 4%, III 2%	78	47	6	Male 44, female 43	94% at 5 y
McMinn [20]	2008	110	BHR (dysplasia cup)	1997–2000	I 5%, II 51%, III 44%	47	47.2	7.8	56 (cup size)	95.2% at 9 y
McBryde [21]	2008	96	BHR (dysplasia cup 35%)	1997–2004	I 42%, II 23%, III 13%, IV 5%, NA 17%	81	43	4.4	46 (median)	96.7% at 5 y
Naal [22]	2009	32	BHR, Durom	2002–2005	I 84%, II 16%	56	44.2	3.6	NA	Revision rate 6%
Wang [23]	2012	37	Conserve Plus	2005–2006	I 84%, II 16%	85	45.7	4.9	43.5	Revision rate 0%
Daniel [16]	2014	103	BHR	1997–2000	NA	100	53[c]	13.7[c]	NA	96% at 5 y, 91% at 10 y, 85% at 15 y
Gaillard [24]	2016	121	Cormet 2000, Recap	2001–2008	G1 31%, G2 8% osteotomy 3%, NA 58%[d]	71	48	6.4	48.1	90% at 7 y
Gaillard [24]	2016	242	Recap	2008–2013	G1 78%, G2 20%, osteotomy 1.6%, NA 0.4%[d]	74	52	2.6	47	99% at 7 y

DDH developmental dysplasia of the hip, *BHR* Birmingham Hip Resurfacing, *NA* not available, *y* years
[a]Survivorship rates with revision for any reason as the end point
[b]Data of all 50 hips including 36 DDH
[c]Data of all 1000 hips including 103 DDH
[d]Degree of dysplasia is graded as follows: grade 1 (G1), 50–80% coverage of the femoral head on standing anterior posterior radiograph, with <1 cm of superior migration; grade 2 (G2), < 50% coverage, but <2 cm of superior migration; grade 3 (G3), >2 cm of superior migration of the head, irrespective of coverage

inclination by the relative acetabular inclination limit listed for each bearing size (Table 3.2). In addition, they normalized intraoperative radiography to the preoperative standing AP pelvic radiograph by rotating the operating table and tilting the portable digital radiography machine. To prevent early femoral failure, they modified early weight bearing and the use of alendronate, with an emphasis on individual bone density. They used cementless femoral fixation. The 7-year Kaplan-Meier survivorship was 89% in the group using the conventional technique versus 99% in the group using the improved technique, although the follow-up period of the improved group was too short to draw any conclusions.

Nishii et al. [17] reported a minimum 5-year follow-up of 50 BHR hip revisions in 45 patients with DDH. Two hips underwent revision surgery due to femoral neck fracture and septic loosening, and one hip showed femoral component loosening but without aseptic loosening of the acetabular component. Nakasone et al. [26] also reported excellent fixation of the acetabular component using the BHR system, with no loosening despite initial polar gaps in 151 hips including those with DDH.

Amstutz et al. [18] also reported excellent fixation of the acetabular component with a Conserve Plus implant with no loosening despite incomplete lateral coverage for 59 patients with Crowe class I and II DDH after a 6-year follow-up. They noted that the acetabular component should be placed with at least 70% bone coverage in the frontal plane. However, the rates of aseptic femoral component loosening (3/59 hips) and femoral neck fracture (2/59 hips) were high. Both femoral neck fracture and femoral component loosening were associated with poor bone quality, large cysts, and inadequate component seating. Amstutz and Le Duff improved the initial stability with changes in their cementing technique [27]. The technique included meticulous bone preparation with removal of cystic material using a high-speed burr, multiple drill holes into the dome and chamfered areas, jet lavage, and drying with the use of suction of both the dome and subsequently the lesser trochanter when the component was placed on the head. They cemented the metaphyseal stem in those hips that required a small femoral component (<48 mm) and had large cysts (>1 cm). The target stem shaft angle was shifted from anatomical (stem aligned with the neck axis) to a greater valgus of 140°. Amstutz et al. reported the influence of improved femoral fixation techniques on the survivorship of Conserve Plus hip resurfacing prostheses in 103 DDH patients after an average 6-year follow-up [19]. Although 7 of 29 hips (24%) that had been resurfaced using the first-generation femoral fixation technique were revised, only 1 of 74 hips (1.3%) that were resurfaced using the second- and third-generation techniques required revision.

Surgical Technique

During the preoperative planning, the cup position was referenced to the bony coverage in the weight-bearing portion on the anteroposterior radiograph in two-dimensional templating or the coronal image through the cup center in three-dimensional templating. We measured the angle between the vertical line and the line drawn from the cup center to the lateral edge of the acetabulum—the cup center-edge angle

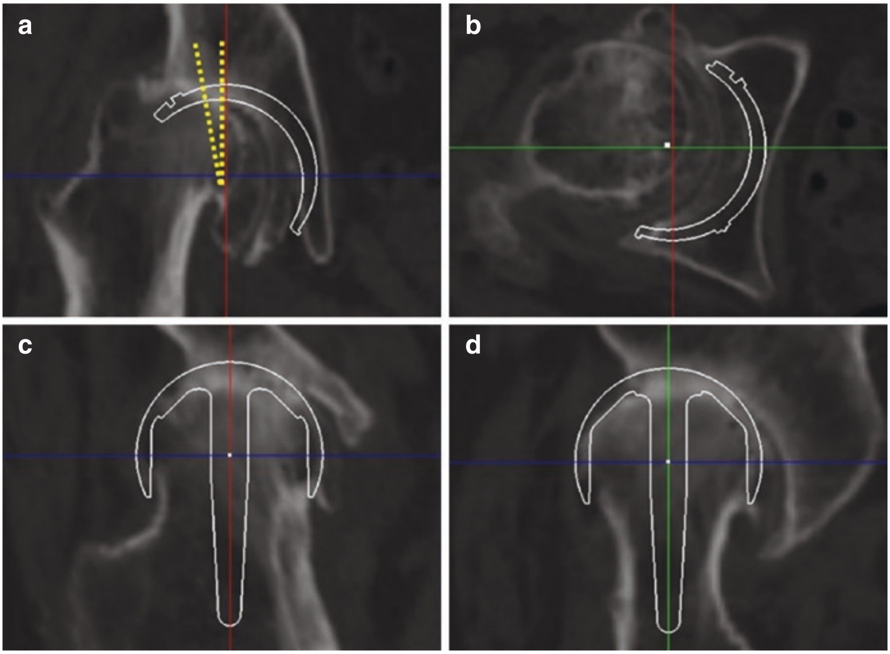

Fig. 3.2 Preoperative three-dimensional templating of hip resurfacing. The position and host bone coverage of the cup are checked on coronal (**a**) and axial (**b**) images through the cup center. The yellow broken lines form the cup center-edge angle representing vertical host bone coverage of the acetabular cup. The position of the femoral component and the risk of notching are checked on oblique coronal (**c**) and oblique sagittal images (**d**) through the femoral component stem axis (these images were agreed by the patient for publication)

(cup CE angle) [28](Fig. 3.2a). We tried to place the cups, so the cup CE angle was >10° by a combination of medial and superior shifts of the cup from the original acetabular position without perforating the medial wall and with <2 cm of maximum superior shift from the inter-teardrop line [28]. The femoral component size and position were planned, so its bearing surface fits the remaining original subchondral bone (Fig. 3.2c, d). The femoral stem axis was aligned with the medial femoral cortex, aiming for a slightly valgus alignment. For three-dimensional templating, multidirectional reconstructed images were created around the femoral stem axis. The occurrence of femoral neck notching was checked and the position and alignment of the femoral component adjusted if necessary.

We have performed primary total hip resurfacing arthroplasty using the BHR system through a posterolateral approach, with the patient in the lateral position. The short rotators and quadratus femoris are divided. The lateral circumflex femoral vessel is usually cauterized, but it does not increase the iatrogenic secondary osteonecrosis of the remaining femoral head because of the abundant medullary vascular network [29]. When mobilization of the femoral head is insufficient, the gluteus maximus tendon is divided at the insertion to the linea aspera. In most female

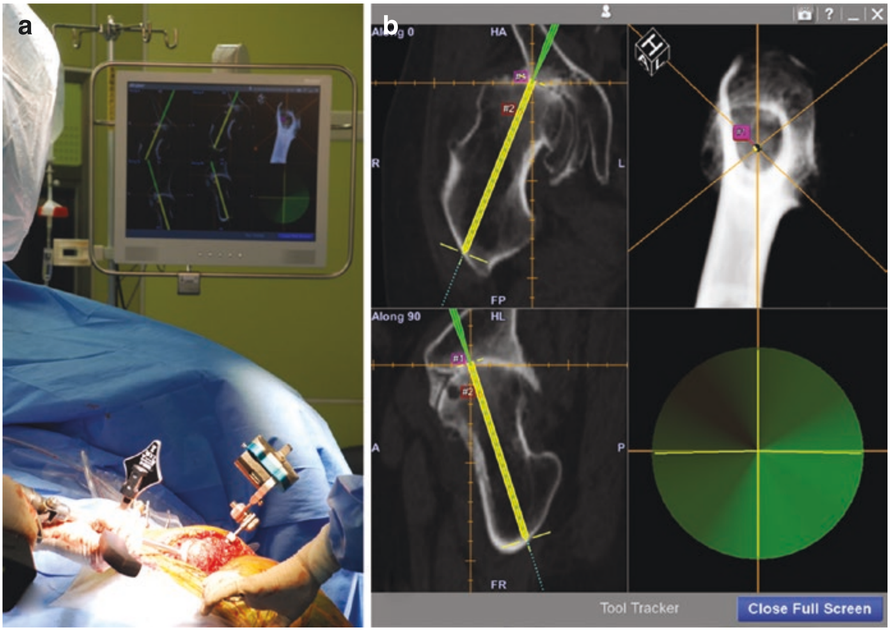

Fig. 3.3 A guidewire is inserted under the guidance of the computed tomography-based navigation system (**a**). The navigation monitor shows the position and direction of the guidewire relative to the femur (**b**) (these pictures were agreed by the patient for publication)

patients with DDH, however, this step is unnecessary. After the entire capsule is released circumferentially, the femoral head is displaced anterosuperiorly. The acetabulum is reamed up to 1 mm less than the actual size. For young and active men with stiff bones, line-to-line reaming is preferable for complete seating. The acetabular component is impacted until fully seated, aiming at 40° of abduction and 15° of anteversion (radiographically defined) [17, 26]. We do not apply the combined anteversion theory to resurfacing hip arthroplasty. We have implanted an acetabular cup using a CT-based navigation system (CT-based hip navigation version 1.1; Stryker, Kalamazoo, MI, USA) to avoid edge loading due to cup malalignment.

On the femoral side, a guidewire is inserted from the surface of the femoral head, aiming for a slightly valgus alignment so that the femoral stem axis is aligned with the medial femoral cortex. We have applied the CT-based navigation system for the guidewire insertion as well as the cup placement [30, 31]. Currently, we use a CT-based navigation system having broad utility (OrthoMap 3D; Stryker, Kalamazoo, MI, USA) to the guidewire insertion (Fig. 3.3). After checking the centralization of the guidewire by rotating the probe around the femoral neck (Fig. 3.4a), the femur is cylindrically reamed and shaped along the direction of the guidewire. After machining the femoral head, all soft tissues, including cysts and granulation, are removed by curettage, burr, and irrigation until normal or dense, white, reactive bone is identified. Anchoring holes are made over the normal bone into the dome

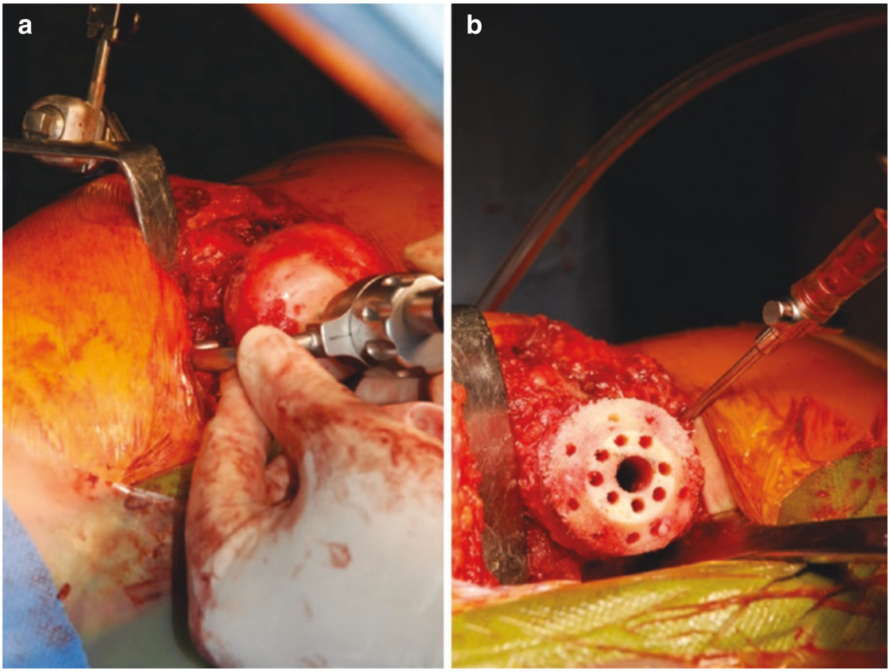

Fig. 3.4 Centralization of the guidewire is checked by rotating the probe around the femoral neck (**a**). After machining the femoral head, all the soft tissue was removed, and the anchoring holes were made over the normal bone into the dome and chamfer areas (**b**) (these pictures were agreed by the patient for publication)

and chamfer areas (Fig. 3.4b). Finally, the femoral component is half-filled with cement (Surgical Simplex, Stryker, Kalamazoo, MI, USA) 2 min after mixing it. We do not cement the stem of the femoral component to avoid stress shielding and stem fracture [32]. During insertion of the femoral component, bone marrow fluid is suctioned via a cannula placed in the lesser trochanter to prevent elevation of the intraosseous pressure.

Summary and Comment

We believe that DDH and the female sex are not true risk factors causing failure of total resurfacing hip arthroplasty. A smaller component size, however, is a significant risk factor because it increases the risk of edge loading and femoral neck notching. The procedure is relatively contraindicated in young women because of the possibility of pregnancy and transplacental transfer of metallic ions [33]. To provide DDH patients with favorable implant survival after hip resurfacing, the surgeon must have sufficient experience with press-fit cup fixation and femoral head preparation. In addition, there must be a properly designed prosthesis, such as the BHR system, and dedicated alignment control via intraoperative radiographic checks or computer technology that includes navigation and patient-specific surgical guidance [30, 31].

There have been many reports of increasing numbers of resurfacing hip arthroplasty revisions because of unexplained pain and adverse local tissue reactions, especially with the Articular Surface Replacement system. Thus, the use of many resurfacing hip replacements has been declining. In contrast, the Birmingham Hip Resurfacing System has shown excellent long-term survivorship compared with other resurfacing prostheses, especially for young and active patients with osteoarthritis.

Some reports on primary total resurfacing hip arthroplasty for developmental dysplasia of the hip (DDH) showed a higher rate of revision than primary osteoarthritis. But whether a diagnosis of DDH itself is an independent risk factor for failure of hip resurfacing or it is related to its characteristics of female dominant gender and smaller component size is still controversial. With most resurfacing prostheses, small components have a small coverage arc, indicating that small acetabular components have a narrower safe zone for the alignment against edge loading. Thus, strict control of acetabular component alignment is essential to prevent adverse wear for patients with DDH. It also requires exceptional surgical skill to fix an acetabular component using the press-fit technique alone. With a severely deformed femoral head, it is technically demanding to determine the proper insertion position and alignment of the guidewire while avoiding notch formation and preparing a healthy host bone with sufficient stability for the femoral components. Sufficient surgical experience, a properly designed prosthesis, and dedicated alignment control via intraoperative radiographic checks and/or computer technology (e.g., navigation or a patient-specific surgical guidance) would be required to improve implant survival of hip resurfacing for patients with DDH. We believe that DDH itself is not a contraindication for primary total hip resurfacing arthroplasty.

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Total Hip Arthroplasty for Adult Patients with Developmental Dysplasia and Dislocation of the Hip

4

Kuo-An Lai

Abstract

Total hip arthroplasty (THA) is indicated for adult DDH patients with advanced arthritis and high dislocations. THA for patients with Crowe I, II, and III or Hartofilakidis dysplasia and low dislocation are not difficult for a surgeon experienced with hip reconstruction. Medialization of the acetabular cup with or without an autologous bone graft is advised for reconstruction of the cup. A protocol for symmetrize the lower limbs is proposed for Crowe IV (or Hartofilakidis high dislocation). This protocol includes iliofemoral distraction before THA, implanting the cup at the best bone stock, proximal femoral osteoplasty (greater trochanter osteotomy, expansion osteoplasty, interlocking wire fixation of the osteoplasty, and shortening-derotation osteotomy of the femur). Middle-term results of THA for DDH/CDH patients are similar to ordinary THA's. But long-term results may be compromised by young age of the patients, small cups, and conventional polyethylene inserts. With improvement of the bearing materials, a better long-term result is expected.

Keywords

Developmental dysplasia of the hip · Congenital high dislocation of the hip · Total hip arthroplasty · Best bone stock of the acetabulum · Iliofemoral distraction · Expansion osteoplasty of the femur · Interlocking wire fixation of the proximal femur · Shortening-derotation osteotomy of the femur · Leg-length equalization

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Early detection and treatment of developmental dysplasia (DDH) and dislocation of the hip (previously called congenital dislocation of the hip, CDH) in infancy and childhood have improved the clinical outcome and reduced the number of untreated adult patients. However, there are still numerous DDH/CDH adult patients for whom early detection and treatment were not available or arthritis develops later in their life [1]. Pelvic osteotomy described in the preceding chapter (Chap. 2) provides better coverage of the dysplastic hip and may deter or even prevent the development of arthritis. However, total hip arthroplasty (THA), a relatively mature technology, may be the final solution for patients with advanced arthritis as a result of DDH/CDH in adulthood.

Classification of Adult DDH/CDH

Crowe's and Hartofilakidis classifications are commonly applied for classification of dysplasia and dislocation in adult patients. **Crowe's classification** uses the height of the true acetabulum as the reference [2]. Subluxation under 50% of the true acetabular height is classified as **type I**, 50–75% as **type II**, 75–100% as **type III**, and over 100% as **type IV** (Fig. 4.1). **Hartofilakidis** classified them as **dysplasia (a), low dislocation (b), and high dislocation (c)** (Fig. 4.2) (see Chap. 1). In the past, the most advanced types were known as congenital dislocation of the hip (CDH), which bear more anatomical deformities and present more difficulty for THA than the less severe types.

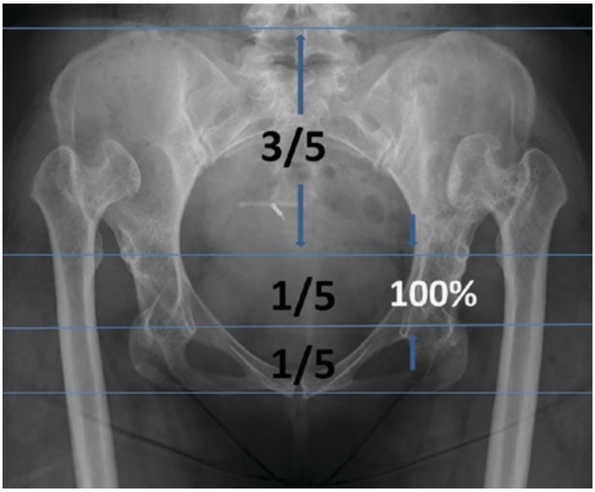

Fig. 4.1 Crowe's classification of adult DDH uses the height of the true acetabulum as the reference [2]. In cases of an underdeveloped acetabulum, the height for reference is the second fifth from the bottom of the height of the innominate bone. Subluxation under 50% of the true acetabular height is classified as **type I**, 50–75% as **type II**, 75–100% as **type III**, and over 100% as **type IV**. (This picture was agreed by the patient for publication)

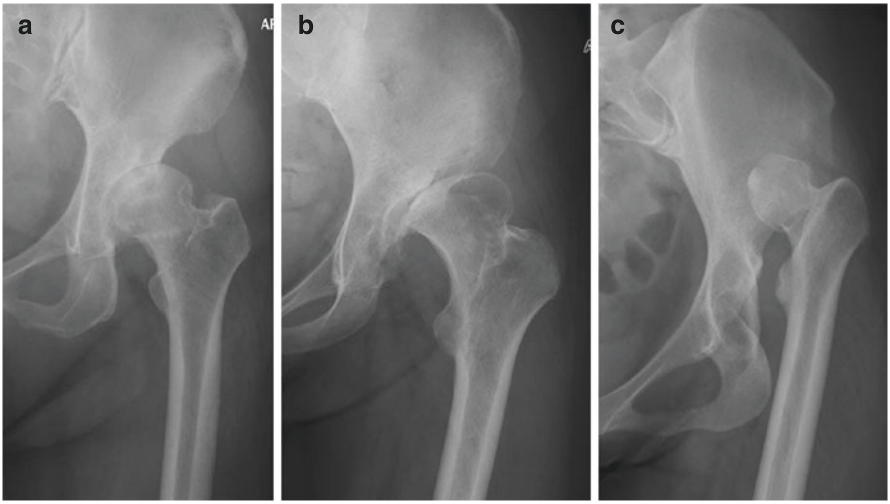

Fig. 4.2 Hartofilakidis classification of adult DDH [3]. Dysplasia (**a**), low dislocation (**b**), and high dislocation (**c**). (These pictures were agreed by the patients for publication)

Total Hip Arthroplasty for Crowe Type I, II, and III Dysplasia

Crowe types I and II are similar to Hartofilakidis dysplasia. They do not have much anatomical anomaly. These patients may have occasional pain as a result of a labrum injury in their youth. Development of painful arthritis is usually late in the sixth or even seventh decades of life. Total hip arthroplasties for these patients are usually not difficult for a surgeon experienced with hip arthroplasty. The acetabulum usually is shallower than that of a normal subject. Anteversion and anatomical deformity of the proximal femur are usually mild. The author advises surgeons to identify the **best bone stock** of the acetabulum during surgery and place the cup at the best bone stock for optimum anchorage of the cup. The best bone stock is the concept of the good-quality subchondral bone around the acetabulum fossa. In a normal subject, the best bone stock is the horseshoe-shaped subchondral bone of the dome, inner cortices of the anterior and posterior walls, and the lateral cortex of the medial acetabular wall. Due to a shallower acetabulum, the best bone stock of the dysplastic acetabulum may be the dome, cortices of the anterior and posterior walls, and medial cortex of the acetabulum. When preparing the dysplastic acetabulum for prosthetic cup implantation, it is advised to medialize the reaming until the medial cortex. The subchondral bone of the dome, anterior and posterior walls have to be well preserved. The author prefers not to penetrate the medial cortex because it is a part of the best bone stock although other authors may like to penetrate the medial cortex for further medialization of the cup [4]. When the medial cortex is penetrated intentionally or accidentally, the periosteum must be kept intact and autogenous cancellous bone graft be packed into the defect for better anchorage of the cup. If the best

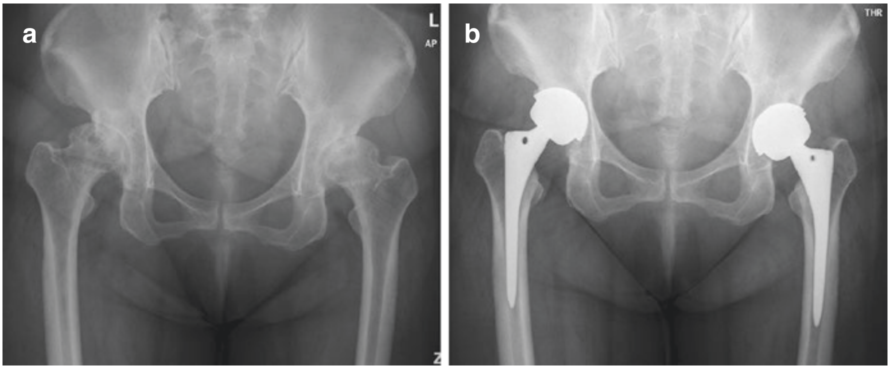

Fig. 4.3 A 48-year-old female patient with dysplasia of bilateral hips and arthritis (**a**) treated with cementless large-head metal-on-metal THA with medialization and press-fit fixation of the cup at the best bone stock (**b**). (These pictures were agreed by the patient for publication)

bone stock is kept intact and the coverage is good, the metal shell of the cup can be implanted with press-fit fixation without screws. However, additional screws may increase the stability of the cup. Accurate implantation of the cup at acceptable inclination and anteversion is important, but the stability of joint can only be checked and proved with trial reduction. In Crowe type I and II dysplasia, structural bone graft augmentation of the roof is rarely necessary if medialization is well done (Fig. 4.3).

