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Joint Replacement in the Dysplastic Patient: Surgical Considerations and Techniques

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Key Learning Points

- Surgical exposure: Wide exposure with complete capsulectomy is critical to allow for mobilization of the proximal femur for restoration of leg length and acetabular reconstruction with the posterior approach being favored.
- Key landmarks: A retractor placed in the obturator foramen will identify the inferior edge of the true acetabulum for reconstruction.
- Adequate preoperative evaluation and preparation/templating will allow for better execution of complex femoral and acetabular reconstruction.
- Adductor tenotomy: Whenever indicated, a percutaneous adductor tenotomy performed at the start of the procedure can facilitate exposure, hip reduction, and restoration of leg length and improve early rehabilitation.
- Restoration of the anatomic hip center improves the post-reconstruction biomechanics.
- When utilizing a structural acetabular bone graft, it is important to orient the trabecular bone perpendicular to the forces being applied across the acetabulum during stance and ambulation.
- Younger hip dysplasia patients benefit from a bone-preserving arthroplasty and adequate restoration of hip biomechanics; this can provide improvements in long-term joint function, increased implant survivorship, and improved gait.
- Avoidance of excessive lengthening and possibly intraoperative nerve monitoring can decrease the incidence of sciatic nerve palsy.
- Beware of the effect of the hip reconstruction on the ipsilateral knee.

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Introduction

The natural progression of both low- and high-grade poorly treated hip dysplasia typically leads to symptomatic and degenerative arthritis that requires sometimes complex surgical management. Subtle abnormalities of the congruency between the femoral head and acetabulum lead to early cartilaginous overload and breakdown, thus setting the pathway for progressive degenerative change at an early age. Arthroplasty for degenerative arthritis secondary to dysplasia increases in complexity depending on the patho-anatomy of the deformity and degree of hip subluxation/dislocation. The technically demanding procedure for the arthroplasty surgeon includes dealing with acetabular column deficiencies or hypoplasia, a typically small diaphyseal canal with excessive femoral anteversion and chronic shortening and contracted neuromuscular structures [1–3]. The long-standing goals of arthroplasty still apply for these patients including restoration of an anatomic hip center, equalization of leg lengths with or without need for soft tissue releases, and femoral shortening osteotomy. In this chapter, we will discuss long-standing and newer proposed techniques for arthroplasty in this complex patient population.

The Morphology of the Dysplastic Femur

In general, the dysplastic femur is smaller than its normal counterpart in terms of head height and medial offset, extracortical width, canal, and minimum canal diameter at the isthmus [1–3]. In addition, dysplastic femora have significantly greater anteversion than the normal cases, with minimal alteration of the inclination of the femoral neck in the true plane of the femoral neck (Fig. 14.1). Compared to the normal controls, the canals of Crowe 1, 2, and 3 femora are 13% narrower in the ML direction and 16% narrower in the AP direction at the level of the proximal femoral osteotomy. More distally, these differences

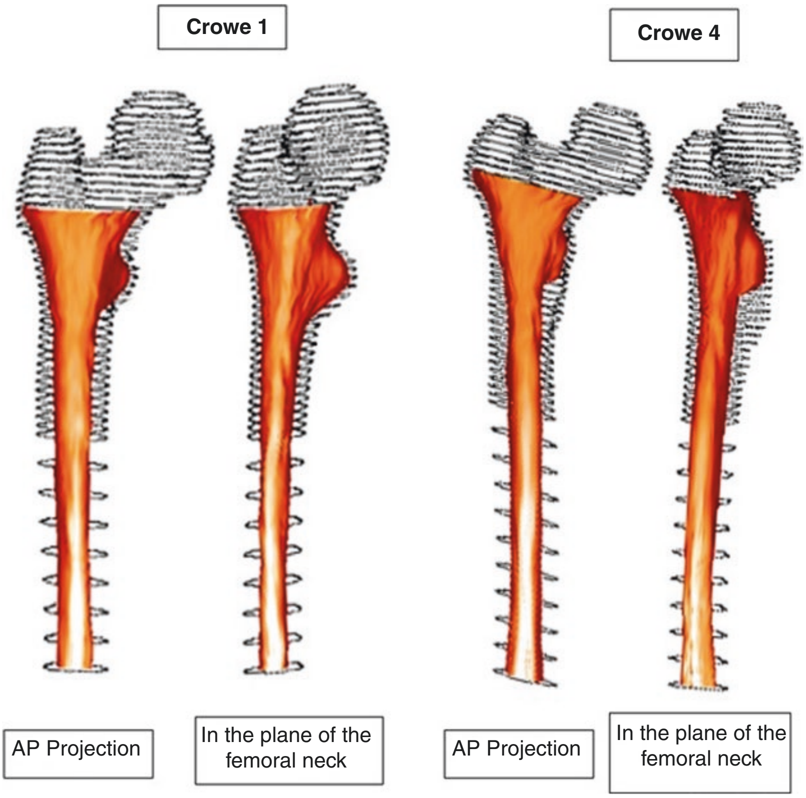

Fig. 14.1 3D computer reconstruction of typical Crowe 1 and Crowe 4 femora showing the appearance of the medullary canal when viewed in the conventional AP projection compared to a rotated view in the plane of the femoral neck (i.e., perpendicular to the neck axis) [1]. (Reprinted from Sugano et al. [1], © 1998, https://online.boneandjoint.org.uk/doi/abs/10.1302/0301-620X.80B4.0800711, with permission from British Editorial Society of Bone and Joint Surgery)

are smaller; however, the diameter of the largest cylinder that can pass through the isthmus is 1.1 mm larger in normal femora (11.0 ± 2.0 mm) than in Crowe 1 femora (9.9 ± 1.5 mm) and 0.6 mm larger in Crowe 2/3 femora (10.5 ± 1.8 mm).

However, the true diameter of the canal is not visible on either the AP or lateral radiograph due to the twist of the dysplastic canal along its length (Fig. 14.2). On average, the projected width of the dysplastic femur at the level of the isthmus is 12.6 mm in the AP projection (18% larger than the

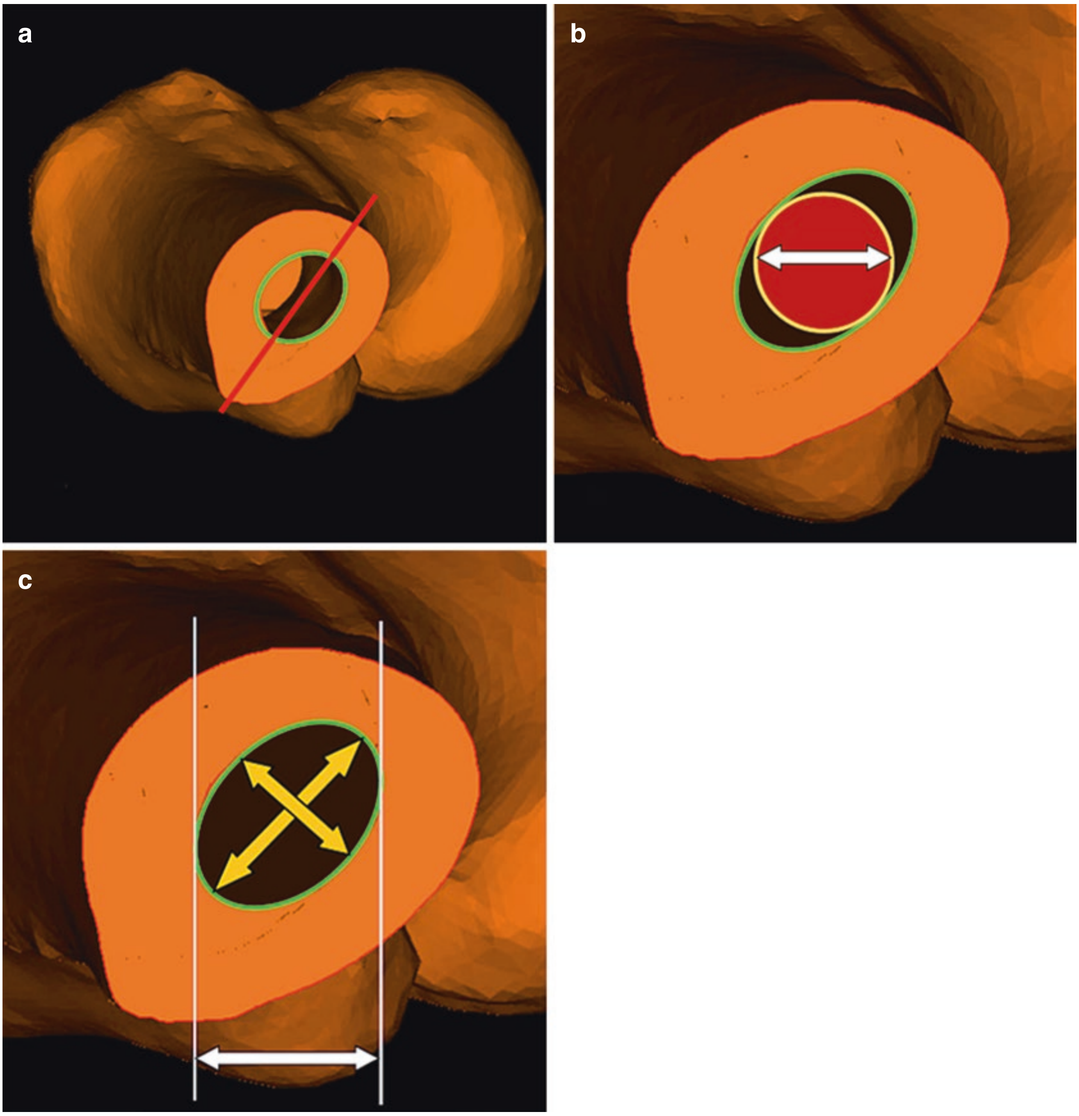

Fig. 14.2 The true dimensions of the canal isthmus and the apparent (radiographic) canal width when viewed in a projection corresponding to the axis of the femoral neck. (**a**) Major axis of the medullary canal within the diaphysis of a dysplastic femur oriented with the horizontal plane parallel to the neck axis (dotted line). (**b**) The largest inscribed circle that can fit within the elliptical femoral canal. (**c**) The major and minor diameters of the medullary canal (yellow) and the apparent width of the canal (white) when projected perpendicular to the femoral neck [2]. (Reprinted from Noble et al. [2] SECTION I SYMPOSIUM: Papers Presented at the Hip Society Meeting, © 2003, https://journals.lww.com/clinorthop/Fulltext/2003/12000/Otto_AuFranc_Award__Three_Dimensional_Shape_of_the.5.aspx, with permission from Wolters Kluwer Health, Inc.)

