Surgery for Residual Femoral Deformity in Adolescents

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INTRODUCTION

Femoral deformity and acetabular dysplasia are often associated with each other. Femoral deformity can be secondary to primary hip dysplasia and hip dysplasia can be secondary to primary femoral deformity,1 because the forces of the femoral head on the acetabulum are integral to the development of acetabular depth and version and, conversely, the forces of the acetabulum on the femoral head are integral to the development of femoral neck inclination and version. The shape of the upper femur is also affected by any imbalance of muscle forces around it. Neurologic changes in the musculature around the hip lead to secondary dysplasia of the acetabulum, which can be caused by spastic muscles (cerebral palsy) or by forces caused by paralysis (polio, Charcot Marie-Tooth) or even subtle neurologic disorders (eg, congenital pseudarthrosis with neurofibromatosis (Fig. 1)). Coxa valga produces lateral and superior forces on the acetabulum, eventually leading to dysplasia.1 Anteverision of the femur similarly leads to less medial force on the acetabulum and creates an apparent coxa valga.

Acetabular dysplasia is often associated with femoral anteversion. Did the anteversion cause the dysplasia; did the dysplasia cause the anteversion; or are they both primary deformities associated with each other? The answer to this chicken-and-egg question remains unknown.

Coxa vara promotes increased medial forces on the hip and therefore better acetabular development. In soft bone diseases, coxa vara leads to coxa profunda and protrusio.1 Therefore, when coxa vara is seen with hip dysplasia, it is not the cause of the dysplasia. The likelihood is that

KEYWORDS

• Coxa valga • Coxa vara • Intertrochanteric osteotomy • Relative neck lengthening
• Trochanteric overgrowth

KEY POINTS

• Proximal femoral deformity and hip dysplasia are interrelated: proximal femoral deformity can affect the final shape of the acetabulum.
• Although there has been a recent emphasis on femoral head shape and head/neck offset abnormalities, the neck shaft angle, medial proximal femoral angle, femoral neck length, and greater and lesser trochanter position are important factors when addressing hip dysplasia.
• Anatomic abnormalities of the proximal femur have an effect on abductor and hip flexor muscle function and strength.
• There are many surgical options to normalize proximal femoral anatomy that should be considered when treating hip dysplasia. Proper analysis of the abnormal geometry of the bony femur, as well as the abductor lever arms around the hip, is an essential part of a successful surgical plan.

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both deformities developed as part of the original disease process. Examples of coxa vara with hip dysplasia are congenital coxa vara, congenital femoral deficiency, and Conradi-Hünermann syndrome.

Femoral deformities can also arise secondary to the treatment of hip dysplasia. For example, avascular necrosis of the proximal femur that occurs following nonoperative or operative treatment can produce a growth arrest of the upper femoral growth plate with either varus or valgus deformity of the femoral head on the femoral neck. Most of these cases do not manifest damage to the greater trochanteric apophysis and therefore there is significant overgrowth of the greater trochanter. Growth arrest also leads to coxa breva, which alters the abductor and psoas tendon lever arms. Avascular necrosis can also lead to deformity of the femoral head, resulting in coxa magna or elliptical or saddle-shaped femoral head.

**Evaluation of Femoral Deformities Associated with Hip Dysplasia**

The history and physical examination are important in the evaluation of deformities around the hip. This evaluation should include the hip range of motion, presence or absence of impingement, rotation profile of the femur and tibia, and hip flexion and abduction strength and pain.

Plain radiographs still provide most of the information needed. Abduction and adduction views are also helpful. Computerized tomography is especially useful to evaluate the shape of the femoral head and acetabulum. Magnetic resonance arthrography is useful to evaluate for labral abnormality and impingement.

The joint orientation angles of the hip and knee in the frontal plane should be evaluated (medial proximal femoral angle [MPFA] and neck shaft angle [NSA] for both hips, and lateral distal femoral angle [LDFA] and medial proximal tibial angle [MPTA] for the knee). The difference between the MPFA of both hips should be compared with the difference between the NSA for both hips. If the differences are the same, then there is no trochanteric overgrowth. If the differences are different, then there is trochanteric overgrowth (Figs. 2–4).