For patients with Crowe type III (Hartofilakidis low dislocation), arthritis develops earlier than types I and II patients. They may need THA in the fifth or even fourth decades of life. Acetabulum preparation for patients with Crowe III DDH is not much different from that for the types I and II patients. An autogenous structural bone graft using the excised femoral head for acetabulum roof augmentation is advised for less than 70% coverage of the cup by the bone. Although long-term survival of the autogenous structural bone is questionable, it can provide better immediate stability for the cup and a better chance of bone on-growth to the implant. The details of acetabulum reconstruction will be discussed in Chap. 6.

Preparation of the proximal femur for Crowe types I, II, and III is similar to non-dysplastic patients. Anteversion of stem broaching can be checked using the patella or the lesser trochanter as the guiding landmarks. The stability of the hip should be confirmed with trial reduction.

Total Hip Arthroplasty for Crowe IV Dislocation

Crowe IV (Hartofilakidis high dislocation) patients may or may not have a false joint above the true acetabulum. When there is a false acetabulum, the leg-length discrepancy of a unilateral patient tends to be less severe than a patient without a

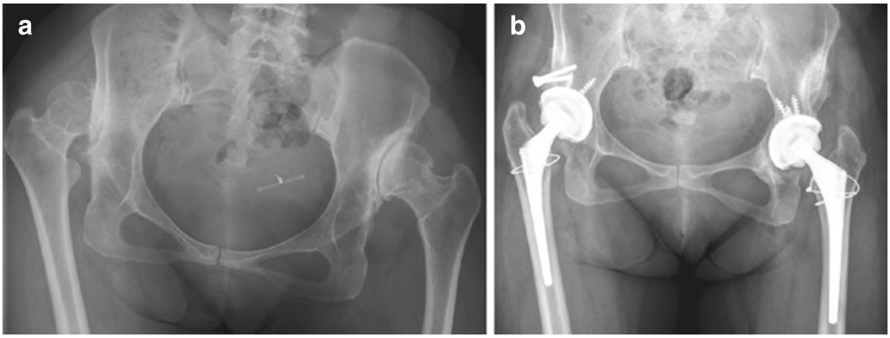

Fig. 4.4 A 33-year-old female patient with bilateral Crowe IV DDH and arthritis of the false joints (**a**). Bilateral cementless THAs were done with medialization of the cup at the best bone stock. An autogenous bone graft was applied for reinforcement of the right acetabulum. Cerclage wires were applied for prevention of crack progression at the proximal femora (**b**). (These pictures were agreed by the patient for publication)

false joint. But arthritis develops earlier at the false joint. Total hip arthroplasty may be necessary at the third and fourth decade of life (Fig. 4.4).

Patients with unilateral high dislocation without a false joint may rarely suffer from arthritis-related pain in their youth, but they have remarkable leg-length discrepancy which may result in gait disturbance, pelvic tilting, back pain, scoliosis, and pain of the sound side knee. These patients may need earlier treatment than patients with bilateral high dislocation. Leg-length discrepancy is the major reason for gait asymmetry and disturbance [5] which can be improved remarkably with shoe-lift [6] or equalization of leg length with total hip arthroplasty [7]. Patients with bilateral high dislocation do not have remarkable leg-length discrepancy. Back pain, scoliosis, and knee pain are observed less in their youth, although they usually have a typical waddling gait.

Open reduction with capsular arthroplasty, proximal femoral osteotomy, leg-lengthening with or without valgus osteotomy of the femur, and innominate bone osteotomy are salvage procedures with the intention to avoid artificial prosthesis in young patients. The results of these procedures are not always satisfactory, and these procedures may make total hip arthroplasty difficult when it becomes necessary. The earliest reports about THA in CDH patients were disappointing. Charnley even concluded that it is contraindicated to perform THA on CDH patients [8]. However, with increased knowledge of the pathological anatomy, improved surgical skills, improved implant design and material, THA has become an acceptable treatment for adult patients with high dislocation of the hip.

Pathological Anatomy of Crowe IV DDH/CDH

A thorough understanding of the pathological anatomy is the key to performing THA on Crowe IV classified DDH/CDH patients. The true acetabulum of the untreated Crowe type IV dislocation in adulthood is hypoplastic, shallow, small, and lower than the sound side. It is also obstructed by osteophytes, joint capsule, and fat. Inexperienced surgeons find it very difficult to locate the true acetabulum.

In patients with a false joint, the anatomical anomaly of the proximal femur is usually mild, only a slightly more anteversion position than that of a normal head and neck is found. However, in patients without a false joint, the hip is highly dislocated with great leg-length discrepancy in unilateral patients. Overgrowth of the greater trochanter, extreme anteversion of the neck, extra-small head, and straight, small caliber of the proximal femur are commonly found.

The joint capsule is redundant and hypertrophic, and the orientation of the abductor muscle becomes anterior-posterior orientated rather than the usual proximal-distal orientation. The adductors, psoas tendon, iliotibial band, femoral nerve, and sciatic nerve are usually tight and make the distal transfer of the femur difficult and dangerous.

Indication and Patient Selection

Patient's Expectation

Patient's expectation of the surgery must be highly respected. For a Crowe IV patient in the sixth or even seventh decade of life, pain may be the most important concern. Leg-length discrepancy usually is not the major concern. For a patient under 50 years of age, leg-length problems can be a very important concern. The author advises to equalize the leg length within 2 cm for patients under 55 years and less than 1 cm for patients under 30 years of age. Equalization of the leg length improves body symmetry and gait patterns [7]. Total hip arthroplasty is known to effectively reduce pain and improve functionality. However, the reliability of total hip replacement depends on surgery that limits tissue damage and the good fixation of the implant. The patient must be informed that safe and stable total hip surgery is more important than leg-length equalization.

Preoperative Planning of THA for Crowe Type IV Dislocation

Preoperative Image Study

Besides roentgenogram of anterior-posterior and lateral views of the hip, the author advises a long triple film to include bilateral hips, knees, and ankles for evaluation of leg-length inequality. A well-experienced surgeon may not need a three-dimensional computerized tomogram. But it will help the less-experienced surgeons to better understand the anatomical deformity of the bone.

Protocol for Procedure Selection

The author has applied a protocol since 1988 to select patients with Crowe IV high dislocation for preoperative distraction, surgical approaches, and surgical procedures (Fig. 4.5).

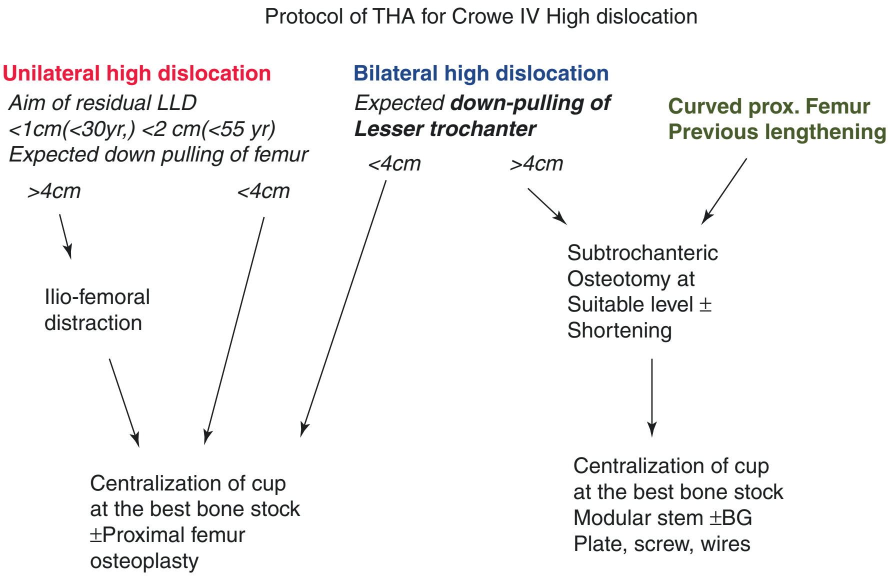

Fig. 4.5 The author's protocol of THA procedure selection for patients with Crowe IV high dislocation

The aim of residual leg-length discrepancy of patients under 30 years of age is less than 1 cm after surgery and less than 2 cm for patients under 55 years of age. If the expected distal transfer of the lower limb exceeds 4 cm for the unilateral Crowe IV high dislocation, iliofemoral distraction is applied to pull down the high dislocation before total hip arthroplasty [9, 10].

Iliofemoral Distraction

The procedure is conducted under spinal or general anesthesia. Two Schanz screws or threaded pins are inserted percutaneously or with minimal exposure into the iliac crest at least 6 cm deep into the bone. The stability of the pin-bone interface is checked. Two Schanz screws or threaded pins are inserted percutaneously into the distal third of the femur through both cortices. A unilateral external fixator-distractor (Wagner or Orthofix external fixator) is assembled for distraction. Gradual distraction for 2.5–3 cm is done in the operation room. The daily distraction of 2 mm divided into four times is instructed from the second day until the planned distraction is achieved. Neurovascular function and stability of the pins should be checked frequently. The distraction is reversed if any neurovascular distress is found. If the pins become loose, the distraction is stopped, the external fixator removed, and THA is carried out as early as possible.

The distraction apparatus is worn for 7–14 days, during which time 4–6 cm of distal transfer of the femur can be achieved if the distraction is successful. The distraction device and pins are removed after anesthesia. The pin tracts are

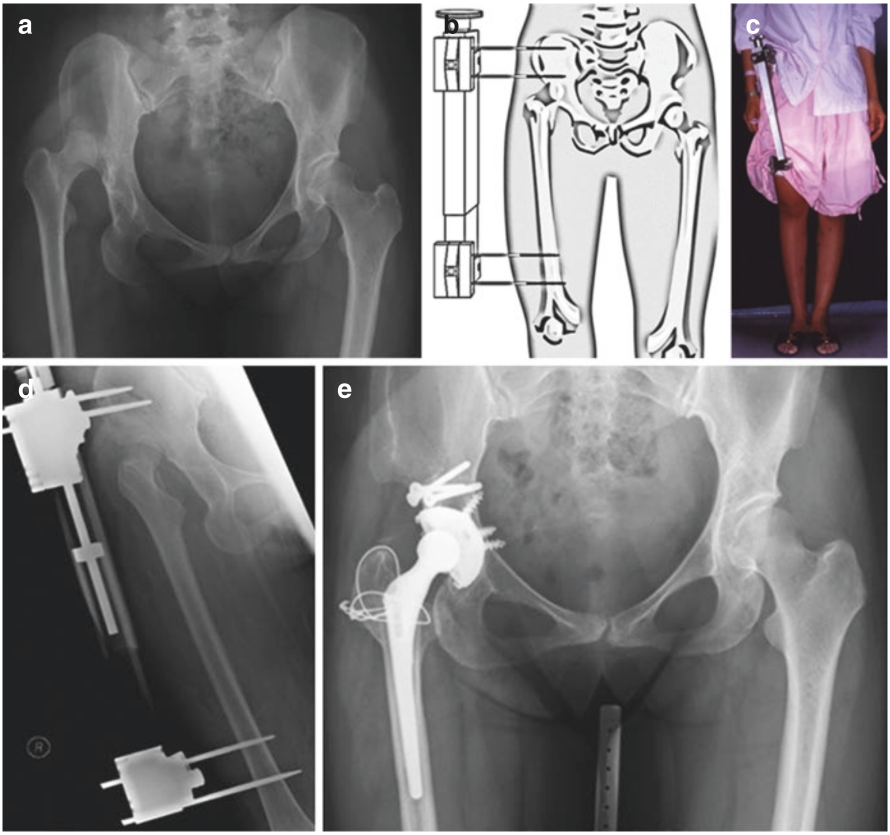

Fig. 4.6 A 28-year-old female patient with Crowe IV high dislocation of the right hip joint (**a**). Illustration (**b**). Drawing to show the assembly of iliofemoral distraction. Pictures (**c** and **d**) showing iliofemoral distraction. Total hip arthroplasty with medialization at the best bone stock and roof augmentation for the cup and osteoplasty for the proximal femur, the symmetry of the lower limbs was achieved (**e**). (**a**, **c**, **d**, and **e** were agreed by the patient for publication. **b** was modified with permission from J Bone Joint Surg Am [10])

irrigated, and an antibiotic solution is injected. The wound is sutured before preparation for THA (Fig. 4.6).

Surgical Approach

An ordinary Hardinge lateral approach, anterior-lateral approach, or posterior-lateral approach can be applied to the patients without much anatomical deformity of the femur, according to the surgeon's preference. The incision wound can be 10–12 cm for a well-experienced surgeon and 15–20 cm in the case of a less-experienced surgeon. The author prefers to approach through the greater trochanteric osteotomy in cases of trochanter overgrowth or obstructed proximal femoral canal. In cases with planned shortening osteotomy, the approach can be an ordinary lateral, posterior lateral, or anterior lateral plus extension to the proximal femur for the subtrochanteric shortening osteotomy. The incision usually needs to be 20–25 cm for an adequate exposure.

The femoral head is removed at the base of the neck for the stem to be prepared at the adequate orientation and avoiding overlengthening of the leg. A less-experienced surgeon may have difficulty finding the true acetabulum. It can be traced through the joint capsule or from the inferior border of the acetabulum. The redundant and hypertrophic joint capsule should be excised as completely as possible for better identification of the hypo-trophic, obstructed true acetabulum and the best bone stock for cup implantation.

The Best Bone Stock of the Acetabulum

The best bone stock should be precisely identified. It is located at the range of the inferior edge of the true acetabulum (the teardrop) as the lower border, 0.5–1 cm above the upper edge of the underdeveloped true acetabulum (the symmetrical level to the upper edge of the sound side acetabulum) as the upper border, and the anterior and posterior walls as the anterior and posterior borders. The center of the "best bone stock" is marked with dye or electrical cautery. The size of the best bone stock is measured. To implant the acetabular cup at the best bone stock to ensure the best possible bone support for the prosthesis symmetrizes the hip centers and avoids overlengthening.

Preparation of the Acetabulum

The osteophytes obstructing the true acetabulum and the best bone stock are removed with a chisel or a high-speed burr. Reaming is started with the smallest sized reamer (36 or 38 mm) and stops before it touches the medial cortex. The next step is to apply a larger reamer with **reverse spin** to impact the cancellous bone and avoid unnecessary penetration of the cortex. The reaming stops with the largest possible reamer without perforation. A metal acetabular cup with the microstructure coating of adequate size is implanted into the prepared acetabulum at the best bone stock with 15–20° of anteversion and 40–50° of inclination. Additional screws can be applied for better anchorage. The excised femoral head can be applied for acetabular roof reinforcement if the coverage of the cup by the bone is less than 70%. The autograft is tailored to an adequate shape and size and fixed with screws. A trial liner is inserted.

There are controversial opinions about cemented or cementless implantation of the cup and structural bone graft for acetabular roof augmentation [11–14]. The author prefers to choose cementless fixation if the cup can be securely fixed with press fit and screws. But for patients with severe osteoporosis and thin cortex, the author never hesitates to cement the cup for a stable fixation, when screws are not able to achieve a secure fixation of the cup. Additional structure bone graft provides better immediate stability of the cup and better conditions for bone on-growth.

Preparation of the Proximal Femur

Normal-Shaped Proximal Femur

Preparation for a normal-shaped proximal femur is similar to that for an ordinary THA. A commonly encountered problem is the difficult reduction of the joint after insertion of the stem and head due to elongation of the leg. Pre-THA iliofemoral distraction effectively reduces this difficulty. However, difficult reduction during surgery is not uncommon. If the distance is less than 1 cm, it can be solved by circumferential protecting wires and deeper insertion of the stem with intentional crack (expansion osteoplasty). A more difficult reduction may need the conversion to shortening osteotomy.

Proximal Femur Osteoplasty

Greater Trochanter Osteotomy

The author prefers to approach the hip joint for patients with overgrowth of the greater trochanter which obstructs the straight and narrow proximal femur canal, with greater trochanter osteotomy. After elevating the obstructing greater trochanter and removing the femoral head at the base of the neck, the proximal femoral canal can be easily identified. As a part of proximal femoral osteoplasty, the greater trochanter is going to be reattached to a distal position for an adequate tension and orientation of the abductor muscles after completion of the prosthesis implantation and reduction. Prolonged protection is not necessary if the greater trochanter osteotomy is well-fixed (Fig. 4.7).

Expansion Osteoplasty

A commercially available normal-shaped regular stem rarely fits a small and straight proximal femur of a highly dislocated Crowe IV hip without a false joint. The surgeon can choose a straight and small-sized stem specially designed for the CDH patients. The author prefers to use a normal-shaped cementless stem for young patients and convert the proximal femur to a nearly normal anatomy because the revision in their later life may be much easier than maintaining a small and straight proximal femur. “Expansion osteoplasty” is the idea of converting a straight and small proximal femur to a normal anatomical shape.

