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Developmental Dysplasia of the Hip in Young Children

Stuart L. Weinstein and Joshua B. Holt

Introduction

Developmental dysplasia of the hip (DDH) is an all-encompassing term used to describe the wide spectrum of disorders of development of the hip that manifests in various forms and at different ages. The longstanding terminology of *congenital dysplasia* of the hip was initially described by Dupuytren in 1832 when he noted the classic features of shortening of the thigh, lack of abduction, prominence of the greater trochanters, and associated abductor lurch [1]. This original term has generally been replaced by developmental dysplasia or *DDH* since the 1980s after it was initially introduced in the 1960s as the former implies the existence of the disorder at the time of birth, while the latter more appropriately conveys the spectrum of associated hip pathology typically being described [2–4]. Failure to maintain the appropriate spatial positioning of the femoral head in relation to the acetabulum results in the clinical findings of *instability*, *subluxation*, *dislocation*, or more inclusively *dysplasia*. As the newer terminology implies, DDH often evolves over time as the structures of the hip are normal during embryogenesis but gradually become abnormal. Importantly, progression of deformity is dynamic and is capable of getting better or worse as the child develops, depending on the multidisciplinary care provided [5]. As such, DDH will be used herein to describe any structural abnormality of the hip resulting from an uncharacteristic relationship between the femoral head and the acetabulum, not associated with a discrete primary insult. The general exception to this rule is the case of “teratologic dislocation of the hip”, in which the femoroacetabular relationship is abnormal before birth and presents as an irreducible hip with limited range of motion during the newborn period. Teratologic dislocation is commonly associated with neuromuscular syndromes, such as arthrogryposis or myelodysplasia. This is a rare unique entity and will be discussed separately.

> ***“Importantly, progression of deformity is dynamic and is capable of getting better or worse as the child develops…depending on the multidisciplinary care provided*** [5]***”.***

Pathophysiology

Normal Growth and Development

During embryonic development, the acetabulum and the femoral head develop from the same primitive mesenchymal cells [6–8]. Around the seventh week of gestation a cleft develops in the precartilaginous cells which progressively distinguish the acetabulum and femoral head. The hip joint is fully

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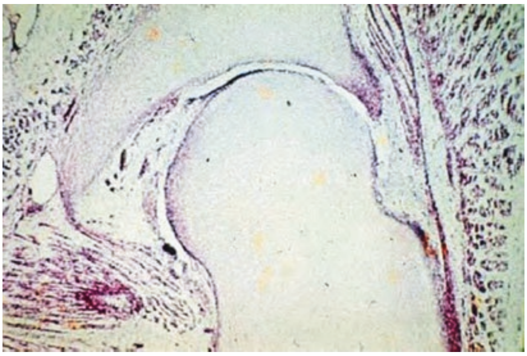

Fig. 4.1 Embryonic hip. Note that the acetabulum and femoral head develop from the same mesenchymal cells before the development of a cleft at about 7 weeks gestation, which eventually divides the acetabulum and femoral head into separate structures. (Used with permission)

formed by the 11th gestational week [7–9] (Fig. 4.1). In the normal hip, acetabular development continues during intrauterine life by way of labral growth and the femoral head remains deeply seated in the acetabulum [10]. This relationship is largely maintained by the surface tension of synovial fluid. Even after incising the joint capsule, dislocation of a normal infant's hip is extremely difficult [11, 12]. This highlights the common misconception that DDH is the consequence of increased capsular laxity. Normal growth and development of the hip continues in the newborn period through a genetically determined relationship between the acetabular and triradiate cartilages and the proximal femur. Of primary importance is the maintenance of this relationship, including a centered, well-positioned femoral head within the developing acetabulum [9, 13–16].

Acetabular Growth and Development

The acetabular cartilage complex is a three-dimensional structure representing the confluence of the ilium, ischium, and pubis. The outer two-thirds of the cup-shaped cavity is formed from acetabular cartilage and remains covered in hyaline cartilage throughout development. The lateral portion of this cartilage is homologous with epiphyseal cartilage of the skeleton [17]. Projecting from the margin of the acetabular cartilage is a fibrocartilaginous extension of tissue, the acetabular labrum. Adjacent to the acetabular cartilage, labral tissues are in continuity with the joint capsule inserting just above it. The articulating surface of the acetabular cartilage is covered with articular cartilage while the opposite side is a typical growth plate. Through interstitial growth within the cartilage and appositional growth beneath the perichondrium, the acetabular cartilage continues to slowly grow throughout childhood. The importance of this growth center becomes all too evident after aggressive periosteal stripping or improper osteotome placement results in growth disturbance.

Growth of the Proximal Femur

The entire proximal end of the femur is composed of cartilage in the infant. Three key growth centers are present in the proximal femur: the physeal plate, the greater trochanter, and the femoral neck isthmus [18] (Fig. 4.2). The trochanter and proxi-

Fig. 4.2 The proximal femur of an infant demonstrating three physeal plates. This includes the growth plates of the greater trochanter, the proximal femoral physis (*physeal plate*), and the femoral neck isthmus, a reflection of the previous common origin of the other two. (Used with permission)

mal femur enlarge by appositional cartilage cell proliferation with the proximal femoral ossification center appearing between the fourth and seventh month of life [18]. Ossification of this cartilaginous anlage continues at a decreasing rate until skeletal maturity when only a thin layer of articular cartilage remains. Influenced by a combination of forces including resting muscle tension, active muscular pull, and normal weight bearing—in conjunction with synovial fluid nutrition and femoral blood supply—the growth and development of the proximal femur is dependent on a balance between the three growth centers. Normal growth and the adult shape of the proximal femur can be altered by changes in any of these factors [18–22].

> ***"Influenced by a combination of muscle forces and normal weight bearing - in conjunction with synovial fluid nutrition and femoral blood supply - the growth and development of the proximal femur is dependent on a balance between three growth centers".***

During infancy, the trochanteric and epiphyseal growth plates are connected by a small cartilaginous isthmus along the lateral border of the femoral neck. This growth cartilage is a reflection of their previous common origin and contributes to the expanding lateral width of the femoral neck until maturity. Any disturbance in growth (e.g. post-traumatic physeal arrest or stimulation secondary to post-inflammatory hyperemia) involving one or more of these three growth centers can alter the eventual shape of the proximal femur.

Approximately 30% of the overall growth and length of the femur is determined by the proximal femoral physeal plate contributions. Any damage to, or alterations in, the physeal blood supply has the potential to disrupt its normal growth, often resulting in varus deformity of the proximal femur. This typical deformity occurs due to an imbalance in growth between the slowed epiphyseal growth plate and continued growth at the trochanteric and femoral neck growth plates [23]. This manifests as an abnormal *articular trochanteric distance*, measured from the tip of the greater trochanter to the superior articular surface of the femoral head. Conversely, the greater trochanteric physis is categorized as a traction apophysis whose normal appositional growth is dependent on abductor muscle pull, resulting in a continuation of growth despite alterations in femoral head and neck physeal activity. As such, "trochanteric overgrowth" is actually normal trochanteric growth in the presence of "undergrowth" of the proximal end of the femur [21].

Determinants of Shape and Depth of the Acetabulum

Both clinical studies in humans with unreduced dislocations and experimental studies in animals have clearly demonstrated that the continued presence of a spherical femoral head is the main stimulus for the development of the typical concave shape of the acetabulum [13, 17, 24–26]. Failed development of adequate acetabular depth and area was demonstrated after excision of the femoral head in rats. Additionally, despite normal innominate bone length and triradiate cartilage histology, the acetabular cartilage is prone to atrophy and degeneration without the normal stimulus of a reduced femoral head [13]. In fact, normal interstitial and appositional growth within the acetabular cartilage, new periosteal bone formation in the adjacent pelvic bones, and a reduced, spherical femoral head, must all occur in concert for the normal depth of the acetabulum to be obtained during development [13, 14]. Further deepening occurs as three secondary ossification centers develop at puberty [17]. The first of these centers is the *os acetabulum* which develops into the thick cartilage that separates the acetabulum from the pubis and forms the anterior wall at about 8 years of age. The second is the *acetabular epiphysis* which functions as the epiphysis of the ilium and forms a major portion of its superior edge. It also appears at the age of 8 and fuses to the remainder of the acetabulum at about 18 years. The third center is a small epiphysis in the ischial region that appears around 9 years and fuses at 17 years [13, 14, 17, 27] (Fig. 4.3).

The coordinated growth of the proximal femoral, acetabular, and triradiate cartilages—and adjacent bones—are together responsible for normal acetabular growth and development. Alterations in this finely balanced, genetically determined growth—coupled with abnormalities

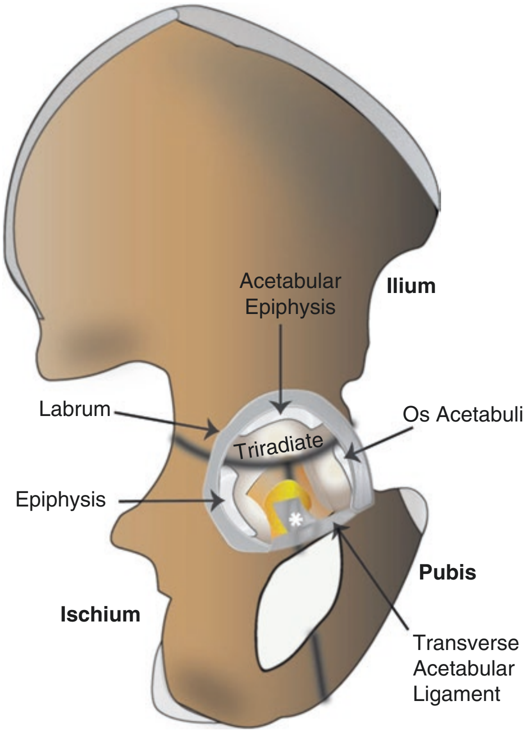

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Fig. 4.3 Diagram of the right innominate bone. Note the os acetabulum within the acetabular cartilage adjoining the pubis. The acetabular epiphysis adjoining the ilium and the epiphysis adjoining the ischium comprise the other two growth centers within the acetabular cartilage. The origin of the ligamentum teres (*) is shown on the non-articular medial wall

in the intrauterine environment, vascular supply, and relatively gentle forces persistently applied—contribute to the pathogenesis of hip dysplasia [28–35].

> *"Alterations in the growth of the proximal femoral, acetabular, and triradiate cartilages - coupled with abnormalities in the intrauterine environment, vascular supply, and joint forces - contribute to the pathogenesis of hip dysplasia".*

Hip Dislocation in the Newborn

DDH in the newborn appropriately describes a broad spectrum of growth abnormalities of the proximal femur and/or acetabulum, ranging from mild dysplastic changes to severe pathologic changes. The more severe pathologic changes are typically seen in teratologic dislocations.

The most common pathoanatomical change in the newborn with DDH is the *neolimbus* described by Ortolani [20, 36], present in up to 98% of DDH cases that occur perinatally. The neolimbus represents a hypertrophied ridge of acetabular cartilage in the superior, posterior, and inferior aspects of the acetabulum [12, 37]. Pressure of the femoral head or neck on this hypertrophied tissue often results in a trough or groove in the acetabular cartilage. The palpable sensation of the femoral head gliding in and out of the acetabulum over this ridge of acetabular cartilage produces the Ortolani sign (see Clinical Presentation section) [20, 36].

> *"The neolimbus represents a hypertrophied ridge of acetabular cartilage in the superior, posterior, and inferior aspects of the acetabulum* [12, 37]*".*

With stabilization of the anatomic relationship between the acetabulum and femoral head, these pathologic changes are typically reversible in the newborn with DDH, as evidenced by the 95% success rate of treating DDH with simple devices such as the Pavlik harness and the von Rosen splint [38–40]. Conversely, an estimated 2% of newborns with DDH have idiopathic teratologic dislocations in the antenatal period not associated with a neuromuscular condition or other syndromes. The pathoanatomy, clinical findings, and treatment success are different in these cases than for typical DDH.

Acetabular Development in DDH

Although it is generally accepted that early identification and successful treatment of DDH in the newborn period typically results in normal hip development, acetabular development may be irreversibly affected and fail to adequately develop even in early-diagnosed and appropriately treated cases. As discussed previously, the primary stimulus for normal growth and development is maintenance of the appropriate relationship between the femoral head and the acetabulum during growth [13, 25, 26]. As soon as subluxation or dislocation has been identified, the femoral head must be reduced as soon as possible and this reduction maintained. With increasing delay in diagnosis, normal growth and development may not occur. If a concentric reduction is achieved and maintained at an early stage, however, the acetabulum has great potential for resumption of normal growth and development [41–43]. The age at which a dysplastic hip can return to "normal" after reduction remains controversial [40, 42–50]. The ability of the acetabular cartilage to resume normal development post reduction is multifactorial, depending on the age at which reduction is obtained, its intrinsic growth potential, and the presence of normal proximal femoral geometry. In patients with treated DDH, *accessory centers of ossification* have been found to contribute to acetabular development in up to two thirds of cases, compared with only 2–3% of normal hips. These *accessory centers* appear 6–10 months after reduction within the peripheral acetabular cartilage [41–44, 51]. They are thought to be caused by persistently abnormal joint forces imparted to the "neolimbus" by the displaced femoral head and/or neck, or from damage incurred from repeated attempts at unsuccessful closed reduction. Evidence of accessory centers of ossification should be sought on post-reduction radiographs to determine whether acetabular development is progressing. This should factor into the decision about proceeding with surgical intervention for residual acetabular dysplasia. Although accessory ossification centers may coalesce to form a normal acetabulum, their presence may indicate injury to the cartilage and does not assure normal acetabular development.

Natural History

Course of DDH in Newborns

The natural history of untreated DDH in the newborn remains an enigma. The rate in which an unstable hip spontaneously reduces, becomes dislocated, subluxated, or dysplastic remains unknown. Barlow reported that over 60% of infants born with any sign of clinical instability (e.g. Ortolani positive) would normalize within the first week of life without treatment and that this number increases to 88% by the third month of life [52]. Similarly, Pratt and colleagues reported that 15 of 18 "dysplastic" hips at age less than 3 months were radiographically normal without treatment at a mean follow-up of 11 years [53]. In contrast, Coleman reported that only 22% of 23 dysplastic hips at age less than 3 months were normal at 3-year follow-up, while 26% were dislocated, 13% subluxated, and 39% remained dysplastic [54]. Further complicating the discussion and classification of instability is the consideration of hips that are clinically stable but have abnormal ultrasonographic findings. Since it is not possible to predict which hips will normalize, which hips will dislocate, and which hips will remain reduced yet dysplastic, all newborns with hip instability on clinical exam should be treated. The decision to treat infants with somewhat abnormal ultrasounds despite normal clinical examination is somewhat more controversial. Most providers, including the authors, typically err on the side of overtreatment and would recommend treatment in the setting of markedly abnormal ultrasound despite a normal clinical exam.

> ***"Since it is not possible to predict which hips will normalize, which hips will dislocate, and which hips will remain reduced yet dysplastic, all newborns with hip instability on clinical exam should be treated".***

Course of DDH in Adults

As in children, the natural history of untreated DDH in the adult is variable. In the setting of complete dislocation, outcomes depend largely on the development of a false acetabulum and bilaterality [28, 55–58].

When a false acetabulum is absent or poorly formed, patients have a greater than 50% chance of a good outcome and often maintain good range of motion with little functional disability; compared to less than 25% chance of a good outcome with a well formed false acetabulum [55]. Hips with well-developed false acetabula are more likely to develop radiographic evidence of degenerative joint disease and experience poor clinical outcomes.

Patients with bilateral dislocations often complain of lower back pain related to hyperlordosis of the lumbar spine [27, 55, 59–61]. In the case of unilateral complete dislocation, problems relating to limb-length inequality, ipsilateral painful knee deformity, compensatory scoliosis, decreased agility, and gait disturbance, are common. Valgus deformity at the knee develops secondary to flexion-adduction deformity at the hip, often leading to attenuation of the medial collateral ligament and degenerative arthritis of the lateral compartment [27, 55, 58].

Course of Dysplasia and Subluxation

After the neonatal period, the term *hip dysplasia* can be used to describe either anatomic or radiographic abnormalities. *Anatomic dysplasia* refers to inadequate development of the acetabulum and/or femoral head often resulting in abnormal contact (i.e. subluxation or dislocation) between the proximal femur and acetabulum [62].

Unlike anatomic dysplasia, which includes the full spectrum of hip displacement, an important distinction is made between radiographic dysplasia and radiographic subluxation. In *radiographic dysplasia*, the Shenton line remains intact [55, 63, 64] but the acetabulum shows increased obliquity and loss of concavity. *Radiographic subluxation* refers to a hip with a disruption of the Shenton line and the femoral head is superiorly, laterally, or superolaterally displaced from the medial wall of the acetabulum. Although these radiographic findings should be described independently as their natural histories are different, secondary degenerative changes at a later stage may lead to conversion from radiographic dysplasia to radiographic subluxation [59, 61, 64–68]. Radiographic subluxation, resulting from untreated or incompletely treated DDH, invariably leads to degenerative joint disease and clinical instability [27, 56, 59, 64, 66, 69–71].

> ***"Radiographic subluxation, resulting from untreated or incompletely treated DDH, invariably leads to degenerative joint disease and clinical instability".***

In the adolescent and young adult population, post-DDH dysplasia should be distinguished from hip dysplasia unrelated to DDH of the newborn. Although multiple studies evaluating hip arthroplasty demonstrate a high prevalence of early degenerative joint disease secondary to adolescent hip dysplasia there is still much to learn about this entity. It is believed, however, that uncorrected dysplasia from DDH in the newborn consistently leads to early degenerative joint disease.