minimum value) and 13.3 mm (29% larger) on the lateral view. This difference renders plain radiographs of limited value for preoperative planning prior to THR. Additional changes are seen at other levels of the medullary canal. Whereas the mid-canal region of the normal femur is conical in shape with an average taper angle of 2.1 ± 1.4°, the dysplastic femora are more cylindrical, with cone angles ranging from 1.8 ± 1.2° in Crowe 1 ($p = 0.012$) to 1.6 ± 1.1° in Crowe 2/3 canals ($p = 0.006$) to only 1.1 ± 1.1° in Crowe 4 cases ($p = 0.0023$).

The shape of the canal also changes with the severity of hip dysplasia. In general, dysplastic femora are straighter than normal controls, as reflected in the average value of the canal flare index, defined as the ratio between the AP widths of the metaphysis and the diaphysis. This ratio averages 3.56 in the normal femur but ranges from an average value of 3.29 in the Crowe 1 femur, to 3.33 in Crowe 2/3, and only 2.69 in Crowe 4.

In published studies examining the effect of dysplasia on femoral morphology in the Japanese population, femoral anteversion has been seen to vary profoundly in all groups of femora, including the controls, ranging from −12° to 123° across the study population, though almost all cases (96.8%) of anteversion were between 15° and 65°. In comparison with the controls, the Crowe 1 femora had 42.8% more anteversion (45.3° vs 31.7°), whereas the Crowe 2 and 3 cases had only a mild increase in anteversion (6.0°).

One of the characteristic features of the dysplastic femur is the variation in canal rotation (antetorsion) that occurs along the length of the canal between the proximal metaphysis and the canal isthmus. At the level of the isthmus, the canal is elliptical in cross section with its major axis oriented approximately perpendicular to the transcondylar (table-top) plane (i.e., in the AP direction) and its minor axis oriented in the medial-lateral direction. In the normal femur, the canal undergoes a twist of 60–75° over a length of approximately 120 mm from the isthmus to the head (Fig. 14.3). Most of this change in orientation (twist) is observed in the mid-canal region extending from

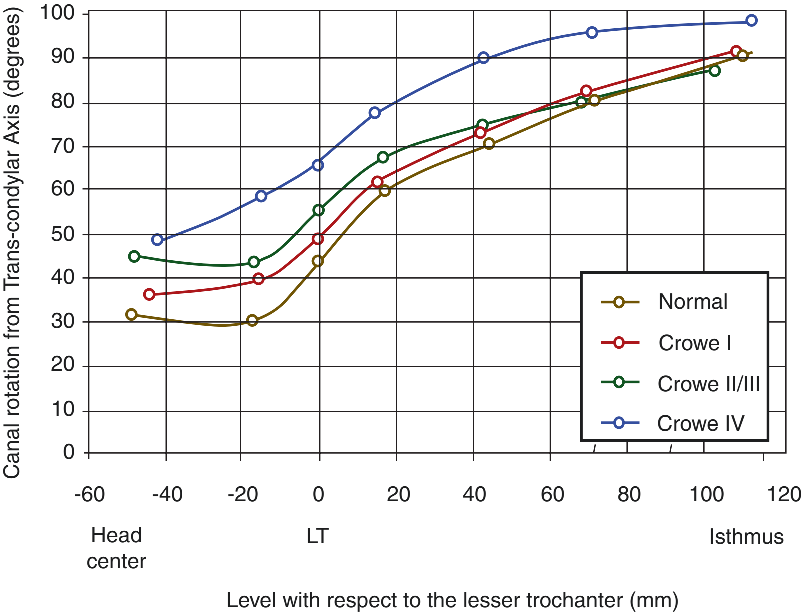

Fig. 14.3 Variation in the direction of the principal axis of the femoral canal as a function of level along the longitudinal axis (origin = center of the lesser trochanter). Average values are shown for normal and dysplastic femora derived from Japanese subjects [2]. (Reprinted from Noble et al. [2] SECTION I SYMPOSIUM: Papers Presented at the Hip Society Meeting, © 2003, https://journals.lww.com/clinorthop/Fulltext/2003/12000/Otto_AuFranc_Award__Three_Dimensional_Shape_of_the.5.aspx, with permission from Wolters Kluwer Health, Inc.)

the base of the neck to 60 mm distal to the lesser trochanter. As a result, at the level of the metaphysis, the femoral neck is oriented at 15–30° to the transcondylar plane. In the normal (non-dysplastic) femur, the average twist of the canal from the level of the proximal osteotomy to the isthmus (127 mm) is 56.6°, compared to 43.6° in the Crowe 1 femur, 52.6 ° in Crowe 2 and 3 femora, and only 39.7° in Crowe 4.

THR in the Setting of Hip Dysplasia: Surgical Management

Crowe 1 Deformities

The degree of structural abnormality is minimal in Crowe 1 deformities, and surgery can be approached utilizing the surgeon's choice of standard operating protocol and surgical techniques. On the acetabular side, the acetabular depth and bone available for circumferential coverage of the acetabular component has minor abnormality and can usually accommodate a standard hemispherical cup, femoral component, and surgical techniques. Care must be taken to ream the acetabulum sufficiently in order to provide stable and adequate component coverage. Medialization of the shallow acetabulum using the protrusio technique described in previous authors will allow placement of a larger shell with increased coverage [4, 5].

Radiographic findings include an upsloping acetabular sourcil and lack of femoral head coverage with a decreased alpha angle (Fig. 14.4). Significant variability in the orientation of the native acetabulum may exist, ranging from an anteverted to a retroverted position, and must be identified and corrected to provide satisfactory component function and durability.

At the time of acetabular preparation, it is important to position the acetabular component close to the natural hip center of rotation to restore the normal biomechanics of the hip, i.e., offset and leg length. The spatial relationship between the femur and the pelvis, and hence the moment arm of the flexors and abductors, may be defined in terms of:

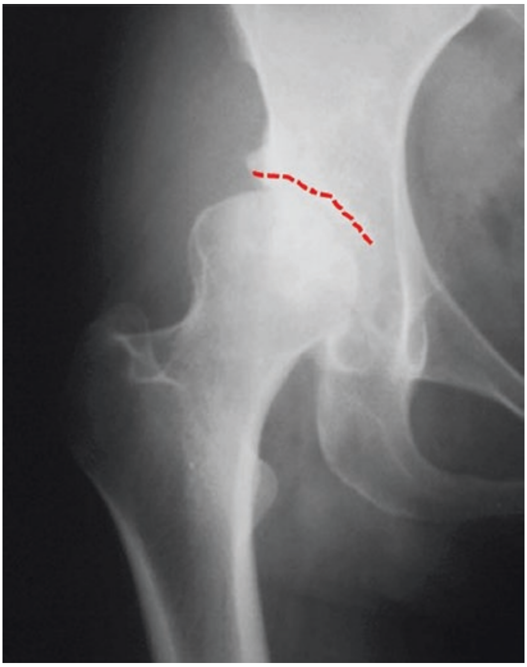

Fig. 14.4 Radiographic findings in Crowe 1 dysplasia with degenerative changes. Note an upsloping acetabular sourcil, the shallow acetabular depth, and decreased alpha angle

1. The medial and anterior components (offsets) of a line connecting muscle insertion sites on the greater trochanter and the iliac crest
2. The height of the tip of the greater trochanter with respect to the center of rotation of the acetabulum

Intraoperative measures can facilitate the restoration of the head center. As a first step, the obturator foramen is located, and an inferior retractor is carefully placed at the inferior aspect of the true acetabulum. This step is of the utmost importance during acetabular preparation, especially in higher levels of dysplasia. Once the true acetabulum is located, careful attention must be paid to the reamer direction and positioning during acetabular preparation to avoid superior or inferior placement of the hip center of rotation [6]. Just as a high hip center can be prepared if the acetabulum floor is not visualized, sclerotic bone at the superolateral dome can inadvertently force the reamer into the softer inferior medial bone leading to an inferior cup placement.