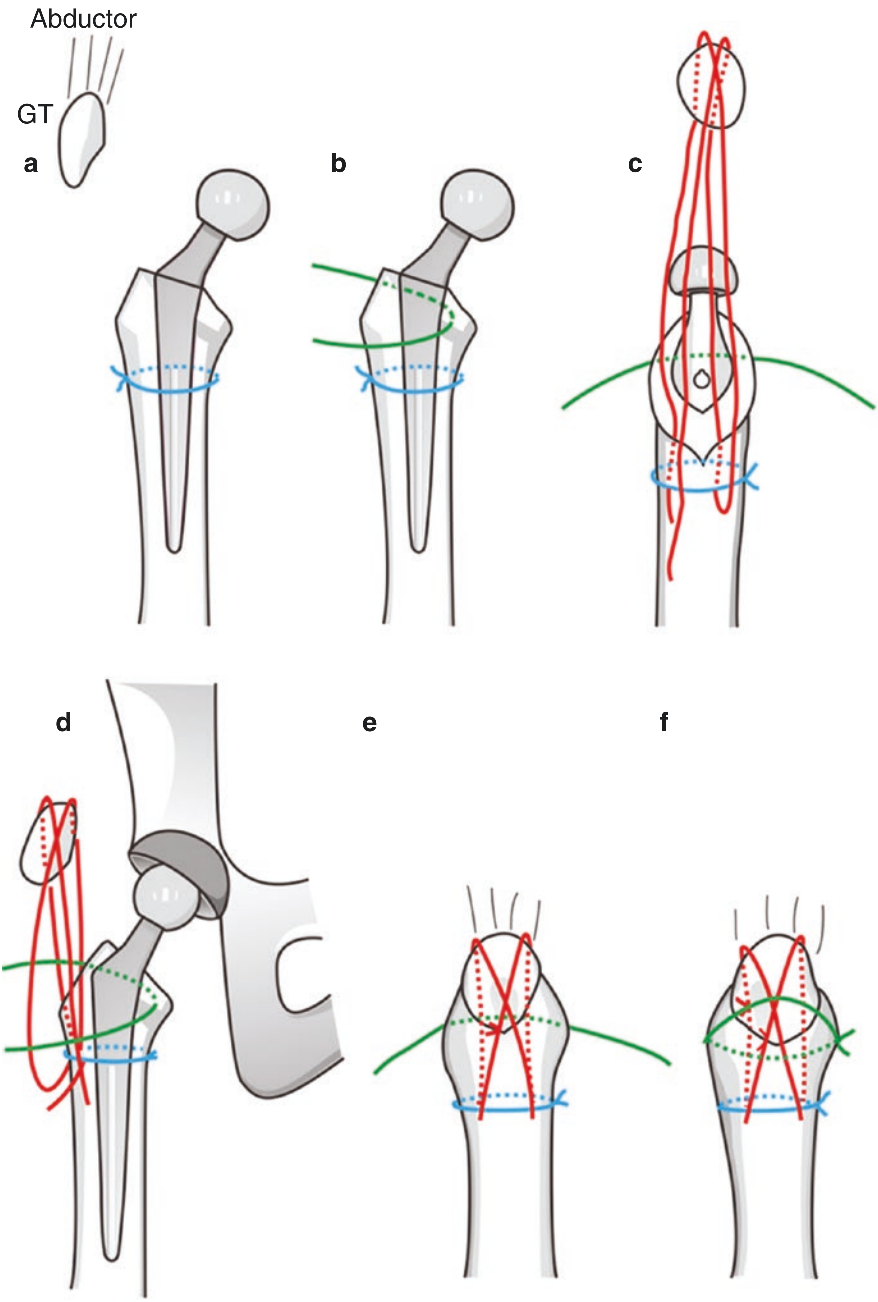

Fig. 4.7 Interlocking wire fixation (figure of 8 plus double loops) for expansion osteoplasty and trochanter osteotomy. A 1.5 mm wire (blue) is passed around the shoulders of the greater and lesser trochanters to prevent progression of the crack for proximal femoral expansion (**a**). The second wire (green) is passed through a hole at the base of the lesser trochanter (**b**). The third wire (red) is passed beneath the first wire and forms a figure of 8 above the greater trochanter (GT) (**c**). The hip is reduced (**d**). The figure of 8 (red) is tightened with the GT in a well-reduced position (**e**). The wire through the base of the lesser trochanter (green) is tightened on the figure of 8 (**f**)

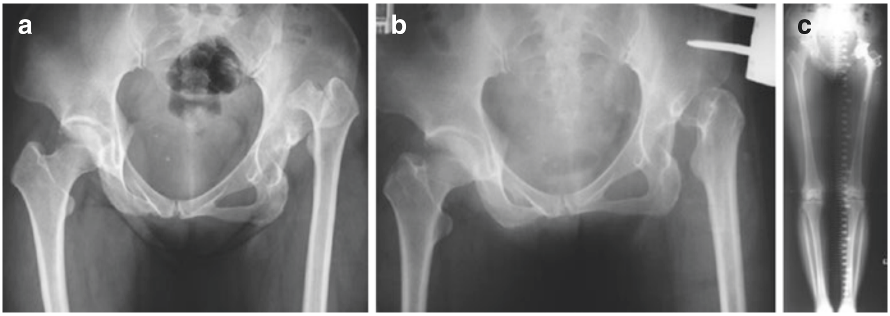

Fig. 4.8 A 28-year-old female patient with Crowe IV high dislocation of the left hip (**a**). Iliofemoral distraction was applied to pull down the femur (**b**). Cementless THA was done with the cup at the best bone stock, roof augmentation, and interlocking wires for fixation of the greater trochanter and expansion osteoplasty of the proximal femur. The triple film showed symmetry of the lower limbs 6 years after surgery (**c**). (These pictures were agreed by the patient for publication)

The remaining calcar obstructing implantation of a regularly shaped stem into correct anteversion is carefully removed with burring. The proximal femur canal is enlarged with reaming and broaching. A 1.5 mm diameter cerclage wire is passed surrounding the shoulders of the greater trochanter and the lesser trochanter if the expected crack is not beyond the level of the lesser trochanter. The wire is tightened. An adequate sized broach is punched carefully until it is completely seated in the canal. A trial head is assembled, and a trial reduction is attempted. A cementless porous-coated femoral stem of the broached size is then inserted after removal of the broach. The crack is filled with autogenous cancellous bone from reaming of the acetabulum. If the expected crack is beyond the lesser trochanter, a double loop cerclage wire is passed through the first loop around the shoulder of the greater trochanter to the upper edge of the lesser trochanter and the second loop around the shoulder of the greater trochanter and the lower edge of the lesser trochanter. One or two longitudinal split of the proximal femur may be necessary to guide the crack into an expected direction without an unexpected explosion of the proximal femur. The cracks are filled with autogenous cancellous bone after implantation of the stem.

Interlocking wire tightening of the greater trochanter osteotomy and expansion osteoplasty (figure of 8 plus double loops) provides a stable and strong fixation for the crack and osteotomy (Figs. 4.6, 4.7, and 4.8).

Trial Reduction

A trial head is assembled to the stem, and reduction of the hip is tried. Stability of the hip in extension external rotation and adduction, flexion internal rotation is tested. The stability can be adjusted with the direction of the liner.

The assembly of the polyethylene liner in the adequate position, femoral head, and reduction are done after the trial.

Reattachment of the Greater Trochanter

Reattachment of the greater trochanter to a distal position reshaped the proximal femur toward the normal anatomy which provides better abductor function and improves the gait. But the reattached greater trochanter has to face a stronger tension force than before surgery and needs a strong and stable fixation. Wires, cables, and trochanter hook can be applied for fixation of the greater trochanter. The author applied 1.5 mm cerclage wires with the "**figure of 8 plus double loops**" interlocking technique for the fixation of the greater trochanter (Figs. 4.6, 4.7, and 4.8).

Shortening-Derotation Osteotomy

Recent literatures have popularized shortening-derotation osteotomy for THA in patients with high dislocation. The readers are referred to the relevant reports about the technical details of shortening osteotomy [15–17].

The author applies subtrochanteric shortening osteotomy for patients with a high dislocation and expected distal transfer of the lesser trochanter of femur over 4 cm in bilateral patients, unilateral patients aged 55 or more, and patients with curved proximal femur or previous lengthening.

The incision usually is 20–25 cm. The femoral head is excised leaving 1–2 cm of calcar. The proximal femoral canal is reamed and broached for the sleeve of the modular stem or a regular stem. Osteotomy of the femur is done at the subtrochanteric level or at the site of angulation. The true acetabulum and the best bone stock are identified. The acetabulum is prepared by applying the abovementioned method. A trial head-neck is assembled to the proximal segment, and the hip is reduced. The distal part of the femur is measured, and an adequate length is shortened for possible reduction of the hip with adequate tension. The trial stem is then inserted through the proximal and distal segments with the head and neck in correct anteversion. A trial head is assembled, and the hip is reduced, and the stability is checked. Final prosthesis is assembled after the trial. The excised segment can be applied for bone graft to add bone mass in case of a small-caliber femur (Fig. 4.9).

A miniature modular system (S-ROM) is advised for shortening-derotation osteotomy of the femur. In cases where a modular stem is not available or applicable, a long stem, combination of plate-screw or intramedullary nail may be useful to maintain the stability of the osteotomy (Fig. 4.10).

Shortening osteotomy allows an easier reduction of the hip and may reduce the risk of nerve palsy, but surgeons should be aware of the possible consequences of

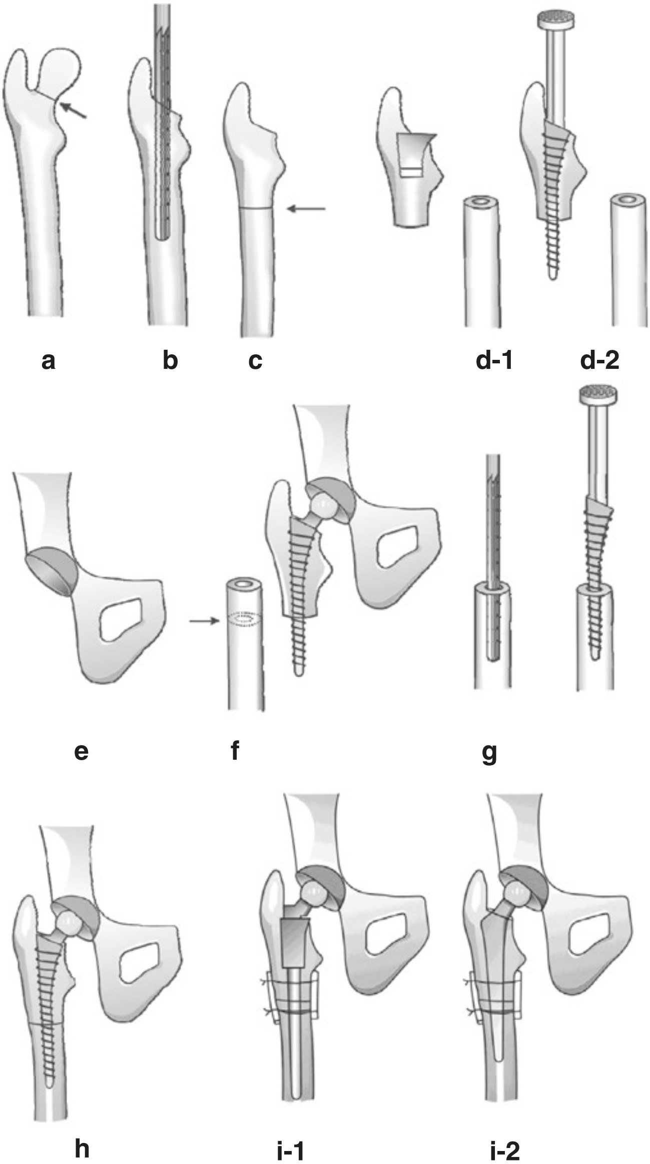

Fig. 4.9 Subtrochanteric shortening-derotation osteotomy. The femoral head is cut at the level leaving 1–2 cm of calcar (**a**). The femoral canal is reamed until the angulation site or the narrowest site is reached (**b**). Osteotomy is done at the angulation or 2–3 cm below the lesser trochanter (**c**). If the S-ROM system is chosen, the proximal femur is prepared, and the trial sleeve of the stem is inserted (**d-1**). If an ordinary stem is chosen, the proximal femur is broached (**d-2**). The acetabulum is exposed and prepared, and the acetabular cup is inserted (**e**). A trial reduction is made with the broach or a trial modular stem. The adequate shortening length is measured and cut (**f**). The distal femur is further prepared for the distal part of the stem (**g**). Trial reduction of the osteotomy and joint is made (**h**). The total hip prosthesis is assembled, and the joint is reduced. The autogenous cortical bone can be applied for augmentation of the bone mass and stability (**i-1** and **i-2**). Plate, screws, and wires can be added to achieve favorable stability

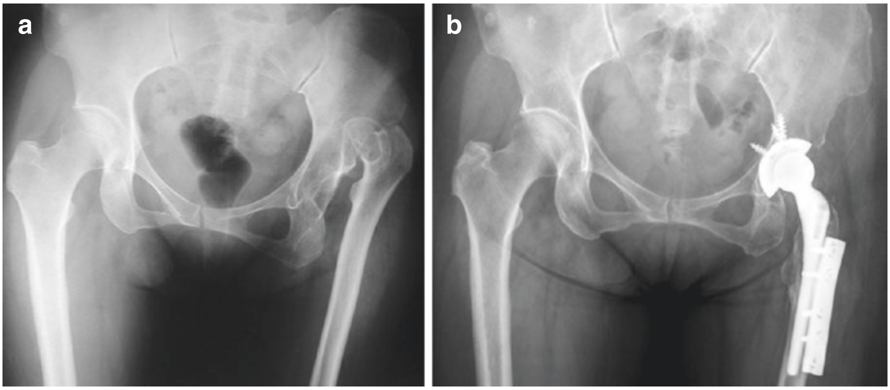

Fig. 4.10 A 41-year-old female patient with high dislocation of the left hip. A slight curvature was noted at the proximal femur (**a**). Fifteen years after cementless THA with subtrochanteric shortening osteotomy and plate augmentation (**b**). (These pictures were agreed by the patient for publication)

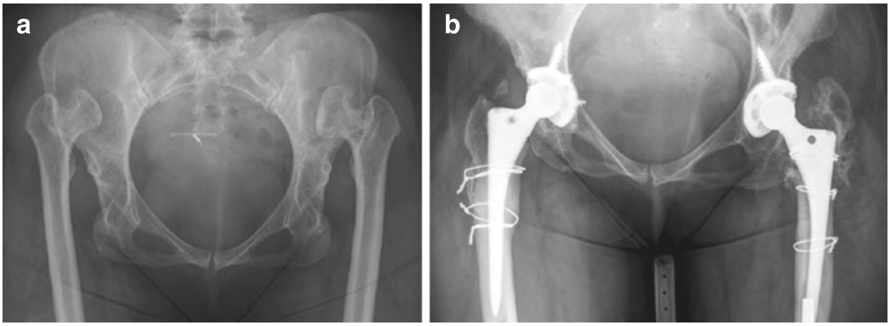

Fig. 4.11 A 48-year-old female patient with high dislocation of bilateral hips (**a**). Three years after bilateral cementless THA with shortening osteotomy and autogenous cortical bone reinforcement at the osteotomy site, although the right side healed well, poor healing at the osteotomy site of the left femur was observed (**b**). (These pictures were agreed by the patient for publication)

residual leg-length inequality in unilateral patients, problems with healing at the osteotomy site and fracture of the stem [11–14] (Figs. 4.11 and 4.12).

Postoperative Care

A patient with Crowe IV high dislocation after THA may have more pain and discomfort than an ordinary THA patient due to more tissue dissection and elongation of the leg. Besides pain management, flexion of the hip and knee and muscle relaxant can palliate the discomfort with leg elongation.

Early motion and muscle exercise are encouraged. For the surgery without reinforcement bone graft and expansion osteoplasty, the patient is advised to walk with

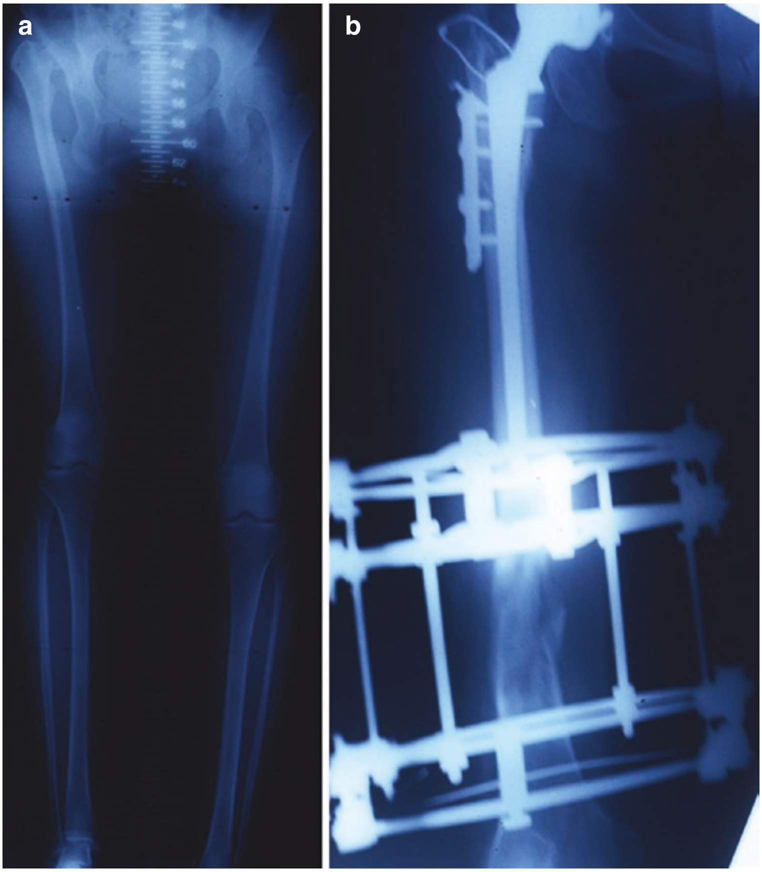

Fig. 4.12 A 27-year-old female patient with high dislocation of the right hip (**a**). Total hip arthroplasty was done with subtrochanteric shortening osteotomy. Leg-length discrepancy of 6 cm was treated with callus distraction using a ring-type external fixator (**b**). (These pictures were agreed by the patient for publication)

a walker or crutches for 6 weeks. The protection should be longer if bone graft, shortening osteotomy, or expansion osteoplasty was done.

Full weight bearing is encouraged after the period of protection. A rehabilitation program is instructed for muscle strengthening and symmetrical gait.

Complications, Prevention, and Management

Total hip arthroplasty for patients with Crowe IV high dislocation is a complicated and difficult surgery with more potential complications than an ordinary THA. Complications usually stem from the difficulty of surgery itself and the difficulty for a surgeon to accumulate enough experience to manage the problems successfully with this complicated surgery. Besides common complications with an ordinary THA, the following problems are more often experienced in THA for patients with the high dislocation.

Nerve Injury

Nerve palsy may be associated with the distal transfer of the femur. Elongation of the leg by more than 4 cm was reported to have a higher rate of nerve complications [18]. But nerve injuries are possibly more related to the difficulty of exposure and retraction [19]. Full understanding of the position of the nerves and blood vessels is of extreme importance to prevent direct injury by the retractors or dissection. Overlengthening should be avoided. The meticulous preoperative planning of an iliofemoral distraction or a planned shortening osteotomy may decrease the difficulty of surgery and reduce nerve injuries.

Early detection of nerve injury is very important. Nerve palsy can be detected with evoked potential monitoring during surgery but usually can only be confirmed after recovery from anesthesia. The surgeon has to check the nerve function in the recovery room as soon as the patient recovers from anesthesia. Recovery from an isolated peroneal branch palsy is usually good and can be managed with flexion of the hip and knee to reduce the tension of the nerve. In cases of femoral nerve or sciatic nerve palsy, the immediate return to the operation room is important for neurolysis or the further shortening of the femur, which may release the pressure to the nerve.

Dislocation

Although there was no dislocation of THA for Crowe IV high dislocation in the author's experience with artificial femoral heads larger than 22 mm in diameter, THAs for high dislocation were known to have higher incidences of dislocation than that of an ordinary THA [20, 21]. Besides a small head as the potential risk of dislocation, malposition of the cup or the stem, over-shortening, and soft tissue damage (especially the abductor) may predispose to dislocation.

Implantation of the acetabular cup at the best bone stock can accommodate a larger cup than at the underdeveloped small true acetabulum and makes it possible to implant a larger femoral head with a better bearing material. Preoperative three-dimensional computerized tomogram provides a better understanding of the best bone stock and orientation of the acetabulum. However, intraoperative identification of the best bone stock and orientation is more important for the preparation of the acetabulum at the correct position and orientation.

The orientation of the stem can be checked by using the patella and lesser trochanter. The orientation of the lesser trochanter in a high dislocated DDH has less retroversion than a normal subject. To place the femoral stem with the posterior margin of the stem at the same orientation as the anterior margin of the lesser trochanter usually is the correct orientation for the stem. A trial reduction is very important to prevent dislocation. Any factor that makes a trial reduction difficult or unstable has to be corrected. A brace to limit the hip adduction and flexion can be applied after surgery to prevent dislocation if the stability is questioned.

Dislocation after surgery is treated with close reduction under anesthesia as the first attempt. Irreducibility or instability has to be treated with revision.

Residual Leg-Length Discrepancy

Leg-length equalization with THA for Crowe IV high dislocation may be compromised by the difficulty of surgery, the distance of distal transfer, and shortening of the femur. Application of iliofemoral distraction before THA for anticipated elongation of more than 4 cm enables an easier and less complicated elongation of the leg [9, 10].

Residual leg-length inequality can be treated with shoe-lift as the first attempt.

Leg-length equalization surgery may be indicated for a young patient with a residual leg length of more than 4 cm. The author prefers the callus distraction procedure using a ring-type or unilateral external fixator to elongate the femur (Fig. 4.12).

Infection

There was no infection in the author's experience of more than 300 THAs for Crowe IV high dislocations. However, THA for high dislocation was reported to have more infections than an ordinary THA. The higher incidence of infection may be due to prolonged surgery [22]. To decrease the difficulty of the surgery reduces surgical time and reduces the chance of infection. The author advises to limit the surgical time to within 90 min.

Total Hip for Patients with Previous Osteotomy

Previous Pelvic Osteotomy

A well-conducted pelvic osteotomy for DDH/CDH patient in infancy or childhood can provide stable reduction of the hip and prevents early degeneration. Total hip arthroplasty for these patients in their later life are usually without difficulty. However, pelvic osteotomy might not always be optimally carried out, and arthritis may develop early with instability of the hip. The author prefers to reconstruct the acetabular cup at the symmetric level to the sound side with centralization at the best bone stock. The excised femoral head is applied for roof augmentation if necessary (Fig. 13).

