Determination and Significance of Femoral Neck Anteversion

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Femoral neck anteversion
Femoral neck retroversion
Hip rotation
Medial femoral torsion

Femoral neck anteversion (FNA) describes the normal torsion or twist present in the femur. Femoral neck anteversion is defined as the angle between an imaginary transverse line that runs medially to laterally through the knee joint and an imaginary transverse line passing through the center of the femoral head and neck (Fig. 1).1,2 In adults without pathology, the femur is twisted so the head and neck of the femur are angled forward between 15 and 20 degrees from the frontal plane of the body.1,2 In some instances, the FNA angle is directed forward or backward well beyond this angle. Some researchers3–8 suggest that FNA angles outside this 15- to 20-degree average are a contributing factor in many different orthopedic problems in the lower extremity that are commonly seen by physical therapists.

The purpose of this Update is to describe how FNA is related to hip rotation, how hip rotation range of motion can be used to predict abnormal FNA, and how asymmetries in hip rotation may be used to identify patients who may be at risk for developing various orthopedic problems in the hip and lower extremity.

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Femoral neck anteversion sometimes is called "medial femoral torsion." It is thought to result from medial (internal) rotation of the limb bud in early intrauterine life. In postnatal development, a reduction of the FNA angle usually occurs during growth. In the newborn, the average FNA angle is 31 degrees. The average FNA angle is 26 degrees by 5 years of age, 21 degrees by 9 years of age, and 15 degrees by 16 years of age. The FNA angle, therefore, diminishes about 1.5 degrees a year until about 15 years of age. In the adult, average femoral head and neck torsion forward of the body's frontal plane is about 15 degrees, a little less in men (less than 15°) and a little more in women (18°). Femoral neck anteversion angle is typically symmetrical from the left side to the right side.

In contrast to FNA, femoral neck retroversion is present when the head and neck of the femur are angled less than the average FNA angle (15°–20°) along the frontal plane of the body. In some cases, the femoral head and neck may even be angled backward from the frontal plane of the body.

How FNA Develops

What stimulates the femur to undergo torsion or twist is not understood. The current opinion is that the femur twists from torsional forces applied perpendicularly to the epiphyseal growth plate. According to the Heuter-Volkmann Law of epiphyseal pressure, increases in pressure across the epiphysis will decrease its growth, whereas decreases in pressure will increase its rate of growth. In adults, the epiphysis is closed and the Heuter-Volkmann Law cannot explain bone remodeling. Wolff's Law explains the remodeling or change in adult bone. Wolff's Law states that every change in the form and the function of a bone is followed by changes in the bone's internal and external architecture in accordance with mathematical laws. Remodeling of the FNA also may occur because of changes in the stress placed on the adult femur's diaphysis by torsional forces.

What creates torsional force on the femur? Muscle, by either its passive elastic connective tissue or its contractile force, contributes the greatest stress on bones. Animal studies suggest that uneven forces, either by maintaining the hip joint in medial or lateral (external) rotation or by resecting the hip rotator muscles, can produce changes in the FNA angle. Bernbeck, Salter, and Wilkinson showed that, when the hind limbs of animals were held fixed in lateral rotation, the FNA angle decreased, whereas when the hind limbs were fixed in medial rotation, the FNA angle increased.

Unilaterally resecting the hip medial or lateral rotators alters the torsional muscular forces acting on the femur. Haike has shown that increased or decreased femoral anteversion resulted after resecting either the medial rotator or the lateral rotator muscles of the hip.

Published reports have suggested that habitual sleeping and sitting postures, in which the hip is held at or near the end of medial or lateral
rotation, may produce changes in the FNA angle. These extreme postures often will produce an increase in hip rotation in one direction, with a corresponding decrease in hip motion in the opposite direction. As expected, hip joint motion increases in the direction the hip is held. Habitually adopting a sleeping or sitting position in which the hip is held in extreme lateral rotation, therefore, favors an increase in lateral rotation motion with an equal loss of medial rotation (Figs. 2 and 3). Maintaining an extreme hip posture also produces changes in the soft connective tissue surrounding the hip, shortening the hip joint capsule and muscles on one side and lengthening the hip joint capsule and muscles on the other side. These asymmetrical changes in soft tissue around the hip likely will create uneven torsional forces placed on the femur.

Figure 2.

Sitting in the "W" or reverse tailor position with maximum hip medial rotation.

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Figure 3.
Sitting in the tailor position with maximum hip lateral rotation.

Examination of children with hemiplegia also lends support to the theory that changes in hip muscle force are related to an abnormal FNA angle. Staheli et al.14 looked at the hips of children with hemiplegia and found that the FNA angle on the nonhemiplegic side is normal, whereas the FNA angle was increased on the hemiplegic side, as was the motion of medial rotation when compared with the normal side.

