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Surgical/Technical Tips

Use of 3D Imaging in Planning Varus Derotation Osteotomy in Neuromuscular Hip Subluxation

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Abstract

Proximal femur varus derotation osteotomy (VDRO) is a primary component of hip reconstruction surgery for the management of hip subluxation/dislocation in patients with neuromuscular dysplasia. Understanding the pathophysiology and abnormal proximal femur geometry is crucial to performing a successful surgery and dosing the surgical correction accurately. Children with neuromuscular hip dysplasia experience increased coxa valga, femoral anteversion, and variable degrees of acetabular dysplasia. Understanding the relationship between these three anatomic aberrations can be difficult with standard two-dimension plain radiography. In this paper, we will review our novel three-dimensional imaging protocol to assess the pathologic anatomy of the proximal femur and acetabulum in children undergoing neuromuscular hip reconstruction. Understanding the anatomic relationship between the neck shaft angle, anteversion and acetabular dysplasia aids in the planning and execution of effective VDRO and hip reconstruction surgery.

Key Concepts

- Preoperative understanding of the unique hip anatomy in a patient with cerebral palsy allows for precise preoperative surgical reconstructive planning and intraoperative execution.
- A preoperative CT, with the described CT Murphy imaging protocol, allows for improved preoperative understanding of patient anatomy.
- 3D reconstruction of the preoperative CT images allows for accurate measurement of the femoral neck angle and femoral anteversion while radial sequence reconstruction allows for accurate assessment of the femoral neck width which further aids with implant selection.

Introduction

Hip displacement in children with cerebral palsy (CP) is the second most common deformity after spastic equinus of the ankle and may progress from initial silent lateral subluxation to painful dislocation when left untreated.[1] Children with CP are born with anatomically normal hips, but the natural history of neuromuscular hip dysplasia is of progressive lateral displacement of the hip.[2] This is associated with abnormal proximal femoral anatomy, including excessive femoral anteversion in the transverse plane and increased femoral neck-shaft angle in the coronal plane.[3] Femoral head subluxation is measured using Reimer's migration percentage (MP) and is abnormally elevated in a direct relationship to a child's Gross Motor Functional Classification System (GMFCS) level. Hip reconstruction surgery is often recommended when the MP is greater than 40-50%.[4-6]

Operative approaches for the management of hip displacement in patients with CP are guided by the degree of femoral head displacement and acetabular dysplasia.[2] Three broad surgical categories (preventative, reconstructive, and salvage) exist for the treatment of hip displacement in patients with CP.[2] For the purpose of this manuscript, we will be focusing on surgical hip reconstruction, which includes soft tissue lengthening around the hip and a VDRO with or without a pelvic osteotomy.[4] For correction of osseous hip deformity, VDRO is a proven, effective technique to improve hip-joint reduction, redirect the femoral neck, and correct excessive anteversion, which is often present in neuromuscular hip dysplasia/subluxation.

Bony reconstruction surgery is associated with moderate morbidity, and good preoperative planning has demonstrated increased surgical efficiency while decreasing complication rates in other subspecialties within orthopaedics.[5-10] In particular for children with neuromuscular hip dysplasia, preoperative planning can be instrumental in illustrating the preoperative pathologic anatomy and aid the surgeon in determining their surgical approach and goals.[3] Here we describe our technique to preoperatively determine the femoral neck shaft angle, femoral anteversion, and femoral neck width, which aids in surgical reconstructive planning regarding dose of correction and implant choice.

Technique: CT Murphy Protocol

Patients are positioned on the gantry feet first, ideally with legs straight and feet in dorsiflexion, though this may not be possible in patients with CP and/or joint contractures. Axial non-contrast CT images are obtained from the supraacetabular iliac bone, between the superior and inferior iliac spines, through the most distal femoral condyle.

2D reformats:

1) True coronal and true sagittal reformats are created of the pelvis and femur, angled to the pelvis.
2) Axial oblique reformats are made of each proximal femur, angled to the long axis of the femoral neck.
3) Radial reformats of the femoral neck, for 360 degrees of rotation at 3 mm intervals. Double oblique reformats are used to create a plane axial to the femoral neck, and the radial reformats rotate around the center of the femoral neck in this plane.