Although it has been suggested that the center-edge (CE) angle is predictive of degenerative joint disease, there is currently no good evidence that supports a definitive correlation between radiographic measures of dysplasia (e.g. CE angle, acetabular index, migration percentage, etc.) and disease progression [51, 64]. The rate of joint deterioration and subsequent clinical disability is, however, directly related to the presence and severity of subluxation and the age at the time of diagnosis [59, 64–66, 68, 72–75]. Once pain associated with degenerative arthritis begins, it typically progresses rapidly over a period of months [55]. In reality, any deviation from the normal radiographic findings (i.e. well-developed teardrop, normal femoral neck-shaft angle, intact Shenton line, downsloping sourcil, and well-developed Gothic arch) of a mature pelvis may lead to degenerative joint disease over time, although a definitive correlation has not been demonstrated [55, 56, 64–68, 76].

Physical signs are often not present in children with radiographic hip dysplasia. The diagnosis is commonly made incidentally or only after the patient develops symptoms related to the dysplasia [28, 29, 51, 68, 77]. Approximately half of patients with degenerative joint disease secondary to hip dysplasia have evidence of radiographic dysplasia in the asymptomatic contralateral hip [68, 78–80]. The severity of subluxation has been shown to correlate with peak periods of pain by Wedge and Wasylenko [55]. They demonstrated that patients with the most severe subluxation developed pain in the second decade of life, those with moderate subluxation developed pain in the third and fourth decades, and those with minimal subluxation developed pain in the fifth decade. Severe degenerative changes on radiographs typically become evident approximately 10 years after the onset of symptoms. A completely dislocated hip typically causes symptoms much later than a subluxated hip [60, 81, 82].

Residual Femoral and Acetabular Dysplasia After Treatment

The goal of treatment of DDH is to have a radiographically confirmed normal hip at skeletal maturity in order to prevent degenerative joint disease in the future. Attempts must be made to correct any amount of hip subluxation identified. Additionally, attempts should be made to correct acetabular dysplasia in the preadolescent phase as this eventually leads to degenerative joint disease even in the absence of subluxation [31, 32]. The treatment of hip dysplasia identified in the adolescent phase remains controversial and will be discussed in the following chapter.

Epidemiology

Causes of DDH

Developmental dysplasia of the hip is multifactorial. Genetic and ethnic factors play a clear role as the incidence of DDH is very low among children of African and Chinese descent and as high as 50 per 1000 live births among Native Americans and Lapps [33, 54, 55, 62, 83–94]. A positive family history of DDH has been reported in up to one in three children with DDH [34, 83, 94]. Phenotypic aspects including femoral acetabular anteversion, primary acetabular dysplasia, various degrees of joint laxity, or a combination of all may contribute to the development of DDH [33, 37]. Antenatal mechanical factors and certain neuromuscular conditions have been demonstrated to profoundly influence the genetically determined intrauterine growth and development of the fetal hip. These factors include breech position, oligohydramnios and myelomeningocele [7, 8, 95, 96].

Risk Factors and Incidence

As a multifactorial condition, clear cause and effect has not demonstrated by any single factor, however, several authors and meta-analyses have highlighted associations between DDH and breech positioning, a positive family history, sex, and first-born status [97, 98]. First born children are more likely to be affected with DDH than subsequent children in white populations [11, 28, 29, 99–102]. The theory that the “crowding phenomenon” plays a role in the pathogenesis of DDH is supported by the higher incidence of DDH in twin pregnancies and first born children as the mother’s unstretched abdominal muscles and primigravid uterus may subject the fetus to prolonged periods of increased pressure and abnormal positioning. As a result, the fetus is forced up against the mother’s spine and pelvis, limiting fetal hip abduction. This positioning theory is further supported by the predilection for left hip involvement in DDH. Most often, this hip is forced into adduction against the mother’s sacrum in one of the most common fetal positions [11, 35, 54]. Additionally, other intrauterine molding abnormalities associated with “crowding”—including torticollis, metatarsus adductus, and oligohydramnios—are all associated with DDH [11, 54].

DDH is more common in girls (80%) and among children delivered in the breech presentation. Twice as many girls are born breech and 17–23% of children with DDH had a breech presentation, compared to only 2–4% of the general population [28, 29, 77, 103]. Further, over half of breech presentations are first-born children, again suggesting a positive association between sex, breech positioning, first-born status, and DDH [28, 29, 77].

The postnatal environment has also been suggested to influence the development of DDH. Most clearly, societies that swaddle newborns with hips maximally adducted and extended in the immediate postnatal period have a very high incidence of DDH [53–55, 70, 104, 105].

The effects of capsular laxity on the development of DDH have been debated. While newborns with DDH do have capsular laxity, it is more likely that this is the result of hip instability rather than the cause. Investigators have argued in favor of laxity as a cause of DDH by citing the fact that secondary reversible acetabular dysplasia can be created in animals by primarily producing ligamentous laxity [25, 26, 34, 37, 103, 106]. Conversely, others have shown that the acetabulum is most shallow at birth and that with the normal laxity of the newborn hip, it is at the highest risk of dislocation during this period [106–108]. Hip capsule laxity has been demonstrated in normal infant hips and may even allow mild instability. During dynamic imaging examinations of Ortolani negative stillborn hips, despite mild contrast dye pooling on arthrogram and the presence of capsular laxity during ultrasonography, all were found to be pathologically normal. This is in distinct contrast to the postmortem findings associated with infants with positive Ortolani signs which showed a cartilaginous ridge separating the hip socket into two sections, inverted labrum, and degeneration of the acetabular cartilage [12, 14, 36, 69, 91, 109]. Further, DDH is not a characteristic feature of conditions associated with hyperlaxity such as Down, Ehlers-Danlos, and Marfan syndromes [36].

Patients at high-risk for development of DDH can be identified by taking into account the epidemiologic, ethnic, and diagnostic criteria as described above. Health providers should be alert to the possibility of DDH in patients presenting with risk factors known to be associated with the diagnosis, most importantly a positive family history and breech positioning.

> ***"Health providers should be alert to the possibility of DDH in patients presenting with risk factors known to be associated with the diagnosis; most importantly a positive family history and breech positioning".***

Risk Factors for DDH

1. **Primary risk factors**
    (a) Positive family history or ethnic background (Native American, Laplander)
    (b) Breech presentation
2. **Secondary risk factors**
    (a) Female gender
    (b) Torticollis
    (c) Metatarsus adductus
    (d) Oligohydramnios
    (e) Persistent hip asymmetry

Clinical Presentation

Early Diagnosis

An expert and artful examination of the infant's hips is a key diagnostic tool in the early diagnosis of DDH. It must occur in a controlled setting and environment by an experienced examiner. A relaxed child should be positioned on a firm surface if possible; otherwise the parent's lap will suffice. Movement of the hip from a reduced to a subluxated or dislocated position is a delicate maneuver and relies on the light touch of the examiner.

The tight fit between the femoral head and the acetabulum is lost in the newborn with DDH. This is manifest clinically as the ability of the examiner to make the femoral head slide in and out of the acetabulum, with a palpable sensation commonly known as the *Ortolani sign* [12, 20, 36, 37]. Although some have tried to distinguish the sensation of manual reduction of a dislocated or subluxated hip (*Ortolani sign*) from that of dislocating or subluxating a located hip (*Barlow sign*), the authors prefer to refer to any hip that can be subluxated or dislocated and subsequently reduced as being *Ortolani positive*, as initially described by Ortolani [36, 52] (Fig. 4.4). It is the opinion of the authors that distinguishing between hips that can be reduced from a dislocated position from those that can be dislocated from a reduced position is of no clinical importance as the clinical treatment of these hips is identical.

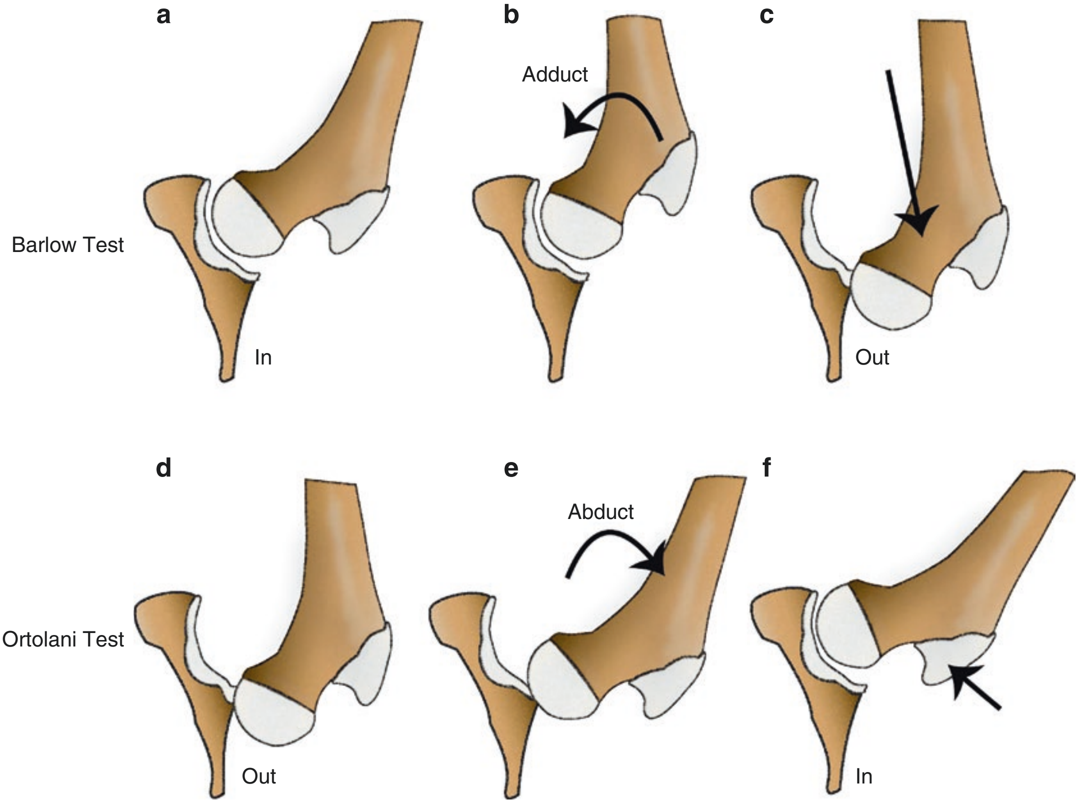

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Fig. 4.4 Diagram of the Barlow (upper) and Ortolani (lower) tests. (**a**) With the infant supine the examiner gently holds the leg in neutral resting position and the femoral head is located within the acetabulum. (**b**) The hip is gently adducted. (**c**) With a posteriorly directed force the hip is dislocated as the examiner feels the femoral head glide over the posterior aspect of the acetabulum. (**d**) While the infant rests supine and the examiner holding the leg in neutral position the hip is resting in the dislocated position. (**e**) The combination of gentle abduction of the hip and (**f**) anteriorly directed pressure on the greater trochanter will reduce the femoral head back into the acetabulum as the examiner feels a palpable "clunk" of the femoral head gliding back into the acetabulum

> ***"Distinguishing between hips that can be reduced from a dislocated position from those that can be dislocated from a reduced position is of no clinical importance as the clinical treatment of these hips is identical".***

In his original description in 1912, LeDamany referred to the palpable sensation of the hip gliding in or out of the acetabulum as the *signe de ressaut* and later, in 1936, Ortolani described it as the *segno dello scotto*, providing a description of the pathogenesis of this exam finding [36, 107, 109]. Ortolani named the hypertrophied ridge of acetabular cartilage responsible for the finding as the *neolimbus*. This key diagnostic sign first described in French and then Italian literature as a palpable sensation was, unfortunately, translated into English as a "click". Unlike the palpable "clunk" described by LeDamany and Ortolani, high-pitched soft tissue related clicks are commonly experienced when examining the hips of normal newborns. These are often transmitted from the iliopsoas, the trochanteric region, or the knee, and generally have no diagnostic significance [110–113]. Unfortunately, a pervasive, poor understanding of the underlying pathoanatomy of DDH and its diagnosis by clinical examination has led to over diagnosis and over treatment of infants [114–117].

Contrary to the Ortolani test, whereby a dislocated hip is reduced into the acetabulum, the *Barlow maneuver* is a provocative maneuver in which the hip is flexed and adducted and the femoral head is palpated to subluxate or dislocate over the acetabular ridge under gentle axial pressure [52]. Some providers have suggested that a reduced hip that is dislocatable (Barlow positive) is more stable than a hip that is dislocated and is reducible on examination (Ortolani positive) and therefore may spontaneously stabilize. The authors, however, agree with the original work of LeDamany and Ortolani who described the palpable sensation of both subluxating or dislocating a reduced hip or reducing a subluxated or dislocating as pathologic and make no distinction in treatment between them.

Idiopathic teratologic (i.e. irreducible) dislocations are extremely rare in newborns. Irreducible hips are most often associated with neuromuscular conditions, such as myelodysplasia, arthrogryposis, or with syndromes; accounting for only 2% of DDH cases in large series [12, 54, 62, 118, 119]. The secondary adaptive changes that are often present in these cases are more typical of those seen in the late-diagnosed DDH case.

Late Diagnosis

If the diagnosis of DDH is not made early, secondary adaptive changes will reliably develop [84]. The most common physical finding associated with late-diagnosis is limited abduction, the clinical manifestation of a shortened adductor longus associated with hip subluxation or dislocation [62]. Additional findings include apparent femoral shortening, called the *Galeazzi sign*, asymmetric gluteal, thigh, or labial folds, high riding greater trochanter (*Klisic test*), and limb length inequality [5, 120, 121]. When bilateral dislocations are present, patients often exhibit a waddling gait and hyperlordosis of the lumbar spine.

> ***"The most common physical finding associated with late-diagnosis is limited abduction, the clinical manifestation of a shortened adductor longus associated with hip subluxation or dislocation".***

Normal hip joint growth and development are impaired if DDH is not detected at an early stage. Older patients at the time of detection, particularly those detected beyond 6 months of age, often do not respond to simple treatment methods such as the Pavlik harness and instead require more substantial interventions including a closed or open reduction (requiring general anesthesia).

Essential Clinical Tests

1. Skillful performance of Ortolani and Barlow maneuvers
2. Assessment for symmetric hip abduction
3. Assessment for *Galeazzi sign* and limb length asymmetry
4. Assessment for symmetric gluteal, thigh, and labial folds

Imaging

Utility of Ultrasound in Hip Dysplasia

Ultrasonography as a diagnostic or screening exam in DDH has gained worldwide popularity. Although some controversy exists, its cost-effectiveness as a universal screening tool for DDH has yet to be clearly demonstrated [122–132]. The earliest advocate of the use of ultrasonography in orthopaedics was Graf in Austria in the 1970s and many proponents of ultrasound argue that it should be used in all newborns as a standard screening tool for DDH [133–137]. Ultrasound use in DDH is unique in that it can provide both a morphologic assessment and a dynamic evaluation [138–143]. The morphologic assessment includes an evaluation of the anatomic characteristics of the hip joint including the determination of two primary angles: the α-angle and β-angle (Figs. 4.5 and 4.6). The α-angle is a measure of the slope of the superior aspect of the bony acetabulum while the β-angle describes the cartilaginous component more laterally. The dynamic aspect of the examination, as popularized by Harcke and colleagues, provides a real-time assessment of the hip during range of motion and stress examinations (e.g. Ortolani and Barlow maneuvers) [144]. The anatomic classification of infant hip dysplasia, initially