![Fig. 1. Severe valgus deformity of the femoral neck secondary to neurofibromatosis and congenital pseudarthrosis of the tibia. The acetabulum is becoming dysplastic and the femoral head is subluxating laterally.](image1)

![Fig. 2. Coxa vara with \(\Delta\text{NSA} = 21^\circ\) and \(\Delta\text{MPFA} = 21^\circ\), therefore there is no greater trochanteric overgrowth. A valgus proximal femoral osteotomy will correct the upper femoral deformity.](image2)
INDICATIONS FOR PROXIMAL FEMORAL DEFORMITY SURGERY

There are 2 categories of surgery of the upper femur: intra-articular and extra-articular. Either or both may be indicated for joint preservation surgery of the hip. Indications for surgery are based on the history and physical, and the plain radiographic, computerized tomography, and magnetic resonance imaging studies. The presence of advanced arthritis and stiffness may be a contraindication to joint preservation surgery. Even in asymptomatic patients there may be an indication for surgery because the prognosis for arthroplasty and hip subluxation are known.

TYPES OF PROXIMAL FEMORAL DEFORMITIES

Extra-articular proximal femoral deformities that involve the entire proximal femur include varus, valgus, flexion, extension, and external rotation, and shortening. Extra-articular femoral deformities that involve parts of the proximal femur are deformities of the greater and lesser trochanter relative to the rest of the proximal femur (eg, overgrowth of the greater trochanter, lesser trochanter too proximal and medial compared with normal). The location of the greater and lesser trochanter is important because both trochanters serve as the insertion point of 2 critical muscle groups. If
the distance of these muscle insertions to the center of the femoral head is altered, lever arm dysfunction ensues manifested as muscle weakness and fatigue. When the greater trochanter is too proximal, then the muscle tension on the hip abductors is reduced. When the greater trochanter is too medial, as in cases of coxa breva, the abductor lever arm is reduced. The combination of reduced lever arm and reduced muscle tension leads to significant weakness that manifests as limp (lurch and Trendelenburg) and muscle fatigue during gait. If the lesser trochanter is too proximal and medial because of coxa breva, then the hip flexion may be weakened. Therefore, incorporating lateralization with distalization of the lesser trochanter is important to treat such weakness. It is important to test hip abduction and flexion strength before surgery.

Varus Osteotomy

The normal NSA of the femur is $130^\circ \pm 5^\circ$. Combined with a dysplastic acetabulum, valgus angles ($>135^\circ$) predispose to subluxation. Although a pelvic osteotomy is the most important first step, combining it with a varus proximal femur osteotomy to stabilize the hip should be considered. The impact of the varus osteotomy is best exemplified by the Nishio varus osteotomy of the femur. This varus osteotomy of the base of the femoral neck was used on its own to treat hip dysplasia (Fig. 5). Because the abductor lever arm is increased by this extreme varus osteotomy, the patient walks with minimal limp. This osteotomy challenges the belief that acetabular dysplasia must be treated by a pelvic, and not femoral, osteotomy, and supports Bombelli’s concept that...
coxa vara applies medial forces on the acetabulum that can change its shape over time.

Because the center of rotation of angulation (CORA) of proximal femoral valgus is at the level of the base of the greater trochanter slightly proximal to a varus osteotomy, the osteotomy should be medially translated to avoid a secondary translation deformity. For consideration of future hip replacement and to avoid secondary mechanical axis deviation at the knee, including the appropriate translation of the osteotomy is important to avoid creating a secondary translation deformity. An additional consideration with a varus osteotomy concerns the muscles attached to the 2 trochanters. Because varus osteotomy shortens the femur, it does not matter whether it is proximal or distal to the level of the lesser trochanter. Varus osteotomy has a greater effect on the greater trochanter. If the femur is in valgus and is brought to a normal 130° angle, then the tension (length) of the hip abductors is decreased but the lever arm is increased. The muscle tension can restore itself, whereas the lever arm cannot. This is therefore a net gain for the hip and reduces muscle fatigue and limp. If the NSA is at 130° and a varus osteotomy is performed, then the greater trochanter is elevated and loses both tension and lever arm, which can lead to a lurch or Trendelenburg gait. To avoid this, the greater trochanter should be transferred distally at the same time as the varus osteotomy, as was recommended by Müller (see Fig. 2).