Previous SectionNext Section

Measuring the FNA Angle Using Imaging Techniques

Although FNA was anatomically described as early as the 19th century, the first method used to measure FNA was the biplane radiograph. Perhaps the most often used technique is the method described by Magilligan in 1956.15 The Magilligan method consists of taking an anteroposterior radiograph and a true lateral radiograph of the hip and an anteroposterior radiograph of the knee. Three lines are used to determine the FNA angle—the long axis of the femur, the axis of the femoral neck, and the axis of the knee. The long axis of the femur is defined as a line that connects 2 points—the center of the base of the knee and the center of the base of the femoral head. The axis of the femoral neck is defined by a line drawn from the center of the femoral head to the center of the base of the femur. The axis of the knee is a line drawn from the medial to the lateral posterior femoral condyles. The angle formed between the axis of the femoral neck and the axis of the knee is measured (Fig. 4). Given this angle, the true angle of torsion is then derived from a graph produced by Magilligan.15 Other researchers16–18 have modified this technique slightly over the years.

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Figure 4.

Illustration showing “cuts” used to determine the femoral neck anterversion angle using computerized tomography scan.

Most femoral torsion problems are evaluated with computerized tomography (CT). The method described by Murphy et
al18 is often used, with slight variations described by others.19–22 This CT technique involves 3 images or scans: 2 proximal and 1 distal. Murphy’s method is based on strict geometrical reconstruction of the angle of anteversion. The patient is positioned in the scanner so that the long axis of the femur is parallel to the long axis of the scanner. One image defines the location of the center of the femoral head, the second image defines the base of the femoral neck, and the third image defines the distal femoral condylar axis (Fig. 4). The angle in the transverse plane between the intersection of the plane of anteversion and the condylar plane defines the angle of anteversion. Murphy et al18 showed the accuracy of CT by comparing CT measurements with direct measurements of 32 dried femoral bone specimens that were used as a gold standard. Murphy et al18 found that measuring anteversion with computerized tomography was accurate within 1 degree when compared with measuring the femoral bone specimens directly.

Previous SectionNext Section

A Clinical Method to Determine the FNA Angle

The idea for using passive hip rotation to determine abnormal femoral torsion arose from observations of children who had an in-toeing or out-toeing posture or gait. In 1957, Sommerville23 reported that extreme differences between hip medial and lateral rotation are related to femoral torsion problems in children. Crane1 found that differences between hip medial and lateral rotation were associated with change in FNA and with the toeing-in and toeing-out of the lower extremity. Crane also discovered that children who toe-out had a low FNA angle and had medial rotation of the hip of 20 degrees or less, whereas lateral rotation exceeded 60 degrees. Those children with a high FNA angle had medial rotation of the hip exceeding 60 degrees and lateral rotation less than 30 degrees, and they tended to toe-in.

Early observations of children who toed-in or toed-out suggested that passive hip rotation could be used clinically to predict an abnormal FNA angle in children. Few studies have looked at the relationship between the FNA angle and passive hip rotation in adults. In 100 adult subjects, Braten et al24 observed that the FNA angle increased as medial rotation increased and lateral rotation decreased. Because subjects without impairments were used, differences were small but significant. Tonnis and Heinecke25 examined 152 adult patients and also found that hip rotation was related to the FNA angle. Patients with greater lateral rotation than medial rotation had femoral neck retroversion, whereas those with greater medial rotation than lateral rotation had FNA.25 Although the hip motion and the FNA angle were smaller in the group of adults than in the group of children, the FNA angle still correlated well with the difference between medial and lateral rotation of the hip in both groups.25

A limitation in using passive hip rotation to determine the FNA angle is that a precise FNA angle cannot be determined from clinical measurements. A precise FNA angle, however, is only needed in the selection of patients and preoperative
planning for a derotation osteotomy of the femur.5,6,8

Because physical therapists do not perform femoral neck operations, determining a precise FNA angle is not of vital importance. Determining the existence of an abnormal FNA angle is of potential importance to physical therapists when dealing with patients with lower-extremity orthopedic problems commonly related to increased or decreased FNA.24,26–29 Because studies show that the FNA angle appears closely linked to differences between hip medial and lateral rotation, I suggest that physical therapists use this information to predict when an abnormal FNA angle might exist.

Researchers have attempted to determine the upper and lower limits for normal hip rotation. Most clinical studies measured hip rotation in the prone position with hips extended and knee flexed to 90 degrees.26,30–38 The pelvis is stabilized, and the hip medially or laterally rotated by grasping the ankle. When a firm end point is reached, the hip angle is measured. Studies performed on subjects without impairments26,33 have consistently shown that hip rotation is consistently equal from the left to right sides, especially when looking at a specific motion such as medial rotation. Differences in hip rotation between the left and right side rarely exceed 10 degrees (Tab. 1).30 The mean difference in hip rotation in adults between the left and right sides is about 8 degrees (Tab. 1). Using a cutoff of 2 standard deviations above or below the mean (a common method used to identify the upper and lower limits of abnormality in a normally distributed measure), an abnormal motion exists when left and right measurements are more than 16 degrees apart in an adult. For example, findings of 40 degrees of left hip medial rotation and 60 degrees of right hip medial rotation would be considered abnormal.