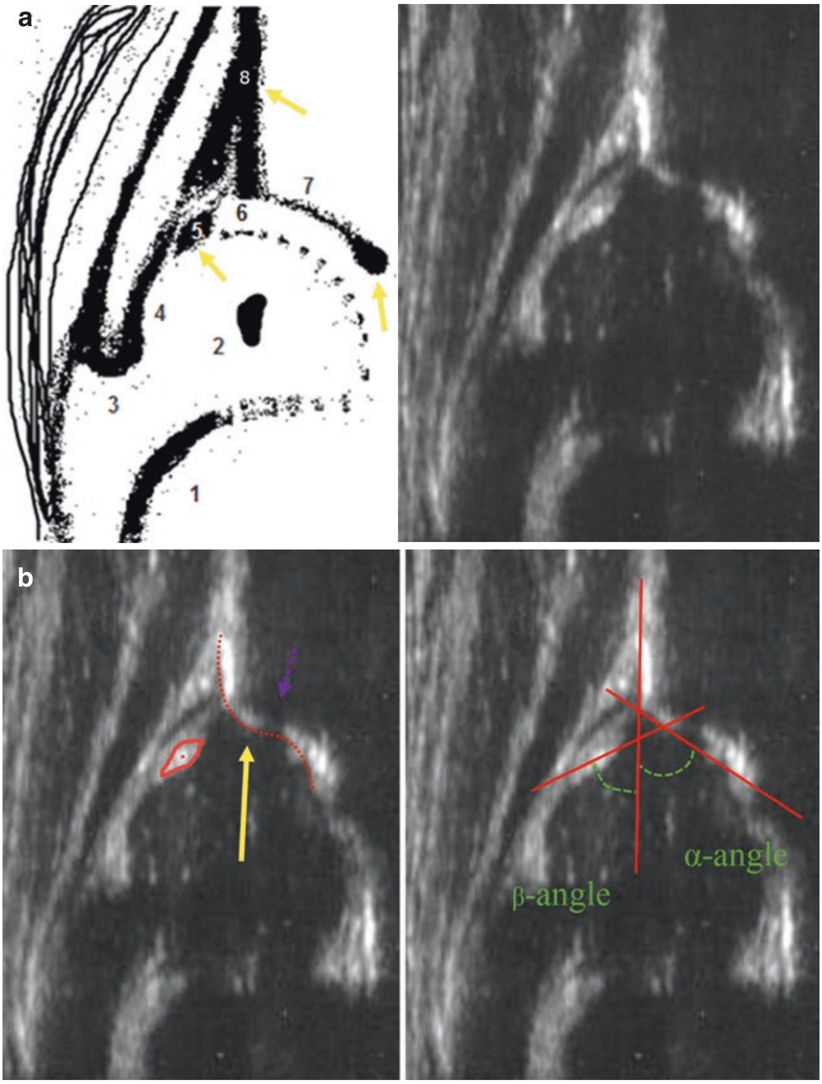

Fig. 4.5 Hip types based on ultrasonographic results, according to the Graf classification. (**a**) Correct hip ultrasound images must fulfil certain criteria. These criteria are divided into two usability checklists: (i) the identification of 6 landmarks (numbered in the figure): (1) chondro-osseous junction, (2) femoral head, (3) synovial fold, (4) joint capsule, (5) labrum, (6) cartilagenous part of the acetabular roof, (7) bony roof, and (8) the plane (i.e. ilium, which must look like a straight line); (ii) the identification of three landmarks (marked with yellow arrows) are essential to establish the standard plane which is required for accurate measurement of infant hip ultrasound: the lower limb of the bony roof (usually it is the brightest and largest lower end of the bony roof), and the midportions of both the Ilium and the labrum. If any of these points are missing or not clearly shown, the sonogram is worthless and should not be used. The only exception is when the joint is decentered (dislocated) (Graf IV). (**b**) When ultrasound images are accepted based on the criteria mentioned above, the angles can be accurately measured. It is important to outline the labrum, mark its centre, and identify the 'turning point' (marked with a yellow arrow). The turning point—confusingly, also called the 'bony rim'—is the most lateral point of the concave bony socket. It is the turning point from concavity to convexity. It is essential to look for the turning point from inner to outer (i.e. distal medial to proximal lateral). There is frequently a small acoustic shadow (purple dashed arrow) just medial to the turning point. Using the turning point as a reference, three independent lines are drawn as follows: the baseline runs tangential to the outer surface of the plane (Ilium), where the cartilaginous roof meets the Ilium. The bony roof line runs tangentially from the lower limb to the turning point. The cartilage roof line is drawn from the turning point to the center of the labrum. The angle between the bony roof line and the base line is the α-angle, whereas the angle between the cartilage roof line and the base line is the β-angle. Note that these lines are often do not meet at the same point. (**c**) Hip types based on ultrasonographic results, according to the Graf classification. (Courtesy Sattar Alshyrda)

Type	Alpha angle (α)			Beta angle (β)		Descriptions
I	> 60°			< 55°	Ia	Normal hip (at any age). This grade is further divided into (Ia; β<55°) and (Ib; β> 55°). The significance of this subdivision is not yet established. Patient dose not need follow-up.
				> 55°	Ib	
II	50–59°	IIa		< 77°		If the child is < 3 months. This may be physiological and does not need treatment; however, Follow up is required.
		IIb		< 77°		> 3 months, delayed ossification.
	43–49°	IIc	Stable	< 77°		Critical zone, labrum not everted. This is further divided into stable and unstable by provocation test.
			Unstable			
D	43–49°			> 77°		This is the first stage where the hip becomes decentred (subluxed). it used to be called IId, but for the above reason, it is a stage on its own now.
III	< 43°	IIIa				Dislocated femoral head with the cartilaginous acetabular roof is pushed **upwards.** This is further divided into IIIa and IIIb depending on the echogenicity of the hyaline cartilage of the acetabular roof (usually compared to the femoral head) which reflects the degenerative changes.
		IIIb				
IV	< 43°					Dislocated femoral head with the cartilaginous acetabular roof is pushed **downwards.**

Fig. 4.5 (continued)

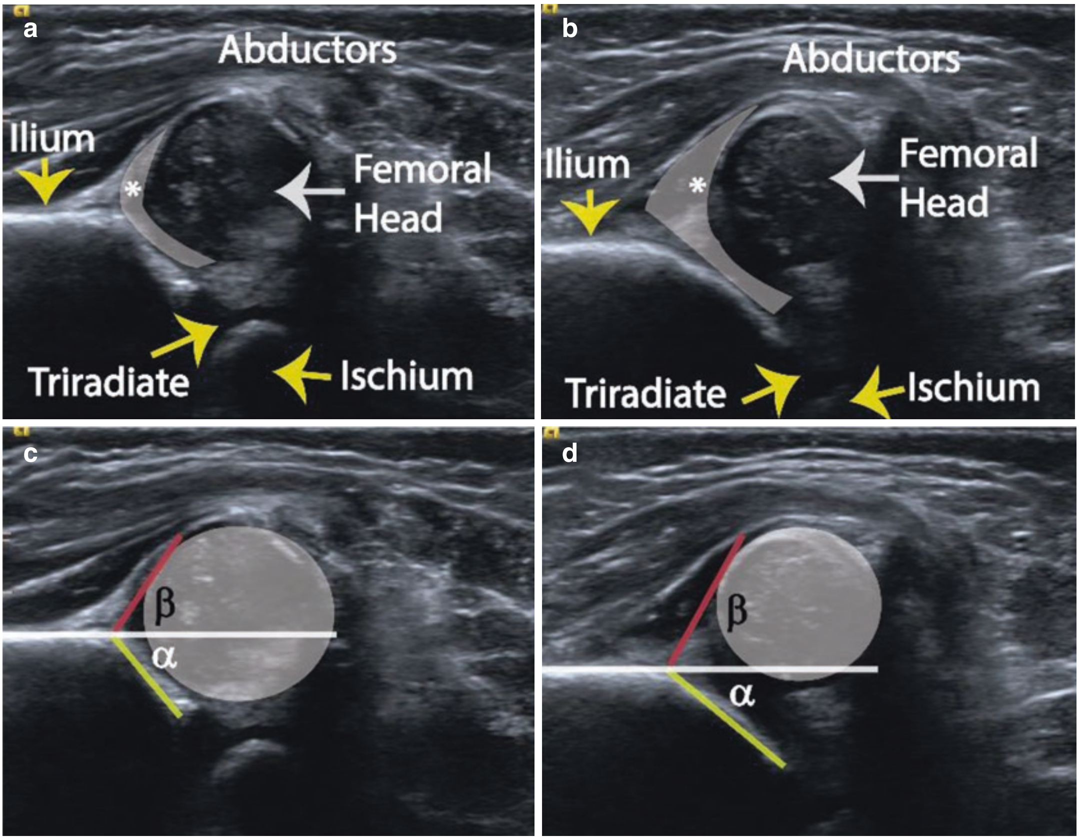

Fig. 4.6 Hip ultrasound. (**a**) Anatomy of a normal newborn demonstrated. Note the sharp edge of the ilium and the echogenic triangular labral fibrocartilage (*). (**b**) Anatomy of a newborn with dysplasia. Note the rounded edge of the ilium. (**c**) Normal anatomy with alpha (α) and beta (β) angles shown as the angles created by base line (white line along ilium), the inclination line (red line along labrum) and the roof line (yellow line along acetabular roof). (**d**) Abnormal anatomy of a newborn with dysplasia shows increased beta angle and decreased alpha angle

introduced by Graf, is widely accepted and remains commonly used throughout the world today. In this system, hips are classified into four types and several subtypes according to various factors including the bony and cartilaginous components of the acetabulum, percentage of acetabular coverage, and shape of the superior bony rim. Hips are then designated as type I (a mature hip with *α-angle >60°*) through type IV (a dislocated hip with *α-angle <43°*) with multiple subtypes (Fig. 4.5c).

Although technical advances have improved image quality and refinement of the examination techniques have contributed to static imaging interpretation, substantial intraobserver variability (particularly in the β-angle) and concern over interobserver reliability during dynamic examination, have been the subjects of criticism [144–146].

Appropriate use of ultrasonography in the diagnosis and treatment of DDH has not been clearly delineated. Widespread universal ultrasound screening of infants in Europe has been performed for decades and many studies from those countries have reported on the successes and benefits of such programs [147–149]. Despite this, many controversies regarding widespread use have yet to be resolved, and, therefore; advocacy for its use in North America has not been generally accepted. Opponents of routine use of hip sonography in newborn nurseries have cited an over diagnosis of DDH and inability to clearly show cost-effectiveness of improvement in long-term outcomes [150–157]. Directed use in high-risk infants may prove to be cost-effective but prospective studies describing the long-term outcomes associated with minor anatomic abnormalities diagnosed on ultrasonography have yet to be completed [153, 158–161]. Interestingly, previous studies have shown that the prevalence of late-diagnosed cases was not reduced with ultrasound screening of all high-risk patients [154, 162].

A major area of controversy regarding the use of ultrasonography in the diagnosis of DDH is what to do with Graf class II hips with a normal clinical exam. Many protocols, most of which involve repeated clinical and ultrasonographic exams at 2- or 6-weeks of life, have been proposed to help guide treatment of these hips [154, 163–165]. Most authors suggest that late-diagnoses and need for surgical treatment in DDH can be reduced, but not eliminated, with increased ultrasound use. However, given the paucity of long-term outcome studies describing the natural history of hips that are clinically stable yet demonstrate mild abnormalities on ultrasound (Graf class II), the authors have no evidence based treatment recommendations for these hips.

The "guided reduction" of a dislocated hip and assessment of stability at the completion of treatment in all Ortolani-positive infants may be the ideal use for ultrasonography [144, 166]. Use of ultrasonography at 7- to 10-day intervals to confirm maintained reduction and stability of a hip during treatment with a Pavlik harness may temporarily obviate the need for radiographic evaluations and exposing the infant to radiation.

> ***"Use of ultrasonography at 7- to 10-day intervals to confirm maintained reduction and stability of a hip during treatment with a Pavlik harness may temporarily obviate the need for radiographic evaluations and exposing the infant to radiation".***

Radiographic Evaluation of Hip Dysplasia

The diagnosis of DDH should be confirmed on radiography after the newborn period as the development of the ossific nucleus obscures any attempt at visualization of the hip by ultrasound. Obtaining and interpreting immature hip radiographs can be problematic, however. Several classic lines can be helpful when evaluating the immature hip. These include the *Hilgenreiner line*, *Perkins line*, *Shenton line*, *acetabular index*, and *center-edge (CE) angle* (Fig. 4.7). Positioning frames should be used as it is often difficult to standardize the positioning of infants and wide interobserver and intraobserver variations in standard measurements have been reported [167–169]. Typical radiographic features of late-diagnosed DDH include an increased acetabular index [54, 170–174], disruption of the

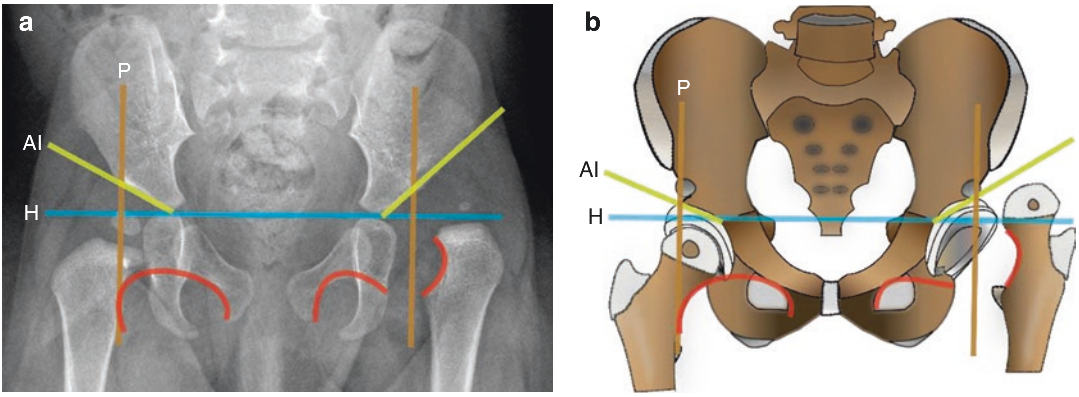

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Fig. 4.7 (**a**) Anteroposterior pelvis radiograph demonstrating typical lines and measures. P, Perkins line (orange). H, Hilgenreiner line (blue). Shenton line (red), with break in line on left hip. AI, Acetabular index (angle between yellow and blue lines), elevated on left. (**b**) Diagram of pelvis demonstrating similar findings. Note the small ossific nucleus on the left hip

Shenton line, a widened medial acetabulum [175, 176], an absent or poorly developed tear drop [177–180], delayed appearance of the ossific nucleus of the femoral head, decreased femoral head coverage, and failure of the proximal femur medial metaphyseal beak to be located in the inferomedial quadrant associated with the intersection of the Hilgenreiner and Perkins lines [181–183]. Routine radiographs should be obtained during scheduled follow-up visits every 3–6 months watching for improvements in the tear drop, the acetabular index, acetabular floor thickness, and appearance of accessory centers of ossification. Treatment decisions should be based on radiographic changes noted over time, not on a single radiograph. Radiation exposure associated with diagnosis, treatment, and follow-up for DDH imparts only a minimal increase in carcinogenic risk to the child [184].

> ***"Routine radiographs should be obtained during scheduled follow-up visits every 3 to 6 months watching for improvements in the tear drop, the acetabular index, acetabular floor thickness, and appearance of accessory centers of ossification".***

The acetabular index is a reliable measurement of acetabular development in children younger than 8 years [167]. Measurement of the center-edge angle becomes reliable only in children over the age of 5 [51]. As radiographs only capture the ossified portions of the skeleton, it is possible to have excellent acetabular coverage by unossified cartilage not visible on radiographs (except by arthrogram). Eventual dysplasia with joint subluxation and degenerative joint disease can result if this cartilage fails to ossify. The Shenton line should be intact on all views only after 3–4 years of age. Prior to this it can only be used as a qualitative assessment of dysplasia.

Essential Imaging Tests and Measurements

1. **Ultrasonography** (Figs. 4.5a, b and 4.6)
   (a) Graf classification (Fig. 4.5c)
   (b) α-angle
   (c) β-angle
2. **Radiography** [185] (Fig. 4.7)
   (a) Tear drop figure
   (b) Medial floor width
   (c) The Shenton line
   (d) Center-edge (CE) angle
   (e) Acetabular index
3. **Arthrography** (Fig. 4.8)

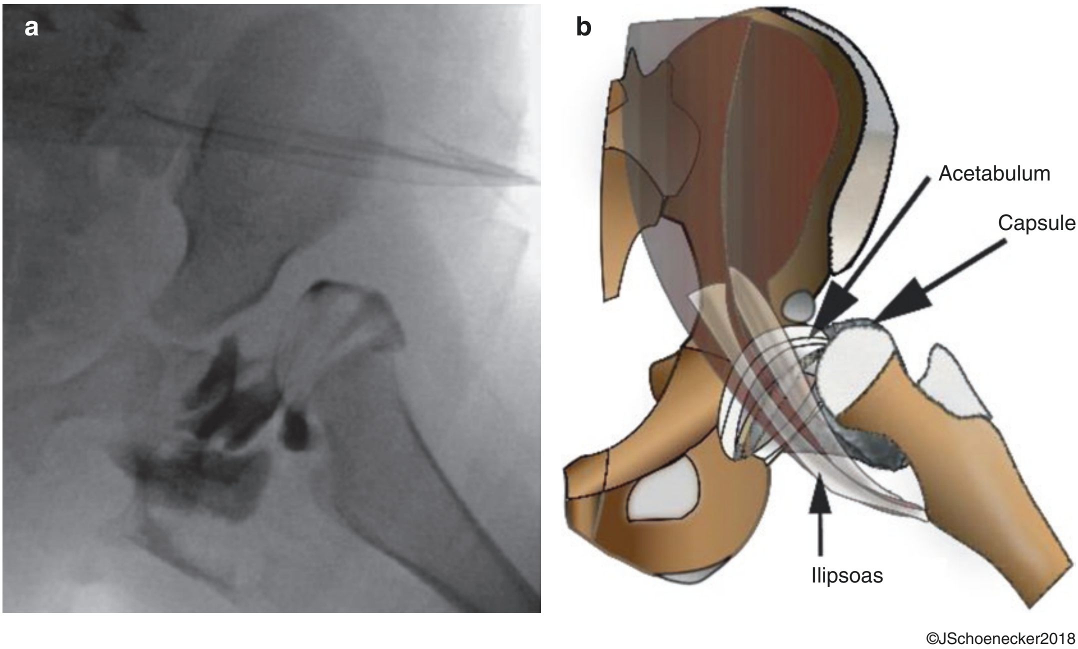

Fig. 4.8 (**a**) Arthrogram of dislocated hip. Note neolimbus being compressed by femoral head in abduction and elongation/enlarged ligamentum teres. (**b**) Diagram of hemipelvis demonstrating similar findings

Non-operative Management

Birth to 6 Months of Age

Although the treatment options vary depending on the age of the patient at time of diagnosis and/or treatment initiation, the goals of treatment are always the same. The primary goal of treatment is to obtain a concentric reduction of the hip joint and to maintain that reduction to provide the best environment for the development of the femoral head and acetabulum. Maintenance of reduction has been shown repeatedly to provide continued opportunity for acetabular modeling and development and the remodeling of excessive femoral anteversion [41–43, 66, 82, 186]. The older the child is at the time of diagnosis, the less growth and remodeling potential remains and the less time is available for any intervention to positively alter the poor natural history of DDH. Additionally, as patient age increases so does the complexity of treatment and the risks of complications.