Valgus Osteotomy

Varus deformity of the proximal femur may be a sequela of previous treatment or a primary congenital deformity. The CORA for a varus deformity is very proximal in the femur and usually at the level of the center of the femoral head. Therefore an intertrochanteric or subtrochanteric valgus osteotomy needs to translate the distal segment laterally to avoid a secondary translation deformity. Coxa vara is often associated with other deformities, especially flexion and rotation. Correction of the proximal femoral deformity could combine correction in all 3 planes. The effect on the 2 trochanters needs to be considered. Because varus osteotomy lengthens the femur, it moves the lesser trochanter distally if the osteotomy is proximal to the trochanter. This result may be desirable in cases of coxa breva in which the lesser trochanter is very proximal and medial, because the osteotomy will move it distally and laterally, improving its lever arm. The only danger is that, if there is already a flexion contracture, then this will aggravate the situation. In most cases, I prefer to perform the osteotomy distal to the lesser trochanter to minimize the tension on the psoas tendon. The effect on the greater trochanter is to move it distally, increasing the tension on the hip abductors, and laterally, increasing the abductor lever arm. The increase of the abductor lever arm occurs until an optimal NSA of 130° is achieved. Angles greater than that begin to decrease the lever arm.

Proximal femoral osteotomy could be stabilized with internal or external fixation. Blade plate fixation is one of the best-designed methods for proximal femoral fixation because it offers excellent control of the osteotomy in the sagittal plane (Fig. 6). Sliding hip screws give excellent control and correction in the plane of fixation (plane of the neck of the femur) but less control in the sagittal plane. Locking plates for the proximal femur are a newer approach to fixate these osteotomies. Intramedullary fixation can be used for fixation if the deformity is first fixed and held corrected by an external fixator. This method, developed by Paley and called fixator-assisted nailing, is best done with retrograde nailing. The external fixation pins are intentionally placed outside the path of the planned nail. The osteotomy is performed and the bone corrected to the desired position. The nail can then be introduced retrograde so as to speak the proximal segment in situ after the correction. Locking of the nail proximally and distally locks the correction into place.

Trochanteric Overgrowth

If trochanteric overgrowth is present, there are 3 approaches to correction of the proximal femoral anatomy: valgus intertrochanteric/subtrochanteric femoral osteotomy combined with lateral-distal transfer of greater trochanteric osteotomy (Wagner osteotomy) (see Fig. 2; Fig. 7); neck lengthening osteotomy of the intertrochanteric/trochanteric femur combined with lateral-distal transfer of greater trochanteric osteotomy (Morscher osteotomy) (see Fig. 2; Fig. 8); relative neck lengthening osteotomy (Ganz). Each of these has separate indications.

Valgus Intertrochanteric/Subtrochanteric Femoral Osteotomy Combined with Lateral-Distal Transfer of Greater Trochanteric Osteotomy (Wagner Osteotomy)

This type of osteotomy is used to change the part of the femoral head that is articulating with the acetabular dome (see Figs. 2 and 7). The main indication is improved congruity, and reduction of joint forces when the femoral head is not spherical. The amount of rotation of the femoral head in the acetabulum corresponds with the degree of
reorientation of the femoral neck out of varus. The other 2 osteotomies do not change the part of the femoral head that articulates with the dome of the acetabulum. The valgus, lateral translation osteotomy reorients the femoral neck out of varus and lengthens the femur. The trochanteric transfer moves the tip of the greater trochanter to the level of the center of the femoral head distally and
moves it laterally to increase the abductor moment arm. The combination of the two lengthens the femoral neck as well as the total length of the femur. Because valgus of the femoral neck moves it distally from the center of the hip joint, the lesser trochanter is advanced by this type of osteotomy. More advancement and lateralization can be achieved by performing the osteotomy proximal to the lesser trochanter. This osteotomy can be combined with derotation of the femur as well as sagittal correction.