3D reformats:

1) Entire femur, with the proximal one-third opaque and the distal two-thirds translucent. This reformat is created as in true coronal orientation, then rotated along its medial-lateral axis, for 360 degrees for a total of 144 images. This includes an "axial" view of the femur, where the posterior margins of the femoral condyles and greater trochanter lie approximately the same horizontal plane, simulating the appearance of the femur being placed flat on a surface.
2) 3D of the entire pelvis demonstrating 360 degrees of rotation.
3) 3D view of the disarticulated pelvis demonstrating 360 degrees of rotation.
4) 3D view of each disarticulated proximal femur demonstrating 360 degrees of rotation.

Femoral Neck Shaft Angle

Robin demonstrated that the neck shaft angle in children with CP is related to their functional level, with nonambulatory GMFCS IV and V children experiencing a neck shaft angle close to 150 degrees.[3] Typically, the surgical goal for varus correction can be determined by the child's functional level, where we aim for a neck shaft angle (NSA) of approximately 100 degrees for non-ambulatory children and 110-120 degrees for ambulatory children.[11] We typically prefer to use a 100 degree blade plate as this allows us to access more of the femoral neck without creating too much varus with our implant. Assessing NSA on radiographs can be challenging due to the effect of leg position and rotation.[12]

Our 3D reconstruction of the proximal femur facilitates accurate assessment of the NSA preoperatively, as the image can be rotated 360 degrees to produce a true AP of the proximal femur, regardless of leg position (Figure 1). The 3D reconstruction model can be internally rotated in order to neutralize femoral anteversion and determine the true femoral neck relationship to the femoral shaft.

Femoral Anteversion

Femoral anteversion is increased in children with CP and the degree of anteversion has been shown to be related to a child's ambulatory status.[3] While femoral anteversion has been shown to correlate with the physical examination, 3D imaging allows more accurate assessment of the degree of anteversion.[13] Typically, we will surgically correct femoral anteversion to 0-10 degrees for GMFCS IV/V and between 10-20 degrees for GMFCS I-III.

Previous CT scan assessments for femoral anteversion have been challenging in patients with CP due to their severe coxa valga and difficulty identifying the long axis of the femoral neck on axial imaging. Modern 3D models of the entire femur allow us to orientate the femur in anatomic position and allow the operator to