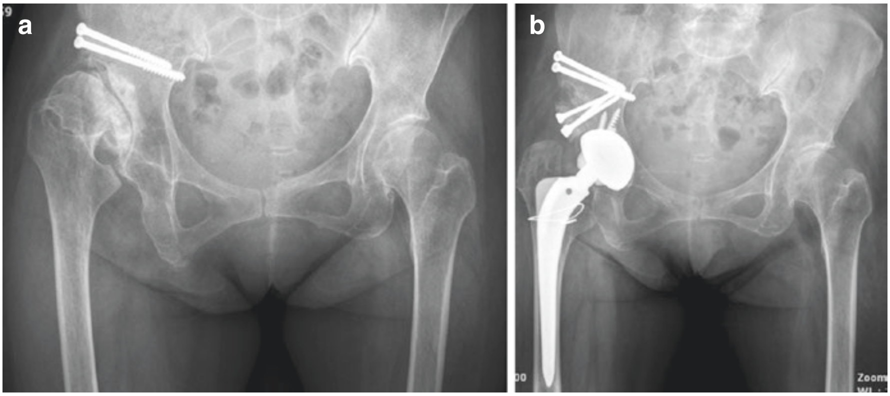

Fig. 4.13 A 52-year-old female patient with high dislocation of the right hip treated with pelvic osteotomy in her youth, arthritis developed at the false joint (**a**). One year after cementless THA using ceramic on ceramic bearing. The cup was implanted at the best bone stock with autogenous bone graft augmentation (**b**). (These pictures were agreed by the patient for publication)

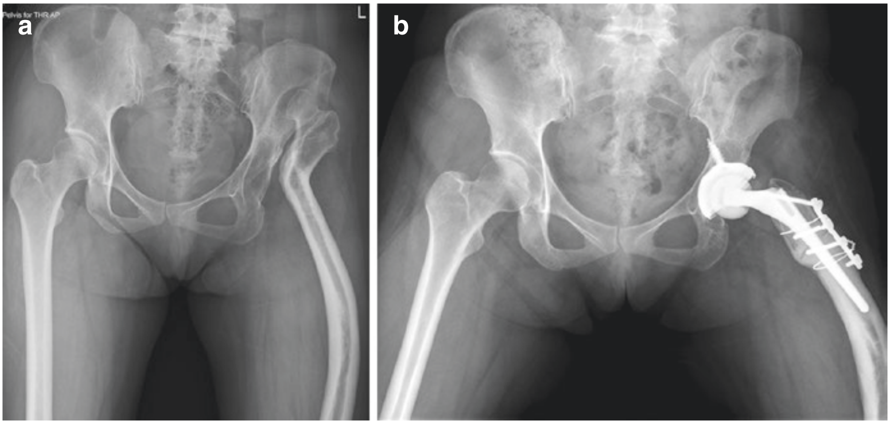

Fig. 4.14 A 29-year-old female patient with high dislocation of the left hip was treated with valgus osteotomy and lengthening of the femur (**a**). One year after cementless THA using highly cross-linked polyethylene liner and ceramic head with shortening osteotomy at the angulation reinforced with autogenous bone graft and plate-screws (**b**). (These pictures were agreed by the patient for publication)

Previous Femoral Osteotomy or Lengthening

If a previous femoral osteotomy does not change much of the anatomy of the proximal femur, preparation of the proximal femur is not complicated. However, in cases where varus or valgus osteotomy has changed the anatomy greatly, it makes it difficult to insert a femoral stem. In cases with a previous lengthening procedure, either the femur or tibia, the leg length may be overlengthened after total hip arthroplasty without a shortening osteotomy. These conditions need to be considered individually (Figs. 4.14 and 4.15).

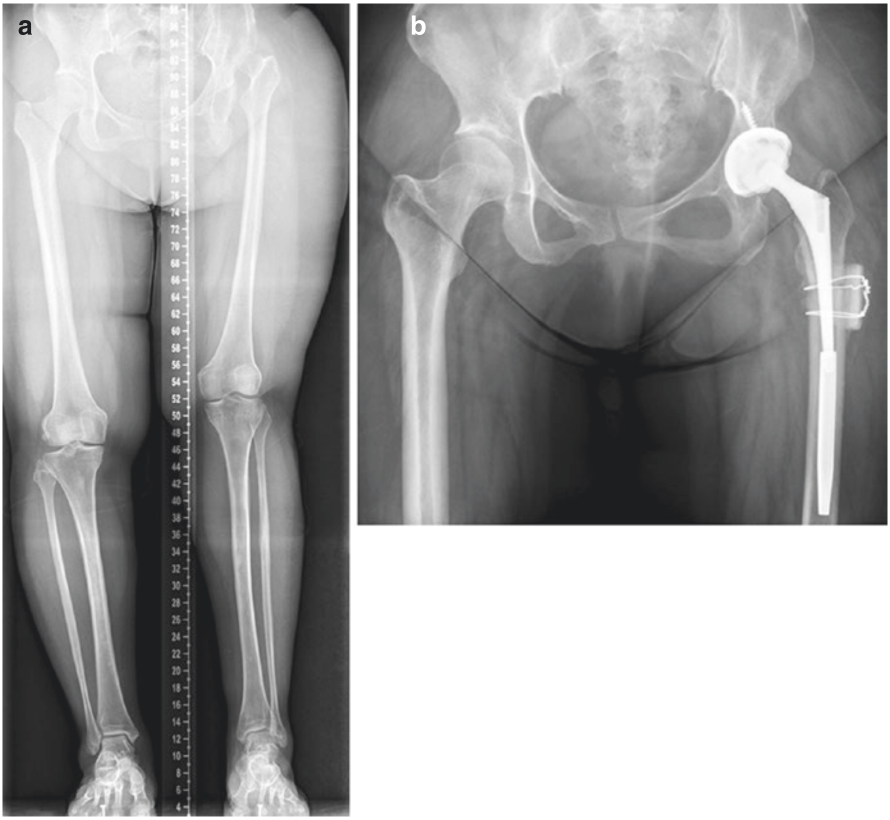

Fig. 4.15 A 26-year-old female patient with high dislocation of the left hip was treated with tibial lengthening before (**a**). One year after cementless THA using highly cross-linked polyethylene liner and ceramic head through shortening osteotomy of the femur, a nail and autogenous cortical bone graft was added for augmentation (**b**). (These pictures were agreed by the patient for publication)

The Author's Experience of THA for Crowe IV High Dislocation

The author has conducted more than 300 total hip arthroplasties for adult patients with Crowe IV high dislocation from 1984 to 2016. A protocol for selecting the patients was applied since 1988 (Fig. 4.5). The selecting criteria and procedure changed little since 1988. However, the prosthesis selection has changed due to the improvements of prosthesis design and bearing material.

During the period from 1988 to 1996, a total of 74 total hip arthroplasties were performed on 68 patients with Crowe IV high dislocation (6 bilateral). The prosthesis used were cementless Osteonics cup—11 dual geometry micro-structured, 19 Omnifit PSL hydroxyapatite (HA) coated, 37 Omnifit

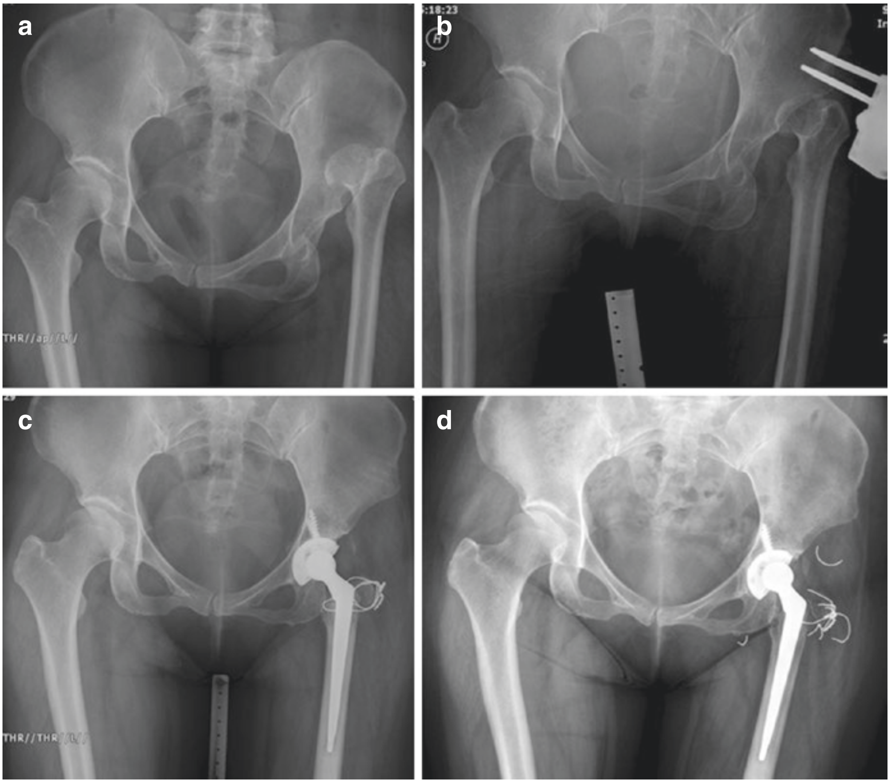

Fig. 4.16 A 48-year-old female patient with high dislocation of the left hip (**a**). Iliofemoral distraction was applied before THA (**b**). One year after THA with titanium mesh-coated cup, cemented straight stem and 22 mm head (**c**). At the age of 59, the THA still functions well, although broken wire and wearing of the liner is observed (**d**). (These pictures were agreed by the patient for publication).

microstructured, and 7 Securfit HA coated. The stems were 43 porous coated and 31 HA coated. The heads used were 26 mm Co-Cr metal heads. And the liners were conventional polyethylene. The overall survival of the cup after 12 years was on average 77%, 64% for the HA-coated smooth-surfaced Omnifit PSL cup, and 87% for other cups with microstructured coating. The survival of the stem was 100% [10].

After 1996, the author ceased using the HA-coated smooth-surfaced Omnifit PSL cup. Titanium mesh-coated cup (Zimmer, Versys) and cemented straight stem (Zimmer) were applied for patients over 45 years of age. A 22 mm head was applied for a cup smaller than 44 mm (Fig. 4.16).

During the period from 1997 to 2004, 94 total hip arthroplasties were done on 86 patients with Crowe IV high dislocation (8 bilateral). Fifty-nine of them were with porous-coated cups and stems and 35 with titanium mesh cups and cemented stems.

There were no aseptic loosening of the cups and stems after an average of 10 years of observation. However, four patients had wearing of the polyethylene liner and needed revision. Dislocation occurred in four patients with 22 mm heads, and they were successfully treated with close reduction and protection. Periprosthetic femoral fracture occurred in three patients, and they were treated with open reduction and fixation without prosthesis exchange.

Osteonics Trident cup (plasma-sprayed titanium and HA), highly cross-linked polyethylene liner, ceramic head, and liner were introduced after 2005. A total of 147 THAs were done for Crowe IV high dislocations (11 bilateral) from 2005 to 2016 with an expectation for a better long-term survival of the prosthesis (Figs. 13, 4.14, and 4.15).

Revision and Other Surgeries After THA for Patients with Crowe IV High Dislocation

During the period of 1988–2016, 34 revision or additional surgeries were done for THA in Crowe IV high dislocation patients by the author. These included 24 for cup wearing or loosening, 2 for stem loosening, 3 periprosthetic femoral fractures and 3 femoral lengthenings for leg-length discrepancy, and 2 for poor healing at the subtrochanteric osteotomy site.

Cup Revision

The author applied cups with HA-coated smooth-surfaced metal shells and conventional polyethylene liners [9] in his early practice. These materials were known to be associated with an earlier loosening and wearing. Besides cups of this design leading to early failure, revision of the cup of THA for Crowe IV high dislocation as a result of wearing and loosening was more common than an ordinary THA due to a smaller cup and thinner polyethylene liner [23, 24] (Fig. 4.17). The details and techniques of cup revision for DDH/CDH patients will be discussed in the following chapters.

Stem Revision

The majority of the proximal femora were reshaped to a near-normal structure in the author's practice. It was deemed that revision would be much easier when it becomes necessary (Fig. 4.18). Revision of a loose stem with a compromised anatomy or excessive bone loss may need a well-planned osteoplasty of the proximal femur, bone graft, and stems for these special conditions.

Leg-Length Discrepancy

For a patient with a remarkable leg-length discrepancy after THA (commonly with shortening osteotomy), a lengthening procedure may be required. Callotasis with either a ring-type external fixator or a unilateral external fixator can be applied for

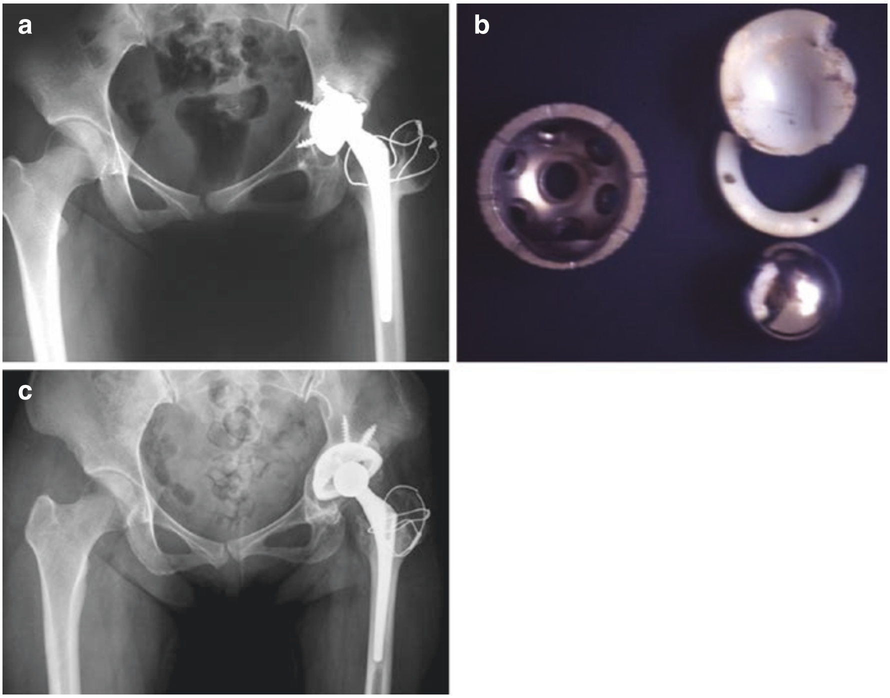

Fig. 4.17 A 31-year-old female patient. Left THA with a HA-coated smooth-surfaced cup was done 8 years ago for high dislocation of the hip. Wearing and loosening of the cup was noted (**a**). The retrieved cup showed wearing of the liner and metal shell (**b**). Eight years after cup revision with a larger cup and allogenic bone graft (**c**). (These pictures were agreed by the patient for publication)

lengthening of the femur if the components are well-fixed (Fig. 4.11). Leg-length problems with the loosening of a component or components at a compromised position will be discussed in the following chapter.

Poor Healing of the Osteotomy Site

Wire breakage and poor healing of the greater trochanter osteotomy may weaken the strength of the abductors but rarely need a revision (Fig. 4.16). Poor healing at the subtrochanteric osteotomy may need revision of the fixation and bone graft or revision of the stem if it becomes loose.

Periprosthetic Fracture

The caliber of the proximal femur of a patient with high dislocation is usually much smaller than that of a normal subject and may be more prone to a periprosthetic fracture (Fig. 4.19). Treatment according to the Vancouver classification [25, 26] is advised.

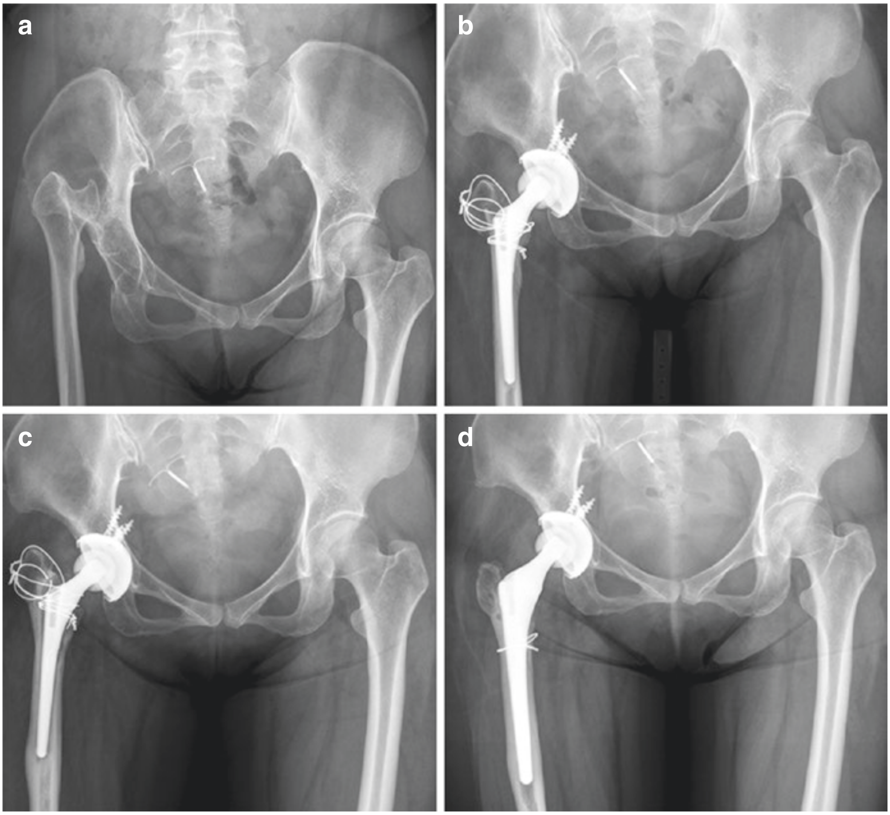

Fig. 4.18 A 41-year-old female patient with high dislocation of the right hip (**a**). Cementless THA was performed with a Trident cup, highly cross-linked liner and ceramic head through greater trochanter osteotomy and expansion osteoplasty (**b**). The stem became loose after 5 years (**c**). Revision of the stem was done with a bigger stem (**d**). (These pictures were agreed by the patient for publication)

Summary

Total hip arthroplasties for arthritic Crowe I, II, and III, or Hartofilakidis dysplasia and low dislocation are not much different from an ordinary THA. They are not difficult surgeries for an experienced surgeon. THA for patients with Crowe IV or Hartofilakidis high dislocation is a challenging surgery even for a surgeon well-experienced in hip reconstruction. The patient's expectation should be highly respected. A meticulous preoperative study is necessary for better understanding of the pathological anatomy, and the surgical plan has to be well discussed with the patient. Selection of surgical procedure is according to the surgeon's preference and dexterity. The surgeon is advised to prepare the facilities as complete as possible because unexpected events during surgery may need a shift from the original plan.

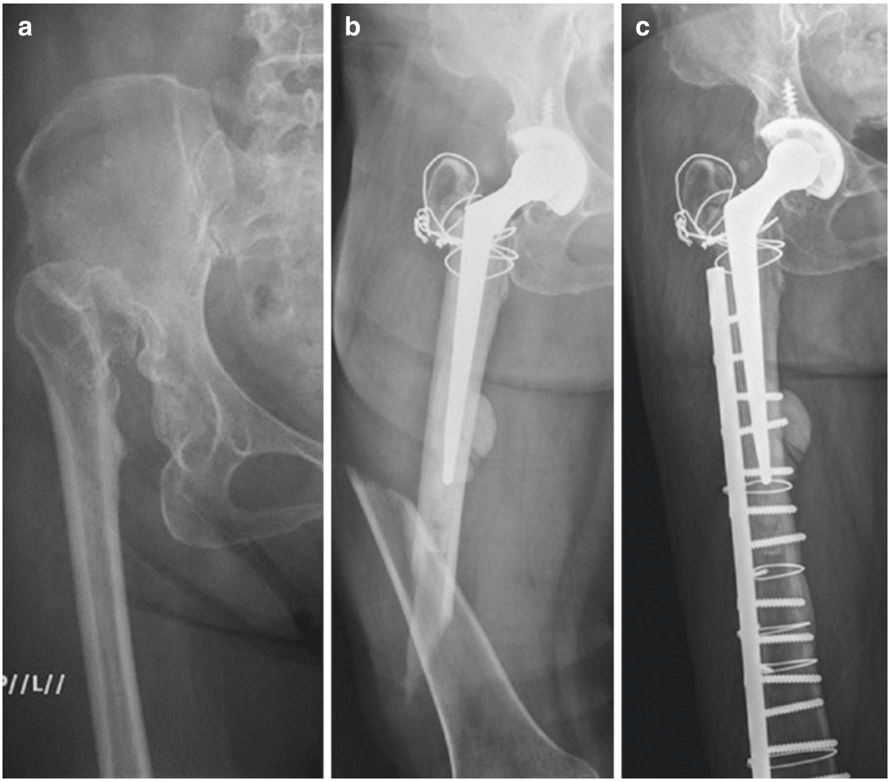

Fig. 4.19 A 62-year-old woman with Crowe IV high dislocation of the right hip (**a**). Periprosthetic femoral fracture (Vancouver type C) occurred 7 years after THA (**b**). The fracture was treated with a plate, screws, and wires (**c**). (These pictures were agreed by the patient for publication)

The surgeon is also advised to master all the skills needed for management of bone defects at the acetabulum, trochanter osteotomy, femoral crack, expansion osteoplasty, and shortening osteotomy.

Pre-THA **iliofemoral distraction** gradually distracts the soft tissue and nerves that make THA safer and easier, prevent more complicated procedures, over-shortening of the femur, reduce surgical time and complications. Stability of pin insertion, especially the iliac pins, and pin tract care are important for this procedure to be safe and effective.

The author advises to implant the acetabular cup at the **best bone stock** because the best bone stock provides the best possible anchorage for the cup. A larger cup can be applied than in the underdeveloped small and shallow true acetabulum. A larger head and better bearing material are more likely applied. To place the cup at the best bone stock also symmetrize the joint centers with the sound side avoids overlengthening and shortening osteotomy of the femur.

Although the author advises to equalize the leg lengths within 1 cm for patients under 30 years and within 2 cm for patients under 55 years of age, it is not always possible. The surgeon should try his best to achieve leg-length equalization for young patients. The patient should also be informed that a safe and stable THA is more important than equalization of the leg length.

Complications are expected to be more common than an ordinary THA. Prevention of these complications is important. The surgeon needs alertness and skill to avoid these complications. The treatments of these complications are usually more painful and difficult than avoiding them.

A well-conducted THA for Crowe IV high dislocation can have a similar middle-term clinical performance like an ordinary THA. However, the long-term results may be compromised by the young age of the patients, small-sized cups, and thin conventional polyethylene liners [23].