**Neck Lengthening Osteotomy of the Intertrochanteric/Subtrochanteric Femur Combined with Lateral-Distal Transfer of Greater Trochanter Osteotomy (Morscher)**

This type of osteotomy does not change the orientation of the femoral head in the acetabulum and therefore the congruity of the hip joint stays the same (see Figs. 2 and 8).\(^6\) The indication for this is when there is no need to change the congruity of the joint. The NSA is created by the angle of the osteotomy. If a 130° NSA is desired then the intertrochanteric/subtrochanteric osteotomy is made at 130°. The greater trochanteric osteotomy is made at the same angle and shifted distally and laterally by sliding down this osteotomy line. The effect of the 2 osteotomies is to lengthen the femoral neck by lateralizing the greater trochanter and the femoral shaft, which also increases the total length of the femur. If the intertrochanteric osteotomy is performed proximal to the lesser trochanter, then the lesser trochanter can be moved laterally and distally. If it is made distal to the lesser trochanter, then there is no effect on the lesser trochanter.

**Ganz Relative Neck Lengthening Osteotomy**

This type of osteotomy is combined with a capsulotomy and hip dislocation (Fig. 9).\(^7\) There is less danger to the circulation of the femoral head than with the other 2 greater trochanteric osteotomies because of the precautions taken to avoid injury to the vascular pedicle of the femoral head. A combined intra-articular and extra-articular impingement of the hip is best addressed with this osteotomy. Extra-articular impingement from the greater trochanter is better addressed with this method of trochanteric transfer than with the other methods, because all of the stable trochanter, which is the part of the greater trochanter that forms the lateral wall of the piriform fossa, is resected. Also, the effect of the osteoplasty can be directly observed with this approach. This osteotomy creates a relative lengthening of the femoral neck on its superior/lateral surface because the trochanter is moved laterally and distally. The shaft of the femur is not lateralized, which is the major difference with the Morscher osteotomy. This difference may not be of any mechanical importance except for the insertion of the psoas tendon and the valgus effect that coxa breva has on the knee joint. The Ganz relative neck lengthening osteotomy does not lengthen the lower limb but the Morscher and Wagner do. It is important to understand the differences between these 3 osteotomies to choose the correct one for the correct indication. In addition, the relative neck lengthening and surgical dislocation can be combined with a Morscher or Wagner-type osteotomy of the intertrochanteric region.

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Fig. 7. (A) Bilateral severe hip dysplasia with an elliptical femoral head on the right side. (B) Wagner-type valgus osteotomy combined with distal lateral transfer of the greater trochanter combined with an extreme periacetabular osteotomy (PAO) osteotomy to gain coverage and congruity. The long axis of the elliptical femoral head is now horizontal (Bombelli principle).
Deformities of the femoral head at its connection with the femoral neck are considered intra-articular. Deformities of the shape of the femoral head are intra-articular. Intra-capsular deformities of the femoral neck are also considered intra-articular. There are intra-articular and extra-articular surgical procedures for intra-articular deformities. For example, the deformity of the femoral head relative to the neck created by a slipped capital femoral epiphysis can be treated by an intra-articular reduction or osteotomy or an extra-articular reorientation osteotomy. The nonspherical femoral head can similarly be treated by a valgus intertrochanteric/subtrochanteric osteotomy or an intra-articular femoral head reduction osteotomy (FHRO) (Figs. 10 and 11). Both of these solutions may still require a periacetabular osteotomy (PAO) for congruity and coverage because the aspherical femoral head would not be congruous if it was reoriented relative to the acetabulum. Performing the PAO allows the proximal

Intra-Articular Femoral Deformities

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femur to be rendered valgus, combined with a similar amount of abduction of the acetabulum to maintain coverage and congruity.