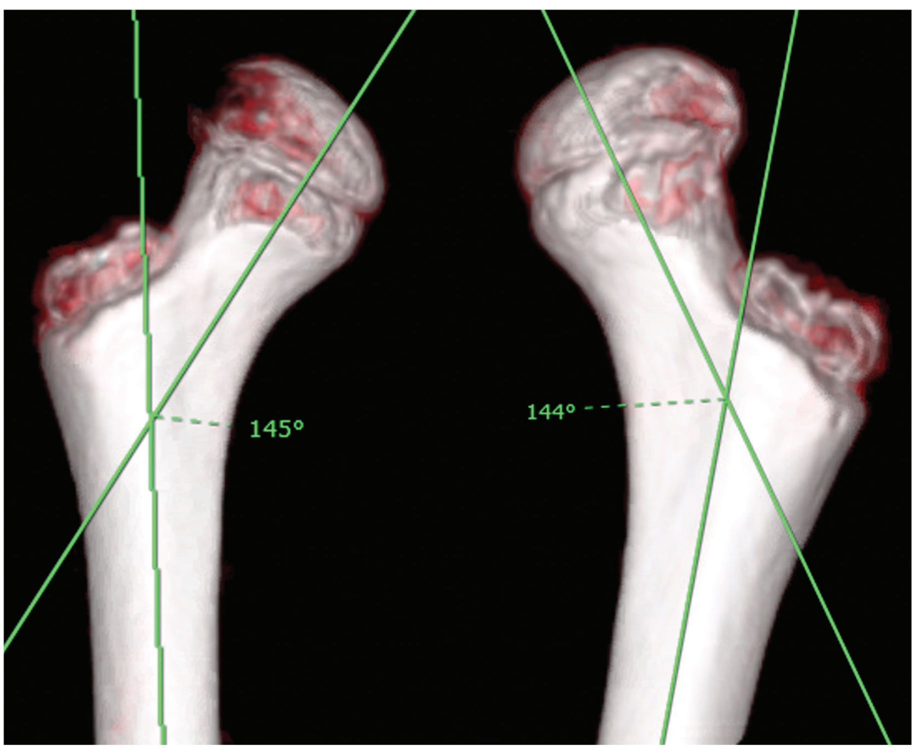

Figure 1. *Femoral neck shaft angle: 3D reconstruction of the right and the left proximal femurs. The femur are rotated to neutralize the anteversion to allow accurate assessment of the femoral neck shaft angle.*

look down the long axis of the femur, viewing the entire femoral neck and femoral condyles at the same time, for improved accuracy of angle measurement. To accomplish this, the distal two-thirds of the 3D reconstructed femur is made translucent as not to obscure visualization of the proximal aspect of the femur, which is fully opaque (Figure 2). The femur can be rotated in the three axes as necessary to achieve appropriate alignment, allowing the surgeon to assess the posterior femoral condyles and axis of the neck in one view, which in our experience is much easier and more reproducible than on the standard axial images.