On the femoral side, common findings in dysplastic hips include apparent or actual variations in the neck shaft angle and increased anteversion [1–3]. Adequate preoperative planning and templating are important to ensure safe restoration of the normal relationship of the femur to the pelvis. If the deformity is unilateral, the normal anatomic relationship of the opposite hip will serve at the template for the involved hip, and the goal should be to restore the same offset and leg length. Implant choices in Crowe 1 dysplastic hips do not deviate much from those utilized in simpler primary arthroplasty. In the majority of circumstances, a standard hemispherical cup and a bone-conserving femoral implant are acceptable. However, care should be taken to ensure that the cup is properly medialized and stabilized with adjunctive screw fixation where needed. In addition, the femoral component should be protected against excessive version based on the preoperative understanding of individual anatomic abnormalities.

Crowe 2 and 3 Deformities

The challenges encountered with Crowe 2 and Crowe 3 deformities are similar and primarily depend on the degree of deformity, so they will be addressed together for the purposes of discussion. As the femoral head is displaced 50–75% above its normal anatomic location, there is significant damage to periacetabular bone stock and, quite frequently, a deficiency of the superior lateral acetabulum (Fig. 14.5a). In the Crowe 2 and 3 acetabula, the ability to achieve stable cup fixation is limited due to structural deficiencies, and preparation for addressing these deformities at the time of surgery is important.

Techniques for acetabular reconstruction in Crowe 2/3 dysplastic hips include medialization, as described in the previous section, as well as superolateral structural augmentation with a femoral head autograft/allograft or porous metal augments. Some studies have shown an increase rate of acetabular loosening requiring revision when acetabular reconstructions are performed more than 15 mm superior to the native acetabulum, yet some authors advocate a high hip center technique [7]. Other concerns with elevating the hip center include compromised hip motion with potential instability secondary to impingement, inconsistent abductor mechanics, and leg length discrepancy in unilateral cases [8–10]. Abnormal loading of trabecular bone rather than cortical pelvic bone is also of concern for short- and long-term stress shielding in young patients [11]. Despite these potential conflicts, in select patients, there is adequate data supporting long-term implant survivorship utilizing a high hip center technique [12–16].

If the decision is made to lower the hip center to the native acetabulum, consideration must be given to the possible increase in postoperative adductor muscle contractures. Before the surgical procedure begins and after anesthesia induction, evaluation of the adductor muscles can be done by placing the surgical leg in a frog-leg position, with passive abduction and external rotation (Fig. 14.6). If contractures are noted and in the setting of significant preoperative leg length discrepancy, a percutaneous release of the tight adductor tendons is recommended. As in the treatment of adductor-related groin pain in athletes, the percutaneous procedure is usually limited to release of the adductor longus. The remaining portions of the adductors are left intact and can be dynamically stretched post-arthroplasty [17]. The author performs this procedure after induction of anesthesia with the patient supine in the frog-leg position. After a simple prep and drape of the groin area, the tendon is identified percutaneously and then released with a #11 blade. Simple dressings are placed with no closure needed. Performing an adductor release prior to hip replacement will facilitate restoration of the anatomical leg length and allows for an easier reduction of the hip intraoperatively.

Surgery can begin with the surgical approach of preference but with a wide exposure of the proximal femur and acetabulum. In the authors' experience, improved mobilization of the proximal femur and excellent visualization of the acetabular deformity can be achieved by utilizing the posterior border of the vastus lateralis and resecting the deformed joint capsule. Adequate

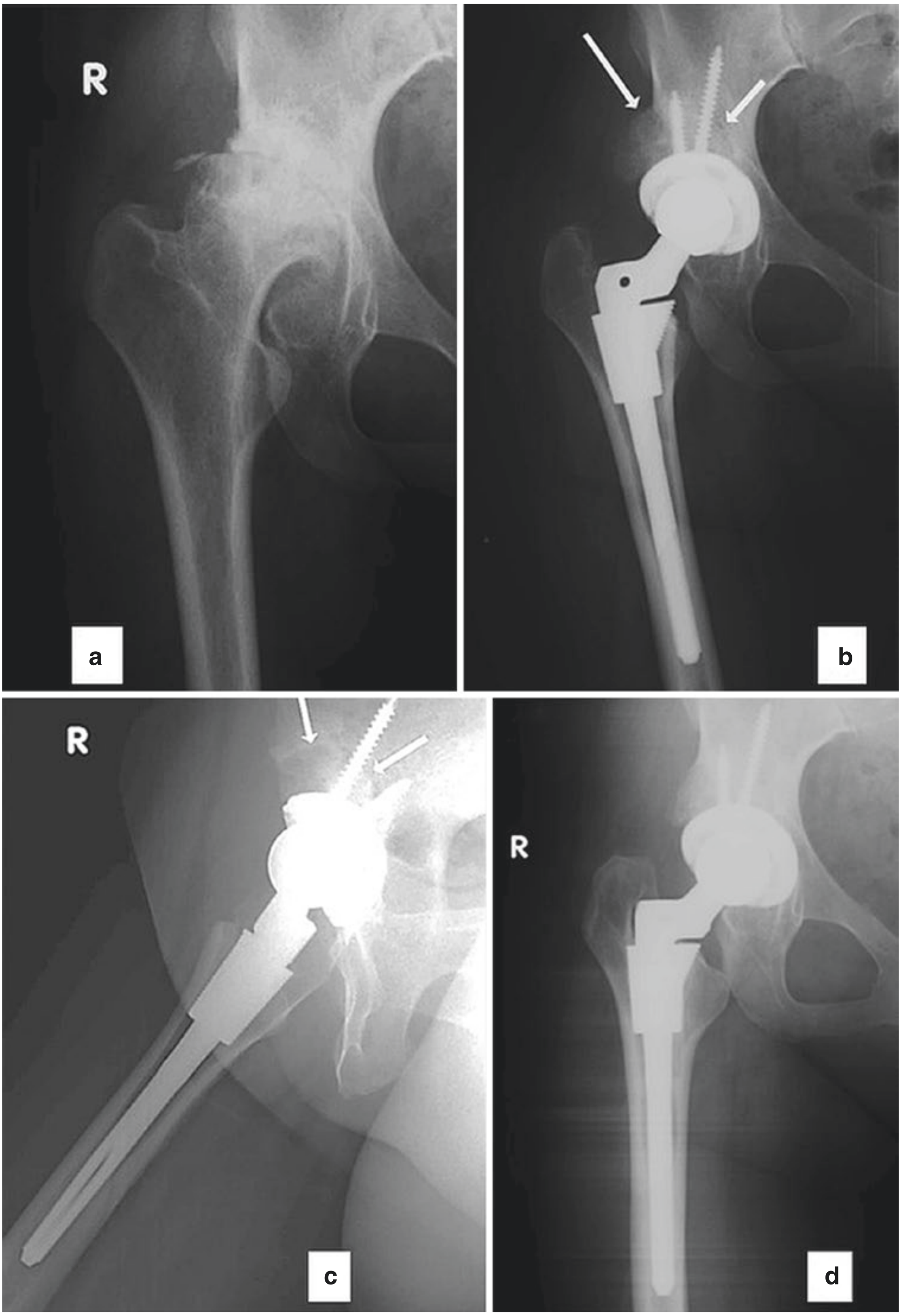

Fig. 14.5 (**a**) Crowe 3 patient with acetabular deficiency. (**b**, **c**) Immediate post-op X-rays of patient following inset autologous structural bone grafting. (**d**) Two-year post-op X-rays showing a stable cup with evidence of junctional healing of the femoral head autograft and positive signs of bone ingrowth into the acetabular component in the areas of contact with host acetabulum

Fig. 14.6 Positioning and draping for the left percutaneous adductor tenotomy. Patient is supine, left hip flexed, abducted, and externally rotated

exposure also facilitates reduction of the joint and restoration of the leg lengths. As previously mentioned, identification of the obturator foramen and careful placement of a retractor in this location will clearly identify the location of the true acetabulum and should be the first goal of acetabular exposure. Once exposure is obtained, assessment of the anterior and posterior column thickness is paramount before initiation of reaming. In most circumstances, the posterior column is significantly thicker than the anterior column due to anteversion of the femoral head and neck and the resultant stress applied to the anterior column during development.

If the superior acetabulum appears to be deficient and augmentation is required, the type and location of the augment should be considered. Options to address superior acetabular deficiency include femoral head autograft available from the native femoral head, femoral head allograft, and augmentation with prefabricated porous metal augments. In younger patients, the recommended choice is to reconstruct superolateral structural bone stock with the patient's own resected femoral head and neck which has proven to be useful if utilized correctly (Fig. 14.7). Studies of femoral head autograft to address acetabular deficiency in dysplasia have shown adequate healing of the bone autograft to the pelvis and good long-term implant survival [18, 19]. Table 14.1 provides the most recent published literature on femoral head autograft utilization to address superolateral acetabular defects [18–22].

Following preparation of the autograft, the area of acetabular structural deficiency is identified by placement of a trial acetabular shell in the anatomic cup location. The smallest available reamer (typically 36 mm in diameter) is used to initiate the preparation of the recipient bed for the structural bone graft (Fig. 14.7d). The superolateral defect is carefully and sequentially reamed to an inner diameter 2–3 mm smaller than the measured femoral head bone graft (following cartilage removal). This will ensure that press fit and autograft bone to host bone contact is maximized. On occasion, it may be necessary to penetrate the medial wall of the ilium in order to get adequate circumferential bone for graft stabilization and fixation. Next, the femoral head structural bone graft is inserted into the recipient bed. It is important for the structural graft to be oriented in such a way to ensure that the trabecular bone pattern is aligned parallel to the direction where the forces will be applied during stance and ambulation. To prevent early graft failure and provide support for the acetabular component, it is important to obtain maximum bone graft fixation by press fit as well as supplemental fixation, if necessary.