> ***"The primary goal of treatment is to obtain and maintain a concentric reduction to provide the best environment for the development of the femoral head and acetabulum".***

The diagnosis of DDH should ideally be made in the newborn nursery and treatment initiated immediately [187, 188]. First line treatment includes application of an abduction device such as a *Pavlik harness* at time of diagnosis. The treatment of Ortolani positive (dislocated hips that are reducible) and Barlow positive (reduced hips that can be dislocated) is identical and should include the immediate application of a Pavlik harness. Although the Pavlik harness is the most commonly used device worldwide, other devices include the von Rosen splint, Ilfeld splint, or Frejka pillow [43, 189–199]. The goal of any device is to prevent hip extension and adduction and maintain a reduced hip on a full-time basis. Doing so for 6 weeks will successfully resolve hip instability in 95% of cases [199].

The Pavlik harness can be used effectively until the age of 6 months but with decreasing effectiveness as the child ages. By 6–9 months of age the child becomes too active with crawling to maintain success with the harness. Successful treatment with the Pavlik harness is predicated on appropriate application and adjustments as necessary. The treating physician must recognize if treatment failure has occurred so as not to prolong unsuccessful treatment resulting in secondary pathologic changes to the femoral head and acetabular cartilage known as *Pavlik harness disease* [200]. Damage to the cartilaginous femoral head and proximal femoral physeal plate resulting in growth disturbance are typically the result of forced abduction in the harness or persistent use despite unsuccessful reduction, and represents the most catastrophic outcome [201, 202]. Other failures of the harness are attributed to inappropriate application or inadequate maintenance of reduction [40, 203]. These include inferior dislocation, femoral nerve compression neuropathy, brachial plexus palsy, and knee subluxation, most of which are iatrogenic and can be avoided [204–206]. Discontinuation of the Pavlik harness and supportive care should be pursued in the setting of femoral nerve compression.

Contraindications to the use of the Pavlik harness include significant muscle imbalance (i.e. myelodysplasia, cerebral palsy), significant joint stiffness (e.g. arthrogryposis), or excessive ligamentous laxity (e.g. Ehlers-Danlos) [40]. The harness should not be used if compliance is impossible due to family, social, or educational limitations. In these situations, the use of closed reduction and casting may be the more judicious option. Double or triple diapering is not an appropriate treatment option for DDH. This gives the family a false sense of security. Any success with diapering should be attributed to the natural resolution of the disorder and not to the diapering itself.

> ***"Double or triple diapering is not an appropriate treatment option for DDH".***

In the setting of complete dislocation, ultrasound-monitored reduction and application of the Pavlik harness is encouraged. Ultrasonography can confirm that reduction is achieved and that the femoral head is pointing toward the triradiate cartilage. Once successful reduction is confirmed and the harness is positioned appropriately, there is great variability in treatment regimen. When used for stabilization of an unstable hip (Ortolani- or Barlow-positive), the harness should be used full time for 6–12 weeks after the clinical exam demonstrates stability of the hip. The author's preference is to use the harness full time for 6 weeks after stability is achieved. During the treatment stage, the harness is checked every 7–10 days to gently assess hip motion within the confines of the harness, adjust straps as needed, and encourage continued compliance with harness therapy. Ultrasound can also be used to assess maintained reduction if clinical exam is equivocal. After clinical, or ultrasound confirmed, stability is achieved, radiographs should be obtained at 3 months of age to assess acetabular development.

Essential Non-operative Management Methods

1. Early diagnosis and immediate treatment
2. Appropriate sizing, placement, and positioning of the Pavlik harness
3. Confirm maintained reduction of the hip during Pavlik harness treatment via ultrasound or physical examination within 3 weeks of application

Non-operative Pitfalls

1. Continued Pavlik harness treatment of an unreduced hip
2. Excessive flexion and abduction in the Pavlik harness
3. Double and triple diapering is not appropriate treatment of DDH

Operative Management

Children 6 Months to 2 Years of Age

Success rates using the Pavlik harness in children older than 6 months of age are less than 50% due to the difficulties maintaining appropriate harness use in an increasingly active child. As such, treatment of DDH in this age group should be by closed or open reduction and casting. Although the obstacles to reduction are different, risks of treatment greater, and results less predictable in the late-diagnosed patient or those who failed treatment with Pavlik harness, the goals of treatment are the same as the newborn with DDH. That is, to obtain and maintain a reduction of the hip to provide an adequate environment for femoral head and acetabular development and remodeling.

The extraarticular obstacles to reduction include the contracted adductor longus and iliopsoas. In the late-diagnosed case, these muscles are shortened secondarily as the hip has been subluxated or dislocated for a prolonged period. The intraarticular obstacles to reduction include the ligamentum teres, the transverse acetabular ligament, rarely an inverted and hypertrophied labrum, and, most significantly, the constricted anteromedial joint capsule [37, 207–212]. The ligamentum teres becomes thickened, and in walking aged children, elongated and enlarged, often becoming a primary obstacle to reduction. It must be excised if enlarged as it can often block concentric reduction by its bulk alone. The transverse acetabular ligament should always be sectioned at time of open reduction as it may hypertrophy secondary to the constant pull of the ligamentum teres, resulting in a decreased acetabular diameter [37, 212].

> ***"The intraarticular obstacles to reduction include the ligamentum teres, the transverse acetabular ligament, rarely an inverted and hypertrophied labrum, and, most significantly, the constricted anteromedial joint capsule".***

A true inverted and hypertrophied labrum, or *limbus*, is a rare finding other than in teratologic dislocations [209]. Although the labrum may be iatrogenically inverted in patients previously undergoing failed closed reduction, the oft misinterpreted arthrogram finding of an inverted labrum is most commonly the neolimbus originally described by Ortolani [12, 37, 213–215]. The acetabular cartilage of the neolimbus is almost never a block to reduction and must not be removed to avoid impairment of acetabular development [12, 216]. Primary pathology or secondary damage to the neolimbus from forceful unsuccessful reduction may be responsible for the appearance of the *accessory centers of ossification* observed in treated DDH [12].

> ***"The acetabular cartilage of the neolimbus is almost never a block to reduction and must not be removed to avoid impairment of acetabular development".***

Traction

Although considered by many to be of only historical significance, a period of skin or skeletal traction prior to proceeding with closed reduction and spica cast application has been recommended by some authors [217–232]. Multiple variations on type, position, location, and duration of traction have been presented [219–221, 225]. Due to controversy regarding the benefits of traction over femoral shortening osteotomy [233–241] and its limited use in contemporary practice, the authors cannot recommend routine use of prereduction traction.

Closed Reduction

Closed reduction of a late-diagnosed or persistently dislocated hip is performed in the operating room under general anesthesia. The proper performance and assessment of closed reduction is difficult and requires experience. The femoral head is gently manipulated into the acetabulum by traction, flexion, and abduction using minimal force. To increase the "*safe zone*" (the arc of adduction and unforced abduction in which the hip remains located) and minimize the risk of proximal femoral growth disturbance, an open or percutaneous adductor tenotomy is usually performed in conjunction with the closed reduction [242]. The authors routinely perform a concurrent psoas tenotomy if the adductor tenotomy is performed openly as the psoas often compresses the joint capsule and serves as a block to concentric reduction.

Although the adequacy of closed reduction is somewhat subjective and controversial, in the authors' opinion only an anatomic reduction is acceptable. A stable hip remains reduced throughout most of the joint's range of motion, only dislocating in extremes of adduction or extension. If reduction can only be maintained in wide forced abduction or internal rotation, closed reduction should be abandoned. Arthrography is essential to assess the adequacy of reduction [243–248]. Dynamic arthrography is used to assess obstacles to reduction prior to manipulation and confirm anatomic reduction after manipulation. In the reduced position, the femoral head should be reduced fully to the acetabular wall and not "docked" against the labrum and constricted capsule. With anatomic reduction, the labrum lies flat over the femoral head and has a sharp border. If the labrum is blunted and interposed between the femoral head and acetabulum, the reduction is not anatomic and should not be accepted. Use of the femoral head as a "dilating sound" should be strictly avoided as it may result in damage to the femoral head and make open reduction more difficult [200, 249, 250] (Fig. 4.9).

> ***"With anatomic reduction, the labrum lies flat over the femoral head and has a sharp border. If the labrum is blunted and interposed between the femoral head and acetabulum, the reduction is not anatomic and should not be accepted".***

Anatomic reduction is maintained in a well-molded plaster spica cast (Fig. 4.10). The reduction should be confirmed by radiography, CT, MRI, or ultrasound after cast application [37, 150, 251–256]. With MRI, the vascular status of the femoral head can be assessed [257]. The plaster cast must be well-molded on the dorsal surface of the greater trochanters to prevent redislocation. The authors believe that when a successful reduction is lost, it is typically in the immediate post-operative period due to a poorly applied and inadequately molded cast. Placing the hips in hyperflexion and limited abduction (the "human position") is the preferred position [258, 259]. Forced, wide abduction and internal rotation should be avoided due to increased risk of proximal femoral growth disturbance due to increased pressure on the femoral head and twisting of the capsular blood supply. The amount of true hip flexion seen on lateral radiographs is often far less than the apparent flexion obtained at time of cast application.

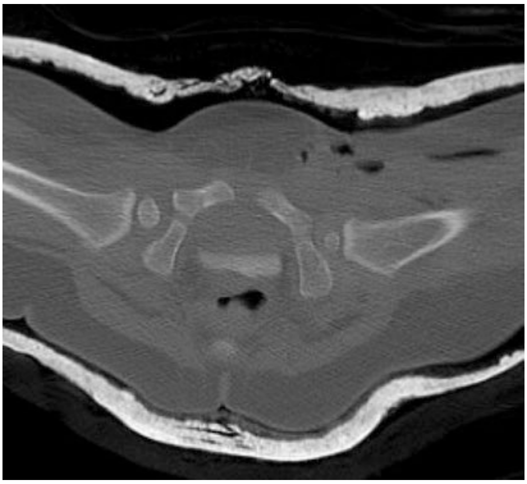

Fig. 4.10 Single cut CT after open reduction of left hip. Note thinly padded and expertly molded (dorsum of greater trochanter) plaster spica cast to maintain position after open reduction

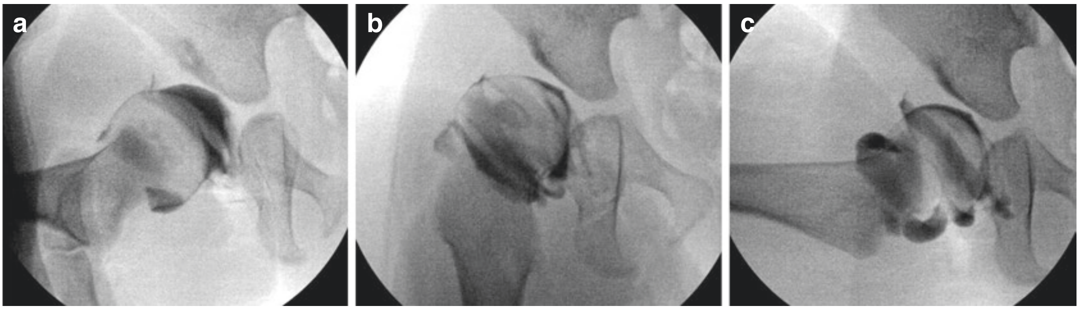

Fig. 4.9 Arthrogram showing successful closed reduction. (**a**) Pre-reduction—note smooth labrum and normal appearing ligamentum teres. (**b**) Post-reduction—note hip adduction. (**c**) Post-reduction—note hip abduction

Duration of cast immobilization for maintenance of reduction is variable. The authors preference is to maintain a below knee plaster spica cast on the involved side(s) (above knee on the uninvolved side) for 6 weeks, regardless of patient age. The cast on the involved side(s) is then cut to above the knee to allow for some hip and knee motion for an additional 6 weeks. Some surgeons prefer to return to the operating room at 6 weeks for examination of the hip under anesthesia and placement of a new spica cast. Most physicians use an abduction orthosis after cast removal, although treatment regimens vary. The author's typical routine includes full-time use of the orthosis for several months; transitioning to part-time use during nights and naps until acetabular development of the involved hip has caught up with the normal side (generally 18–24 months).

Open Reduction

Open reduction is indicated in the setting of failed closed treatment, persistent subluxation, soft-tissue interposition, or unstable reductions other than in extreme positions of abduction. As with all other treatments for DDH, the goals of open reduction are to obtain and maintain anatomic reduction, avoid damage to the femoral head, and provide an optimal environment for acetabular and proximal femoral development. Although some literature suggested a reduced rate of damage to the proximal femur if open reduction is delayed until the presence of an ossific nucleus, this idea has been since dispelled [260–263]. After successful open reduction, a well-molded plaster spica cast should be placed as described above and appropriate imaging obtained to confirm maintain concentric reduction.

Anterior Approach to the Hip for DDH

Open reduction of the hip in DDH can be performed through a variety of surgical approaches [47, 50, 208, 210–212, 242, 264–271]. The most commonly used approach is the anterior or anterolateral Smith-Petersen approach with a modified "bikini" incision as described by Salter and Dubos [256, 272]. Benefits of this approach include the familiarity with the approach by most surgeons, the ability to perform capsular plication, a wide exposure of the hip, and the option to perform a pelvic osteotomy through the same approach if deemed necessary [269–271]. This anterior approach allows the surgeon to address all possible blocks to reduction as the capsule and the superior and inferior aspects of the acetabulum are exposed. The capsulorrhaphy can help to hold the femoral head in the acetabulum and provides a great deal of stability immediately post-reduction. Further, after successful reduction the hip is immobilized in a function position with minimal hip flexion and abduction required to maintain stability. Disadvantages may include greater blood loss, damage to the iliac crest apophysis and hip abductors, and stiffness. The depths of the acetabulum may be difficult to expose through an anterolateral approach, particularly in the case of high dislocation. Care should be taken to ensure that the false acetabulum is not mistakenly exposed. In the case of bilateral hip involvement, surgery is generally staged at 2- to 6-week intervals. See *Essential Surgical Techniques* below for details of the procedure.

Medial Approach to the Hip for DDH

The described medial approaches to the hip have the advantage of approaching the joint directly at the site of possible obstacles to reduction [210–212, 273–278]. Advocates of the medial approach described by Ferguson claim that it minimizes soft-tissue dissection and blood loss, provides direct access to the medial joint capsule and iliopsoas tendon, avoids damage to the iliac apophysis and abductor muscles, and provides excellent cosmesis. Disadvantages of the approach may include less familiarity with the approach by most surgeons, somewhat impaired visualization, and inability to perform capsular repair through the approach. Further, the stability of the reduction is completely reliant on post-operative cast immobilization, it is more challenging in older patients, no further surgical intervention can utilize the same incision, and proximal femur growth disturbance may be higher after this approach [279]. Although the surgical details of the medial approach are not complex, the procedure itself can be somewhat challenging as the exposed area is narrow. Some authors recommend transection of the adductor longus and iliopsoas and evaluation of the reduction by arthrogram. If reduction is concentric, the procedure is concluded and a spica cast applied. If reduction is not perfect, open reduction is performed [235, 236].

Anteromedial Approach to the Hip for DDH

A third approach to open reduction in DDH in this age group is the anteromedial approach described by Ludloff in 1913 and modified by Weinstein and Ponseti in 1979 [50, 82, 123, 210, 280–283]. Although often referred to as a *medial approach*, this approach is actually an anterior approach to the hip through an anteromedial skin incision. It is an ideal approach for children less than 18 months of age in whom closed reduction has failed. It was designed to remove extra- and intra-articular obstacles to reduction (i.e. tight iliopsoas tendon, constricted capsule, and transverse acetabular ligament). Blood loss is minimal, damage to the abductor muscles and iliac apophysis is avoided, scarring is cosmetically acceptable, and both hips can be operated on safely in a single surgical setting. Disadvantages to the anteromedial approach include a general lack of familiarity amongst surgeons, inability to perform secondary procedures (i.e. femoral or pelvic osteotomies, capsular plication), and difficulty in older patients due to the depth of hip joint and resulting troubles with visualization. Although many reports suggest a higher rate of aseptic necrosis [279, 284], the authors have previously reported long term follow up of their experience of over 100 hips, finding a similar rate of necrosis to that reported for the anterior approach in other series (14%) [212, 285]. In this approach, capsular repair cannot be accomplished so post-operative stability depends on a well-applied and well-molded spica cast. See *Essential Surgical Techniques* below for details of the approach.

Assessment of secondary ossification centers after closed or open reduction provides the physician with important insight into the development of the acetabulum. If present, secondary ossification centers may suggest the potential for ossification of cartilage at the periphery of the acetabulum (region of the neolimbus) and normal acetabular development. If absent over serial imaging studies, the physician may consider secondary acetabular procedures. However, patients younger than 18 months at time of closed or open reduction rarely require secondary acetabular or femoral procedures. Acetabular development and improvement in radiographic markers (i.e. acetabular index, teardrop figure, and medial floor width) is most rapid in the first 18 months after surgery, but continues for up to 4–8 years after reduction [43, 44, 50, 286–290]. Failure of acetabular normalization in 18–36 months post reduction warrants secondary corrective procedures [291].