The newly available **alternative bearings** such as highly cross-linked polyethylene liner, ceramic, and metal-on-metal articulation may provide better long-term survival for the total hip. The possible disadvantages of these materials such as squeak, breakage, and metal ion problems should be evaluated.

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Outcome of Total Hip Arthroplasty in Patients with Dysplasia/Dislocation and Planning for Revision

5

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Abstract

The reported outcomes of total hip arthroplasty (THA) for developmental dysplasia of the hip (DDH) varied widely because a wide range of deformities were included and different treating protocols and different materials were applied. The most common complications were dislocation, infection, and nerve palsy. The middle-term results are similar to ordinary THAs. But long-term results are compromised by young age of the patients, small cups, and conventional polyethylene insert. To reconstruct the acetabular cup at or near the anatomic level without lateral placement is better than a high center and lateral placement. Application of ceramic head, liner, and highly cross-linked polyethylene insert may improve the complications caused by wearing. Loosening and component wearing are the most common reasons for revision. A comprehensive planning is advised to face the problems of the cup, the stem, and the leg length discrepancy at revision.

Keywords

Developmental dysplasia of the hip · Total hip arthroplasty · Outcome · Complications · Revision

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Total hip arthroplasty (THA) is widely accepted for treating end-stage arthropathy secondary to developmental dysplasia and dislocation of the hip (DDH/CDH). However, **DDH** is a complex disorder and contains a wide range of severity of anatomical anomalies. Implant materials and designs of hip arthroplasty are also changing. It is not surprising to see a wide range of results reported for THAs in DDH/CDH patients. Most of the recent reports for THA in DDH/CDH patients showed a high percentage of pain-free [1] and good to excellent outcomes [2]. But patients with DDH/CDH receiving THA are relatively younger, and the components are smaller than other THA patients and had a higher chance of component wear and loosening. The failure rate of the acetabulum component could be as high as 46% at a mean follow-up period of 12 years [3, 4]. The overall complication rate is also higher than that of other patients with osteoarthritis, and this difference cannot be accounted for only by the younger age of the dysplastic patients [1, 5, 6].

Complications

Dislocation, nerve palsy, and infection are the most common complications.

Dislocation

A high rate of dislocation has been reported following THA for dysplasia in the early series [6–8]. Mallory et al. reported more dislocations in total hip arthroplasty for dysplastic hips when compared with other etiology [9], and up to 11% dislocation had been reported by Ito et al. [10]. It is thought that the risk of dislocation may result from trochanteric nonunion or the impingement of the femoral component on the anterior acetabulum column with the hip in flexion and internal rotation [11]. The dislocation rate has decreased, and an acceptable rate (0–4%) in recent long-term follow-up series [12–17] has been reported. In dysplastic hips with high dislocation (Crowe type IV or Hartofilakidis type C) following THA with femur osteotomy, the reported dislocation rate varies from 1.3% to 13.3% [18–24]. The size of the femoral head component may also influence the risk of dislocation. One of our authors (KAL) noted dislocations only with 22 mm femoral heads in his experience, while no dislocations occurred with head sizes of 26 mm or larger (see Chap. 4).

Nerve Palsy or Injury

The majority of nerve palsy or injury is to the sciatic nerve. The rate of sciatic nerve palsy following THA for dysplastic hips has been reported higher by ten times or more when compared with non-dysplastic hips [7, 8, 25]. The reported rates of sciatic nerve palsy were from 1.7% to 4.1% in long-term follow-up series [12, 14, 17] for DDH and from 2.6% to 14.2% for highly dislocated hips [19, 26–29]. The range of safe limb lengthening is suggested to be 2 cm by Garvin et al. [5], and the risk of sciatic nerve palsy would greatly increase with lengthening of more than 4 cm [30]. Injury or palsy of other nerves, including the femoral nerve [14, 18] and gluteal nerve [18], has also been reported.

Infection

Due to the difficulty of the surgery associated with longer operation time, larger incision, more extensive dissection and more complicated reconstructive procedures [11], a higher infection rate, ranging from 2.6% to 6.7%, is reported for dysplastic hips when compared with other osteoarthritic hips receiving THA [8, 31, 32].

Longevity

Due to young age and small acetabular size, the major concern of THA longevity in dysplastic hips is wearing and cup loosening [14]. Higher failure rates compared with those of other osteoarthritis were reported [1, 33]. Charnley and Feagin, in 1973, advised that THA was contraindicated for patients with untreated congenital dislocation of the hip because of lack of bone stock necessary for acetabular reconstruction [34]. High rates of aseptic cup loosening, ranging from 24% to 53%, have also been reported in this patient population in midterm and long-term follow-up [5, 31, 35]. Surgical techniques, including cotyloplasty (impaction graft) [14], cemented acetabulum component [12, 17], bone cement augmentation [8], and structural bone graft [13, 15, 19], were evolved to improve the cup fixation and long-term outcomes. With the placement of the cup at the level of the true acetabulum and reconstruction of the acetabular defect with autologous femoral head, the long-term results were acceptable. Survival was from 88% to 100% with press-fit cup at about 10 years [13, 18, 36, 37] and from 56% to 93% with cemented [12, 14] or cementless [15, 17] technique at more than 20 years.

The aseptic loosening rate of femoral component at a mean of 10-year follow-up is also variable and was reported as 0 in 48 hips [37] with cementless regular-shaped stems; 0 in 25 hips [21], 1.32% in 76 hips [19], and 10.7% in 28 hips [22] with transverse femoral shortening osteotomy; and 8% in 68 hips [18] with the shortening technique described by Paavilainen [38].

Influence of Severity of Dysplasia/Dislocation

A highly dislocated dysplastic hip (Crowe type IV or Hartofilakidis C) is a surgical challenge for hip arthroplasty due to the severe acetabulum deficiency and limb-length discrepancy. The possible complications of THA for highly dislocated hip include early dislocation, early cup loosening, intra-operation femoral fracture, nonunion of osteotomy site, and sciatic nerve palsy [11]. Chougle et al. reported a higher failure rate of the acetabular component with increasing severity of hip dysplasia using the cemented technique [39] at 20 years. Survivor of the cup was 76.4% in Hartofilakidis type A, 57.1% in type B, and 12.2% in type C patients. But in contrast, Karachalios et al. reported better survival rates of THA for high dislocated hips than low dislocated hips at 15 years after surgery [14].

High Hip Center or Anatomical Hip Center

Placing the acetabular cup near the anatomical level is the most common method applied for DDH. However, for Hartofilakidis type B and type C DDHs, this method is technique-demanding. Morsi et al. reported a 90% (27/30) success at an average of 8.1 years. All the structured autografts at the shelf are united to the host bone. Resorption of autograft with either cemented or uncemented cups was minor and restricted to the lateral non-weight bearing part of the graft [40]. However, in a longer follow-up of 14 years by the same group, survival of the acetabular component decreased to 78%. More parts of the bone grafts were resorbed. Seven hips showed resorption of more than one-third of their grafts. Six of them showed resorption of between one-third and one-half of the graft. But only one hip required a new graft at revision surgery [41]. With the structured autograft augmentation of the roof, Harris and his group reported good midterm results, but the rate of failure increased after a mean follow-up of 11.8 years, and the graft was progressively resorbed [3, 4, 7]. Bobak et al. reported their experience with a shelf graft of the femoral head for THA in 41 patients with DDH. All grafts had united at a mean follow-up of 11 years, and no revisions were needed [42]. Hasegawa et al. showed, in a series of 25 patients, the grafted femoral head had incorporated 7 months after surgery and had remodeled completely by 18 months, although the grafted bone had reduced in size significantly [43].

On the other hand, due to a high failure rate of structured autologous bone grafts of up to 46% in 12 years, Russotti et al. reconstructed the acetabular component at a high hip center. They reported an 11-year follow-up with proximal placement of the cup in 37 patients, and 31 hips (84%) were rated as having a good or excellent result. Only six cups (16%) were loose [44]. They concluded that proximal positioning of the acetabular component without lateral displacement can have an acceptable result with a cemented THA. The advantages of a high hip center include good host bone contact with acetabular component and no need for structured bone graft. However, Callaghan et al. reported that as high as 41% of acetabular loosening was attributed to a high placement of the cup in 146 revision hip surgeries [45]. Later, high hip center, even without lateral displacement, had been reported to lead to increased rates of components loosening [46, 47]. Morag et al. [48]reported that the height of the cup is significantly correlated with functional outcome and high hip center correlated with a worse outcome score. Patients with a hip center of less than 3.5 cm above the anatomical level had a better survivorship than those with centers higher than this (86% vs. 64% at 15 years). Furthermore, a high hip centered cup may worsen limb-length discrepancy and bone stock for revision surgery and is associated with a higher rate of dislocation due to ischial impingement [41, 48]. However, the high hip centered cup without lateralization might be an alternative choice for Crowe II and III (Hartofilakidis type B) dysplastic hip with a good survivorship of cup component in midterm (90.3% survival rate at 5 years) [49] and long-term (97% survival rate at a mean of 12 years [50]; 97% survival rate at 15 years [51]) reports showing no significant difference in survivorship compared with anatomically centered cups [50, 51]. In summary, it is still preferable to place the cup at the level of the true acetabulum with appropriate inclination [11]. The high hip center of less than 3.5 cm above the anatomical level in THA might be an acceptable alternative for Crowe II and III (Hartofilakidis type B) dysplastic hip.

Age of the Patient

Young age has been considered as a potential risk for revision [52–54]. Dorr et al. reported 49 patients aged 45 years or younger when undergoing THA. At a mean follow-up of 16.2 years, 67% were revised, and 81% of the remaining unrevised hips were considered impending failures [53]. DDH is one of the most common causes of hip arthritis in young adults [55]. The patients usually undergo primary THA at a young age due to intolerable pain, severe arthritis, severe limping, and leg length discrepancy [56, 57]. In recent studies, outcomes after THA in patients with dysplastic hips have been showed to be comparable to patients with other osteoarthritis in the short term [58] and in the long term after adjusting for patients' age and types of prostheses [59]. But a higher rate of acetabular revision was reported by Chougle et al. in patients younger than 50 years of age at a mean of 15.7-year follow-up [12]. Swarup et al. [60] also reported that in patients with dysplastic hips and aged 35 years or younger at the time of surgery, significantly better THA survivor and HOOS-symptom scores were observed in patients over 25 years of age than younger. In this young population, 10-year and 20-year implant survival were 87% and 55%, respectively. Young patients with dysplastic hips have good outcomes after THA as well as young patients with other etiologies. However, the longevity of implants is still a concern in this population.

Size of Acetabular Component

Because of a shallow true acetabulum with bony deficiency of the anterior column and the roof, a small-sized acetabular component with or without bulk autologous femoral head graft is applied for reconstruction of the acetabulum. Small-sized (42–44 mm) acetabular components with medial protrusion technique without bone graft were reported to have satisfactory results [61, 62]. A small-sized acetabular component with a small-sized femoral head might lead to less range of motion arc and stability [63, 64]. Verettas et al. [61] reported 3% dislocation (2 in 66 hips) and needed a revision. There is no osteolytic lesion in the periacetabular area, implant migration, and revision required for aseptic loosening in a study with a mean 9-year follow-up [61] and in another study with a follow-up ranging from 3 to 9 years [62].

In a long-term study (16–26 years) performed by some of our authors (YHC, MSL, and CHS), young women under the age of 35 (41 hips in 33 patients) receiving THA for dysplasia or other reasons were analyzed according to the different implant suppliers, cup sizes, body mass index, pregnancy, and childbirth. The only factor that influenced the long-term survival was the size of the acetabular cup. The survival time for cups less than or equal to 46 mm in diameter was 81.9 ± 9.4 (95% confidence interval: 63.4–100.5) months and was 142.5 + 10.9 (95% confidence interval 121–164) months for cups larger than 46 mm in diameter (*p*:0.002).

Previous Pelvic Osteotomy

Periacetabular osteotomy (PAO), rotational acetabular osteotomy (RAO), and salvage osteotomies have been widely accepted for joint preservation in patients with DDH [65]. THA may be indicated for persistent pain and progressive arthritis after the osteotomy [66]. A high proportion of retroverted acetabulum (10 of the 23 hips, 44%) after Bernese PAO and at the time of THA was reported [67]. The retroverted placement of the acetabulum component may lead to impingement and subsequent recurrent dislocation. Trimming of the anterior wall to place the acetabular component in the proper anteversion with bone graft for a deficient posterior wall is recommended by Amanatullah et al. [67]. It is reported that a previous PAO does not compromise the result of subsequent THA in two cases series [68, 69]. Amanatullah et al. reported that there is no significant difference in the clinical outcomes in patients undergoing THA after Bernese PAO done via a modern abductor-sparing approach when compared with a matched cohort. But the acetabular component in patients with previous PAO was placed at a mean of 17° more retroversion during THA compared with the control group. Tamaki et al. [70] reported significantly longer operation time for THA in the RAO group than the group without previous osteotomy (control) and the more frequent need for bulk bone for augmentation of the acetabular component in the Chiari osteotomy group and the RAO group than in control. It is concluded that conversion to THA is more complicated in the RAO group than in the Chiari osteotomy group or the shelf acetabuloplasty group.

Bearing Materials

Because dysplastic hip is one of the most common causes of hip arthritis in young adults [55], a higher revision rate of acetabular components with the conventional bearing materials was reported [14]. So-called alternative bearing materials may provide a better solution for wearing. The hard-on-hard bearings in THA are gaining in popularity because of improved tribology and biocompatibility with the promise of increased longevity. However, the metal-on-metal bearing is not recommended for young patients with dysplastic hips [11] because of symptomatic periprosthetic inflammatory reactions [71, 72] and elevated serum metal ion concentrations [73, 74]. In fact, in April 2010 the UK Medicines and Healthcare

Products Regulatory Agency issued a medical device alert regarding the safety of all types of metal-on-metal hips [75]. Therefore, ceramic-on-ceramic articulation is the current main choice of the hard-on-hard bearings, and metal-on-highly cross-linked polyethylene (HXLPE) and ceramic-on-HXLPE are alternative choices for better longevity. Up to date, there is no study addressing the longevity of ceramic bearings only in patients with dysplastic hips. Tozun et al. [76] report good midterm survivorship as high as 100% following ceramic bearings in THA at a mean 8.2-year follow-up (range, 5–13.2 years) in a general population with the majority of dysplastic hips (34%, 205/540 hips), and Kim et al. [77] also reported 100% survivorship in patients 30 years of age or younger using ceramic bearings in cementless THA after a minimum follow-up of 10 years. However, patients younger than 20 years have a lower survival rate of ceramic-on-ceramic THA (90.3%) compared with the published estimates in older patients, with aseptic loosening as the end-point [78]. Therefore, THA is only suggested to be performed as a last resort on patients younger than 20 years of age, even with ceramic bearings [78]. For other alternative bearing combinations, such as metal or ceramic-on-HXLPE, lower wearing rates have also been reported compared with conventional metal-on-ultrahigh-molecular-weight polyethylene (UHMWPE) [79, 80]. Even in patients younger than 50 years of age, Garvin et al. reported very low wearing rates of HXLPE regardless of the femoral head component material (cobalt chrome, ceramic, and Oxinium) [81]. The improved articulation materials indeed increased the longevity of THA in general and may also be true for DDH/CDH patients.

Summary of Outcomes

Placing the acetabular component near the anatomical level and the careful reconstruction with an autologous femoral head bone graft (when necessary) is recommended for THA in patients with dysplastic hips. For Crowe II and III (Hartofilakidis type II) dysplastic hips, placing the acetabular component at a high hip center of less than 3.5 cm above the anatomical level might be an acceptable alternative. With appropriate surgical techniques, promising long-term outcomes are expected. However, in very young patients, a lower survival rate of THA is reported, even with the use of ceramic bearings, and frequent revision with short intervals is expected. Despite the advances of tribology and biocompatibility, the wearing rate of THA can significantly be reduced using ceramic-on-ceramic bearings or HXLPE, but THA should still only be considered a last resort for patients with dysplastic hips, especially in very young patients.

Planning and Preparation for Revisions of THA in DDH/CDH Patients

The original condition of the hip before THA is important in dealing with bone defects when revision is considered. Total hip arthroplasty for adult DDH/CDH was described in detail in the previous chapter (Chap. 4). The acetabulum

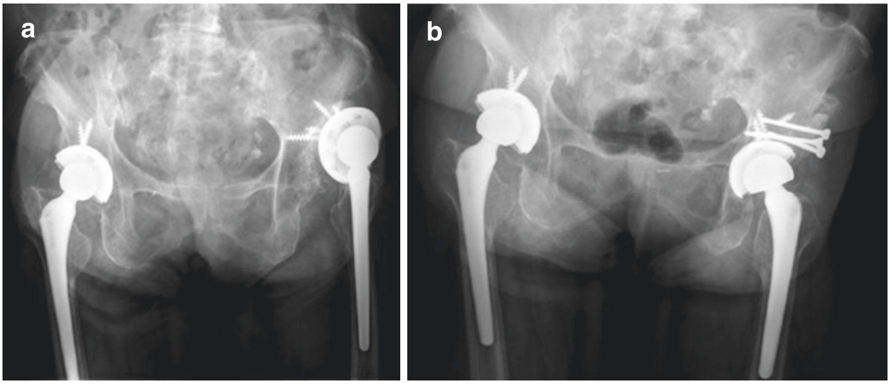

Fig. 5.1 A 69-year-old female patient after the cup of the left THA was placed at a superior-lateral position, and loosening was noted (**a**). Three years after the revision of the cup at the best bone stock plus allogenic structural bone graft for roof augmentation (**b**). (these pictures were agreed by the patient for publication)

component was advised to be placed at the "best bone stock," which is close to the normal anatomic hip center and symmetric to the sound side. But in revision surgery, the surgeon still has to face the acetabular component in a compromised position (Fig. 5.1).

Cup Position of the Previous Surgery

Anatomic Hip Center

Reconstruction of the acetabular cup near the anatomical level with or without a shelf autograft is the most common method applied for Hartofilakidis type B and type C DDHs. Although the loosening rate of the cup after shelf bone graft is higher than THAs in general population, the regeneration of the bone graft is predictable and provides better bone stock for the revision surgery when it becomes necessary. Bal et al. showed that a healed bulk graft of the primary THA provided valuable bone stock for the support of acetabular component during revision [82].

High Hip Center

Various studies have investigated the biomechanics of the hip in relation to changes of the rotation center of the hip. Johnston et al. [83] used a mathematical model to analyze joint contact forces and found that the most important factor influencing the load on the hip was the location of the hip center. High hip center with or without lateralization may cause increased joint contact force and contributes to component loosening.

It was found that in either structural bone grafting with anatomic hip center or high hip center for a DDH patient, the failure rate of THA was higher than that of the other patients. The dysplastic acetabulum has a reduced anterior-posterior diameter combined with poor superior support from the dome. The bone defects may be worsened by previous surgeries, particle-induced osteolysis, and migration of the cup. Revision for THA in DDH/CDH patients has to face the problems of a deficient bone stock and leg length discrepancy. The goals of revision are to restore the normal hip center, secure mechanical support, fix the cup by using a larger acetabular component and structured bone grafts, and balance the leg lengths with an adequate offset and head.

Clinical Evaluation of a Symptomatic THA in a DDH/CDH Patient

History and Examination

Pain and instability are the most common symptoms after THA for a DDH/CDH patient to indicate a revision. The clinical histories of pain, including the time of onset, position, characteristics, relationship to activities, radiation, relieving or aggravating factors, duration, and associated symptoms, were carefully recorded. Comorbidities and the history of their treatments were also recorded. When recording the history of treatment of the hip, it is better to include the original type of DDH, history of previous surgeries—the approaches, bone graft, and components applied—and complications of the previous surgeries such as infection, dislocation, and neurovascular injuries.

Symmetry of bilateral hips, three-dimensional range of motion, contracture, muscle power, strength of the abductor muscles, gait pattern, leg length inequality, swelling, redness, discharging sinus or fluid accumulation, and scars of previous surgery were observed and recorded.

Laboratory Examination

Besides a routine blood examination, an erythrocyte sedimentation rate test, C-reactive protein, and Gallium scans are useful to screen for the possibility of infection. Aspiration of the joint for bacterial culture is necessary when periprosthetic infection is suspected.

Image Study

The preoperative radiographic examination includes an anteroposterior (AP) view of the pelvis, cross-table lateral view of the hip, Judet obturator oblique and iliac oblique views, and a weight-bearing lower leg triple film. The AP view of the pelvis provides basic information about the position of the cup, stem, and condition of the bone. Lateral and oblique views are useful for the measurement of the anterior and posterior columns and further assessment of the bone defect. The weight-bearing triple film includes bilateral hips, knees, and ankles, and it is useful for measuring leg length inequality. It is also helpful when deciding to equalize the leg length from the acetabular side or from the femoral side. For the evaluation of impingement of the vessels by the cup, angiography and computerized tomography with contrast are recommended in case of a deeply migrated cup.

Bone defects of the acetabulum and the femur are classified according to the American Association of Orthopaedic Surgeons (AAOS) or Paprosky classifications [84–87]. They may be assessed from the preoperative image but can only be confirmed during surgery (see Chap. 6).

Indications for Revision

Loosening and wearing of the components are the most common indications for revision of THAs in DDH/CDH patients. Instability with frequent dislocation, mismatch between the cup and the femoral component, a high riding cup with the stem impinging on the ischium, and periprosthetic fractures leading to instability are other indications [41, 46].

Contraindications

An active periprosthetic infection can be evaluated according to the definition by the Musculoskeletal Infection Society [88] and is better treated with a two-stage exchange arthroplasty. Relative contraindications are neuropathic pain, insufficiency of the abductor muscles, and expectations unable to be achieved with a revision.