Following stabilization of the structural graft, the true acetabulum is identified, and excess overhanging graft bone is removed with a saw or burr. The true acetabulum is then carefully and sequentially reamed beginning with a small diameter reamer to achieve the correct central location of the proposed hip center in the AP plane and to ensure adequate depth of coverage. The effacement of the anterior and posterior column thickness should be checked between each reaming to ensure that the cup position is being centralized and that adequate columnar bone stock is preserved. The goal should be for optimal cup sizing in the AP dimension to maximize contact with available host bone. Maximal medialization of the acetabular component is often necessary due to the presence of a shallow native

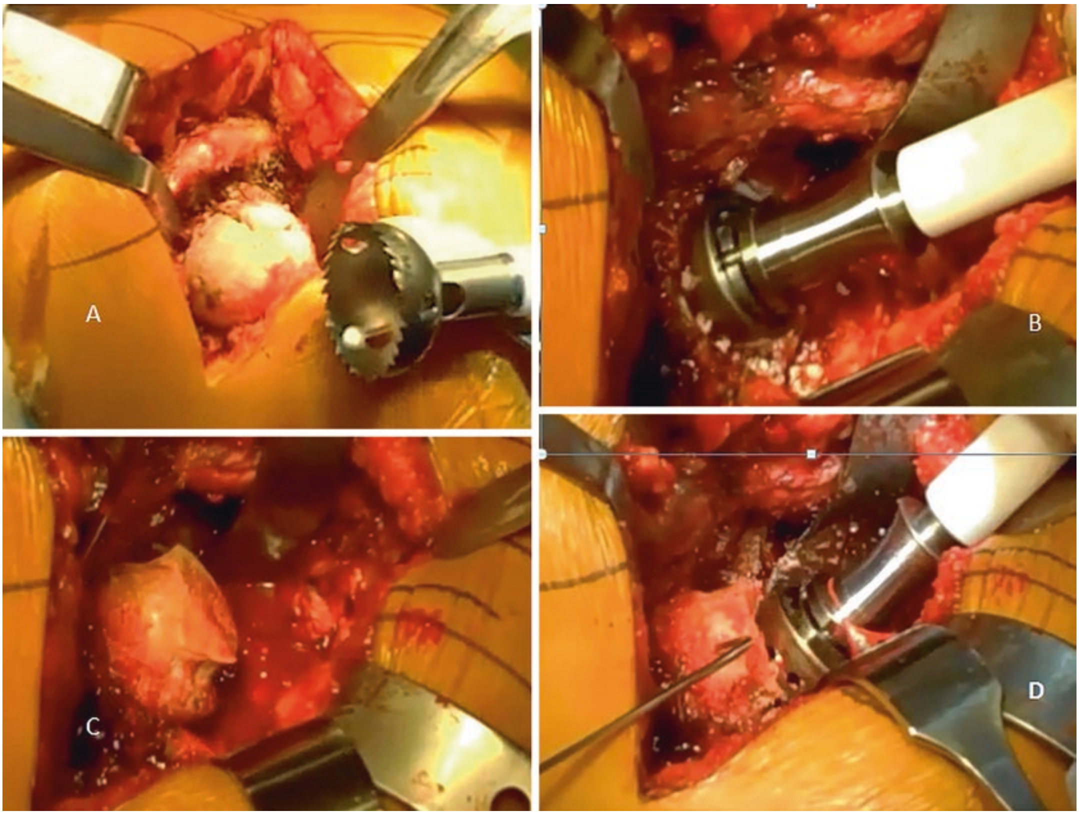

Fig. 14.7 Treatment of Crowe 3 with acetabular deficiency. (**a**) Right hip exposure and femoral head preparation for autografting with hallow reverse reamers. (**b**) Preparation of the recipient bed for structural graft placement. (**c**) Structural femoral head graft placement to restore the superior lateral rim. (**d**) Initial reaming into true acetabulum to restore anatomic cup position

Table 14.1 Results of utilization of femoral head autograft for reconstruction of acetabular defects in patients with developmental dysplasia of the hip

Author (year)	Type of implant	No. of cases	Mean age (years)	Mean follow-up in years	Results
Kim et al. [19]	Noncemented head autograft	83	57 years (range, 33–72)	11 (range, 9–14)	94% cup survival at 10-year follow-up
Abdel et al. [18]	Noncemented head autograft	35	43 years (range, 12–60)	21.3 (range,13–26)	3% revision for loosening 34% mechanical failure
Ozden et al. [20]	Noncemented head autograft	38	47 years (range, 29–64)	20.3 years (range, 15–26 yrs)	66% cup survival at 20-year follow-up No graft resorption
Saito et al. [21]	Noncemented head autograft	37	53.8 years (range, 40–65)	18.5 years (range, 15–24 yrs)	94.5% implant survival at 18.5 years of follow-up
Zahar et al. [22]	Cemented and noncemented head autograft	115	52.5 years (range, 34–80)	11.6 years (range 7–24 yrs)	16% revisions for aseptic loosening

acetabulum. A minimum of two screws is recommended to stabilize the construct (Fig. 14.7). In older patients whose bone may not be optimal for autografting, augmentation of the superior lateral deficiency can be performed successfully with a femoral head allograft or porous metal augments. Adequate survivorship has been documented with the use of porous metal augments at mid-term follow-up in the setting of complex acetabular deficiencies, including Paprosky 3A and 3B defects [23–25].

On the femoral side, the choice of implant is quite important, and the correct implant decision typically depends on the proximal femoral anatomy. Adequate preoperative radiographs and accurate templating of the femoral canal and metaphyseal-diaphyseal mismatch together with the expected anteversion are determinants of adequate implant selection [26]. The optimal implant will restore the dysplastic hip to its anatomic center and allow for restoration of its offset and the patient's leg length without compromising bone fixation or increasing fracture risk. Implant options include the more "primary" dual wedge tapered stems or even blade stems when possible (Fig. 14.8). If excessive anteversion is present or in cases with abrupt metaphyseal-diaphyseal transitions to tight canals (Dorr A canals), modular implants can allow dissociation of the diaphyseal/metaphyseal fixation from the version of the implant [27, 28]. Lastly, the femoral stem version can also be "dialed" with monopolar, splined, tapered stems as these stems engage in the diaphysis and bypass the proximal morphologic inconsistencies [29]. Due to the abnormal proximal femoral anatomy, identification of the central anatomical canal and the location of the metaphyseal flair are important, particularly with diaphyseal engaging stems to prevent stem undersizing, varus malpositioning and even intraoperative

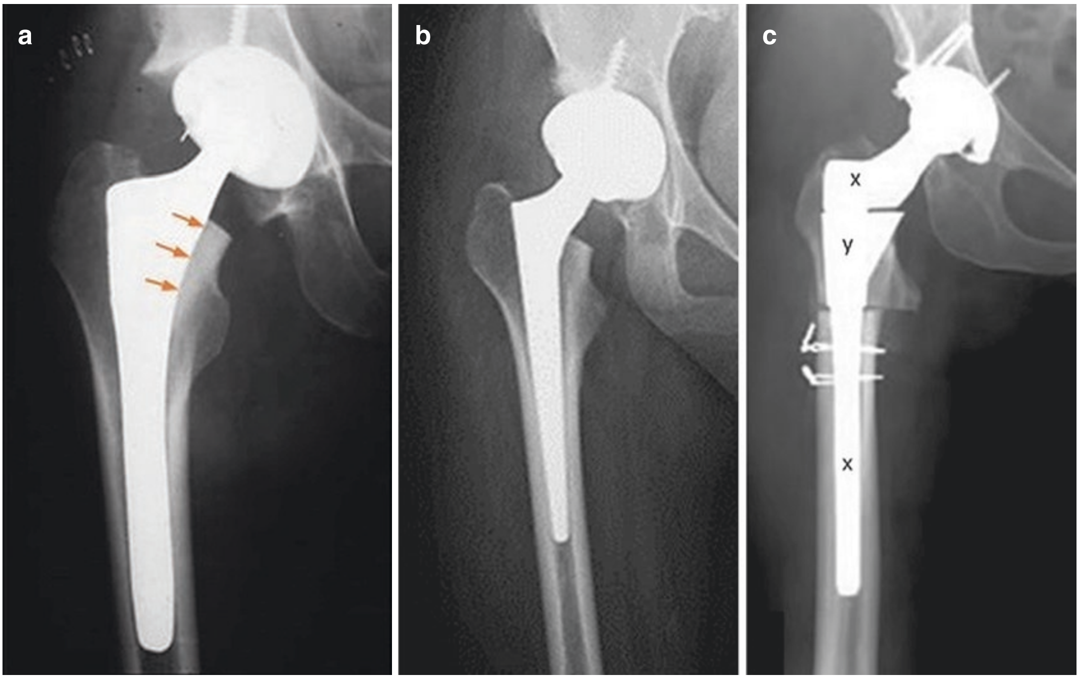

Fig. 14.8 Classic designs of femoral prostheses commonly used for THA in hip dysplasia. (**a**) Conventional cementless stem with proximal medial flare (arrows); (**b**) Wagner-style prosthesis with tapered stem with longitudinal flutes for rotational fixation; (**c**) S-ROM prosthesis consisting of a cylindrical stem and neck component (x) and a modular proximal sleeve (y) (**a**): Author's own collection (**b**): (Reprinted from Zhen et al. [33]. https://bmc-musculoskeletdisord.biomedcentral.com/articles/10.1186/s12891-017-1554-9 https://doi.org/10.1186/s12891-017-1554-9 [33] (**c**) Image courtesy Park et al. [34] Department of Orthopedic Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea. Copyright 2018 by Korean Hip Society [34])

femoral/trochanteric fractures. The greater trochanter is also commonly located posterior to the normal hip position as a result of pathological coxa valga and neck anteversion which can further risk intraoperative fracture and implant malposition. Despite the availability of biologically capable implants, some surgeons may still prefer to utilize a cemented femoral prosthesis in this circumstance in spite of the high rate of aseptic loosening, especially on the acetabular side [30–32].