> ***“Failure of acetabular normalization in 18-36 months post reduction warrants secondary corrective procedures”.***

Children Older than 18 Months of Age

When the diagnosis of hip dislocation is made after 18 months of age, open reduction is usually necessary. Additionally, a femoral shortening osteotomy should be considered in conjunction with the open reduction. Femoral shortening osteotomy results in far lower rates of proximal femoral growth disturbance than pre-reduction traction in children older than 3 years of age [292–296]. In fact, proximal femoral growth disturbance rates over 50% and re-dislocation rates over 30% have been reported after preliminary traction and subsequent open reduction in children over 3 years [292]. A femoral shortening osteotomy allows correction of excessive femoral anteversion but does require a second incision, internal fixation, and subsequent hardware removal. At the time of open reduction, gentle axial tension on the extremity should easily distract the femoral head away from the acetabulum a few millimeters. If this is not possible, femoral shortening osteotomy should be considered.

In children aged 18 months to 3 years, more providers are now advocating for femoral shortening osteotomy rather than preliminary traction with open reduction [5, 297, 298]. Given the decreased potential for acetabular development/remodeling in this age group, many surgeons recommend a concomitant acetabular procedure in conjunction with open reduction and femoral osteotomy. The decision to proceed with an acetabular procedure is based on the stability of the reduced hip, is subjective in nature, and is often made intra-operatively [299]. An acetabular procedure can be performed in the subsequent months to years if expected acetabular development (i.e. improvement in teardrop shape, decreasing acetabular index) does not ensue following open reduction [175, 300, 301]. In children older than 3 years, open reduction, femoral shortening, and an acetabular procedure should be performed based on stability of the hip [290, 296, 302–305].

The acetabular deficiency in this age group is usually anterior. As such, the most commonly performed concomitant acetabular procedures are those that provide additional anterior coverage, namely the Salter [47, 306–309] and Pemberton [46, 310–314] innominate osteotomies. The Pemberton osteotomy can also provide additional lateral coverage, depending on the direction of the osteotomy.

The ideal incision in this age group is the standard anterior approach described by Smith-Petersen with the Salter modification. This approach enables open reduction of the hip, capsular plication, immobilization of the hip joint in a more functional position, and innominate osteotomy through a single incision.

Surgical Techniques

Proximal Femoral Osteotomy

Deformity of the proximal femur is clinically significant if it results in subluxation of the hip joint. Subluxation can be lateral with extreme coxa valga or anterior with excessive anteversion. Although the neck-shaft-angle in patients with DDH is typically normal, increased anteversion gives the suggestion of radiographic subluxation with disruption of Shenton line. After successful reduction is achieved, the excessive anteversion spontaneously corrects in most patients [315]. If spontaneous improvement in anteversion is not demonstrated within 2–3 years after reduction and the patient has residual acetabular dysplasia, proximal femoral rotational osteotomy may be considered. The proper relation between the proximal femur and acetabulum can be restored in cases where the Shenton line is disrupted by a derotational osteotomy. This can be performed with or without varus correction. Some authors suggest a varus derotation osteotomy be performed in hopes that a redirected femoral head toward the center of the acetabulum will stimulate normal acetabular development [61, 154, 173, 316–324]. If this approach is used, an isolated varus derotation osteotomy with the goal of stimulating acetabular development must be performed in patients younger than 4 years [316]. No improvement in acetabular dysplasia will result from this procedure after the age of 8 years.

The ability to achieve concentric reduction should be confirmed radiographically prior to proceeding with derotational osteotomy. This can be accomplished by obtaining a radiograph while holding the involved extremity in maximal internal rotation and 30 abduction. This view demonstrates the true femoral neck-shaft-angle and confirms that concentric reduction is possible. If concentric reduction is not clearly demonstrated on this view, the treating surgeon should additionally perform an open reduction with the proximal femoral osteotomy.

Intertrochanteric osteotomy is a commonly performed operation on a child's hip. In DDH, it can be as simple as a derotation osteotomy or be performed concurrently with open reduction, femoral shortening, or in combination. Variations including varus, valgus, extension, flexion, rotation, shortening, medialization, lateralization, and trochanteric transfer can all be considered in specific, age-appropriate situations. Appropriate application of these variations can be determined by consideration of the patient's age and careful analysis of the preoperative physical exam and radiographs. Given the significant effects that alteration of the varus inclination of the femoral neck can have on the abductor lever arm and the forces across the knee joint, one should consider a greater trochanter transfer to restore the articulotrochanteric distance and medialization of the femoral shaft to maintain equal weight distribution across knee compartments. This is particularly important in the older child who has less remodeling potential. In situations which the remainder of the limb is in normal alignment, a varus intertrochanteric osteotomy results in genu varum and requires medialization of the femoral shaft to restore normal alignment. Similarly, a valgus intertrochanteric osteotomy will result in genu valgum and requires lateral displacement of the femoral shaft to restore normal alignment.

If the hip is otherwise normal, a varus intertrochanteric osteotomy of greater than 25 may require greater trochanter advancement, particularly in the older child. In a patient with a history of proximal physeal growth arrest (frequently seen in Perthes disease) or medial displacement pelvic osteotomy (e.g. Chiari osteotomy), an already decreased articulotrochanteric distance is often present and the need to transfer the greater trochanter is increased. A valgus intertrochanteric osteotomy lengthens the leg and results in increased pressure on the femoral head. In older children, shortening of the bone or release of tight musculature should be considered.

Preoperative planning of an intertrochanteric osteotomy should always include a thorough physical exam and confirmation of concentric reduction on abduction/internal rotation radiographs. Detailed planning, as described by Muller in 1975 [325] and as presented here, should only be necessary in children older than 18–24 months as the potential for acetabular and femoral remodeling is less, the mechanical effects of realignment are greater, and the derangements are more complex.

The degree of functional femoral anteversion is best determined by a careful and directed physical exam. This should be performed in extension. In this way, the surgeon can be sure to correct the clinical rotational profile of the hip and not simply improve the radiographic appearance without correcting the functional internal rotation of the hip.

Radiographic evaluation begins with a standard anteroposterior view of the pelvis and both hips with the legs in internal rotation. A full-length standing image from the hips to the ankles with the patient standing should be obtained if there are other mechanical alterations in the limb. In this way, the surgeon can determine the need and location for additional osteotomies. Further radiographs may be obtained with the limb in various positions to evaluate the range of motion of the femoral head in the acetabulum and position of greatest congruity.

Preoperative planning for Intertrochanteric Osteotomy of the Femur (See Fig. 4.11)

1. Two drawings are made on two separate sheets of transparent paper or radiographic film. The first drawing outlines the femoral head, proximal shaft of the femur, and the acetabulum. A dotted line is placed down the axis of the femur shaft (A) and a second line is drawn perpendicular to the dotted line at the proximal extent of the lesser trochanter (B). This second line is the site of the osteotomy (Fig. 4.11a).
2. On the second sheet of paper, the acetabulum is once again outlined and a line is again placed down the axis of the femoral shaft (Fig. 4.11b).
3. The second drawing is the superimposed on the first with the acetabulum overlapping. The drawings are then rotated until the outlined femoral head of the first drawing is in the desired relationship to the outlined acetabulum of the second drawing. The proximal femur and femoral axis are then outlined on the second sheet down to the level of planned osteotomy (as drawn with the second line on drawing one). The angle (ϕ) created between the original femoral axis drawn on sheet 2 and the new femoral axis drawn after appropriately rotating sheet 1 is the amount of varus that is needed to produce the desired result (Fig. 4.11c).
4. The drawings are the superimposed with the original femoral axis aligned on each. By

sliding the drawing up and down the intersection of A′ and B of the second drawing are positioned at the level of the planned osteotomy (line B) of the drawing one. A line is then drawn perpendicular to the axis of the femoral shaft through this intersection point (line B′). This is the definitive osteotomy line. The triangle of bone that is created below this line is the wedge that will be resected during the osteotomy. By superimposing and thereby maintaining the femoral axis, the correct amount of medial displacement will be performed and no changes in the alignment of the remaining limb will occur (Fig. 4.11d).

5. The distal aspect of the femur is then drawn in below the osteotomy line. Using the transparent templates of the desired plating system,

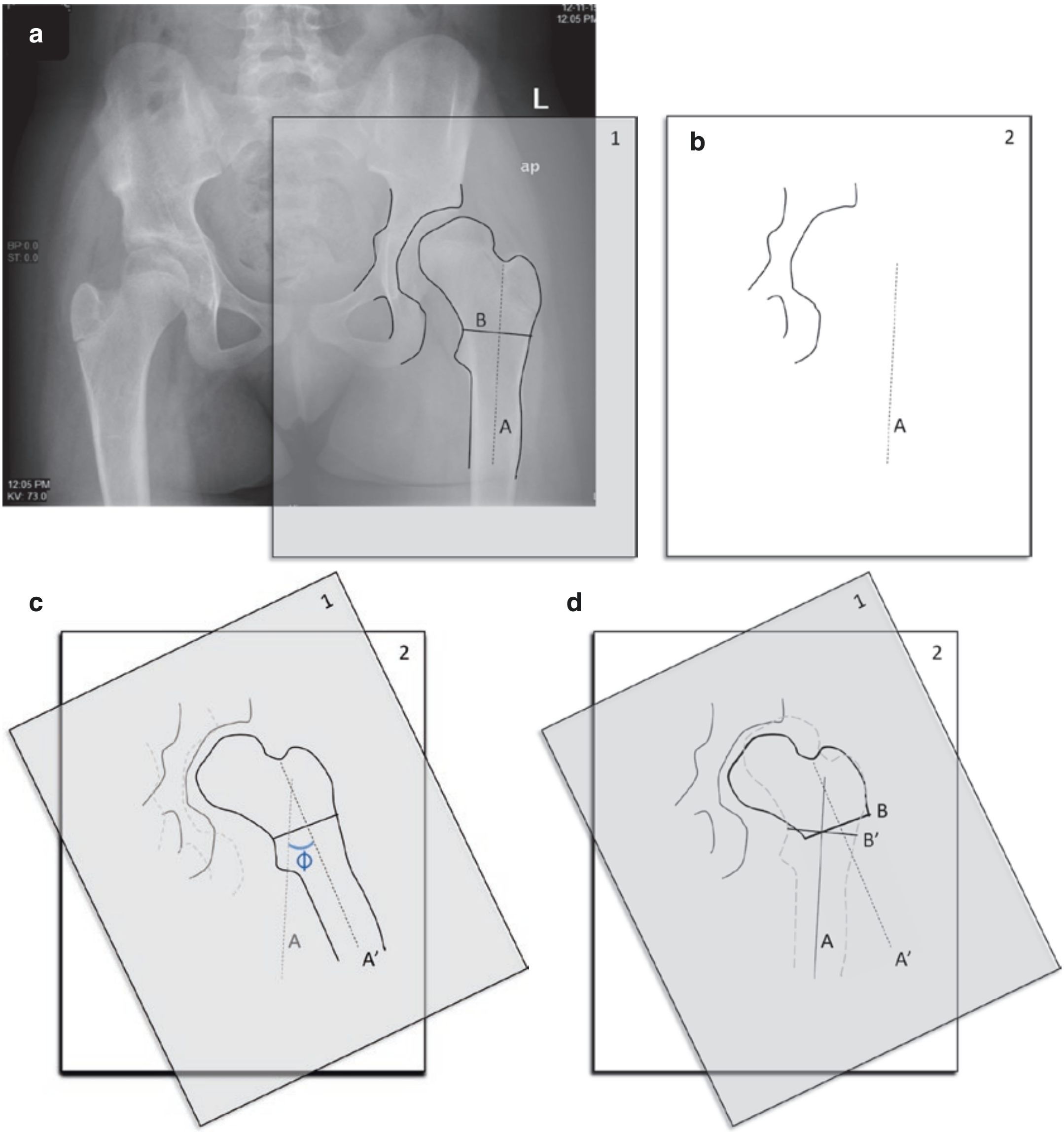

Fig. 4.11 Preoperative planning for intertrochanteric osteotomy of the femur. 11 year-old girl with coxa valga and hip subluxation secondary to avascular necrosis following closed reduction as an infant. Drawings depicting the steps to plan a varus intertrochanteric osteotomy (**a**–**e**). See *Surgical Techniques* section for text description. (Illustrations drawn by Jason J. Howard)

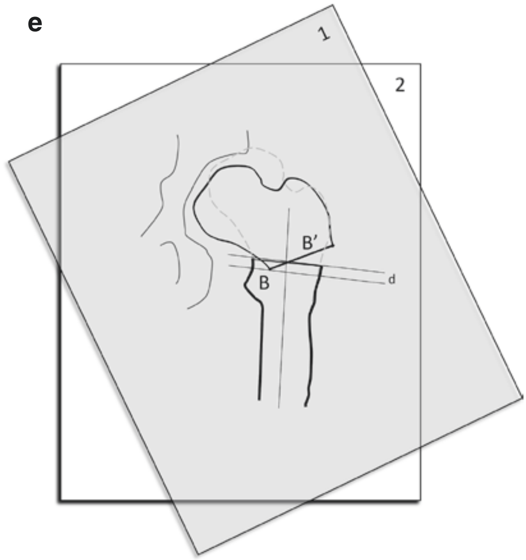

Fig. 4.11 (continued)

the appropriate positioning of the plate and starting point for the chisel can be determined. The correct size of implant can be planned for which will allow for measurement of the appropriate amount of medial displacement to be obtained intraoperatively. The amount of shortening performed can also be determined by measuring the distance between the planned osteotomy (B) of drawing one and the definitive osteotomy (B′) of drawing two (Fig. 4.11e).

The extent of immobilization required during the postoperative period depends on the size of the patient, the strength of the plate used, the strength of the bone, the stability of the osteotomy site, and the ability of the patient to comply with weightbearing restrictions. Small children should be placed in a one leg spica cast and made non-weightbearing while older, cooperative patients may be allowed to partial weightbearing through a crouched gait. Unrestricted weightbearing is permitted once radiographic union is confirmed which is typically 6–8 weeks. Internal fixation devices are typically removed 12–18 months postoperatively. If they are not removed in young children they will become encased in bone, posing more challenging problems if future operations are necessary.

It is the authors’ preference to perform only a reduction, closed or open, in patients under 18 months of age with complete dislocations. In children older than 18 months with complete dislocation, subluxation, or residual dysplasia after treatment, it is the authors’ preference to correct all anatomic abnormalities on both the femoral and acetabular sides of the joint. It the decision is made to perform an osteotomy at the time of open reduction, combining an acetabular osteotomy with open reduction was shown to be more effective at resolving dysplasia than open reduction combined with varus derotational osteotomy of the femur [80].

Pelvic Osteotomies

The goal of any treatment for DDH is to restore the anatomy to as near normal as possible at the time of skeletal maturity. As previously discussed, the remodeling potential of the acetabulum after concentric reduction of the femoral head in a very young child continues for many years [41, 43, 44, 50]. However, this potential is markedly decreased after the age of 4.

Improvement of residual acetabular dysplasia is believed to provide a better weight-bearing surface for the femoral head and thereby reduce the contact pressures encountered during the normal gait cycle [326, 327]. This may also increase the longevity of the hip and prevent or delay the development of degenerative joint disease that should be otherwise expected based on the natural history of DDH. Although acetabular deficiency may be directly assessed at the time of open reduction or through arthrography at the time of closed reduction, in the authors’ experience, the problem is typically not one of deficiency, but of a failure of ossification of the peripheral acetabular cartilage. Indeed, arthrography at the time of reduction often shows a well-covered femoral head by the unossified acetabular cartilage. Failure of normal development and ossification then ensues because of intrinsic abnormality of the acetabular cartilage or secondary to damage produced by pressure from the unreduced femoral head. Once concentric reduction is obtained, the acetabular cartilage may resume normal ossification and correction of acetabular dysplasia ensues. Unfortunately, in some cases this does not occur to an acceptable degree and intervention should be undertaken after the acetabulum has had reasonable time to develop on its own [66, 212, 328]. The neovascularity stimulated by healing of any osteotomy of the innominate bone may increase the ossification of the acetabular cartilage. Further, the appropriate redirection of the acetabulum improves bony anatomy and biomechanics that may stimulate further ossification [329]. Innominate osteotomy may be indicated at the time of open reduction, especially in children older than 18 months of age. Imaging of the hip with the leg in extension, neutral rotation, and abduction after concentric reduction is obtained will provide an understanding of the true acetabular coverage and determine the need for an innominate osteotomy.

Shelf procedures of the pelvis were described in the 1800s and used widely until the 1950s when the medial displacement osteotomy was described by Chiari [330], relying on fibrous metaplasia for any additional surface contact of the pelvis with the femoral head. Various pelvic osteotomies were later described by Salter, Pemberton, and others for redirecting the acetabulum to cover the femoral head with articular cartilage. Currently, treatment options for residual acetabular dysplasia are divided into four groups which will each be discussed. First, osteotomies that redirect the entire acetabulum; second, acetabuloplasties involving incomplete cuts and hinge on various aspects of the triradiate cartilage; third, placement of bone over the hip joint capsule over the uncovered portion of the femoral head; and fourth, hybrids of the above groups.