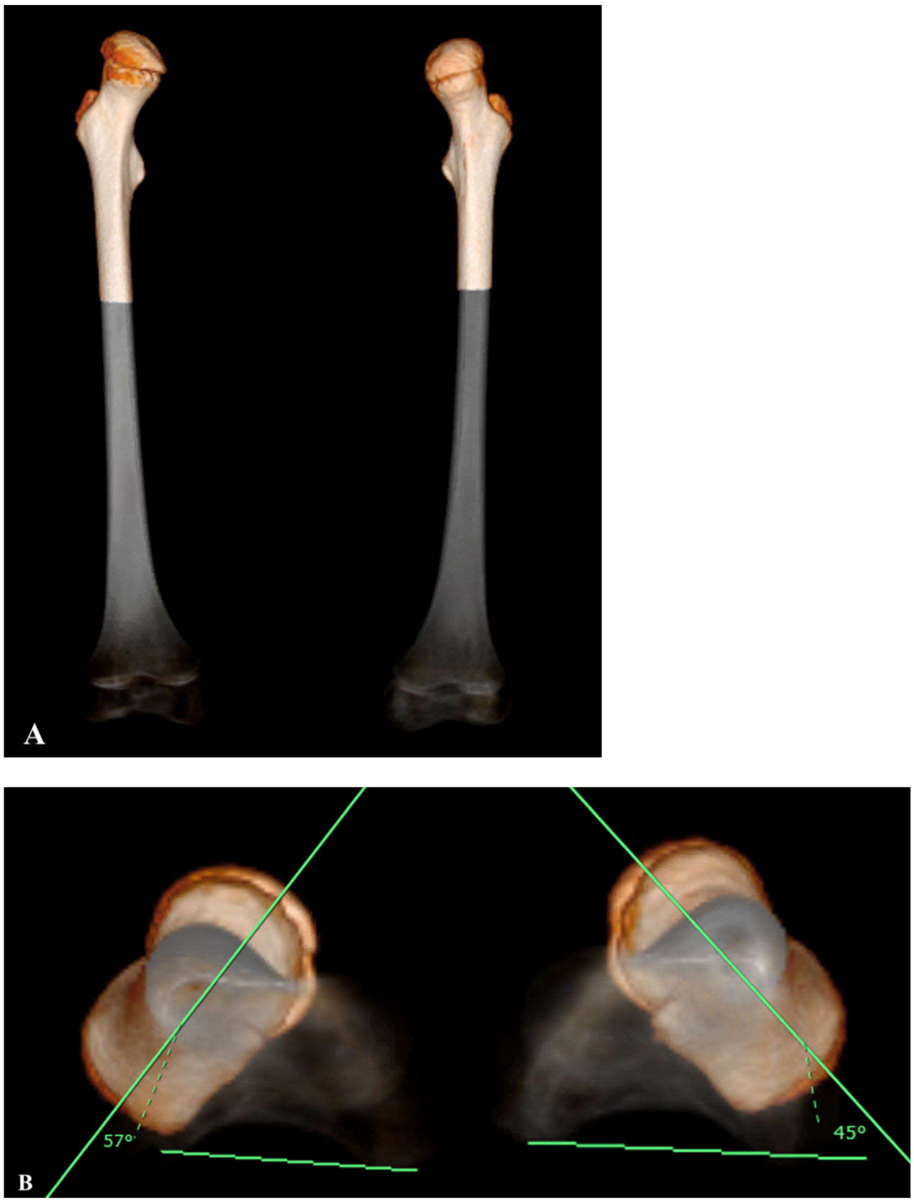

Figure 2. *Femoral anteversion: A) 3D reconstruction of both the left and the right femurs. The proximal aspect of the femur is opaque while the distal aspect of the femur is partially. translucent. B) When the femurs are rotated on the y-axis, the axis of femoral necks and the condyles can be visualized simultaneously, and the anteversion can be readily measured.*

Femoral Neck Width

The femoral neck width (FNW) is important to understand because it determines what size implant (i.e., blade plate) can be used in the femoral neck. The radial sequence CT scan is centered on the femoral neck (Figure 3). The different slices of the radial sequence CT rotate along the long axis of the femoral neck, allowing accurate preoperative assessment of the anterior to posterior diameter of the femoral neck. This allows for preoperative selection of an implant that fits inside the femoral neck without perforation. We have found in reviewing our cases that typically there is about 0.5 cm in diameter difference between hips, with the dysplastic hip