Crowe 4 Deformities

Bony and Soft Tissue Morphology

The Crowe 4 Acetabulum

The most severe deformities are seen in Crowe 4 dysplastic hips which involve complete dislocation of the hip usually since birth or shortly thereafter. As a result, bony development of the acetabulum is unable to occur normally secondary to the absence of forces being applied to the developing acetabular growth centers by the femoral head. Consequently, acetabular development yields a small, shallow, but circular socket with intact anterior and posterior columns and an intact superolateral roof. The posterior column is often larger and thicker than the anterior column, and this should be accounted for as previously described during acetabular preparation. Hence, cup fixation is often challenging and is often compounded by the hypotrophic morphology of the pelvis and the small size of the implantation site (typically 38–50 mm in diameter). This significantly limits the area of the implant-bone interface and the range of acetabular shells and liners that are commercially available. To achieve a stable construct, bony coverage must be present within the acetabular dome at the desired level of implantation for restoring joint function. In view of the distorted anatomy, it is important to be prepared to utilize an augment or allograft to fill the gap between the shell and the acetabular dome after reaming. Bone screws are essential to augment initial press-fit fixation between the shell and the native socket.

Crowe 4 Femoral Anatomy

The typical Crowe 4 femur has a hypotrophic appearance and is 10% to 25% smaller than the normal femur of individuals of the same age and gender. Typical differences are seen in neck length (17%), external diameter of the diaphysis (12%), and the thickness of the medullary cortex (24%). The femoral canal is frequently narrow, with an internal diameter of 7–10 mm in approximately half of cases. As noted above, the Crowe 4 canal is also more cylindrical than the typical conical shape of the non- or less-dysplastic femur, with a canal flare index of 2.3–2.9 in Crowe 4 cases versus 3.2–3.8 in non-dysplastic controls [2]. The location and magnitude of the anterior bow is also highly variable (depth below lesser trochanter: 103 ± 24 mm; range: 54–145 mm) which may limit the length of the femoral component implanted during joint replacement in DDH patients.

A common characteristic of the DDH femur has a flattened aspherical femoral head with a short femoral neck. Typically, the head is displaced anterolaterally, with reduced medial (−13%) and increased anterior offset (35%) compared to normal controls. Although the Crowe 4 femur is often depicted with increased inclination of the femoral neck (coxa valga) compared to normally accepted values, this appearance is primarily an illusion created by external rotation of the femur with respect to the coronal plane (Fig. 14.1). Detailed analysis shows that the neck inclination of the average Crowe 4 femur is slightly more horizontal than normal controls (118.2 ± 7.1° versus 124.9 ± 6.4°; $p = 0.002$); however, individual cases varied widely, ranging from 103° to 126°. In one study of normal versus dysplastic femora in the Japanese population, the incidence of coxa valga (neck-shaft angle >135°) was found to be 6% in normal femora and 0% in the Crowe 4 cases, while coxa vara (neck-shaft angle <115°) occurred in 6% of the normal femora compared to 31% of the DDH cases. The average anteversion of the DDH femora was 19.2° larger than the normal controls (46.1 ± 8.1° versus 26.9 ± 11.5°; $p < 0.0000$). In addition, only 15% of normal femora had extreme anteversion (>40°), compared to 77% of the Crowe 4 cases ($p < 0.0001$).

The Biomechanics of the Crowe 4 Hip

The structural changes present in the dislocated (Crowe 4) hip involve both the bony and soft tissues and include shortening of the extremity secondary to dislocation, superior migration of the point of articulation, and shortening and atrophy of the hip flexors, abductors, and extensors Reconstruction of the Crowe 4 hip with THR combined with a femoral shortening osteotomy leads to dramatic improvements in pain and hip function, including increased power of abduction, reduced leg length inequality, and substantial gains in gait symmetry and efficiency, all leading to improved hip outcome scores [35]. From a biomechanical perspective, these benefits are derived from:

(a) The presence of a normal fulcrum to allow muscle contraction to drive the angulation of the hip.
(b) Restoration of the moment arms of the hip muscles, principally the abductors, through correction of the exaggerated anteversion of the dysplastic femur (Fig. 14.9) [36].
(c) Relocation of the hip center within the native acetabulum where motion can occur with the lowest values of the hip forces [37, 38].
(d) Elongation of the hip muscles to their physiologic resting length, thereby increasing the force of muscle contraction (Fig. 14.9) [39].
(e) Restoration of equal leg lengths.

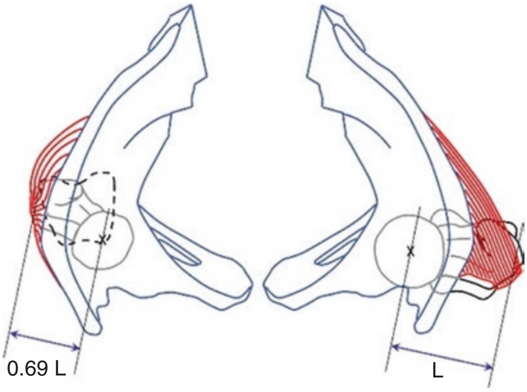

Fig. 14.9 Schematic view of identical hemipelves with a normal femur within the native acetabulum of the left hip and a Crowe 4 femur within the pseudo-acetabulum on the contralateral side. A profound difference is evident in abductor tension. Moreover the moment arm of the musculature of the Crowe 4 hip is reduced by approximately 30%

Crowe 4 THR: Surgical Management

As previously described and more importantly in Crowe 4 hips, prior to initiating the surgical incision and while the patient is in the supine position, the adductor muscles should be assessed, and the adductor tendon release should be performed via a percutaneous incision. Next, the patient is positioned in the lateral decubitus position. The posterolateral approach is the authors' group preferred approach, though different surgeons may favor approaches with which they are more familiar. A wide surgical exposure should be carried out, and should a proximal femoral osteotomy be planned, the incision should be extended distally to expose the proposed location of the femoral osteotomy. Following release of the soft tissue envelope posteriorly, dissection should be carefully extended along the capsule down to the level of the acetabulum. The obturator foramen should be identified and a retractor placed to identify the location of the true acetabulum. Often, a release of the psoas tendon is required due to marked contracture. The femoral neck can be exposed next which is best facilitated by a complete capsulectomy. This will allow for safe mobilization of the proximal femur.

Surgical shortening of the femur should be performed in cases of severe dysplasia where more than 3 cm of caudal displacement of the femur is required to restore the femoral head to the native hip center [40–43]. Femoral shortening allows less traumatic hip reduction and reduces the risk of traction sciatic nerve injury and foot drop. The transverse subtrochanteric osteotomy as described by Krych et al. is the most frequently used technique and has shown very adequate union rates of 93% when cortical strut autografts are utilized to augment the osteotomy fixation [44]. This and other subtrochanteric osteotomy techniques (i.e., step-cut and oblique osteotomies) also allow for preservation of the abductor musculature as well as correction and control of rotational deformities and excessive anteversion. Low revision rates at mid- to long term have been reported using these approaches [45, 46]. An alternative osteotomy technique will be described in the Author Preference section.

In Crowe 4 hips, a femoral osteotomy allows for better acetabular exposure, so the decision whether or not to perform an osteotomy should be made prior to acetabular exposure and bony preparation. The surgeon can then begin reaming with the smallest reamer resting in the central aspect of the true acetabulum. It is important to evaluate the anterior and posterior wall effacement during each step of the reaming process. The surgeon should direct the reamer more centrally to place the cup close to the true acetabular center. The selected implant system must include reamers and shells of the smaller diameters encountered in DDH cases, typically commencing at 38–40 mm. Reaming should continue to expand the opening to accommodate the largest possible size of shell and femoral head combination without compromising the stability of the acetabular component, the coverage of the shell, or the structural integrity of the pelvis. It is not uncommon to have to use a 22 mm diameter femoral head.

Preparation of the femoral side is determined by the technique associated with the selected implant. For Crowe 4 femurs, the canal diameter should receive special attention, as the canal tends to be extremely narrow, so that small diameter reamers should be available. As the morphology of the femur is distorted, the medullary canal should be identified first, followed by enlargement of the proximal metaphysis by 1–2 mm to allow the first canal reamer to be aligned centrally within the diaphysis and not be malaligned through contact with more proximal bone. If a tapered fluted stem design is selected, the diaphyseal fixation is critical to the stability. If a modular-type stem design is selected, the metaphyseal area will be prepared to accommodate a larger porous-coated sleeve once the diaphyseal stem diameter has been established. This will minimize the risk of canal perforation and fracture as well as component malposition due to a misguided reamer. If a tapered, fluted stem is selected, a trial reduction can be performed after diaphyseal reaming. If a modular metaphyseal sleeve stem design is selected, then metaphyseal preparation is performed prior to trial reduction. At the time of reduction, a second chance presents itself to opt for a shortening osteotomy if this decision was not made prior to acetabular preparation.