THE ROLE OF CONTRACTURES AROUND THE HIP FOR HIP OSTEOTOMY

In the absence of an intra-articular bony obstruction caused by deformity of the femoral head, the limitations of corrective proximal femoral osteotomy are the surrounding soft tissues. The more extreme and the more chronic a hip deformity, the more likely there are to be associated contractures. For example, to correct a severe coxa vara, the femoral neck needs to be adducted by the degree of deformity. The surrounding soft tissues may restrict this movement. For example, contractures of the lateral soft tissues around the hip may limit femoral neck adduction. The most common limiting soft tissue tether is the fascia lata and iliotibial band. The other tethers may include the hip abductors (gluteus medius and minimus), the tensor fascia lata, the gluteus maximus, and the hip joint capsule. Before embarking on a valgus osteotomy, it is important to perform a stress radiograph with the hip in maximum adduction. If the hip cannot be adducted by the amount of desired angular correction, then a valgus osteotomy cannot be performed without an accompanying soft tissue release. The easiest and most successful soft tissue release is surgical lengthening of the fascia lata at the musculo-tendinous junction with the tensor fascia lata and gluteus maximus muscles. This tissue can be transected at this level and the amount of adduction of the hip reevaluated. If the hip adducts to the level required, then the valgus osteotomy can proceed. If not, then the condition is probably a contracture of the glutei. To address this requires a hip abductor slide procedure. In children, the apophysis can be split from anterior to two-thirds of the way posterior on the iliac crest, and the periosteum peeled distally with the glutei. This untethers the proximal femur and allows complete correction of even the most severe coxa vara deformities. After the proximal femur and pelvic osteotomy (if needed) are performed, the apophysis is pulled proximally and the level to which it reaches is marked with a pen. The iliac crest proximal to this mark is resected. The apophysis is closed after completion of this resection. The iliac crest can regenerate some of its height through the growth of this apophysis. The muscle tension of the glutei returns to normal. In adults, the proximal 1 cm of the crest is osteotomized and reflected distally with the attached glutei. After the osteotomies of the femur and, in some cases, pelvis, the iliac wing is shortened by the requisite amount to allow reattachment of the abductor muscles via the 1-cm top of the iliac crest. Both of these techniques are called abductor muscle slides and are only used in severe and chronic cases. The most common indication for this are the shepherd’s crook deformity seen with fibrous dysplasia or congenital femoral deficiency. This technique forms part of the procedure described by Paley and Standard, called the superhip procedure (Fig. 12).

Flexion contracture of the hip is another common, limiting factor. It can be addressed by...
lengthening of the psoas tendon as it passes over the pubis (fractional lengthening of the psoas). Release of the rectus femoris and the tensor fascia lata may also be needed. In the most severe cases, an abductor muscle slide is also used because most of the gluteus medius and minimus pass anterior to the center of rotation of the hip joint.

Fig. 10. (A) Coxa magna with deformity of femoral head. (B) Surgical dislocation performed with partial greater trochanter flip osteotomy. (C) Relative neck lengthening accomplished by removal of the stable trochanter, which forms the lateral wall of the piriformis fossa. (D) Osteotomy of the lateral part of the femoral head on its vascular pedicle while preserving the vascular supply of the medial femoral head. As an alternative, this segment could be resected to reduce the size of the femoral head (H, left hip). (E) Resection of central segment of femoral head while preserving the blood supply to the medial femoral head. (F) Reconstruction of the femoral head by reducing the lateral mobile head to the medial stable head. Fixation with headless screws and prophylactic neck screw to prevent fracture (H, right hip). The femoral head is now well contained. In some cases, this should be combined with a PAO. (G) Anteroposterior pelvis radiograph of bilateral coxa magna with elliptical femoral heads. There is impingement and the femoral head is uncovered. (H) Bilateral femoral head reduction osteotomies: right, performed by the Ganz FHRO method shown in A–F; left, performed by resecting the lateral part of the femoral head as in D.
Fig. 11. For elliptical femoral heads, a valgus osteotomy to reorient the ellipse is one option (see also Fig. 7A, B).

Fig. 12. (A) Severe congenital coxa vara. (B) Maximum adduction radiograph. The greater trochanter does not come down all of the way. (C) After superhip procedure with abductor muscle slide.
SUMMARY

Abnormalities of the femur frequently accompany acetabular dysplasia as primary or secondary deformities. Femoral surgery is often a component of surgical treatment of acetabular dysplasia either at the onset or to treat a secondary or residual deformity. Proper analysis of the abnormal geometry of the bony femur, as well as the abnormal lever arms around the hip related to the lesser and greater trochanteric positions, is an essential part of a successful surgical plan. An à la carte approach makes the most sense in the treatment of the wide variety of disorders of the upper femur. Time has proved that normalizing the anatomy and muscle forces as much as possible extends the life of the hip the most, while also addressing current on pain and disability.

REFERENCES

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