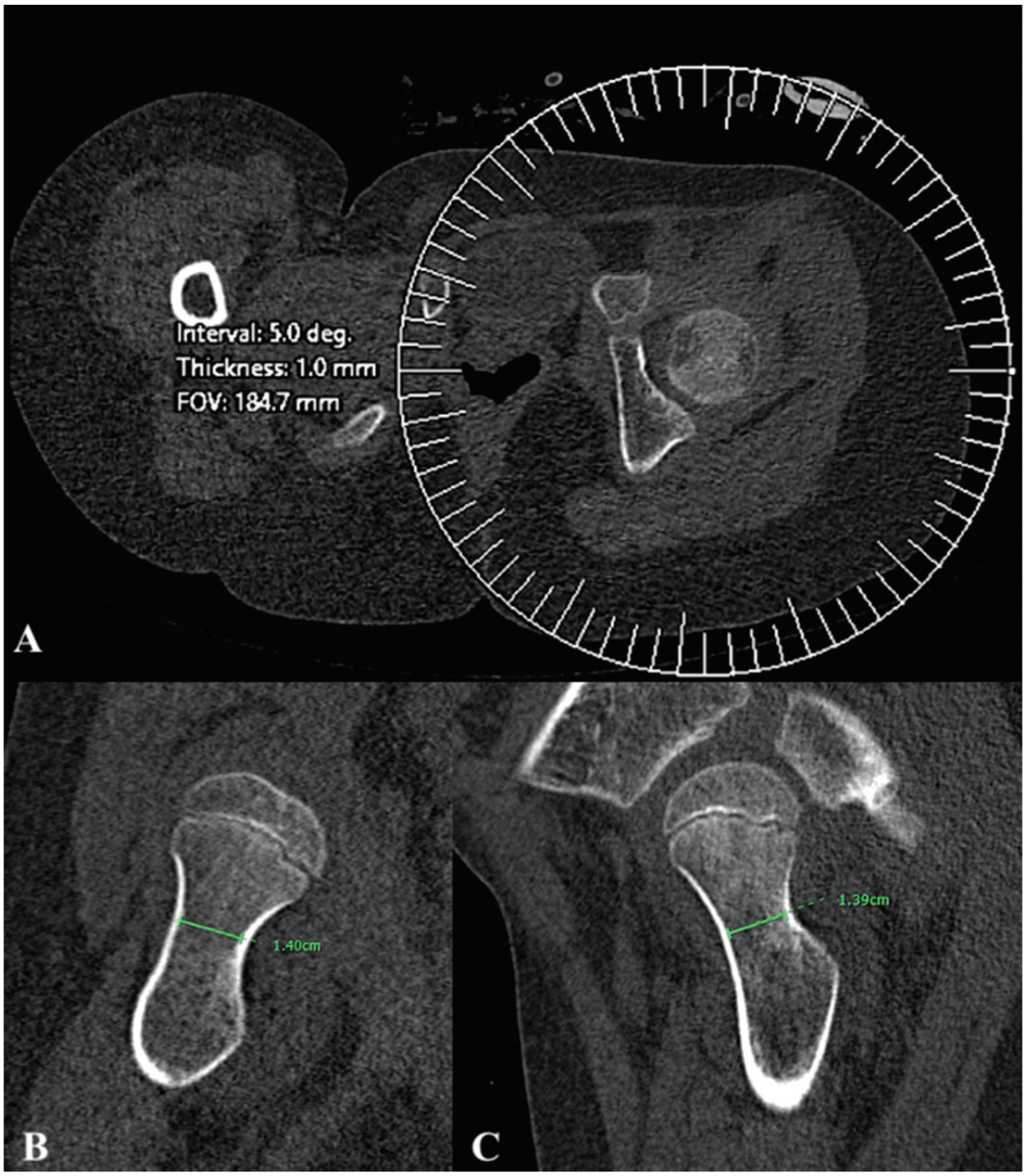

Figure 3. *Femoral neck width: The radial sequence provides assessment of the femoral neck in the plane of the neck. A) Localizer image at the level of the femoral head, demonstrating the planned radial slices. Images of the right (B) and left (C) femoral neck from radial images, demonstrating measurement of the femoral neck width.*

having a smaller FNW than the non-dysplastic side, but this has yet to be published.

Illustrative Case

A 9-year-old male with spastic quadriplegic cerebral palsy, GMFCS IV, and right greater than left hip subluxation presented to the clinic for his preoperative visit. The patient had exhausted conservative measures, including physical therapy, tone management, and bracing. He had previously undergone preventative surgery, with bilateral adductor, iliopsoas, and gracilis lengthening. He was scheduled to undergo single-event multilevel surgery consisting of bilateral VDRO, right Dega osteotomy, and possible open reduction in addition to bilateral peroneal lengthenings and gastrocnemius recessions.

To aid in the surgical planning for the hip reconstruction, a preoperative CT was obtained. The preoperative imaging showed NSA of 145 degrees on the right and 144 degrees on the left, 57 degrees of anteversion on the right and 45 degrees of anteversion on the left, a FNW of 14 mm on both the right and the left side (Figures 1-3). As a result of the preoperative imaging, we planned for varus correction of 30 degrees on the right and 40 degrees on the left, derotation of 50 degrees on the right and 35 degrees on the left, and use of a blade plate with a 11 mm width. Intraoperative findings were consistent with preoperative imaging, and the surgery was executed as planned (Figures 4 and 5).

Figure 4. *Preoperative AP X-ray of a 9-year-old child with cerebral palsy who has right greater than left hip subluxation and acetabular dysplasia with valgus deformity of both femurs, which is difficult to quantify on radiographs.*

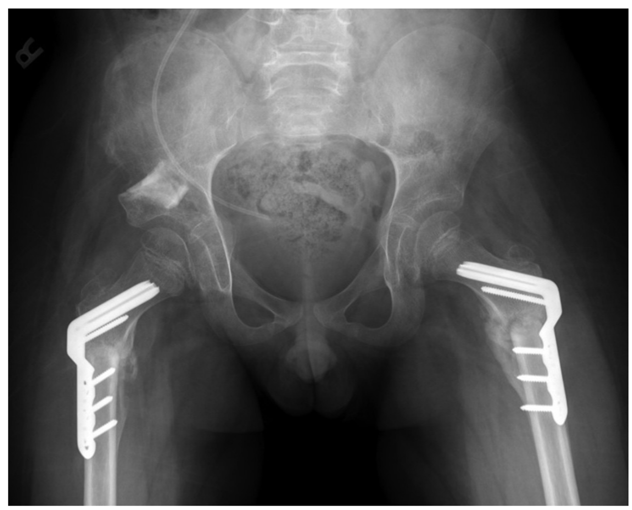

Figure 5. *Postoperative AP X-ray 3 months after right Dega osteotomy and bilateral varus derotation ostoeotomies demonstrating well reduced hips with decreased femoral neck shaft angle.*

Discussion

The VDRO is a primary component of hip reconstruction in children with neuromuscular hip dysplasia but can be challenging due to varying proximal femur anatomy and inconsistent bone health in children with CP.[11,14] A thorough preoperative understanding of the NSA, femoral anteversion, and femoral neck width allows for precise preoperative surgical planning and intraoperative execution.