Acetabular redirection osteotomies provide coverage of the femoral head by acetabular cartilage by complete cuts through various pelvic bones and rotation of the acetabulum. The general prerequisites for rotational osteotomies include the ability to obtain a concentric reduction, release of soft tissue contractures including the iliopsoas and adductor muscles, a congruous joint, and good range of motion. Rotational osteotomies include the Salter innominate osteotomy [47, 103, 269–271, 331–333], the Sutherland double-innominate osteotomy [334], the triple-innominate osteotomy of Tonnis [174, 264, 335–338], Steel [339–345], Ganz [346–350], the spherical osteotomies of Wagner [351–353], and Eppright [354, 355]. The indications for rotational osteotomies are persisting dysplasia after primary treatment and acetabular dysplasia in an untreated child. Although often difficult to recommend to the families of children who are typically asymptomatic and with normal function, acetabular osteotomy should be recommended in the setting of failure of the acetabular angle to improve within 2 years of open or closed reduction or persistent dysplasia after the age of 5.

> ***"The general prerequisites for rotational osteotomies include the ability to obtain a concentric reduction, release of soft tissue contractures including the iliopsoas and adductor muscles, a congruous joint, and good range of motion".***

The Salter innominate osteotomy, described in 1961, was the first to entail the redirection of the entire acetabulum as a unit. This was accomplished by completing a transverse osteotomy of the ilium above the acetabulum and opening the osteotomy anterolaterally by hinging and rotating the acetabular segment on the symphysis pubis [47, 270]. This allowed maintenance of the acetabular shape while correcting the abnormal anterolateral facing of the acetabulum. Several reports [306, 309, 356, 357] have confirmed the initial results of Salter and Dubos [270], likely making this the most commonly written-about pelvic osteotomy in DDH. Although apparently easy to perform, surgeons should exercise caution and diligence when performing the Salter osteotomy. A common error is failure to obtain a complete and concentric reduction before performing the osteotomy. The Salter osteotomy provides about 15° of lateral coverage and 25° of anterior coverage. If performed correctly, there is no significant lateralization of the hip [358]. It is better performed in the child or adolescent between 2 and 9 years of age as it hinges on the pubic symphysis and the increased flexibility in a younger patient provides increased rotational capabilities and possibly more lateral coverage. In children younger than 18 months, the iliac wings are often not thick enough to support that bone graft.

> ***"Although often difficult to recommend to the families of children who are typically asymptomatic and with normal function, acetabular osteotomy should be recommended in the setting of failure of the acetabular angle to improve within 2 years of open or closed reduction or persistent dysplasia after the age of 5".***

The double-innominate osteotomy of Sutherland is rarely performed today. It aims to allow greater rotation of the pelvis fragment than the Salter osteotomy by cutting through the pubis, rather than just hinging on it [334]. The triple-innominate osteotomy of the pelvis allows even greater coverage by performing cuts of all three bones of the hip [359]. Using a similar osteotomy of the iliac bone as in the Salter osteotomy, it further divides the pubic and ischial bones to provide increased mobility in obtaining anterior and lateral coverage. It is typically performed in older children, whose tri-radiate cartilages have closed. It differs from the Salter and Pemberton osteotomies as the acetabular component is completely free and it does not use a hinge. Similar to the Salter osteotomy, a concentric reduction of the acetabulum and femoral head must be obtained when the osteotomy is complete. Several reports have confirmed the effectiveness of the triple-innominate osteotomy [339–344, 359]. It could be considered in younger children when adequate coverage of the femoral head cannot be obtained with the Salter or Pemberton osteotomy. In his original description of the procedure, Steel described one incision for the pubic and iliac bone osteotomies and a separate incision on the buttocks to divide the ischium. Some surgeons prefer to divide the ischium and pubis through a groin incision similar to that used in adductor myotomy [360]. Tonnis [174] described an ischial cut that is closer to the acetabulum in his version of a triple-innominate osteotomy.

The patient is usually placed in a spica cast postoperatively. The healing time for the triple-innominate osteotomy is typically longer than that for the Salter osteotomy in a patient of the same age and is roughly 8 weeks for young children and 12 weeks or longer for adolescents.

The second group of treatment options includes acetabuloplasties involving incomplete cuts and hinge on various aspects of the tri-radiate cartilage, such as those described by Pemberton [46, 287, 289, 312–314, 361–363] and Dega [364–368]. Although disputed by more recent authors [369], these procedures have long been believed to decrease the volume of the acetabulum as they hinge on the triradiate cartilage as a fulcrum and seemingly decreasing the diameter of the lateral opening of the acetabulum [370].

The Pemberton osteotomy typically improves anterior and lateral coverage of the femoral head. Benefits of the Pemberton pericapsular osteotomy are its ability to redirect a forward and laterally facing acetabulum while accounting for the large acetabulum to femoral head ratio in subluxating hips. By altering the direction of the osteotomy, Pemberton observed that the direction of coverage obtained could be varied. In cases where the acetabulum is relatively large in relation to the femoral head, due to subluxation or neurogenic dislocation, the Pemberton osteotomy is an ideal operation as it may decrease the diameter of the lateral opening of the acetabulum, thereby making it deeper, and increasing the overall volume [369]. This commonly includes children with cerebral palsy and myelomeningocele. As the bone graft is stable at the time of placement, hardware is not required.

Prerequisites for the procedure include a concentric reduction of the hip and open triradiate cartilage. The triradiate cartilage is open enough to allow for sufficient mobility in normal children until the age of 7 or 8. In children with severe cerebral palsy or myelomeningocele in whom this procedure is commonly performed, adequate mobility of the triradiate cartilage often remains until 10 years of age or later.

Some degree of incongruence will exist between the acetabulum and femoral head after acetabular redirection. However, the amount of remodeling potential is dependent on the child's age and should be considered at the time of surgery when determining patient positioning and incision used. In this way, an open reduction can be performed if necessary to obtain concentric reduction if the incongruity is determined to exceed acceptable amounts.

Premature closure of the triradiate cartilage has been reported after Pemberton osteotomy [371]. Damage to the acetabulum growth centers can occur if the osteotomy is made too close to the acetabulum, a possible complication of any procedure on the innominate bone when strict caution is not observed.

The patient is usually placed in a single-leg spica cast postoperatively. After 6 weeks of immobilization the patient should be allowed to progress with protected weight bearing and motion activities.

The Dega osteotomy is another innominate osteotomy involving incomplete cuts and hinging near the triradiate cartilage. It can be performed in conjunction with open reduction or alone for residual dysplasia. The Dega osteotomy was developed to provide anterolateral coverage by altering the shape of the acetabulum through a posterior hinge. It differs from the Pemberton osteotomy in that the cuts of the osteotomy end just above the horizontal limb (ilioischial and iliopubic portions) of the triradiate cartilage, leaving a small posterior portion of both the inner and outer tables of the iliac cortex intact just anterior to the sciatic notch. This remaining cortical bone functions as the hinge of the Dega osteotomy, compared to the triradiate cartilage hinge of the Pemberton.

Significant confusion regarding what specifically a Dega osteotomy is has permeated the literature. Mubarak and colleagues [372] have clarified their understanding of the osteotomy originally described by Dega and the osteotomy they were performing. Although they describe their osteotomy as a modification of the Dega osteotomy, it is more a modification of the shelf osteotomy described by Albee [373]. In a report on the use of their osteotomy in a single-stage correction for dysplastic hip in cerebral palsy, it was fittingly referred to as the *San Diego acetabuloplasty* [374] (Chap. 18, *The Hip in Cerebral Palsy*).

The patient is usually placed in a single-leg or one-and-one-half leg spica cast. This should be maintained until radiographic healing occurs at 6–8 weeks postoperatively.

A third group of acetabular reconstructive procedures involves providing coverage of the femoral head by placing bone graft over the hip joint capsule near the uncovered portion of the head. These procedures rely on capsular fibrous metaplasia [373, 375, 376] and include the various shelf procedures [377–382] and the Chiari medial displacement osteotomy [330, 375, 376, 383–388]. The Staheli shelf arthroplasty, introduced in 1981, is a modification of a previously described arthroplasty that has gained widespread use both on its own in the setting of significant anatomic dysplasia, as well as an augmentation to provide increased femoral head coverage when done in conjunction with other rotational procedures [382].

The shelf arthroplasty and Chiari osteotomy are often referred to as "salvage" procedures because they are generally reserved for hip that lack the ability to obtain adequate femoral head coverage with articular cartilage by one of the other procedures mentioned. They are occasionally performed in patients with early degenerative changes in hopes of delaying arthroplasty or arthrodesis.

The Chiari medial displacement osteotomy is actually a rotational osteotomy of the entire distal fragment as it hinges on the symphysis pubis while the distal fragment rotates medially and upward. This medicalization of the hip joint center reduced the loading forces through the hip and theoretically improves abductor muscle function. As a salvage procedure, the acetabular cartilage is not redirected in the Chiari osteotomy. Rather, cancellous bone of the ilium with interposed hip joint capsule provides increased femoral head coverage and containment. Unlike many of the previously described osteotomies, the Chiari osteotomy does not require a concentrically reduced femoral head and can be used in the presence of persistent hip subluxation.

Study of the anatomy of the pelvis has demonstrated that the Chiari osteotomy is unable to provide much coverage to the posterior aspect of the femoral head due to the decreased width of the proximal fragment [389] at this spot. Because of this, many authors recommend augmentation with bone graft to increase the lateral coverage obtained [383, 390, 391]. Bilateral Chiari osteotomies in females should be considered cautiously as there is some concern that this may interfere with a woman's ability to deliver children vaginally.

Postoperatively, it is not necessary to place older, reliable patients in a cast. Younger children may require a spica cast until radiographic healing at 8–12 weeks. Stable internal fixation allows for a partial weight-bearing crutch gait. This should be continued until radiographic healing is evident and the abductor muscles have been rehabilitated. Persistent limp for up to 1 year is relatively common following a Chiari osteotomy.

Augmentation of a deficient acetabulum by creating a shelf of bone surgically was described in the 1800s. Various forms of shelf augmentation provided the primary surgical treatment option for dysplastic acetabulum until the Chiari medial displacement osteotomy was introduced in the 1950s and subsequent redirection of the acetabulum gained popularity in the 1980s. Similar to redirection osteotomies of the acetabulum, the primary goal of shelf arthroplasty is to increase the stability of the hip. In acetabular shelf augmentation, this is completed by increasing the load-bearing area between the femoral head and acetabulum by using bone over capsule rather than articular cartilage. Thus, like the Chiari osteotomy, the shelf procedures are salvage procedures. The proper indication for a shelf procedure is a hip with asymmetric incongruity and ideally an intact capsule. Hips with congruity are better served with acetabular redirection. A popular shelf procedure was that introduced by Staheli in which a slot in the ilium aids in the correct and secure placement of bone graft.

The patient is placed in a single-leg spica cast postoperatively. The hip should be in mild abduction, flexion and neutral rotation. Partial weight bearing can be allowed in reliable patients once radiographic incorporation of the graft is confirmed. Less-reliable patients should weight bear in a walking spica at this point. Complete graft incorporation is typically around 4 months.

The fourth group of acetabular reconstruction procedures includes a thoughtful combination of the above described procedures. A commonly used example of this would be the addition of a shelf procedure to a Pemberton or Salter osteotomy when the surgeon feels that the primary procedure has provided inadequate coverage.

Overcorrection can result from each of the described procedures. The surgeon should assess hip range of motion at the time of temporary osteotomy fixation to ensure that functional range of motion is preserved. Important considerations when determining the best suited acetabular osteotomy for a given patient include the presence of a concentrically reduced hip, the status of the triradiate cartilage, and whether the articular surface of the hip is congruent or incongruent. Any osteotomy of the innominate bone should be placed high enough to avoid damage to the cartilaginous margin of the acetabulum.

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Essential Surgical Techniques

1. Anterior Approach to the Hip for DDH (Figs. 4.12, 4.13, and 4.14)
    (a) The patient is first positioned in the lateral position with the operative hip up. A sandbag is placed behind the back with care not to extend to the buttocks. The patient is allowed to roll back onto the sandbag, keep the buttocks free with the hip in an oblique position.
    (b) A transverse or oblique incision can be used and begins 2 cm below the anterosuperior iliac spine. The iliac crest is exposed and the interval between the Sartorius and the tensor muscles is identified.

(c) Scissors are used to open the fascia overlying the interval between the tensor and Sartorius muscles, with care to stay toward the tensor muscle to avoid injury to the lateral femoral cutaneous nerve.

(d) Once identified, the nerve should be gently retracted medially and protected throughout the case.

(e) Using a Cobb elevator the tensor-sartorius interval is separated with gentle blunt dissection until the underlying rectus femoris is exposed.

(f) The ascending branch of the medial circumflex artery and veins should be identified passing between the Sartorius and tensor muscles in the inferior extent of the wound. It is necessary that these vessels are divided to allow adequate exposure.

(g) The cartilaginous iliac apophysis is split down to bone and the inner and outer tables of the ilium are exposed subperiosteally.

(h) The straight and reflected heads of the rectus muscle are identified and the muscle is divided at its conjoined tendon and allowed to retract distally.

(i) The capsule is cleared of pericapsular fat and fibrous tissue.

(j) Care should be taken to ensure that the capsule is elevated off the false acetabulum if present. This will allow complete visualization of the capsular tissues and appropriate resection of abundant tissue and tensioning during capsulorrhaphy.

(k) To aid in visualization of the transverse acetabular ligament, the inferior capsule should be exposed to its insertion into the pubis and ischium.

(l) A right angled clamp is used to isolate the psoas tendon on the underside of the iliac muscle as it crosses the pubic ramus just medial to the anteroinferior iliac spine. Once isolated, the tendon is divided with care to leave the muscle intact.

(m) Correct placement of the capsular incision is key to performing a successful capsulorrhaphy. The initial capsular incision extends from the superoposterior aspect of the acetabulum to the most inferior aspect and is parallel to the acetabular rim.

(n) A transverse incision over the femoral neck is then made, dividing the capsule into superior and inferior leaflets.

(o) The ligamentum teres is identified and sectioned at its femoral head insertion. It is grasped and traced into the depths of the acetabulum, leading to the transverse acetabular ligament, and then excised in entirety.

(p) The transverse acetabular ligament is the divided as it often limits the size of the acetabulum and prevents concentric reduction of the femoral head and medial acetabular wall.

(q) The femoral head is reduced into the acetabulum with gentle manipulation. Excess force should not be required.

(r) With the femoral head retracted laterally, strong non-resorbing suture is placed in the acetabular side of joint. The authors prefer to grab periosteum with the stich for stronger repair.

(s) The capsule is then gathered and closed tightly. Excess capsular tissue is resected.

(t) The hip is maintained in approximately 30 degrees flexion and 30 degrees abduction while a single-leg or one-and-one-half-leg spica cast is placed with careful molding along the dorsal aspect of the greater trochanter.

2. Anteromedial Approach to the Hip for DDH (Figs. 28.11, 28.12, 28.13, 28.14, 28.15, 28.16, 28.17, and 28.18)
   (a) The patient is positioned supine on the operative table.
   (b) With the hip flexed to 70 degrees and gentle abduction, the femoral neurovascular bundle is identified and the superior and inferior borders of the adductor longus are palpated.
   (c) An incision is made in the groin crease extending from the inferior border of the adductor longus to just inferior to the neurovascular bundle.
   (d) The fascia of the adductor longus is incised in line with the muscle fibers and the muscle is isolated and divided near its origin.
   (e) The adductor brevis is identified. The anterior branch of the obturator nerve is seen crossing the brevis muscle as it courses from proximally and medially. It disappears beneath the pectineus muscle.
   (f) The fascia over the pectineus muscle is incised and the muscle borders are identified. The interval between the superior border of the pectineus and the neurovascular bundle (femoral vein) is bluntly dissected. Exposing this interval leads directly onto the hip capsule. Care must be taken to preserve the medial femoral circumflex artery which travels from superior to inferior on the capsule.
   (g) The leg is externally rotated to aid in the identification of the iliopsoas tendon. This can be palpated just distal to the medial femoral circumflex artery as it inserts on the lesser trochanter.
   (h) The iliopsoas tendon is isolated with a curved hemostat and sectioned sharply from the trochanter. The hip joint can then be isolated both medial and lateral to the medial femoral circumflex artery.
   (i) In high dislocations, the capsular incision must extend further along the posterosuperior rim of the acetabulum. To accomplish this safely, the femoral neurovascular bundle must be carefully separated from the capsule and retracted proximally.
   (j) A small opening incision is made in the capsule parallel to the anterior acetabular margin. The ligamentum teres is visualized and grasped. It can then be traced to its insertion on the femoral head while the capsule is further incised in the same trajectory.
   (k) The leg is rotated to bring the femoral head into the field and the ligamentum teres is sharply detached from the femoral head. The ligament can be traced back to the acetabulum to help identify the inferomedial margin of the joint capsule. The entire anteromedial capsule in incised.
   (l) The ligamentum teres and transverse acetabular ligament are the sectioned from the acetabulum.
   (m) Fibrofatty pulvinar tissue is removed with a pituitary rongeur.
   (n) No tissue of the peripheral acetabulum should be excised.
   (o) In the setting of prolonged dislocation and severe capsular constriction, a “T” incision of the capsule, similar to that performed in the anterior approach to the hip, must be performed.