The femoral shortening osteotomy is performed in the subtrochanteric location below the vastus ridge as described by Ollivier et al. and others [45]. Both preoperative templating and intraoperative assessments guide the amount of shortening required. Some surgeons advocate for a transverse osteotomy resection for ease of rotation of the proximal femur, while others prefer a biplane oblique osteotomy that allows for rotational correction and femoral shortening but provides for more rotational stability of the two proximal femoral segments [46]. Both osteotomy techniques can be successful if executed properly. The femoral canal distal to the osteotomy should be reamed prior to the bone cut to accommodate the prosthesis in the shortened femur. Once the trial reduction has been performed, and implant stability and correct coupling have been confirmed, the trial implant can be removed, and the final implant inserted. Care should be taken to mark the appropriate rotational position of the proximal and distal segments, and this should be maintained during final implant insertion. The osteotomy site should be stabilized if necessary and augmented in all cases with the cancellous acetabular reamings or the cortical autograft fragments from the femoral shortening.

Avoiding Nerve Injury During THR in the Dysplastic Hip

Sciatic nerve injury can be a rare but devastating complication of total hip arthroplasty and may reach up to 3.7% in complicated primary arthroplasty and up to 8% in revision arthroplasty [47, 48]. Historically, developmental hip dysplasia with leg shortening has been described as a non-modifiable risk factor for nerve injury during arthroplasty [49]. Lengthening more than 4 cm during arthroplasty has been correlated with nerve injury in some studies, but some have shown no direct correlation with leg lengthening and palsy [50]. Even though no guidelines exist to predict safe amount of lengthening to prevent neurapraxia, use of intraoperative neurologic monitoring with continuous electromyographic monitoring

(EMG monitoring), nerve conduction velocities, and somatosensory evoked potentials (SSEP) can be recommended in high-risk cases. Dysplasia patients and their proposed arthroplasty bring multiple risk factors for postoperative nerve palsy. Included are the dysplasia diagnosis, expected leg lengthening, prolonged surgical time, and complex surgical exposure.

Studies have shown that, despite the inherent limitations of EMG (inability to detect ischemic/traction injury) and SSEP (sensitivity to anesthetic agents and inability to assess immediate injury or motor tract integrity), both modalities have a role in the detection of intraoperative injury. Motor evoked potentials, in which activity in sciatic nerve innervated muscles is detected following transcranial stimulation, also provides a more physiological reading in multimodal nerve monitoring systems. In complex primary or revision hip arthroplasty, the efficacy of intraoperative nerve monitoring techniques in decreasing the incidence of nerve palsy has not been established. Previous studies have not demonstrated that nerve palsy occurs less frequently when nerve monitoring is used during hip arthroplasty, though changes in nerve conduction are most frequently detected in complicated hip reductions and during acetabular reaming/preparation [51–53]. In hip dysplasia patients, particularly Crowe 3 and 4 cases, where complex and prolonged reconstruction is commonplace and may be combined with limb lengthening, nerve monitoring can play a role in detecting intraoperative nerve injury leading to immediate correction.

Implant Selection

Femoral Components for the Dysplastic Hip

For successful, durable THR, stable fixation must be achieved between the femoral stem and the medullary canal, and the femoral head center must be restored to a biomechanically acceptable position (Fig. 14.8). Several cementless stem designs are currently available to achieve rigid implant fixation through mechanical interlock with the endosteal surface, including:

1. **Monolithic** (i.e., non-modular) stems of tapered geometry. These implants come in two basic forms that are suitable for use in mild dysplasia:
   (a) **Zweymuller-style** stems with a rectangular cross section and a grit-blasted surface and a fixed (non-modular) neck.
   (b) **Conventional** femoral stems, often with a reduced medial curvature and increased sagittal plane taper to fit the dysplastic canal. Implants of this style may be symmetrical (i.e., same implant fits left and right femora) or bowed (i.e., separate left and right components) [54, 55]. They may also be metaphyseal filling or have an anterior-posterior width that is narrower than the medullary canal (i.e., have a "blade-shaped" geometry).
2. The **S-ROM** (Sivash-Range of Motion) implant, consisting of a smooth, fluted cylindrical stem with a fixed femoral neck coupled with a modular proximal body [27, 28]. It accommodates a wide range of femoral geometries spanning canal diameters of 6–19 mm with nine sizes. Sizes 6–10 mm come in 1 mm increments and are particularly suitable for DDH cases.
3. A **Wagner-style** prosthesis consisting of a generously (5°) tapered stem with aggressive longitudinal flutes and a fixed femoral neck supplied in two neck-shaft angles (125° and 135°) [29]. Twelve stem sizes are available spanning small to large (isthmus diameters: 7–18 mm). Mid-shaft diameters range from 13 to 24 mm.

All of these implants are fabricated from forged titanium alloys, and while each has its own individual advantages, a clear benefit of the two cylindrical designs (S-ROM and Wagner) is their ability to be positioned in any rotational orientation within the medullary canal without point contact with the endosteal surface. The S-ROM has the additional advantage that the modular proximal sleeve provides metaphyseal support of the stem thereby distributing the applied load over a greater length of the canal and increasing the rotational stability of the construct. When a canal-filling stem is implanted in the femur, its final rotational orientation is determined by the

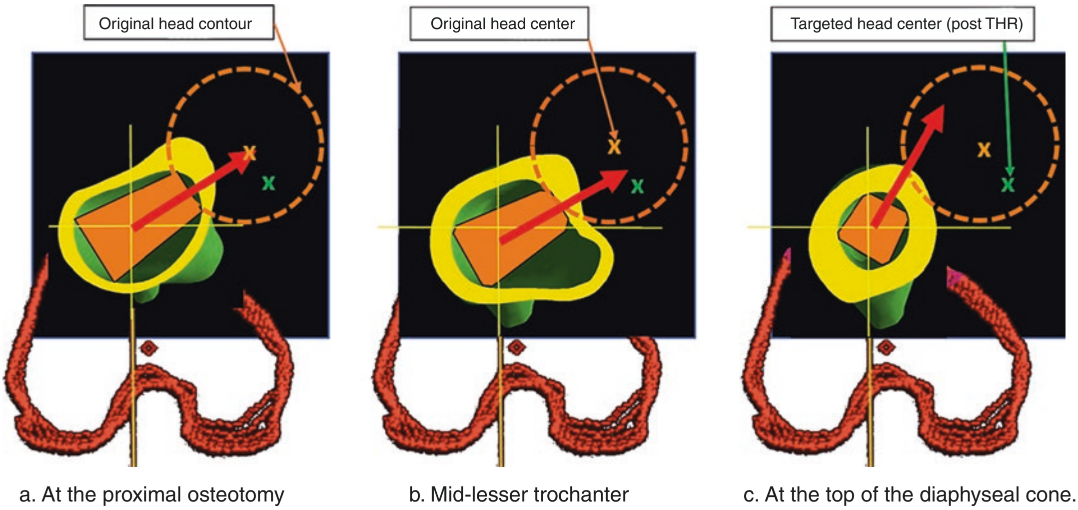

Fig. 14.10 The level of engagement of the femoral stem within the canal changes the axial rotation of the implant and thus the position of the head of the prosthesis. In this figure, a symmetrical non-modular femoral stem of generic design has been implanted in a typical dysplastic femur. By varying stem dimensions (but not the cross-sectional shape), stem engagement is achieved at different levels of the medullary canal. The resulting stem rotation is shown by the red arrow which depicts the fixed neck of the prosthesis. The new head center corresponds to the tip of the arrow. The targeted head position corresponds to 20° of anteversion (**a**): Original head contour (orange arrow) at the proximal osteotomy. (**b**): Original head center (orange arrow) at the mid-lesser trochanter. (**c**): Targeted head center (post-THR) (orange arrow) at the top of the diaphyseal cone

interaction between the cross-sectional geometry of the implant at the level of first contact with the canal (Fig. 14.10). As the widest diameter of the canal is more anteverted below the lesser trochanter, conventional press-fit stems that lock in at this level tend to place the neck of the prosthesis in excessive anteversion, depending on the original anteversion of the femur and the degree of flexion of the stem in the sagittal view. This is not generally a concern in cases where the femur has less than 25° of anteversion; however, in the Crowe 4 femur where excessive anteversion is almost always present, the cross-sectional shape of the canal cannot determine the rotational orientation of the femoral stem. In many dysplastic cases, satisfactory restoration of head position with respect to the pelvis is only possible through de-rotation of the neck of the prosthesis by more than 15° and, in extreme cases, the addition of a de-rotational osteotomy below the level of the lesser trochanter [31]. Some correction of head position can be achieved by displacing the head posteriorly in addition to reducing anteversion (Fig. 14.11).