Surgical Planning

Surgical Approach and Planned Methods

The surgical approach can be chosen according to the extent of the surgery and the preference of the surgeon. Trochanteric osteotomy provides excellent pelvic exposure, but the surgeon has to be familiar with the techniques for fixation of the trochanter and proximal femoral osteoplasty (see Chap. 4) to prevent nonunion and migration of the greater trochanter [89]. Trochanter osteotomy allows the surgeon to identify the true acetabulum clearly and to reconstruct the acetabulum with a bone graft easier than without it. Trochanteric slide osteotomy retains the attachment of the vastus lateralis, provides good vision for acetabular reconstruction, can be easily fixed in lengthening of more than 3 cm, and protects the greater trochanter from migration [89, 90]. Extensive trochanteric osteotomy can be chosen for revising a well-fixed stem or a loosened cemented stem. The approach through subtrochanteric osteotomy is better suited for revision of the stem with shortening and derotation of the femur [91, 92].

Acetabular Reconstruction

A failed acetabular component with previous off-the-shelf bone graft may be revised with a larger hemispherical cementless cup based on the well-regenerated bone graft. If more than one-third of the bone graft was resorbed, the acetabulum reconstruction may require another structured bone graft with a cemented or cementless cup [41]. An allogenic structured bone graft from the bone bank is required if the reinforcement of the acetabulum in revision is necessary (unless the patient has kept his/her own bone from the previous surgery in the bone bank). Tools for removing the cup, stem, and cement (if any) have to be prepared. Cages, trabecular metal cups, and blocks need to be prepared to meet a severe bone defect of the acetabulum (sea Chap. 6). Cerclage or cable wires and tools for reduction-fixation of the osteotomy and bone graft are also prepared.

The overall outcomes of revision for DDH/CDH patients are inferior to the general population. Patients with a hip center of less than 3.5 cm above the anatomical level had a statistically better survivorship of the cup than those with a hip center higher than 3.5 cm [51]. The 10- and 20-year cup survival rate was 88% and 76% in the cementless group and 67% and 36% in the cemented group [93]. To reconstruct the acetabular cup near the "normal level" with a cementless cup is the best choice when technically possible. Techniques for fixation of the greater trochanter and osteoplasty were described in Chap. 4. Techniques of acetabular revision and reconstruction will be detailed in the following chapter.

Stem Revision

Stem loosening was less common than cup loosening in THA for DDH/CDH patients. But during revision surgery, the operation field is clearer when the stem is removed rather than when it is not. Bone defects after the removal of the stem and debridement may influence the choice of reconstruction procedure and a stem for reimplantation. Revision of a loose stem with a compromised anatomy may need a well-planned osteoplasty of the proximal femur and specific stems for the special conditions.

Extensive wear of polyethylene in young DDH patients can result in periprosthetic osteolysis, loosening of the stem, and segmental bone defects. An allograft prosthetic composite should be considered for revising a segmental defect of the stem [94].

Limb-Length Equalization

Leg length discrepancy after THA in DDH/CDH patients can be the result of the high placement of the cup, over-shortening of the femur, wearing and migration of the cup, and sinking of the stem.

Increasing the leg length can be done from the cup side or the femoral side or both sides. Surgical planning to equalize leg length with revision has to take into

Table 5.1 Options of leg lengthening with revision surgery

	High cup location	Cup at anatomic position
Well-fixed cup and stem	Shoe lift without revision Restoration of the cup at anatomic position	Shoe lift without revision Leg lengthening with callous distraction
Loosened cup, well-fixed stem	Restoration of the cup at anatomic position A longer head	Restoration of the cup at anatomic position A longer head
Well-fixed cup, loosened stem	A bigger and longer stem with a longer offset A longer head Restoration of the cup at anatomic position	A bigger and longer stem with a longer offset A longer head
Loosened cup and stem	Restoration of the cup at anatomic position A bigger and longer stem with a longer offset A longer head	Restoration of the cup at anatomic position A bigger and longer stem with a longer offset A longer head

account the conditions of the cup, stem, acetabulum, and femur. The options for leg lengthening with revision surgery are shown in Table 5.1.

The safety of leg lengthening during revision surgery has to be considered seriously. More than 4 cm of lengthening could be hazardous [30]. The sciatic nerve must be carefully monitored when the leg is lengthened by more than 2 cm. The sciatica nerve can be palpated for its tension after the reduction of trial components. The excessive dissection of the sciatic nerve may devascularized the nerve and should be avoided. Wake-up test and the monitoring of somatosensory evoked potentials are useful for checking the nerve function. During the wake-up test, the patient is instructed to dorsiflex his/her toes on command. The excessive lengthening may also damage the femoral nerve. The position of the retractors and force applied on them may also induce nerve damage. The operator has to understand the location of the nerves and how to apply the retractors at safe positions and avoid forceful retractions.

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Reconstruction of Acetabular Deficiency

6

Jun-Wen Wang

Abstract

Management of the acetabular deficiency in revision total hip arthroplasty (THA) or dysplastic hips (DDH) is a technical demanding procedure. Preoperatively, the acetabular deficiency must be assessed and classified into contained or uncontained defects. A contained defect may be reconstructed with morselized allografts and a noncemented acetabular component. Uncontained loss of bone stock involving ≤50% of the acetabulum can be reconstructed with structural or morselized allografts and noncemented acetabular component. In case of uncontained defect involving >50% of the acetabulum, with or without associated pelvic discontinuity, structural allografts in conjunction with a reconstruction cage may be required. In some occasions, the acetabular deficiency is so severe, and the host acetabular bed is poorly vascularized; autogenous iliac bone grafts may be required in the host-allograft junction to facilitate healing of the allografts. The general principles of this type of reconstruction include to restore the center of rotation of the hip joint, achieve stable fixation of the component, and restore the bone deficiency and adequate healing of the grafts to the host bone.

Keywords

Development dysplasia of the hip · Acetabular deficiency · Revision total hip · Arthroplasty · Morselized allografts · Structural allograft · Reconstruction cage

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Management of acetabular deficiencies in dysplastic hips and revision of total hip arthroplasty (THA) can be very challenging depending upon the severity of the bone defect. Therefore, a comprehensive understanding of acetabular and pelvic anatomy and accurate assessment of severity of the acetabular deficiency by preoperative radiographs and intraoperative findings are very important. Of course, the surgeon has to be familiar with the complex acetabular reconstruction techniques and has to prepare the tools, implants, and bone grafts for acetabular reconstruction before surgery.

Acetabular Anatomy

The acetabulum is composed of three pelvic bones: (1) the ilium (superiorly), (2) the pubis (anteromedially), and (3) the ischium (posteroinferiorly).

Surgically, it is divided into four regions: the superior dome (roof), anterior wall, posterior wall, and medial wall. During surgery, a combination of bone deficiencies of these regions may be encountered.

Classification of Acetabular Bone Defect

The commonly used classification systems in literature are those developed by the American Academy of Orthopaedic Surgeons (AAOS) committee of the hip [1] and Paprosky et al. [2]

The AAOS Classification System

There are five defect types described in the AAOS classification [1] (Table 6.1):

Type I defects: segmental deficiencies that support the rim of the acetabulum.

Type II defects: a cavitary deficiency of acetabular bone with an intact rim, a central defect involving the medial wall, and peripheral defects involving the anterior, posterior, and superior dome were included.

Type III defects: a combination of type I and type II defects.

Table 6.1 AAOS classification for acetabular deficiency

Type	Defect
Type I	Segmental deficiency
IA	Peripheral
IB	Medial
Type II	Cavitary deficiency
IIA	Peripheral
IIB	Central
Type III	Combined deficiency
Type IV	Pelvic discontinuity
Type V	Arthrodesis

(Reproduced with permission from Techniques in Orthopaedics)

Type IV defect is defined as pelvic discontinuity.
Type V defect means a fused hip (Table 6.1).

Paprosky Classification System of Acetabular Defects (Fig. 6.1)
Type I Defects (Fig. 6.1a)

No cavitary or rim deficiencies of the acetabulum.

Type II Defects

Definition: Some enlargement of the acetabulum.

1. Type IIA defects (Fig. 6.1b)

Less than 2 cm of superior migration with mild ischial lysis and medial migration lateral to Kohler's line or mild teardrop osteolysis. About 85–90% host bone contact is present with the implant except for 10–15% superior defects.

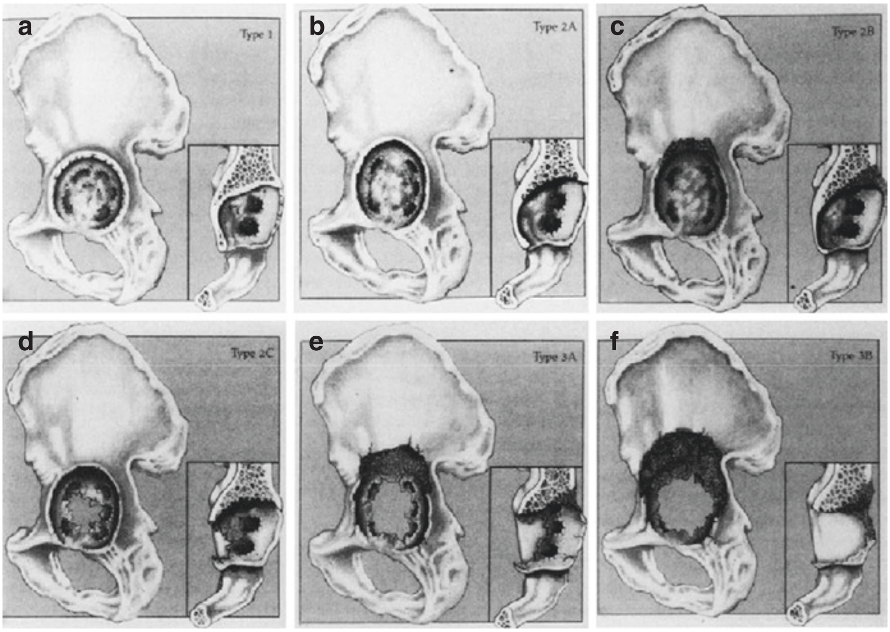

Fig. 6.1 Paprosky classification system of acetabular defects. (**a**) Type I. Supportive rim with no bone lysis or component migration. (**b** through **d**) Type II. Distorted hemisphere with intact supportive columns and less than 2 cm of superomedial or lateral migration. (**e**) Type IIIA. Superior migration greater than 2 cm and severe ischial lysis with Kohler's line intact. (**f**) Type IIIB. Superior migration greater than 2 cm and severe ischial lysis with Kohler's line broken. (Reproduced with permission from Paprosky WG, Perona PG, Lawrence JM: Acetabular defect classification and surgical reconstruction in revision arthroplasty: A 6-year follow-up evaluation. *J Arthroplasty* 1994;9:33-44). (Reproduced with permission from the Journal of Arthroplasty)

2. Type IIB defects (Fig. 6.1c)

Some superior migration with mild ischial and teardrop lysis and medial migration to Kohler's line. About 60% of the implant has contact with host bone, and about 20–30% of superior defect is still present.

3. Type IIC defects (Fig. 6.1d)

Mainly medial migration with disruption of the Kohler's line, mild ischial lysis less than 2 cm superior migration and moderate to severe teardrop lysis.

Type III Defects

Definition: Major defects with sizable structural bone loss.

1. Type IIIA defects (Fig. 6.1e)

More than 3 cm of superior migration, moderate ischial and teardrop lysis, and medial migration against or through pelvic wall. About 50% of the host bone is in contact with the implant.

2. Type IIIB defects (Fig. 6.1f)

Most severe type of the defects: significant superior migration (more than 3 cm), grade III^+ medial migration, and severe teardrop and ischial lysis. Less than 40% of the host bone is available for reconstruction.

Management of Defects of the Acetabulum [3]

Type I Defects

Can be managed as primary arthroplasty using a cementless cup with screws fixation with morselized grafts. Structural grafts may be used if a host bone augmentation is necessary (Fig. 6.2b).

Type II Defects

Generally, type IIA and IIB defects have less than 2 cm superior defects without major ischial osteolysis. Several options are available for insignificant superior migration with maintained anterior and posterior column.

1. High hip center (Figs. 6.2c and 6.3)
2. Medial placement of the implants (Fig. 6.3)
3. Bulk auto- or allograft (Fig. 6.4)
4. Large porous cup (Fig. 6.5)

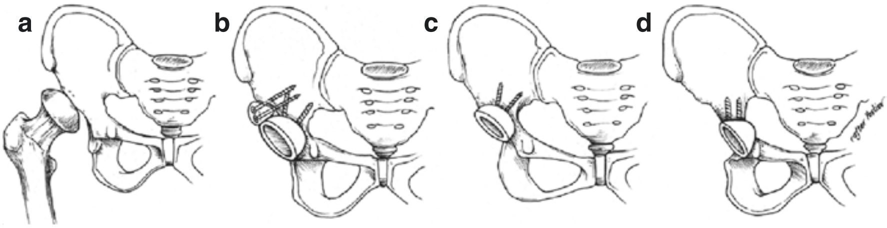

Fig. 6.2 Three alternative methods to reconstruct (**a**) Crowe type II and III dysplastic acetabuli: (**b**) augmentation with bone grafting, (**c**) high hip center, and (**d**) medialization of the cup. (Reproduced with permission from the Mayo Foundation) (Reproduced with permission from the American Academy of Orthopaedic Surgeons)

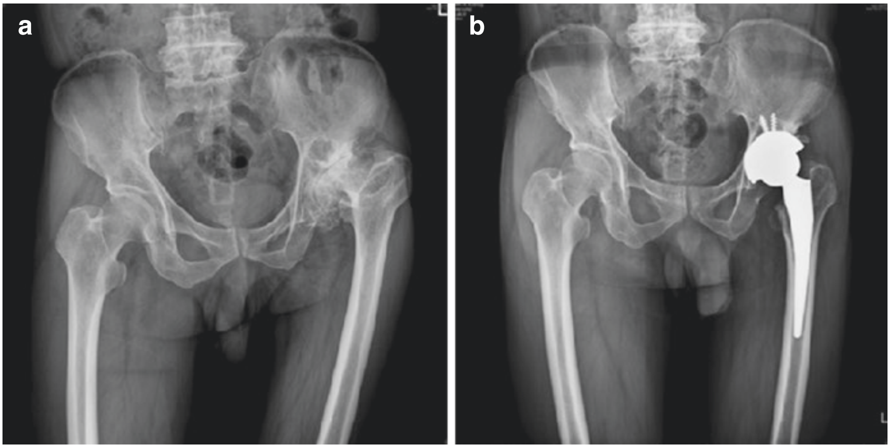

Fig. 6.3 A 62-year-old man had left DDH with high riding femur and LLD 4 cm due to childhood trauma (**a**). Radiograph taken 1 year after superomedial placement of the cup and THA showed good position and bone ingrowth of the implant and restoration of leg length (**b**) (these pictures were agreed by the patient for publication)

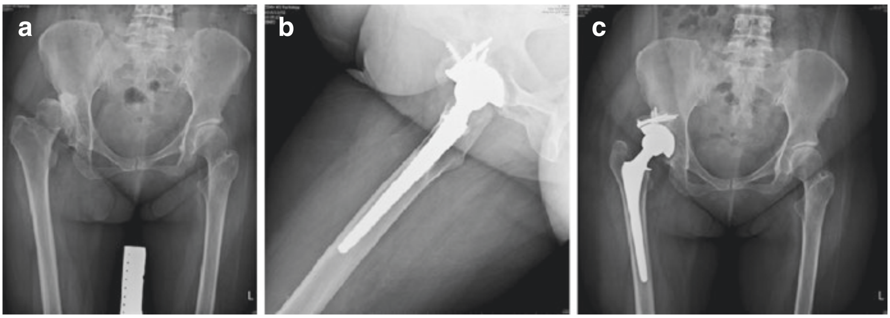

Fig. 6.4 A Crowe type III DDH with severe arthritis in a 43-year-old woman (**a**). Radiograph taken 1 year after THA with autograft augmentation of the superior deficiency (**b** and **c**) (these pictures were agreed by the patient for publication)

Special Occasion of Acetabular Deficiency in Primary Total Hip Arthroplasty

Techniques of Acetabular Reconstruction in Dysplastic Hip (DDH)

Approach

The procedure can be performed by conventional anterolateral or posterolateral approach depending on the surgeon's experience. Transtrochanteric approach may be required in patients with a very stiff hip or those that have had an osteotomy previously.

Methods of Reconstruction

There are three methods of acetabular reconstruction of this problem according to Professor Miguel E. Cabanela [4] (Fig. 6.2)

1. Augmentation with bone grafting (Fig. 6.4)
2. High hip center (Fig. 6.3)
3. Medialization of the cup (Fig. 6.6)

Our previous clinical experience of autogenous femoral head augmentation and cemented acetabular component resulted in a high failure as reported by Anderson and Harris [5]. The augmentation of acetabular defect with bulk graft only and uncemented socket requires longer postoperative care with support until healing of the graft (Fig. 6.4). We now prefer a combination of techniques of somewhat higher hip center and medialization of the socket according to the concept of "the best bone stock" described in Chap. 4 (Fig. 6.7). Morselized autografts from femoral head will be augmented at 15% to 20% superolateral remaining defect of the acetabulum after screw fixation of the cup (Fig. 6.7). In this way, medialization of the hip center will be beneficial to place the acetabular component at an optimum position (35–45° inclination and 25–35° anteversion in posterolateral approach) (Fig. 6.7) which increases the weight-bearing surface of the component, reduces the postoperative dislocation rate, and minimizes the joint loading and less Trendelenburg gait during walking after leg length equalization [6]. Augmentation of the 15–20% superolateral cup using morselized femoral head autografts will increase bone stock. In our experience, graft resorption has been minimal and limited compared with bulk autografts (Fig. 6.7). A better clinical outcome can be expected. Most patients recover quicker after rehabilitation and return to work earlier after the operation.

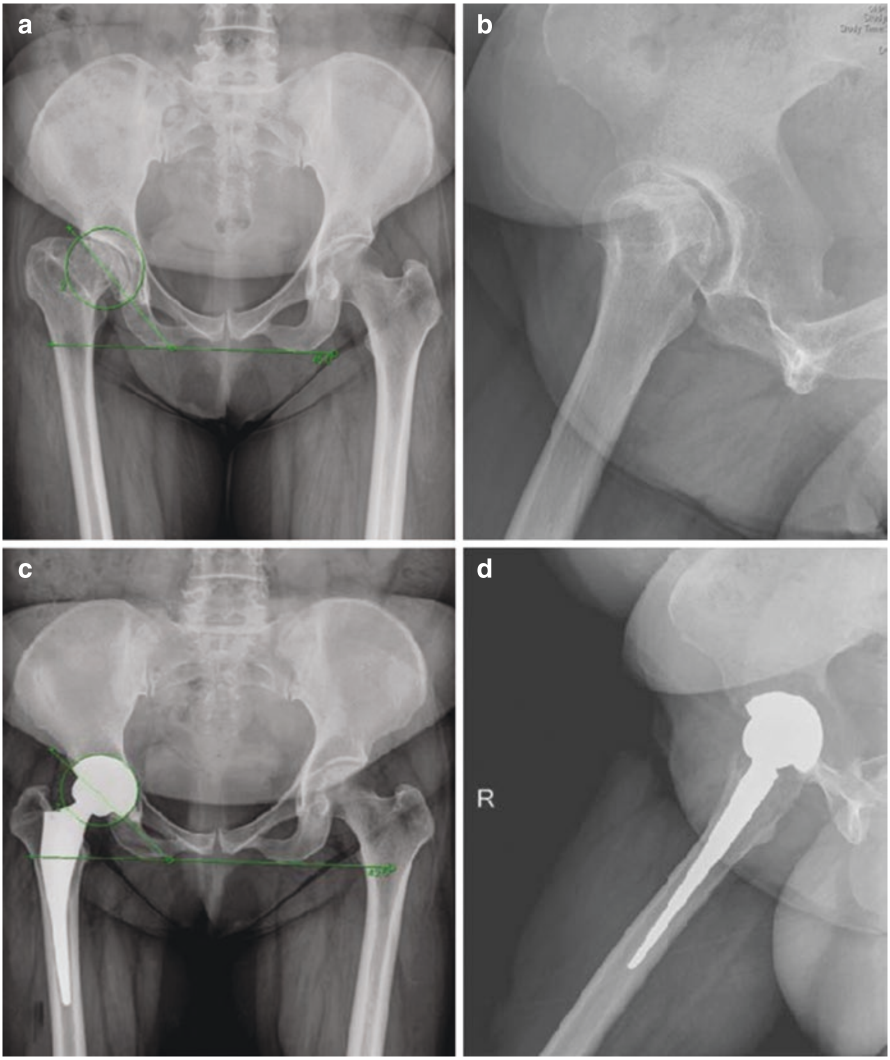

Fig. 6.5 A 48-year-old woman with severe arthritis of the right hip secondary to DDH or Perthes disease. Radiograph showed a severe dysplastic acetabulum (Paprosky type IIA). Plan of cup placement is to achieve medialization as possible (**a** and **b**). Radiographs performed 10 months postoperatively showed good cup medialization and well osteointegration of the cup porous surface (**c** and **d**) (these pictures were agreed by the patient for publication)