   (p) The hip is gently reduced concentrically.
   (q) The hip capsule is left open and the hip is maintained in 110 degrees of flexion and 35–40 degrees of abduction.
   (r) A well-molded one-and-one-half-leg spica cast is applied with careful molding dorsal to the greater trochanters. When compared with the anterior approach, careful positioning of the leg and expert dorsal molding of the greater trochanter is of even more importance after open reduction through the anteromedial approach as a capsulorrhaphy is not possible and the spica cast serves as a major stabilizer of the hip and is key to preventing recurrent dislocation.

3. Peri-trochanteric Proximal Femur Osteotomy (Fig. 4.15)
   (a) The patient is positioned supine on a radiolucent operative table or fracture table. Positioning is such that anteroposterior and lateral fluoroscopic views of the hip can be obtained.
   (b) A lateral incision is made extending from the tip of the greater trochanter as distal as necessary. If additional procedures will be performed concurrently, the incision can be extended proximally as necessary.
   (c) The central aspect of the fascia lata is gently exposed with a Cobb elevator to aid in later closure. It is incised sharply longitudinally.
   (d) The insertion of the vastus lateralis onto the vastus ridge is identified proximally. Electrocautery is used to cut the vastus lateralis transversely along the vastus ridge, extending anteriorly from the anterior femoral shaft to the posterior edge of the insertion.
   (e) The vastus lateralis is then elevated anteriorly as the posterior margin is released approximately 1 cm anterior to its attachment to the linea aspera. Leaving a cuff of tissue at the insertion will allow visualization and cauterization of the deep perforating vessels that enter the muscle around the posterior aspect.
   (f) The anterior compartment musculature is then elevated from the femur at the site of planned osteotomy. This should be done subperiosteally to prevent involvement of the neurovascular structures medial to the femur.
   (g) If a rotational osteotomy is planned, the surgeon must ensure that all periosteal attachments are released, particularly around the linea aspera, so that rotation is not impeded.
   (h) If a shortening osteotomy is desired, the subtrochanteric region is identified and the periosteum only in the region to be excised is elevated circumferentially.
   (i) The inferior femoral neck, greater, and lesser trochanter are palpated to ensure proper placement of the osteotomy.
   (j) The amount of femoral anteversion is determined by passing a Kirschner wire along the top of the femoral neck until it contacts the femoral head. This identifies the proper insertion of the blade into the femoral head.
   (k) The angle in which the blade should be inserted related to the femoral shaft is guided by the amount of desired varus/valgus correction desired and the angle of the plate selected.
   (l) Using the templating device provided in the selected instrument

tray, the necessary angle of entry into the femoral head is determined to result in the desired varus/valgus correction. A second Kirschner wire is placed along the most cephalad portion of the femoral neck, matching the anteversion of the first wire and using the template to determine the varus/valgus.

(m) This second wire will guide the direction of the chisel and blade. The first wire is removed.

(n) While palpating the lesser trochanter with a finger, a third Kirschner wire is placed into the center of the lesser trochanter perpendicular to the shaft of the femur. The wire should be placed in the anterior aspect of the femur so as to not interfere with chisel placement. This wire is approximately 5 mm distal to the site of osteotomy, which will be completed at the superior margin of the lesser trochanter.

(o) The distance from the osteotomy site to the entry site for the chisel depends on the size of plate selected. The distance was determined during pre-operative templating, or can be measured directly from the plate.

(p) Care must be taken to ensure that the entry site of the chisel is not too far posterior. This can result in the blade cutting out of the posterior femoral neck. Because the flat face of the greater trochanter is tilted approximately 25 posterior to the axis of the femoral neck, this mistake is easy to make if care is not taken. To prevent this, the geometry of the greater trochanter should be ignored and the chisel inserted in line with the femoral neck. When done correctly, this will give the sensation that the chisel is starting far anteriorly on the greater trochanter.

(q) With the starting point selected, the chisel guide is placed and the angle between the guide and the femoral shaft is assessed. If no flexion or extension correction is desired, the guide should be directly in line with the shaft. If sagittal plane correction is desired, the angle created by the shaft and the guide represents that flexion or extension that will be created by the osteotomy.

(r) Using the Kirschner wire and chisel guide as guides, the chisel is driven into the femoral neck to the depth determined on pre-operative templating.

(s) An anteroposterior image is obtained to confirm placement of the chisel and the osteotomy site as marked by the Kirschner wire. A frog-leg lateral radiograph can confirm the placement of the chisel in a center-center position.

(t) The anterior femoral shaft should be longitudinally scored with the saw prior to making the osteotomy. Pins can be used to determine the appropriate rotational changes as described.

(u) The first cut of the osteotomy is performed perpendicular to the shaft of the femur just cephalad to the lesser trochanter with an oscillating saw. Copious irrigation should be used during cutting to minimize thermal energy to bone.

(v) The chisel in the femoral head can then be used to tip the fragment into varus.

(w) The planned sized wedge of bone is removed from the medial side of the proximal fragment beginning halfway across the bone.

   - (x) The seating chisel is then removed and the selected blade plate is inserted. Once seated it is rotated the appropriate extent, if rotation of the osteotomy is desired, and held to the femoral shaft with a bone clamp prior to screw fixation.
   - (y) If a subtrochanteric femoral shortening osteotomy is performed, either a blade plate or simple lateral plate fixation can be used.

4. Salter Innominate Osteotomy (Fig. 4.16)
   - (a) The patient is positioned supine on the operative table as for open reduction of the hip through the anterior approach.
   - (b) The inner and outer tables of the ilium are exposed with careful elevation of the periosteum from the sciatic notch. With a finger in the sciatic notch on the outer table, a right-angled forceps is passed from medial to lateral at the notch and used to pass the Gigli saw. Soft tissues on each side of the ilium are protected with wide retractors as the osteotomy is completed with a Gigli saw, exiting just above the anterior inferior iliac spine.
   - (c) Using a power saw or bone biting forceps a triangular full-thickness bone graft should be taken from the anterior part of the iliac crest. This graft is then used to hold the osteotomy open.
   - (d) An intramuscular tenotomy of the iliopsoas must then be performed. Occasionally the adductors must also be lengthened.
   - (e) Towel clamps are used to grasp the two fragments. The distal fragment should be grasped as far posterior as possible to avoid accidentally breaking off a piece of bone.
   - (f) The proximal fragment should not be manipulated with the clamp in effort to open the osteotomy as this will only provide a false correction and result in the appearance of a high iliac crest and apparent leg length difference.
   - (g) If the hip capsule has not been opened, the desired correction can be obtained by placing the limb in the “figure of 4” position, with the foot on the opposite knee.
   - (h) If the hip capsule has been opened, the desired correction can be obtained by using the towel clamp on the distal fragment to manipulate the fragment in an anteroinferior direction, in line with the ilium. The fragment typically slips posterior when the osteotomy is completed so it should also be pulled forward while the desired rotation is achieved.
   - (i) The bone graft is the tailored to fit tightly into the osteotomy site while maintaining the gap in the desired position.
   - (j) The distal fragment should be checked to ensure that it does not displace posterior with the graft in place. This can be accomplished by creating a notch in the posteriorly cut surface of the proximally fragment and inserting the cut surface of the distal fragment into this notch if necessary [322].
   - (k) Two threaded Kirchner wires should then be passed from the proximal fragment into the distal fragment through the appropriately positioned graft. The distal end of the wires should lie medial and posterior to the acetabulum and the surgeon should ensure that they do not penetrate the hip joint.

5. Triple Innominate Osteotomy (Fig. 5.12)
    (a) For the ischial osteotomy, the patient is positioned in the lateral decubitus position with the hip flexed to 90 degrees.
    (b) A transverse incision is made 1-cm cephalad from the natal crease. A wide exposure is gained as the incision is extended down to the gluteus maximus muscle.
    (c) The gluteus maximus is then retracted laterally as the medial border is identified and freed.
    (d) The ischial tuberosity and associated muscle attachments are then identified.
    (e) The biceps femoris and semitendinosus share a common origin on the ischial tuberosity. By dissecting free the long head of the biceps femoris and detaching it from the ischial tuberosity the interval between the semitendinosus and semimembranosus can be identified. This is the ideal site for the ischial osteotomy.
    (f) The ischial ramus is dissected subperiosteally. A curved retractor is placed through the obturator foremen to elevate the obturator muscles and protect the internal pudendal neurovascular structures. The ischial osteotomy is performed with resection of at least 1 cm of bone. This will ensure that the mobility of the fragment is not limited by periosteal attachments and allow for medial displacement of the acetabulum, which tends to be lateralized with this procedure. Although not the original description of the procedure by Steel, it is generally easiest to complete this osteotomy by removal of a small section of bone with a rongeur.
    (g) The iliac and pubic osteotomies are completed through an oblique incision at the iliac crest with exposure of the innominate bone as in the Salter osteotomy. The medial exposure required to complete the pubic osteotomy pushes the limits of the incision but can be eased by having an assistant push the leg into flexion and adduction to relax the anterior structures and allow adequate medial placement of the osteotomy.
    (h) Medial dissection around the pubic ramus should be continued until identification of the pectineal tubercle. The osteotomy should be performed medial to this to ensure that it does not enter the anteromedial acetabulum.
    (i) A curved forceps or retractor is placed around the pubic ramus and out the obturator foramen in a subperiosteal manner. The osteotome is then directed medially to complete the osteotomy, or a rongeur can be used to create the osteotomy and resect a section of bone.
    (j) The iliac osteotomy is completed in the exact manner as described for the Salter osteotomy.
    (k) With the acetabular fragment completely mobile, it is grasped with a large towel clamp, as posterior as possible. Alternatively, a large threaded Steinman pin or Schanz screw can be placed into the fragment and used as a joy stick.
    (l) A laminar spreader can be used in the iliac osteotomy site to aid in mobilization if necessary.
    (m) A bone graft from the anterior iliac crest is fashioned to fit tightly into the osteotomy site once the acetabular fragment has been

rotated into its desired position. Fixation is obtained with large cannulated screws placed from cephalad to caudal and caudal to cephalad directions.

6. Pemberton Iliac Osteotomy (Fig. 5.9)
   (a) The patient is positioned supine on the operative table.
   (b) The inner and outer tables of the ilium are exposed subperiosteally after the cartilaginous iliac apophysis is split according to Salter's technique. Exposure of the sciatic notch as inferior as possible will aid in visualization during the osteotomy and help prevent extension of the osteotomy into the notch.
   (c) Division of the psoas tendon should be performed although not described by Pemberton as the osteotomy lengthens the pelvis.
   (d) The osteotomy is then performed based on the direction that coverage is needed. A transverse osteotomy will provide more anterior coverage. A laterally inclined osteotomy will provide more lateral coverage.
   (e) The osteotomy starts 1 cm above the anteroinferior iliac spine and aimed inferior through the lateral table. Care must be taken to avoid exiting into the sciatic notch. A cobra retractor placed in the notch can help provide additional visualization. The inner table osteotomy is completed in similar manner.
   (f) The more distal the inner wall cut is made, the greater the extent of lateral coverage. If more anterior than superior coverage is desired, the medial and lateral wall cuts should be parallel.
   (g) A wider curved osteotome is then used to connect the two cuts.
   (h) Once the osteotomy has been completed to the extent possible without exiting the sciatic notch, the Pemberton osteotome with a right-angled curve is used. The cut is then completed into the triradiate cartilage.
   (i) The final portion of the cut can be aided by placing a lamina spreader into the osteotomy to help pry down the acetabular roof. Fluoroscopy can be used to aid in this section of the procedure.
   (j) While holding the osteotomy open with the lamina spreaders, a curette is used to create grooves in the cancellous bone on each side to hold the graft in place.
   (k) A triangular wedge of autograft is cut from the anterior iliac crest (unless a femoral shortening osteotomy has been performed in which case the removed section of bone can be used). Of note, the graft should be slightly larger than the osteotomy side as it will be recessed into the grooves created in the cancellous bone.
   (l) Confirmation that the graft is secure and stable should be performed by manual manipulation. No internal fixation should be necessary.
7. Dega Iliac Osteotomy (Fig. 18.22)
   (a) The patient is positioned supine on the operative table.
   (b) The outer table of the ilium is exposed subperiosteally. Exposure of the inner table is not necessary, but may be performed based on the comfort level of the surgeon.
   (c) Beginning just above the anteroinferior iliac spine, a curvilinear osteotomy is performed, continuing posteriorly using caution to remain above the acetabulum. The osteotomy ends approximately

1 cm prior to the sciatic notch and is completed only through the outer table.

(d) The use of guide pins to outline the acetabulum/osteotomy can be helpful.

(e) A straight osteotome is placed in the osteotomy site. The osteotome is directed medially and caudally and advanced until it is just above the horizontal ilioischial and iliopubic portions of the triradiate cartilage.

(f) The direction of rotation achieved with the osteotomy is dependent on the amount of inner wall cortex that is cut

(g) For more anterior coverage, the osteotomy is continued along the inner table until only a 1 cm posterior hinge remains anterior to the notch.

(h) For more lateral coverage, the osteotomy should not extend as far posteriorly and approximately 1/3 of the inner cortex should remain intact. The more inner table that is left intact, the more lateral coverage can be expected.

(i) An osteotome is used to pry open the osteotomy while bone graft (tricortical iliac crest or resected femoral bone) is placed with the larger bone placed most anterior.

(j) No internal fixation should be necessary.

8. Albee Shelf Acetabuloplasty

(a) The patient is positioned supine on the operative table.

(b) The outer table of the ilium is exposed subperiosteally.

(c) Remaining approximately 0.5–1 cm above the acetabulum, the osteotomy is outlined initially with a straight osteotome extending from the anteroinferior iliac spine to the sciatic notch. This first cut is only extending only through the cortex of the outer table along the anticipated line.

(d) The osteotomy is then progressively deepened in a medial and caudal direction with care to remain between the medial wall of the acetabulum and the medial wall of the ilium. This is best performed using a combination of straight and curved osteotomes.

(e) The osteotomy can be extended as far as the triradiate cartilage but typically does not have to go this far in the soft bones of young children.

(f) To allow the bone fragment to move more freely, a Kerrison rongeur is then used to remove the cortical bone from the anterior and posterior extents of the osteotomy as it begins to curve around into the medial iliac wall.

(g) A broad osteotome is then used to pry down the acetabulum and a lamina spreader is placed in the osteotomy.

(h) Autograft bone is obtained from the anterosuperior iliac spine or femur if shortening osteotomy has been performed.

(i) Three triangular pieces of bone are fashioned and placed in the osteotomy. The largest piece is typically placed anteriorly to provide additional anterior coverage.

(j) No internal fixation should be necessary.

9. Chiari Medial Displacement Osteotomy (Fig. 20.5b)

(a) Precise placement of the osteotomy is critical to a successful operation. Placed too high, it does not provide beneficial coverage to the hip. Placed too low, there is not adequate capsule between the femoral head and the ilium. To aid in placement of the osteotomy, ensure that the superior aspect of the hip capsule is well exposed and freed of surrounding tissues. Thinning of a markedly thickened capsule may be necessary.

(b) Although Chiari did not expose the inner wall of the ilium, we recommend visualizing the inner table and making the cuts of the lateral and medial cortex separately as this adds no morbidity to the procedure but adds safety and aids in orientation.

(c) Choosing the appropriate direction of the osteotomy is important for obtaining the appropriate displacement of the distal fragment. Because the distal fragment externally rotates on the symphysis pubis to obtain medial displacement, the osteotomy should be angled cephalad by 10 to allow for this rotation.

(d) Consider use of image intensifier to confirm both the location of the acetabular roof and the direction of the osteotomy given the importance of these steps in performing successful surgery.

(e) Once confirming the placement and direction of the osteotomy, the lateral cortex is first cut while visually confirming the proper orientation of the cut.

(f) The medial cortex is then cut. Both the medial and lateral cortical cuts should stop before entering the sciatic notch, leaving the posterior cortex of the sciatic notch intact. This is done to prevent splintering of the sciatic notch and injury to the sciatic nerve during rotation of the distal fragment.

(g) The Gigli saw is passed through the sciatic notch and used to complete the osteotomy.

(h) The distal fragment is displaced (rotated) medially by abducting the leg. Care should be taken to ensure that the posterior aspect of the osteotomy is complete and that no posterior tether is present.

(i) If further displacement is desired, direct pressure over the greater trochanter can be applied laterally.

(j) Although posterior displacement of the inferior fragment increases the amount of coverage because of the wider ilium posteriorly, this should be avoided or minimized in order to prevent increased pressure on the sciatic nerve.

(k) The amount of displacement advisable is controversial. Some authors have recommended only 50% displacement while others recommend 100% displacement at that mid portion of the osteotomy over the hip joint.

(l) If significant displacement is achieved, rigid fixation should be used to prevent further displacement and supplemental bone graft should be used to avoid delayed union or nonunion.

(m) Fixation necessary is dependent on the amount of displacement and anticipated healing potential of the patient. For older patients with greater displacement of the osteotomy, three heavy screws should be used for several months to prevent unwanted displacement. In younger patients where rapid healing is anticipated, heavy-threaded Kirschner wires can be used. These can be left subcutaneous for easy removal while screws should be left in place for several months.

(n) Lateral coverage and healing potential of the osteotomy can be augmented with bone grafting. This is especially important when the anterior ilium is very thin.