The trade-off between monolithic (i.e., non-modular) and modular implant selection has been studied by Peters et al. in a retrospective review of 50 cases of THR performed in dysplastic hips [26]. In this series, the authors retrospectively reviewed radiographic indices of patients receiving either a monolithic cementless stem of a narrow, tapered design and conventional medial flare

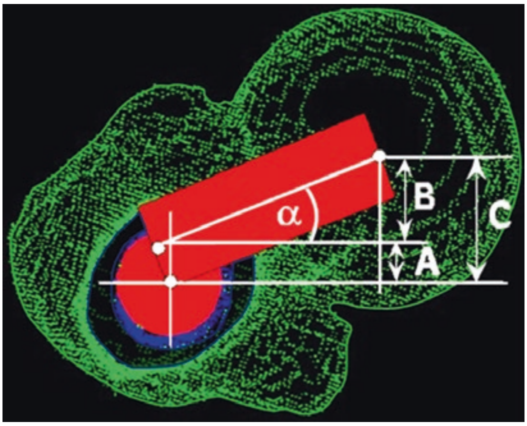

Fig. 14.11 A wire-frame reconstruction of a dysplastic femur implanted with a cylindrical femoral stem and the cylinder of best fit to the femoral neck. The anterior offset of the head center from the canal axis (**c**) is seen to be a combination of offset due to stem anteversion (**b**) and the offset of the neck with respect to the canal (**a**; typically 4–8 mm). α – anteversion, A – anterior neck offset, B – head offset due to anteversion, C – anterior head offset (C = A + B)

or a modular implant (S-ROM) consisting of a cylindrical fluted stem with a proximal sleeve. Patients receiving the modular implant presented with more femoral anteversion (45° vs. 21°, $p < 0.0001$), a higher neck-shaft angle on standard AP radiographs (152° vs. 137°, $p < 0.0001$), and a smaller lateral center-edge angle (9° vs. 19°, $p = 0.003$) than those receiving monolithic components. Receiver-operator analysis revealed that the best predictor of selection of a modular stem was initial femoral anteversion ≥32°.

Despite their ease of use intraoperatively and versatility in allowing adjustment of femoral head position, modular stems present a number of long-term concerns, especially in younger female patients with advanced hip dysplasia [56]. Potential complications include adverse metal reactions arising from debris generated at modular connections, mechanical failure of the narrow femoral stem, and proximal bone loss due to long-term stress shielding of the metaphysis following rigid fixation of the distal stem [57, 58]. Alternative 3D monolithic designs consisting of stems specifically developed for the dysplastic femur and asymmetric femoral necks have proven clinically successful in regions where DDH is common (e.g., Japan).

Another approach has been the use of custom-fabricated components in which the orientation of the body of the implant is designed to fill the patient's metaphysis while the head and neck are placed in a corrected location [59, 60]. In theory, this provides customized canal fit without compromising the 3D position of the femoral head, as defined by the anterior and medial offset of the articulation at the ideal height with respect to the greater trochanter. Although this is an elegant approach, the cost of this solution has been prohibitive in the past, though this may again become feasible with the advent of 3D printing and other more cost-effective technologies.

Do Not Forget the Ipsilateral Knee

Though developmental dysplasia is primarily an abnormality of the hip joint, alterations of the normal growth patterns of the entire lower extremity often occur. These structural alterations arise in response to the mechanical environment at the time of birth and during the early development period. As a result, it is important to evaluate the overall mechanical alignment of the leg, the knee, and the foot and ankle as well as the soft tissue alterations when initially examining a patient with developmental dysplasia. The developmental effects on the lower extremity can be quite variable primarily as a function of the degree of dysplasia of the hip. Detailed studies investigating the structural changes of the knee in patients with neglected developmental dysplasia of the hip have demonstrated that subjects with hip dysplasia have increased height of the medial femoral condyle, leading to valgus inclination of the articular surface in the AP view [61]. A concomitant increase in the medial proximal tibial angle was also present, further contributing to the overall valgus malalignment. It is speculated that during skeletal development, vertical enlargement of the medial femoral condyle occurs as a result of tensile forces present medially while the lateral condyle remains relatively small due to the compressive loads. This eccentric growth helps to maintain the perpendicular force transfer across the knee joint created by muscle tension and body weight [61].

As a result of these mechanical alterations, many patients have concomitant pain or arthritic changes of the knee at the time of proposed hip surgery. Evaluation of the local anatomy of the entire lower extremity should be performed and analyzed in detail during the planning phase in order to anticipate the mechanical alterations of the proposed surgical procedure. Patients who demonstrate tibiofemoral angular deformities and arthritis prior to corrective hip surgery will experience exacerbation of symptoms following surgery.

Special Considerations for Crowe 4 Cases

The surgical influences of corrective hip surgery on the lower extremity alone cannot be overlooked. One study looked at patients with Crowe 3 and 4 dysplasia who were undergoing THR with radiographically normal asymptomatic knees [62]. After restoration of the hip center to its normal anatomic position at the time of surgery, all knees shifted into increased valgus angulation and displayed progressive radiographic changes with onset of knee pain. This was true even after femoral shortening. The length of femoral resection did not correlate with the change in Q-angle. Rather, the changes observed and the resulting symptoms occurred in cases with lengthening of the extremity though not the extent of the lengthening itself. This observation supports the conclusion that increased tension of the iliotibial band (ITB) following limb lengthening leads to valgus deformity, overloading of the lateral compartment, and joint pain. Based on the senior author's clinical experience, it is important to evaluate the tension of the ITB at the time of placement of femoral trials for consideration of further femoral shortening prior to final implant insertion. Other treatment options to consider include periarticular ITB fractional lengthening or lengthening of the ITB via a distal site near the knee using a separate incision.

Authors' Preference

An alternative technique to manage this difficult and rare problem has been performed over the past 20 years successfully and involves a different type of trochanteric osteotomy. Following the extensile approach with wide exposure of the acetabulum, the capsular removal, and the psoas tendon release, gentle traction is applied to the lower extremity for maximum leg length restoration. The femoral shaft is then marked at the level of the superior obturator foramen, and the vastus lateralis is elevated to permit a transverse osteotomy of the femur at this level (Fig. 14.12). The proximal femoral segment is then rotated and split in the sagittal plane with a reciprocating saw, in a fashion similar to an extended

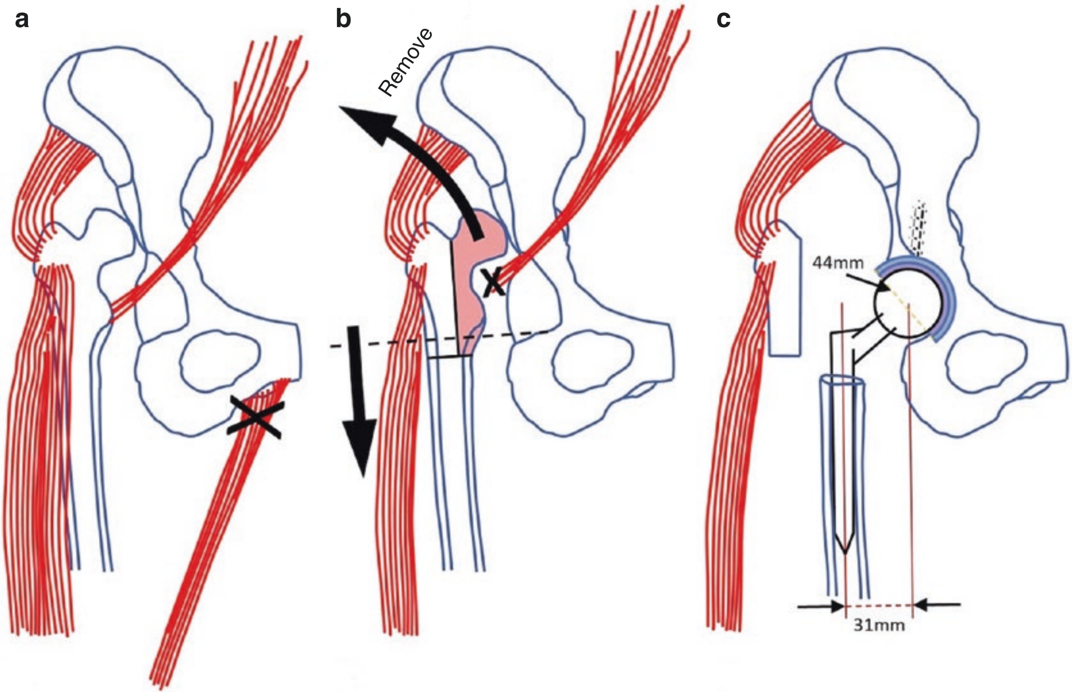

Fig. 14.12 Sequence of steps for treatment of a chronic high dislocation of the dysplastic hip. (**a**) A percutaneous adductor release is performed at the start of the procedure. (**b**) Following wide surgical exposure and release of the psoas tendon, the femur is retracted distally, and a transverse osteotomy of the femur is performed at the level of the superior obturator foramen. The proximal body is split and the medial side removed preserving the greater trochanter with the abductor envelope intact. (**c**) Next, the acetabulum and the femur are prepared and the components inserted and reduced

trochanteric osteotomy with the resection line aligned parallel to the medial edge of the greater trochanter. The medial portion of the proximal femur including the medial calcar is then excised. The remaining lateral proximal femur segment retains the entire abductor mechanism attached to the trochanter as well as the vastus lateralis. Performing the osteotomy prior to acetabular preparation greatly improves acetabular exposure for complex acetabular preparation which is done as previously described.

Following acetabular preparation and cup placement, the femoral shaft distal to the osteotomy is then prepared for either a tapered, fluted stem or a spout-less modular stem which will accommodate this small diameter canal. A prophylactic proximal wire or cable is recommended in extremely small diameter bones to prevent against a longitudinal split of the proximal femur. A trial implant is placed, and the hip reduction allows for evaluation of soft tissue tightness, implant positioning, and hip stability. Easy access to the sciatic nerve is also available to assess soft tissue tension. Adjustments in leg length and stem height can be made at this time.