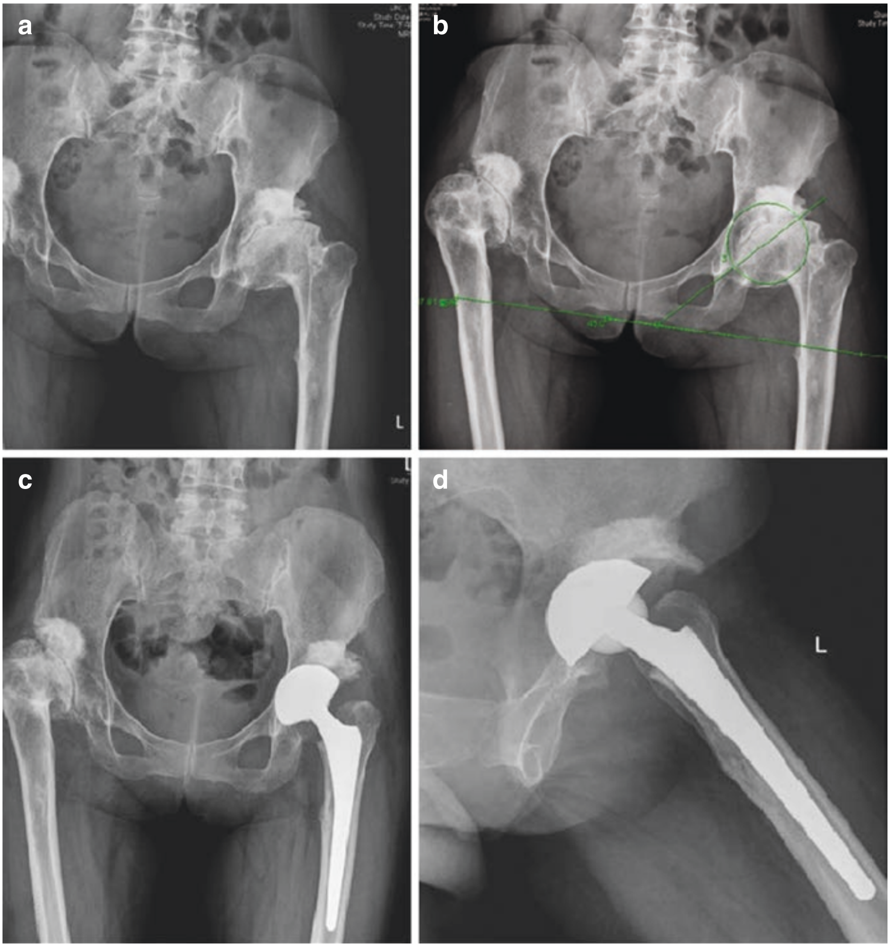

Fig. 6.6 A 36-year-old woman had bilateral DDH post-osteotomy in childhood. A THA was indicated for severe arthritis (**a**). Medialization and superiorization of the cup were planned to achieve good coverage and stable fixation (**b**). At 2 years, successful outcome was achieved after left THA by placement of the acetabular socket in medial position of the acetabulum and good osteointegration of the prosthesis was achieved (**c** and **d**) (these pictures were agreed by the patient for publication)

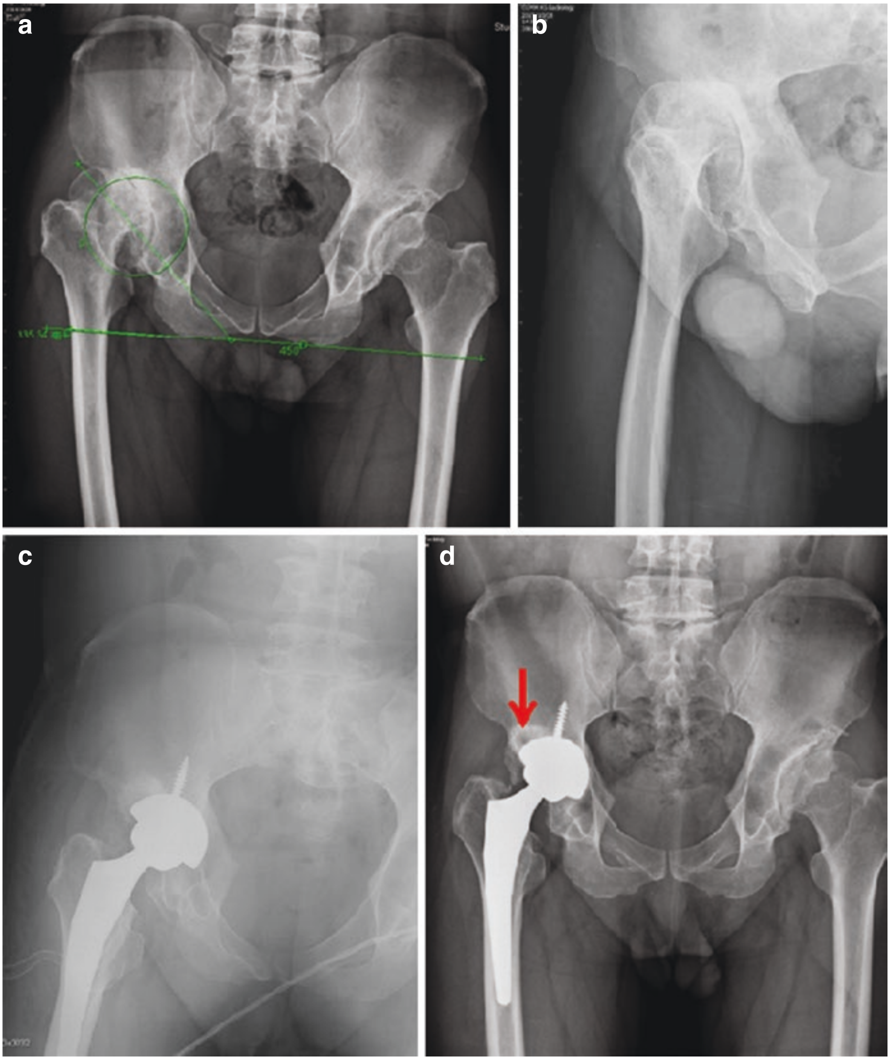

Fig. 6.7 A 42-year-old man with bilateral DDH and with secondary arthritis. Plane radiographs showed a Paprosky type IIB acetabular defect of the right hip (**a** and **b**). Immediately postoperative radiograph showed a superomedial placement of the socket and morselized grafts on the lateral wall (**c**). Radiograph performed 3 years after the operation shows the optimum position of the acetabular socket, good healing of autografts (arrow), good bone ingrowth of both components, and good leg length restoration (**d**) (these pictures were agreed by the patient for publication)

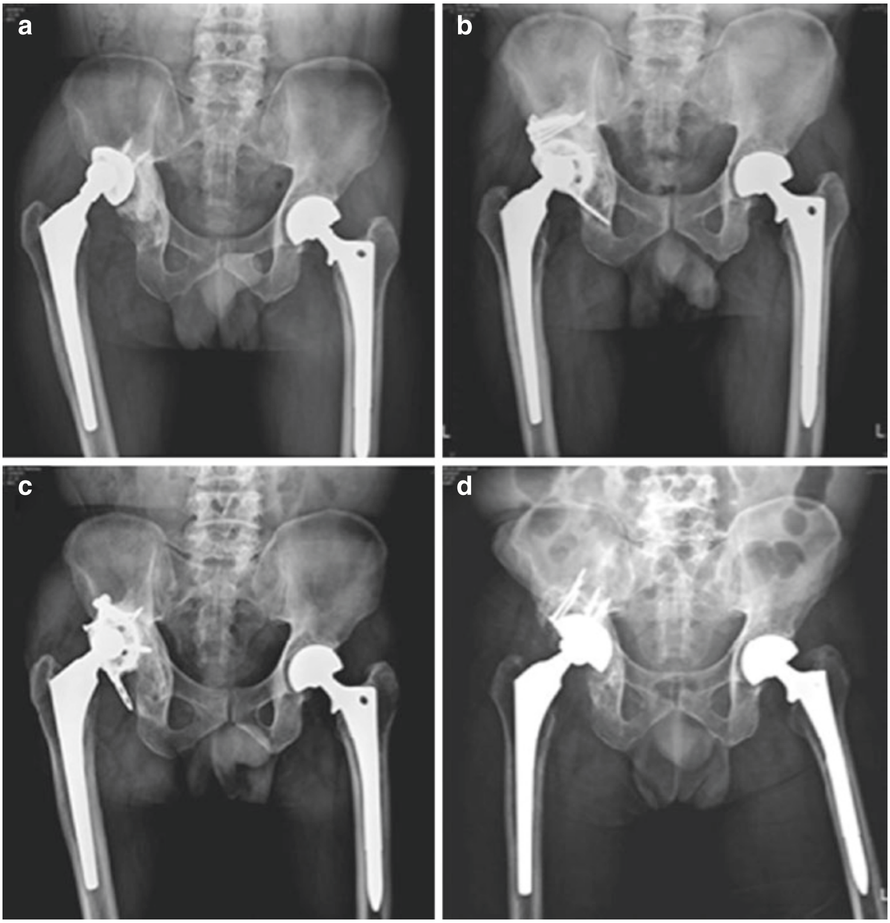

Fig. 6.8 A 52-year-old man with aseptic loosening of the right THA. Radiographic and operative findings showed a 7 × 5 cm superoposterior deficiency of the acetabulum causing Paprosky type IIIA defect (**a**). Partial consolidation of the bulk allograft of the superior wall reconstruction and good position of reconstruction cage at 1-year radiograph were seen (**b**). However, because of no distal screw fixation and inadequate superior support of the cage without additional screw fixation from inside the cage, loosening of the cage with graft failure was seen 6.5 years after the index reconstruction (**c**). The failed cage was easily reconstructed with an uncemented primary acetabular component and a bulk allograft because of partial healing of the previous structural allograft in the superior wall (**d**) (these pictures were agreed by the patient for publication)

Type IIC Defects

This defect shows significant medial wall defects with or without significant superior migration. The options for reconstruction of complex deficiencies are:

1. Structural bulk allografts for superior migration plus morselized grafts for medial wall defects if more than 50% of the host bone is in contact with the noncemented implant (Fig. 6.8).

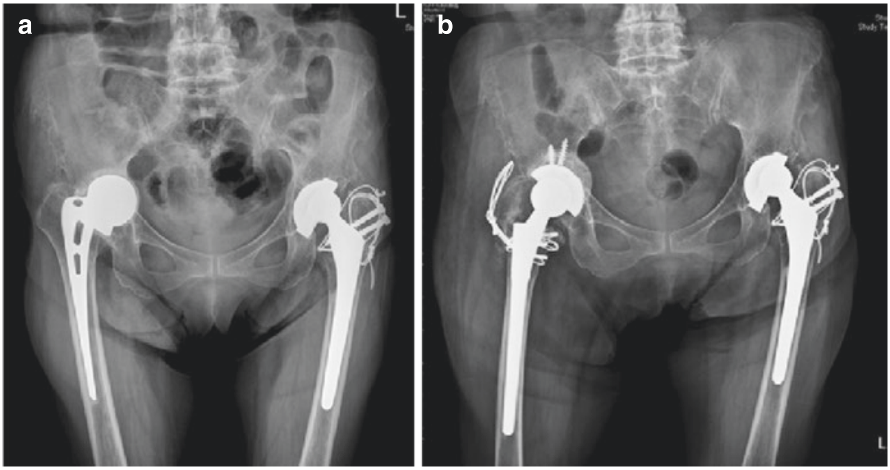

Fig. 6.9 A 75-year-old woman with a central protrusion of Moore endoprosthesis which was implanted in the right hip 38 years previously. Radiograph showed a Paprosky type IIC acetabular defect (**a**). One year after revision of THA using an uncemented acetabular component and impacting allograft, the medial defect shows well-fixed cup to the acetabular rim and consolidation of the morselized allografts (**b**) (these pictures were agreed by the patient for publication)

2. Impacting morselized allograft for medial and superior defects with an uncemented socket and screw fixation if press fit is achieved of the porous socket on the rim of the acetabulum (Fig. 6.9) or cemented socket and screw fixation if the socket is still unstable after grafting (Fig. 6.10).
3. Structural bulk allografts for superior defects, morselized grafts for medial and remaining defects, and a reinforcement ring or reconstruction cage for rigid fixation then cement cup if the host bone defects (medial, anterior and inferior walls) are too extensive to support an uncemented socket (Fig. 6.11).

Type IIIA and B Defects

A type III defect indicates more than 3 cm superior column deficiency. Preoperatively, a careful radiographic evaluation of the anterior and posterior column bone loss is mandatory. Severe ischial osteolysis indicates posterior column deficiency, and lysis of the teardrop and protrusion past the iliopectineal line indicate anterior column deficiency. Care must be taken to determine whether a pelvic discontinuity is present.

Reconstruction Options for Type III Defects

1. Uncemented acetabular implants or press fit porous-coated implants are occasionally used on a type III defect. However, the implant should be placed medially and superiorly to obtain more than 60% host bone contact and good stability after screw fixation. In most cases, a bulk femoral head allograft should be used for superior deficiencies to restore the hip center of rotation.

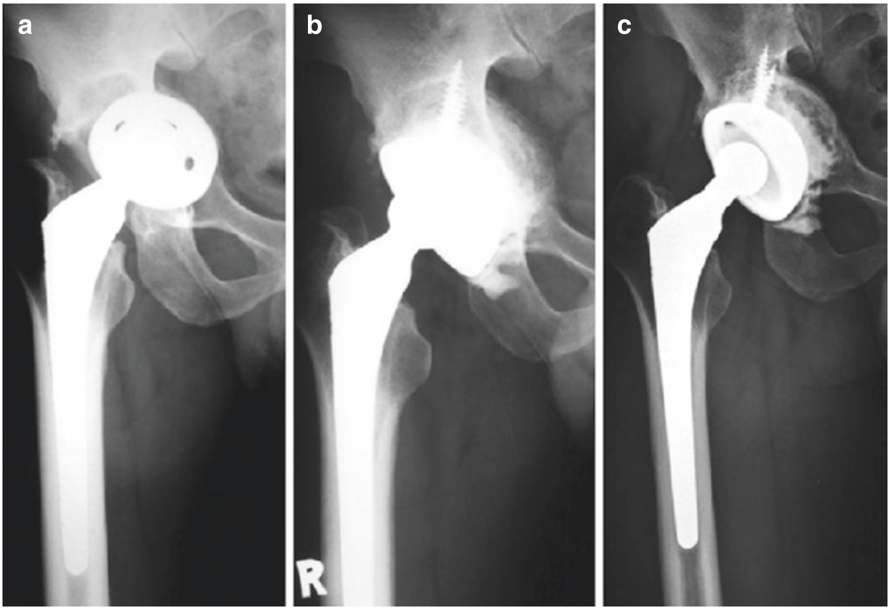

Fig. 6.10 A 40-year-old man with aseptic loosening of the right THA. Type IIC defect with intrapelvic cup migration (**a**). Three months after revision of the acetabular component with morselized allograft to fill the medial defect and cemented fixation, the radiograph shows early consolidation of the allografts (**b**). Six years later, there was good incorporation of the graft without migration of the acetabular component (**c**) (these pictures were agreed by the patient for publication)

2. Structural bulk allografts for anterosuperior or posterosuperior segmental deficiencies of the acetabulum, morselized grafts for remaining medial and inferior lysis, and cemented metal-back socket with screw fixation [7] (Fig. 6.12).

3. Reconstruction cages
   Surgical Techniques of Cage Reconstruction
   1. With morselized grafts only
   2. With structural grafts

We used posterolateral approach of the hip for this procedure. After adequate debridement of the loose acetabular implant, cement, and all the soft tissue between implant and the host bone beds, the acetabular bone defect was carefully inspected. In case of a type IIC defect where superior migration of the loose implant is not severe and where the anti-protrusion cage can be applied directly to

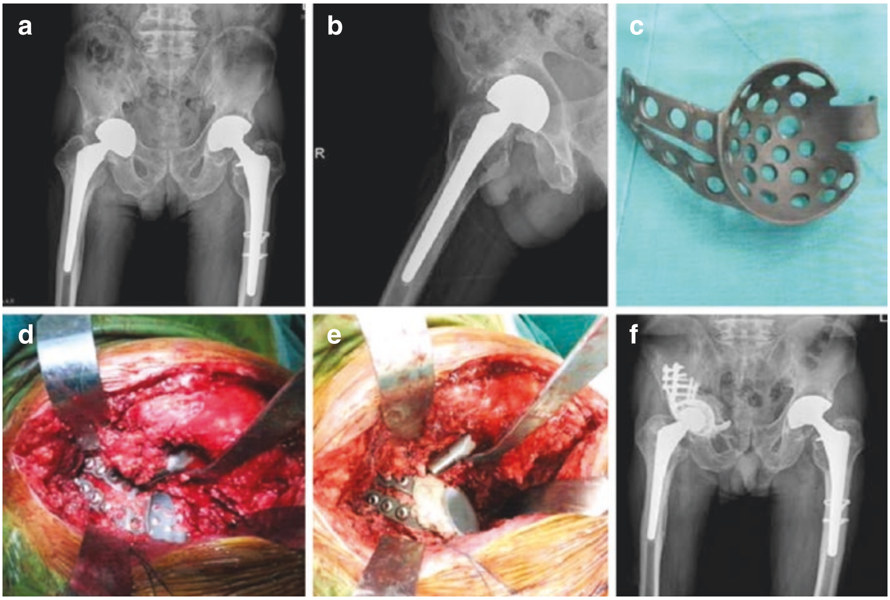

Fig. 6.11 A 75-year-old man had a right bipolar hemiarthroplasty 20 years previously. Preoperative radiography showed a Paprosky type IIC defect of the acetabulum with segmental medial wall defect and ischial osteolysis (**a** and **b**). An anti-protrusion cage (Stryker GAP-2) was prepared because of huge medial wall defect 6 × 7 cm (**c**). Intraoperative pictures showing the cage and allografts reconstruction of the acetabulum (**d**). And the polyethylene insert was cemented in the optimum position (**e**). Postoperative radiographs showed a well-fixed cage placed in the optimum position with additional screws fixation from cage to ilium (**f**) (these pictures were agreed by the patient for publication)

the host bone (ilium and posterior wall) and get solid fixation, a structural graft will be avoided (Fig. 6.11). It is better to put the cage in the optimum position like the primary acetabular socket at a 40–50° inclination. The cage we used was a Burch-Schneider cage (Braun, Aesculap, Tuttlingen, Germany). The ischial flange was slotted into the obturator space with or without screw fixation depending on the ischial bone stock. The iliac flange was placed on the lateral space of the ilium and fixed with two to four titanium screws (Fig. 6.13). In case of severe anterosuperior or posterosuperior bone deficiency (Paprosky type III defect), a structural allograft, usually a femoral head is used for defect reconstruction. The graft is shaped and sized to fit the column defect and fixed to the ilium with two to three cancellous screws (Figs. 6.13c, 6.14d, 6.15b). In this condition, the cage will sit on the structural allograft fixed to the ilium, and an impactor is used to achieve tight contact of the cage to the acetabular bone and the bulk allograft. Then the remaining bone defects in the acetabulum will be packed with morselized

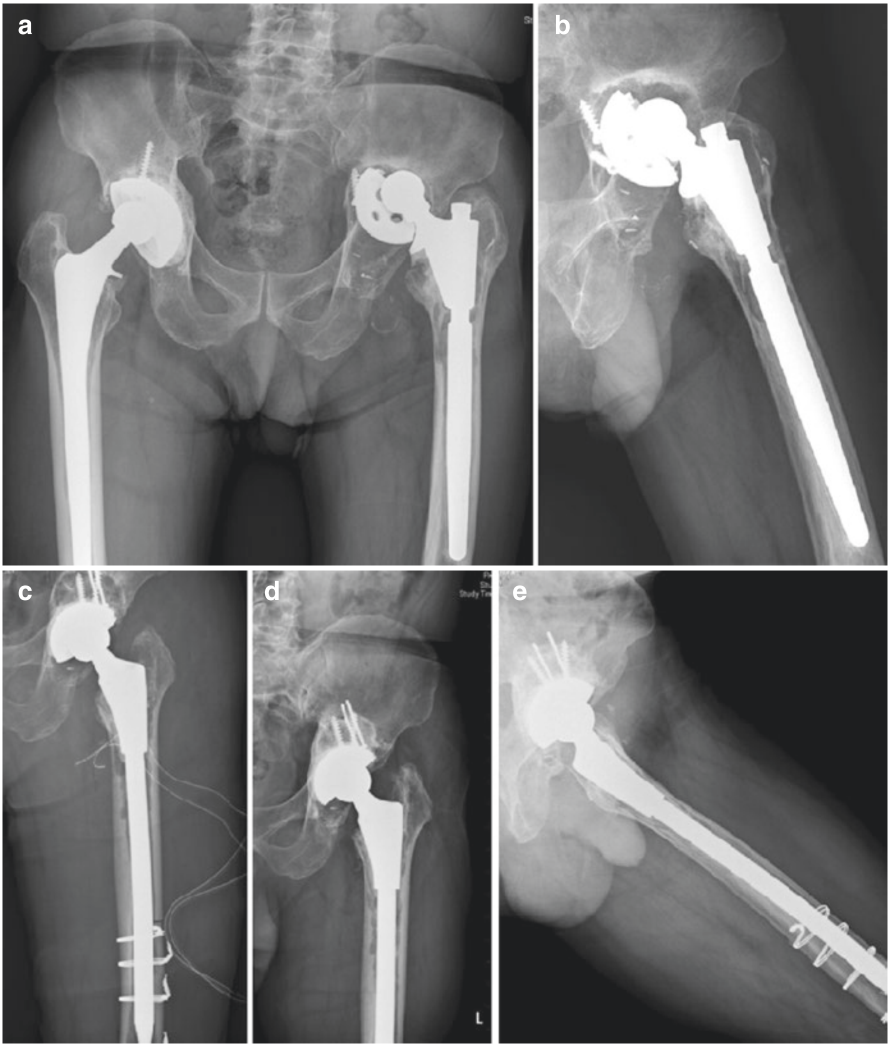

Fig. 6.12 A 65-year-old man with failed left revision THA. Preoperative radiographs showed a Paprosky type IIIB defect of the acetabulum (**a** and **b**). Revision THA was performed using a structural femoral head allograft and cemented acetabular component with screw fixation; the stem was revised as well (**c**). Four years later, radiographs showed consolidation of the femoral head allograft without loosening of the cup and femoral revision (**d** and **e**) (these pictures were agreed by the patient for publication)

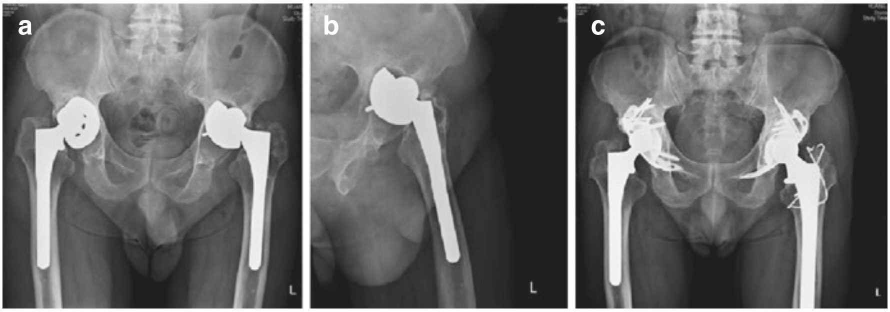

Fig. 6.13 A 55-year-old man had bilateral aseptic loosening THA with Paprosky type IIIB acetabular defects (**a** and **b**). Radiographs after revision THA using anti-protrusion cage and bulk and morselized allografts. Reconstruction was at 7 years on right and 6 years on left side, showing optimum position of cages and cups (**c**). There was good healing of the grafts and no cage failure (these pictures were agreed by the patient for publication)

allografts which are premixed with 1 g of vancomycin powder (Fig. 6.14). Care must be taken that the cage optimum position (40–50° inclination) is achieved because it is critical (Fig. 6.15). If possible, an additional two to three 6.5 mm cancellous screws driven from inside of the cage to the ilium are very helpful for the stability of the cage (Fig. 6.15c). At last, the polyethylene liner was fixed on the cage using bone cement in a position of 35–45° inclination and 30–35° anteversion (Fig. 6.15). If the bone defect is too severe that a femoral head is inadequate, a distal femoral allograft is necessary. On a rare occasion, a case with severe bone defect in the acetabulum and the ilium secondary to a comminuted fracture of the pelvis received open reduction and internal fixation which resulted in posttraumatic arthritis of the hip. However, the subsequent THA failed because of pelvic nonunion with loss of bone stock around the hip and septic loosening (Fig. 6.16a). After extensive debridement and removal of the prosthesis, a major revision THA by the use of a distal femoral allograft, massive morselized grafts, and an anti-protrusion cage in conjunction with a mega prosthetic femur was required (Fig. 6.16).