There are multiple different methods for assessing the NSA.[15] Radiographs can be used to assess the NSA if the femur can be rotated to neutralize the anteversion and obtain a true frontal projection of the proximal femur on the image. However, this technique is especially challenging in patients with CP due to the joint contractures around the hip and knee as well as the varying degrees of spasticity and compliance. 2D CT images can be reformatted to produce true coronal views of the proximal femur for assessment of neck shaft angle. Again, this process becomes less straight forward in patients with severe coxa valga, as the orientation of the neck is more difficult to discern on sequential axial images. Coronal views of the CT scan may theoretically be used to assess NSA; however, due to contractures and anteversion, it is often difficult to visualize the neck and shaft in a single slice of the CT to determine an accurate NSA. Assessing the NSA using the 3D reconstructed image works in all settings and is not limited by contractures or large degrees of proximal femur deformity.

Determining the anteversion preoperatively can be challenging, particularly in the setting of revision surgery. Anteversion can be measured on physical exam by assessing the patient in the prone position and rotating the leg to determine the point at which the greater trochanter is most prominent.[16] While many have felt this technique to be accurate, recent data suggests that 3D imaging may perform better.[13] Historically, anteversion was measured on axial cuts of the CT scan, performed by placing a horizontal reference line parallel to the posterior aspects of the femoral condyles and measuring the angle between the reference line and mid axis of the femoral neck. While this method is the historical gold standard, there can be challenges in accurately determining the anteversion in the setting of extreme coxa valga often encountered in patients with cerebral palsy.[17] As with assessing NSA, the orientation of a valgus femoral neck is more difficult to discern on sequential axial images. 3D reconstruction has been shown to allow more accurate version assessment than 2D CT.[13]

Our approach to 3D CT modeling of the femur makes the distal two-thirds of the femur partially transparent. In clinical practice we have found that, compared to entirely opaque 3D models, our method facilitates anteversion measurement by allowing both the femoral neck and the margins of the condyles to be viewed in a single longitudinal projection, eliminating the need to rotate the 3D model during the process of measurement. Further study is required to determine if our approach to 3D models increases accuracy and reliability of anteversion measurements.

Children with neuromuscular hip dysplasia are often associated with some element of impaired nutrition and small size. Historically, FNW is "guessed" based on the size and weight of the patient. While perhaps more applicable when using a blade plate compared to a locking plate, any implant should not violate the anterior or posterior cortex of the femoral neck. Violations may place the patient at increased risk for fracture or avascular necrosis. Determining the FNW on the axial slice CT scan is difficult due to the oblique orientation of the slice in relation to the femoral neck and coxa valga. The oblique orientation prevents true anterior to posterior assessment of femoral neck width. The radial sequence performed as part of our protocol allows for accurate visualization of the femoral neck along a rotating plane centered on the long axis of the neck, more readily demonstrating the widest and narrowest portion of each femoral neck to aid in assessing optimal implant size. In using these radial sequence images, we have observed that the dysplastic hip often will have a more narrow FNW which is important to be aware of prior to embarking on hip reconstruction surgery. Determining the diameter of the neck preoperatively will limit the amount of time wasted intra-operatively deciding what type of blade is necessary, help nurses streamline the preoperative implant selection, and avoid situations where the desired implant is unavailable.

Understanding proximal femoral anatomy is crucial when executing a proximal VDRO for neuromuscular hip dysplasia. Here we describe a novel technique, combining 3D and radial reformats of the femur, which facilitate determination of the femoral neck shaft angle, anteversion, and neck width. We have found this technique very helpful in preoperative planning for VDRO surgery.

Disclaimer

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