Following insertion of the final femoral component and head, the hip is reduced, and the leg is placed onto the padded Mayo tray with the hip slightly abducted (Fig. 14.13). The outer diameter of the lateral shaft of the femur is measured. The greater trochanteric segment is inverted, and the inner diameter of the bone is expanded with a burr or backhanded saw such that it is wide enough to accommodate the lateral shaft of the femur. The recipient site on the femur lateral cortex is decorticated to enhance bone healing. Two cables or wires are placed around the proximal portion of the femoral shaft, and the greater trochanter is advanced onto the lateral femoral shaft as far distally as possible taking care to maintain an anatomic rotational position of the trochanter

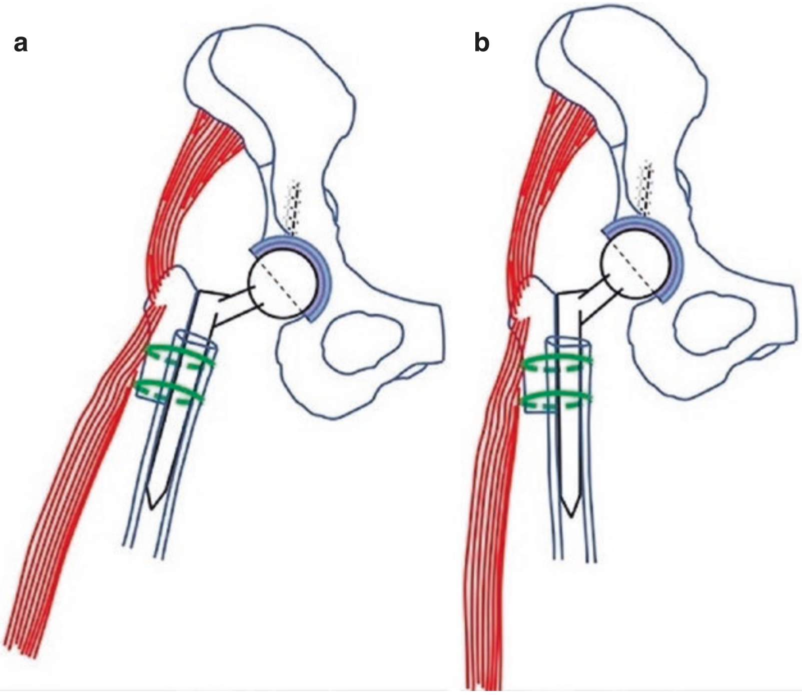

Fig. 14.13 (**a**) The leg is placed in an abducted position on the padded Mayo tray. The trochanter is advanced onto the lateral shaft of the femur and reduced. The trochanter is fixed to the femur using two cables or wires. (**b**) The hip is checked for stability

while the two cables (or wires) are tensioned. Adequate abductor musculature tension is also accounted for during reduction of the proximal fragment (Fig. 14.14). The cancellous bone fragments salvaged from the reaming of the acetabulum are layered between the trochanteric section and the lateral femur cortex prior to securing the cable fixation. The hip can be taken through a range of motion to ensure that the greater trochanteric fixation is stable.

Postoperatively, we recommend that patients walk the day of surgery with foot flat touchdown weight-bearing restrictions for 4–6 weeks. An abduction hip brace can be used at the discretion of the surgeon, but instructions to avoid active abduction can be given to the patient. Gradually, progressive active abduction can be permitted according to evidence of radiographic union of the osteotomy site, usually at 6–8 weeks postoperatively (Fig. 14.15).

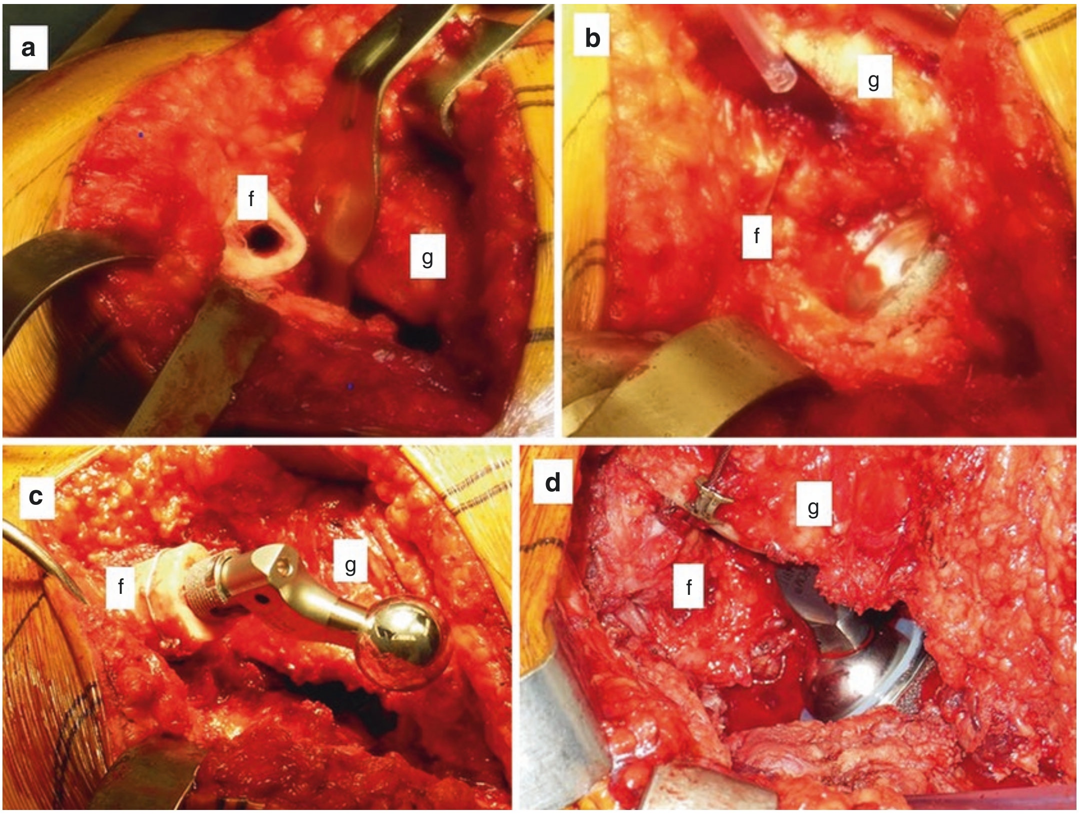

Fig. 14.14 (**a**) Left femoral canal (f) exposure following proximal femoral osteotomy and proximal medial calcar resection. (**b**) The greater trochanter (g) with the abductor envelope is easily retracted allowing full visualization of the acetabulum for preparation. (**c**) Femoral canal preparation and implant insertion followed by reduction into the acetabulum. (**d**) Post-reduction of the greater trochanter (**a**) onto the lateral shaft of the femur and secured with two cables (**b**)

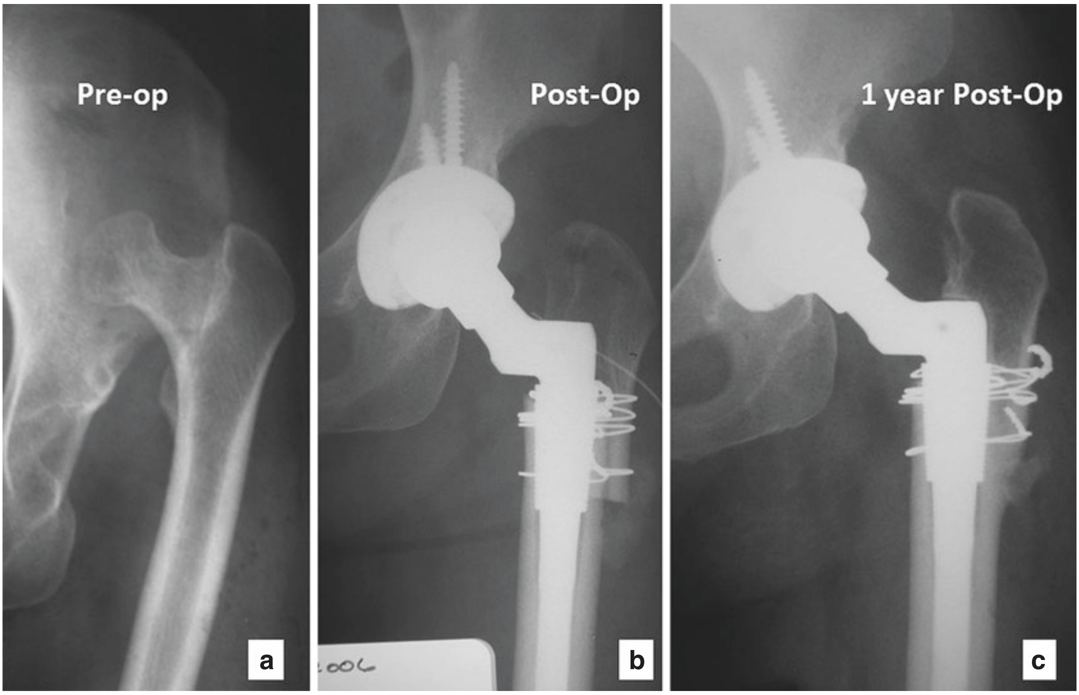

Fig. 14.15 Radiographs of a Crowe 4 DDH case. (**a**) Pre-op, (**b**) Immediate post-op, and (**c**) 1-year post-op with excellent remodeling

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