10. Staheli Shelf Procedure (Fig. 5.17)
    (a) The patient is positioned supine on the operative table.
    (b) The outer table of the ilium is exposed subperiosteally. The entire superior capsule must be visible.
    (c) The reflected head of the rectus tendon should be identified during the exposure. It is then freed from the capsule and divided between its midportion and its junction with to the conjoined tendon. This will be used to secure the graft down. If not present, flaps should be created from the thickened capsule.
    (d) Locating the proper position for the slot cut is the key step in the procedure. It should be positioned at the exact acetabular edge.
    (e) Confirmation of acetabular location should be performed radiographically after placing a guide pin into the ilium at the acetabular edge.
    (f) After the correct location is verified, a 5/32-in. drill is used to create a series of holes that outline the edge of the acetabulum. Each hole should be angled in a cephalad direction approximately 20° and drilled to 1-cm depth. The holes should extend anteriorly and posteriorly enough to provide necessary coverage.
    (g) A slot is then created as the drill holes are connected with a narrow rongeur. The floor of the slot should be subchondral bone of the acetabulum.
    (h) Alternatively, a high-speed burr can be used to create a groove along acetabular edge. This groove can then be deepened at the appropriate angle with curettes.
    (i) Corticocancellous and cancellous strips of bone autograft are then obtained from the outer table of the ilium.
    (j) Care should be taken to perform only shallow decortication at the region directly above the slot as this will allow incorporation of the graft without compromising the integrity of the slot. Autograft may be supplemented with allograft bone if necessary.
    (k) Each strip of graft is cut to the appropriate length to provide the desired amount of lateral coverage without causing a loss of motion secondary to impingement laterally and anteriorly. The grafts are then placed in the slot, extending laterally over the capsule. A second layer of graft strips are placed above the prior layer, at 90 to the first layer.
    (l) After placement of all bone graft, the reflected head of the rectus tendon is sutured into place, securing the bone graft in place.
    (m) Any remaining autograft is cut into small chips and placed over the strips. The abductor muscles are used to hold these chips in place at time of closure.

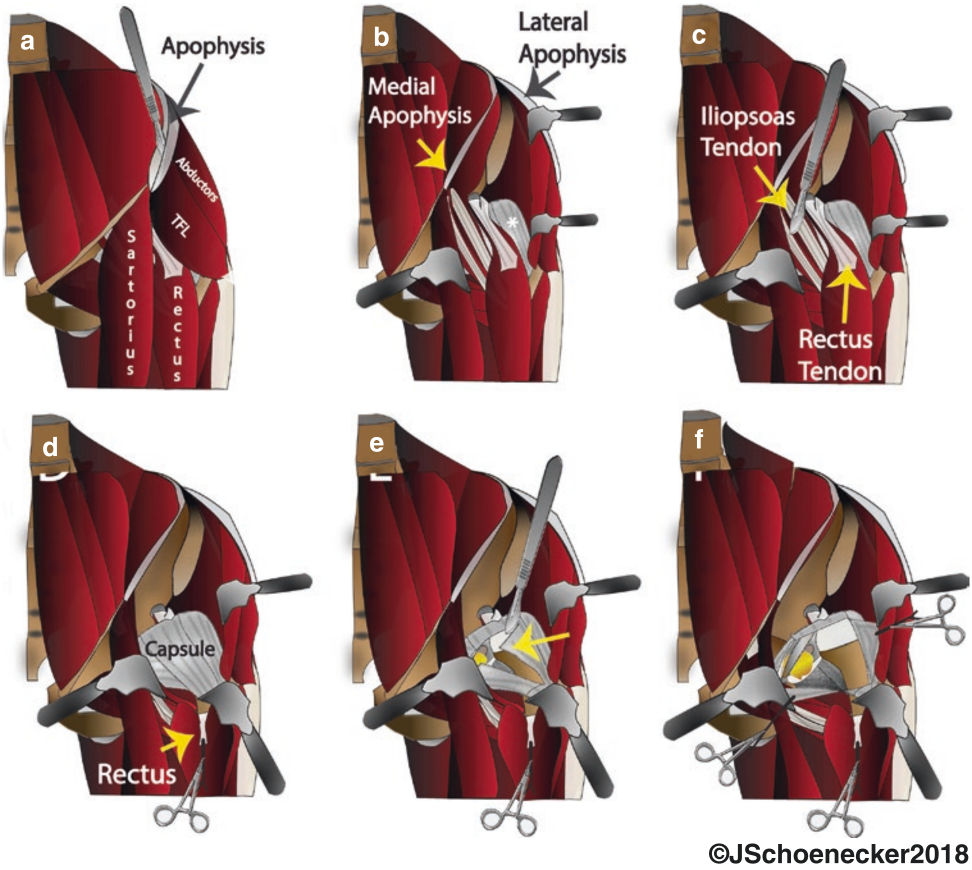

Fig. 4.12 Anterior approach to the hip for DDH. Initial exposure, psoas tenotomy and capsulotomy illustrated (**a**–**f**). See *Essential Surgical Techniques* Box for text description

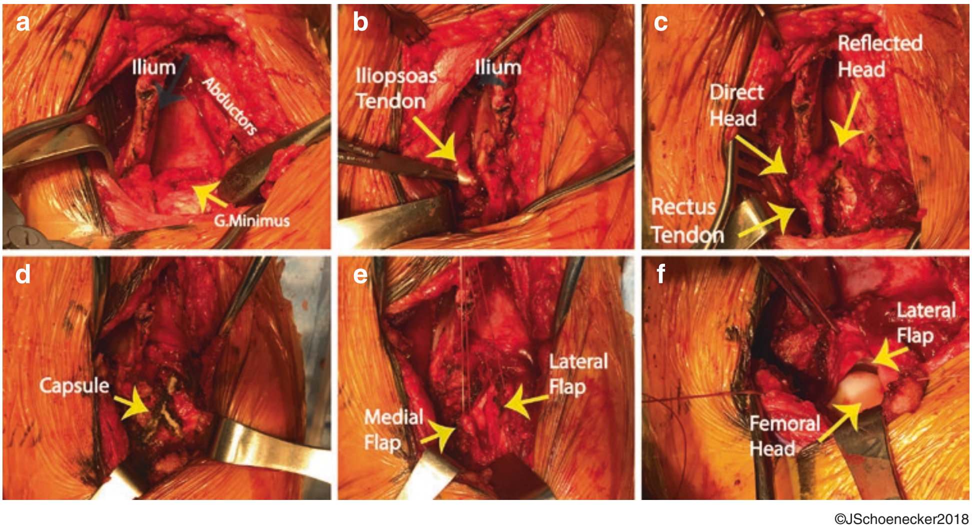

Fig. 4.13 Anterior approach to the hip for DDH. Intraoperative pictures depicting the initial exposure, psoas tenotomy and capsulotomy (**a**–**f**). See *Essential Surgical Techniques* Box for text description

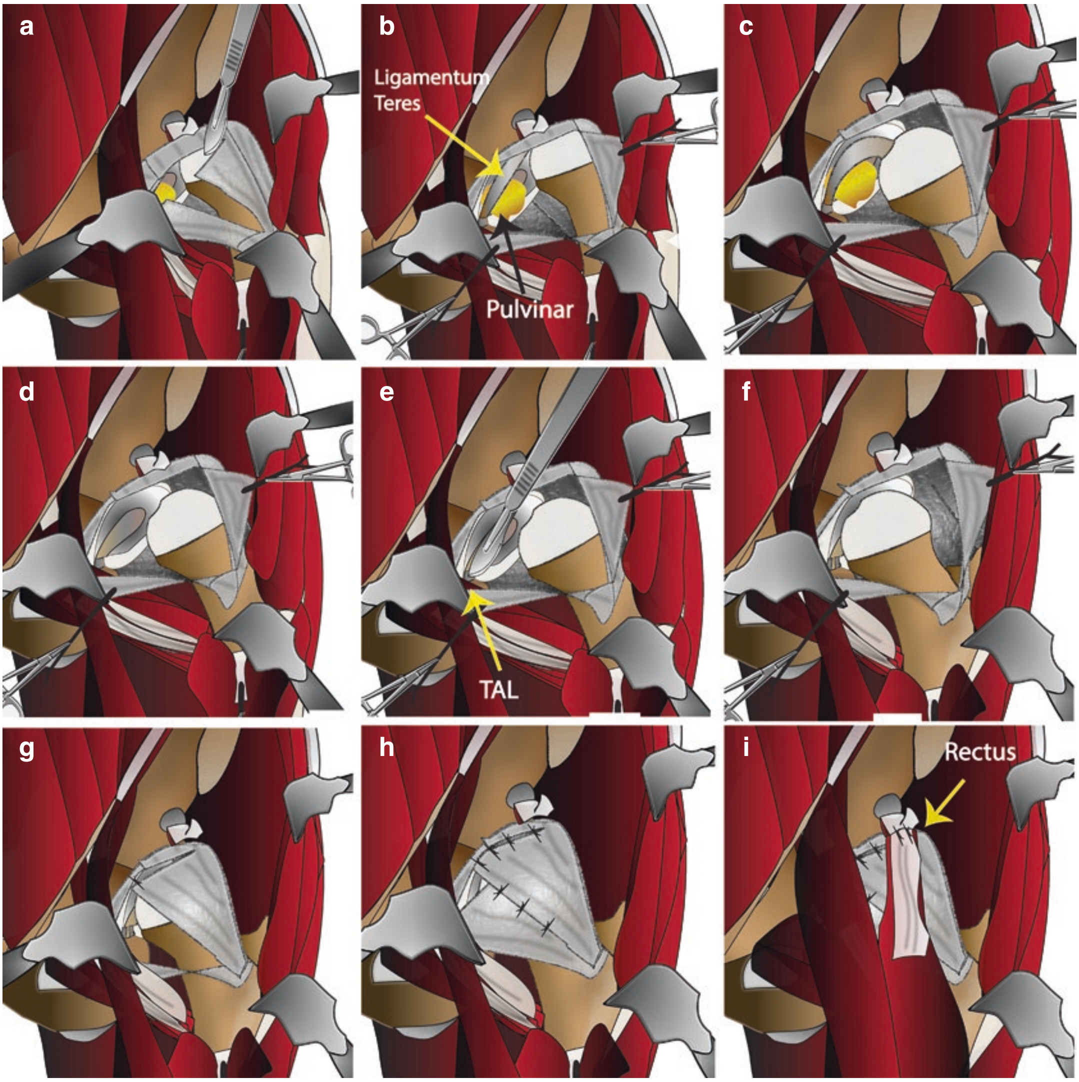

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Fig. 4.14 Anterior approach to the hip for DDH. Excision of ligamentum teres, sectioning of the transverse acetabular ligament, reduction of the hip, and capsulorrhaphy illustrated (**a**–**i**). See *Essential Surgical Techniques* Box for text description

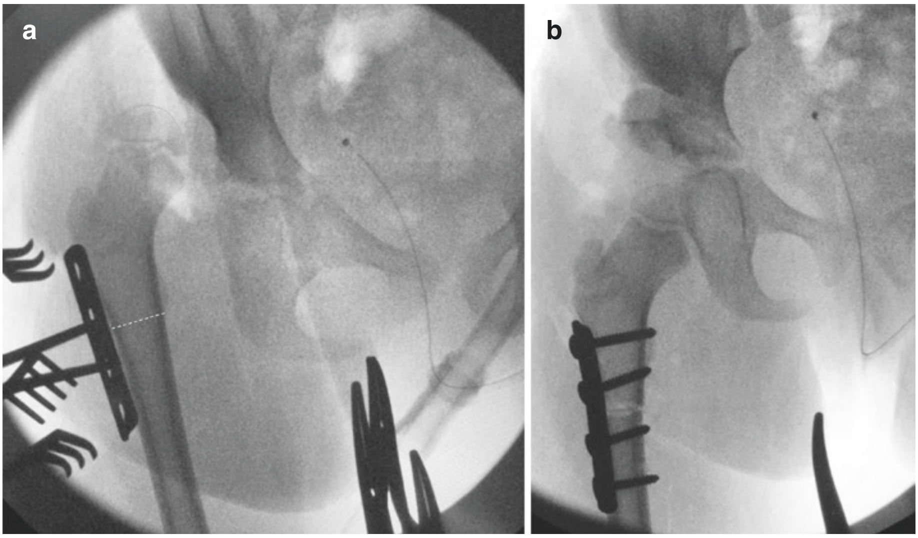

Fig. 4.15 Subtrochanteric femoral shortening osteotomy in a 4 year-old girl with late diagnosis of right DDH. (**a**) Osteotomy just inferior to lesser trochanter (dotted line) with 4-hole 1/3 tubular plate applied to the lateral femur for sizing. Femoral epiphysis outlined for clarity. (**b**) Concentric reduction of the right hip post femoral shortening (approximately 1.5 cm removed in this case) and derotation. Concomitant anterior open reduction and Pemberton acetabuloplasty also performed. (Courtesy Jason J. Howard)

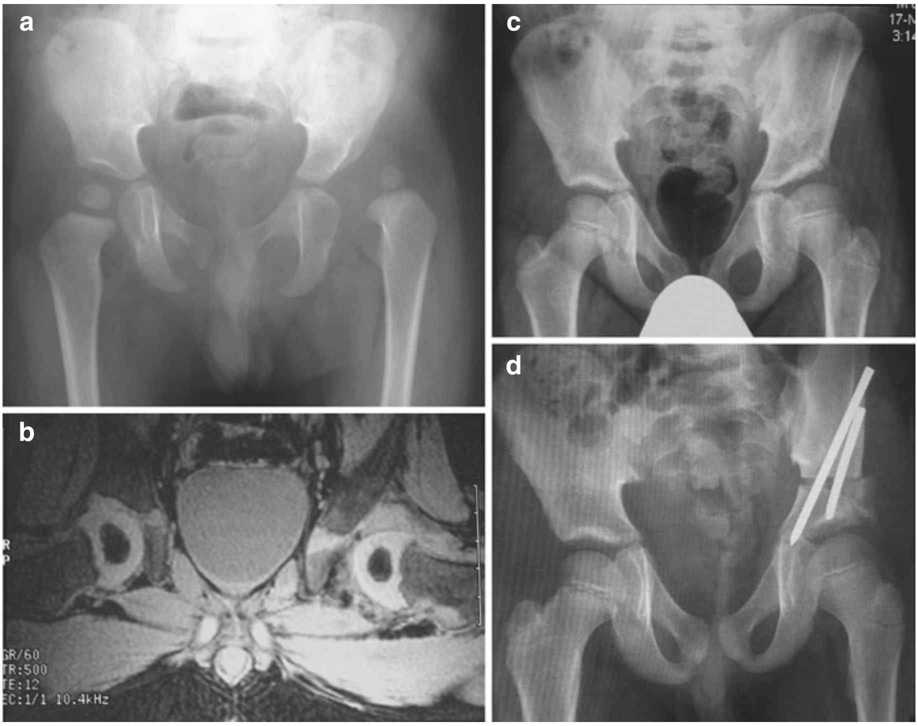

Fig. 4.16 Salter osteotomy. (**a**) 15 month-old boy with a dislocated left hip and severe acetabular dysplasia. (**b**) Axial MRI scan showing concentric reduction of the left hip post medial open approach. (**c**) Persistent acetabular dysplasia at age 6 years. (**d**) Subsequent Salter innominate osteotomy performed with improvement of acetabular index and femoral head coverage. (Courtesy Jason J. Howard)

Operative Pitfalls

1. Failure to obtain and maintain concentric reduction is the most common complication in the management of DDH. Reduction should be confirmed with axial imaging after cast application and "nearly" concentric reductions should not be accepted.
2. Immobilization of the hip after open or closed reduction in a position that places excessive pressure on the femoral head can result in avascular necrosis, a major cause of long term disability after treatment of DDH. Extreme force or limb positioning (abduction and internal rotation) to maintain concentric reduction should not be accepted.
3. Altering the varus inclination of the femoral neck will have profound effects on the abductor lever arm and forces across the knee joint. Consider both a greater trochanter transfer, to restore normal articulotrochanteric distance, and medialization of the femoral shaft, to maintain an equal weight distribution through the medial and lateral compartments of the knee.
4. If a false acetabulum is present, the adherent capsule must be stripped off the ilium down to the true acetabulum. This allows for redundant capsule to be excised adequately during capsulorrhaphy.
5. Pelvic osteotomies should not be performed unless concentric reduction of the hip joint is present (except Chiari or shelf procedures).
6. Penetration of the hip joint with the osteotomy while performing pelvic osteotomies should be strictly avoided. Radiographs should confirm that K-wires used for fixation of a pelvic osteotomy do not enter the hip joint.
7. Obtaining inadequate medial exposure during the triple innominate osteotomy can result in extension of the pubic osteotomy into the anteromedial acetabulum.

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Take Home Messages

- Early detection is the key to successful treatment of DDH
- Proper education of primary care providers regarding diagnosis and prompt referral guidelines will provide the greatest avenue for success.
- Goals of treatment of DDH include obtaining and maintaining a concentric reduction of the hip while minimizing the risks of immediate and late complications.
- Application of a Pavlik harness should be performed at the time of diagnosis and the status of the hip within the harness confirmed by physical exam or ultrasound within 3 weeks of application.
- Only a concentric reduction should be accepted when attempts at closed reduction are made. Open reduction should be performed for anything less.
- Removal of all extra-capsular and intra-capsular blocks to reduction should be thorough at time of open reduction.
- Thoughtful use of femoral and/or acetabular osteotomies should be considered at time of open reduction on an individual patient level.
- Acetabular osteotomies should be performed only after concentric reduction of the hip has been confirmed (with the exception of the salvage procedures).

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