Other Comments for Reconstruction Cage

The anti-protrusion rings were developed for the reconstruction of large type III acetabular defects. The aim of this kind of device is to provide proximal fixation to the ilium and distal fixation of the ischium to protect large segmental allografts. The early Müller reinforcement ring (Sulzer Orthopaedics Ltd., Switzerland) only

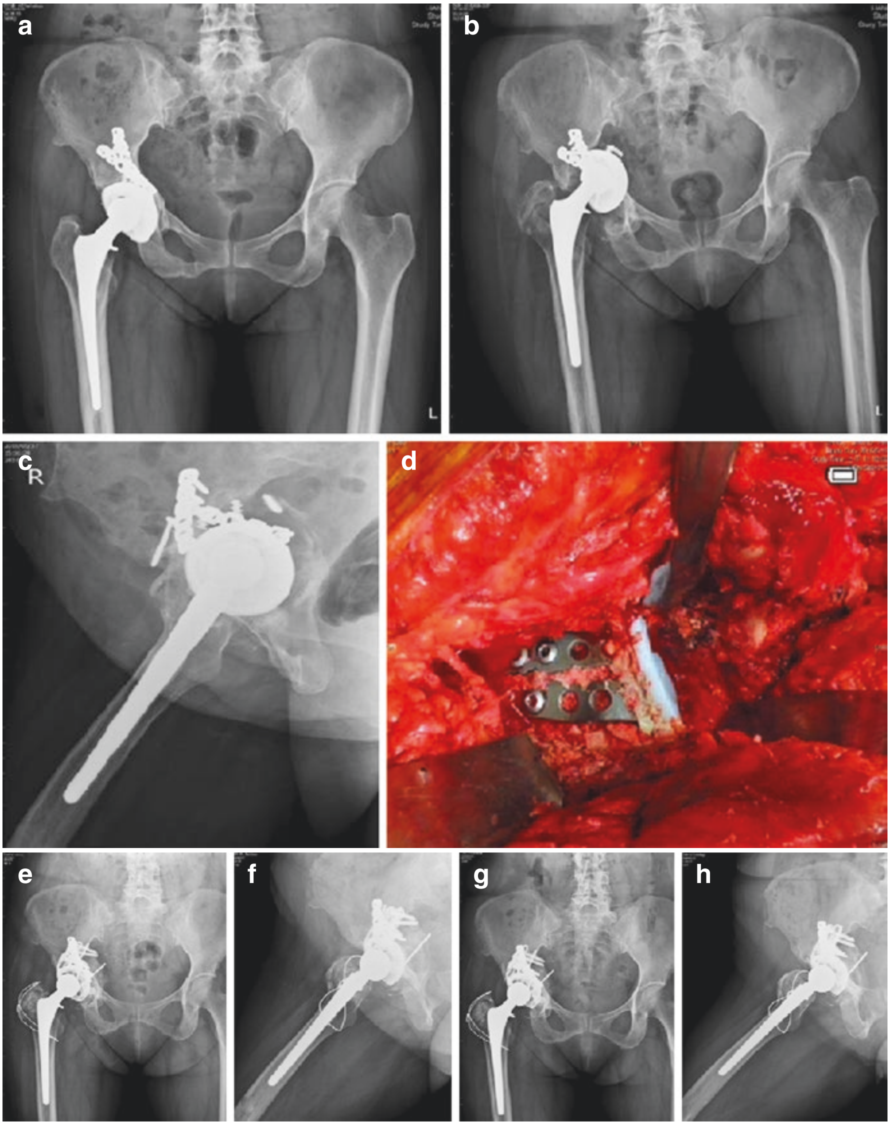

Fig. 6.14 A 40-year-old woman sustained a fracture-dislocation of the right hip complicated with posttraumatic arthritis S/P right THA in 2003 (**a**). Twelve years later, aseptic loosening of the right THA with Paprosky type IIIB acetabular defect including severe superoposterior and medial wall segmental bone loss was noted (**b** and **c**). Intraoperative picture showed cage reconstruction in conjunction with structural and morselized allografts for acetabular defects (**d**). Three months after revision of THA, the radiographs showed partial consolidation of the grafts and well-fixed cage fixation (**e** and **f**). Two years after the operation, the radiographs showed improved consolidation of all the allografts and no loosening of the cage or broken screws (**g** and **h**) (these pictures were agreed by the patient for publication)

Fig. 6.15 A 75-year-old woman had a failed revision of a THA performed at another hospital 1 year previously. Radiograph showed a loose acetabular reconstruction with screw incorporated into cement and all poly cup resulting in a Paprosky type IIIA defect as well as the long-stem femoral component (**a**). During surgery, a femoral head allograft was used to reconstruct the superior dome defect, and it was fixed to the ilium with three screws (**b**). Postoperative radiograph showed well reconstruction of the acetabulum with a bulk allograft and cage which was fixed to the ilium with three additional screws from inside of the cage (arrow). The cage was put in an optimum and stable position which is beneficial for healing of the grafts (**c**) (these pictures were agreed by the patient for publication)

provides proximal fixation. Ganz reinforcement rings add a hook for distal fixation. However, Gerber et al. reported their experience of Ganz reinforcement rings and concluded that the lack of primary stability was the main cause of late graft failure and loosening of the reconstruction [8]. The Burch-Schneider cage offers stable proximal fixation of the ring to the ilium and distal fixation of the ischium with screws. The GAP II cage (Osteonics, Allendale, NJ, USA) has a similar function. Bonnomet et al. reported better results using the Burch-Schneider cage than with the Müller ring in patients with severe acetabular bone deficiency which resulted in an 89% success rate in 57 patients followed 5–21 years [9]. Our 3- to 10-year experience of the Burch-Schneider cage and structural allografts in complex acetabular deficiencies of 31 hips showed improved outcome with a 76% survival rate. Even with failed cage reconstruction, re-revision surgery with a cementless acetabular component may be feasible once the structural allograft has healed [10] (Fig. 6.8).

However, there was still a substantial failure rate of the cage reconstruction in patients with severe cranial or posterior wall defects of the acetabulum. Goodman et al. reported 4 loose rings, 3 fractured flanges, 3 loose cups, 7 dislocations, 3 deep infections in 61 B-S cages follow-up averaged 4.6 years. Forty-eight cages required structural allograft reconstruction because of a large (>50%) uncontained defect superiorly or pelvic dissociation [11]. Nonunion of the allograft to host bone or pelvic dissociation is one of the causes of failure (Fig. 6.17). Recently, we performed autogenous iliac autografting at the host-allograft junction or the pelvic dissociation site associated with failure cage reconstruction to improve allograft or fracture union which may prevent late failure of the cage (Fig. 6.17).

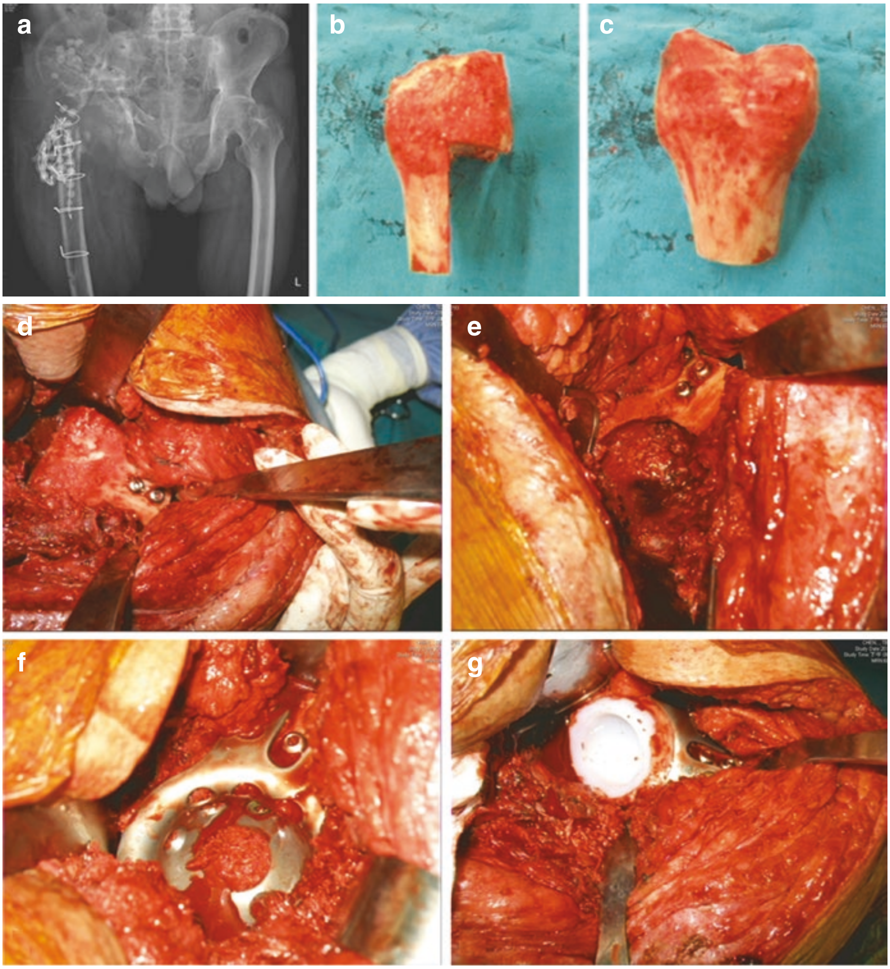

Fig. 6.16 A 53-year-old man sustained a severe pelvic fracture nonunion and failed right hip replacement because of septic loosening. Radiograph showed a massive bone loss of the acetabulum with pelvic dissociation and the proximal femur (**a**). A distal femoral structural allograft was selected and cut into a shape of “7” ready for pelvic reconstruction (**b** and **c**) (these pictures were agreed by the patient for publication) At operation, the distal femoral structural allograft was fixed to the ilium with two screws (**d**), and the allograft femoral condyle was prepared and reamed into a shape of acetabulum up to 52 mm in diameter (**e**). Then an anti-protrusion cage was applied and fixed to the host ilium and allografts (**f**). At last, a suitable size of polyethylene insert was cemented to the cage in an optimum position (**g**). Immediate postoperative radiograph showed a well-reconstructed new acetabulum with the anti-protrusion cage and a proximal femoral replacement with a megaprosthesis (**h**). Radiograph taken 1 year after revision THA showed a well-fixed revision implant (**i**) (these pictures were agreed by the patient for publication)

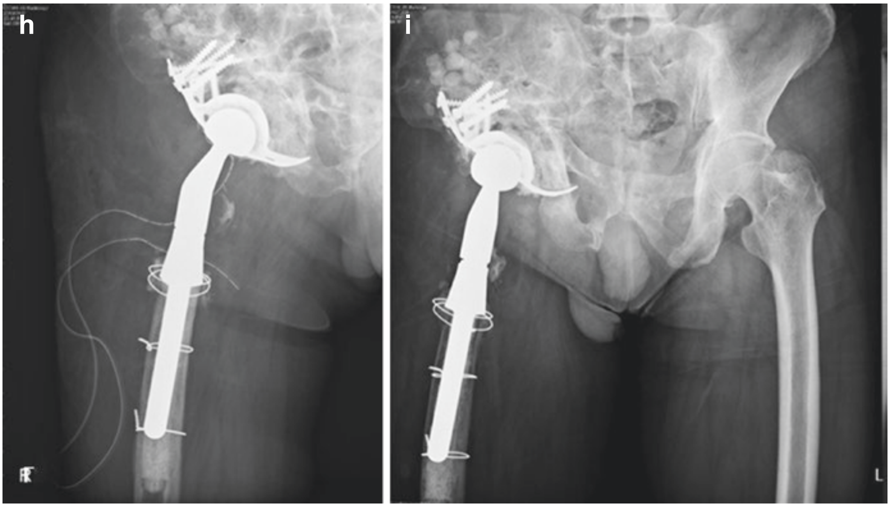

Fig. 6.16 (continued)

Case Experience in Paprosky Type III Defect Treated with Allografts and Trabecular Metal ™ Cup

Recently, owing to the introduction of trabecular metal™ material in the joint replacement surgery by Zimmer company, I tried to use the TM cup instead of a reconstruction cage in some cases with Paprosky type III acetabular deficiency. The early outcomes of these cases were satisfactory. The first case was a 43-year-old woman with DDH presented with aseptic loosening of revision THA using morselized allografts and cemented acetabular socket 15 years previously. The reason for the failure of the primary THA was hydroxylapatite (HA) coating of a smooth surface metal cup (Osteonic, Omnifit PSL). At the time, the acetabular defect was classified as Paprosky type IIIA which involved superior and posterior walls requiring a bulk femoral head allograft reconstruction superoposteriorly, medialization of the cup position, packing the remaining defects with morselized allografts, and a press fit TM cup with screw fixation. She had a painless hip 1.5 years after re-revision THA (Fig. 6.18). The second case was a 67-year-old man with failure of the large head metal-on-metal THA (Wright). Radiograph and intraoperative findings disclosed a Paprosky type IIIB defect (superior migrating 3 cm, ischial lysis, and medial wall segmental loss). It was successfully reconstructed with medial morselized allografts and a cementless TM cup (Fig. 6.19).

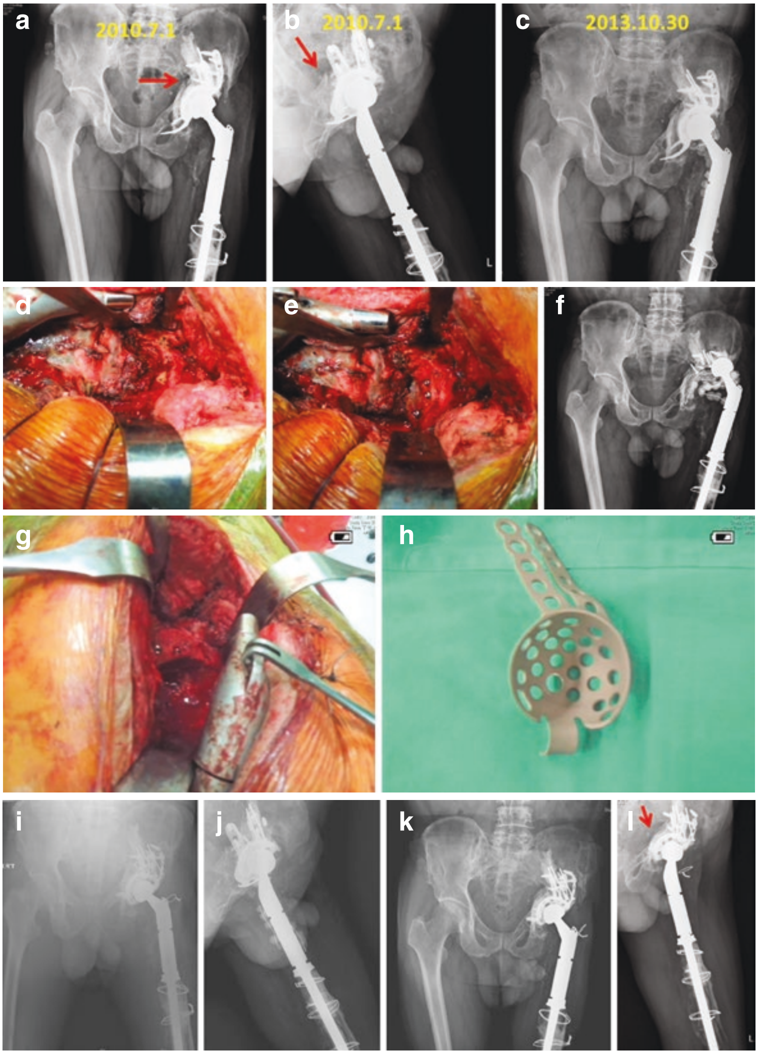

Fig. 6.17 A 57-year-old man with failed cage reconstruction due to the nonunion of the acetabulum (pelvic discontinuity) for 5 years. Radiographs showing acetabular floor nonunion (arrows) and loose cage (**a** and **b**). Three years later, the patient complained of pain and crepitation of the left hip during hip motion. Radiograph showed migration of the cage (**c**). During surgery (2014-02-25), obvious nonunion of the acetabular superior wall was observed (**d**). The defect was repaired with a strut corticocancellous iliac autograft and fixed to the remaining acetabulum with three screws (**e**). Three months after autografting, healing of the acetabular defect was seen (**f**). A new anti-protrusion cage in conjunction with a bulk allograft fixed with screws was used for acetabular reconstruction on 2014-08-21 (**g** and **h**). Postoperative radiograph showed no visible gap in the acetabulum and optimum cage position (**i** and **j**). Two years later (2016-11-02), the radiograph showed solid healing of the pelvic discontinuity (arrows) and well-fixed cage and cup without radiolucent line. Patient was satisfied with the clinical outcome (**k** and **l**) (these pictures were agreed by the patient for publication)

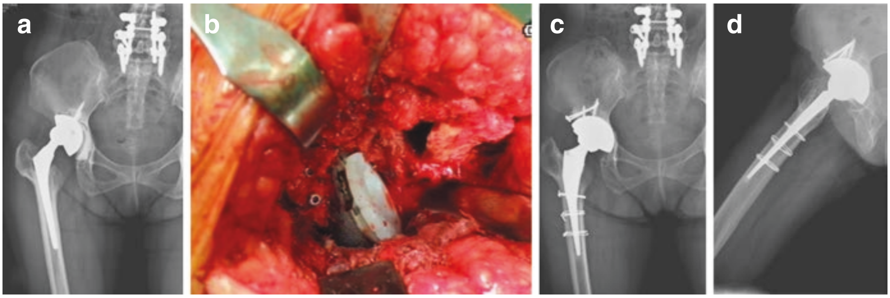

Fig. 6.18 A 43-year-old woman with failed revision, right THA performed 15 years previously. Preoperative radiographs and intraoperative findings showing a Paprosky type IIIA acetabular defect involving superior and posterior wall (**a** and **b**). One and a half year after bulk and morselized allografts reconstruction of the acetabular defect and noncemented TM cup revision showing well-fixed cup and graft healing in radiographs of the pelvis and hip (**c** and **d**) (these pictures were agreed by the patient for publication)

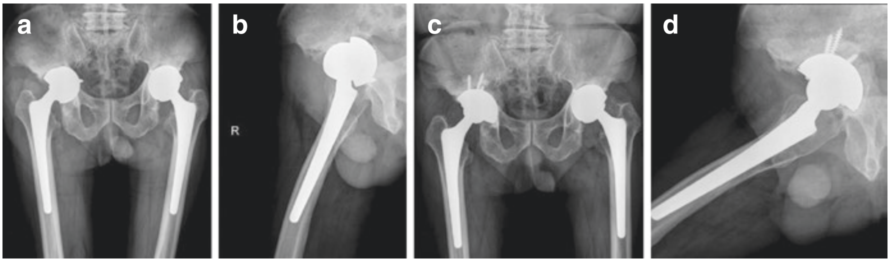

Fig. 6.19 A 67-year-old man sustained intrapelvic migration of the loose metal cup 6 years after metal-on-metal THA. Radiographs showed Paprosky type IIIB acetabular defect (superior migration 3 cm, ischial lysis, and loss of Kohler line (**a** and **b**). One year after revision with impacting grafts of the medial wall and cementless acetabular component TM (trabecular metal) cup showing osteointegration of the porous surface of the TM cup to the superior wall and ischium (**c** and **d**) (these pictures were agreed by the patient for publication)

Conclusion

Revision of a total hip arthroplasty with complex acetabular deficiency is a technically demanding procedure. A good clinical outcome requires an experienced hand and good team with well-prepared implants, instrumentation, and sophisticated bone grafting techniques.

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