Table 1.

Hip Rotation Medial Rotation/Lateral Rotation (SD)a

In patients with suspected abnormal FNA, observing the difference between the left and right sides for a specific movement such as hip medial rotation is not as important as observing the difference in motion between medial and lateral rotation of the hip on one side. Studies that have examined hip motion on subjects without impairments have found only small differences.
between medial and lateral rotation. Svenningsen et al.26 examined children and adults without impairments and found the greatest disparity between hip medial rotation and lateral rotation (Tab. 1). Svenningsen and colleagues found that medial rotation exceeded lateral rotation by 2 to 16 degrees, with the greatest differences occurring in the 4- and 6-year-old groups. Staheli and colleagues' examination of children without impairments31 showed that females had little difference between medial and lateral rotation of the hip, whereas males had differences ranging from 3 to 11 degrees, with medial rotation exceeding lateral rotation (Tab. 1). In adults, Staheli et al.,31 Roaas and Andersson,33 Ellison and colleagues,35 and Chesworth et al.36 found little difference between medial and lateral rotation of the hip, ranging from as little as 1 to 5 degrees of difference.

Previous Section Next Section

Studies That Examined the Relationship Between FNA and Passive Hip Rotation

Hip rotation often is used to estimate FNA in clinical settings.39 Recent studies24,26–29 have shown that the FNA angle, measured radiographically using the method described or adapted by Magilligan, is related to the difference between medial and lateral rotation of the hip. In most studies, hip rotation was measured with the subjects positioned prone, with the hip extended and the knee flexed to 90 degrees. Patients with a high FNA angle tended to have more medial rotation of the hip and less lateral rotation of the hip (Tab. 2). In contrast, patients with a low FNA angle tended to have more lateral rotation of the hip and less medial rotation of the hip. Total hip rotation usually remained the same. Only in a study by Gelberman et al.40 did some patients exhibit a complete reversal in how the hip was limited. In that study, the patients' hips showed an increase in medial rotation and less lateral rotation in the fully extended 0-degree position, whereas the motion was reversed when the hips were flexed.

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Table 2.

Studios That Examined the Relationship Between Femoral Neck Anteversion (FNA) and Passive Hip Rotationa
many clinical observations.\textsuperscript{1,3–5,8} A trade-off in medial and lateral rotation of the hip appears to occur as one movement or direction increases, the other usually decreases while the total hip motion remains equal. For example, as medial rotation increases, lateral rotation usually decreases. The results of the study by Swanson et al\textsuperscript{8} suggest that femoral torsion deformity exists when medial rotation exceeds lateral rotation by more than 30 degrees and that an abnormal FNA exists when lateral rotation exceeds medial rotation by more than 30 degrees.

Previous Section Next Section

A Clinical Test to Accurately Determine FNA?

Two groups of investigators\textsuperscript{30,38} have studied the trochanteric prominence angle test (TPAT) or Craig test, and the reports show conflicting data on the validity of measurements this test provides. In 1992, Ruwe et al\textsuperscript{30} evaluated FNA preoperatively in 59 patients (91 hips), and based on their findings, they claimed that the TPAT can be used to accurately and validly measure the FNA angle of the femur. Femoral neck anteversion was determined at the time of the operation by Magilligan radiographs and by CT scanning using the Murphy technique. The FNA values were then compared with the clinical TPAT measurements. The TPAT was performed with the patients lying prone. The examiner palpated the patients' greater trochanter with one hand while passively rotating the hip with the other hand. The accuracy of TPAT depends on having the greater trochanter at its most laterally prominent position with the femoral neck axis parallel to the condylar axis at the knee. The amount of hip medial rotation when the greater trochanter is at its most laterally prominent position, therefore, should equal the FNA angle. The reliability of the TPAT measurements was not assessed. Ruwe and colleagues\textsuperscript{30} showed that the TPAT predicted the FNA, measured intraoperatively, more accurately than either the CT or Magilligan method. The mean differences between direct clinical measurements and those determined by intraoperative measurements were 4.1 degrees (SD=3.2) on the left (Pearson $r=.88$) and 3.5 degrees (SD=3.9) on the right (Pearson $r=.93$). The differences between measurements obtained from the Magilligan radiographs and measurements found on operation were 9.5 degrees (SD=9.1) on the left side and 9.6 degrees (SD=8.4) on the right side.

Davids et al\textsuperscript{38} studied the TPAT on 20 children with cerebral palsy. Davids et al used a retrospective case series design to show the relationship between the TPAT and a modified Murphy CT analysis performed before surgery. No data on tester reliability were given. Davids et al concluded that the TPAT performed poorly by either overestimating or underestimating FNA by more than 5 degrees in 24 hips and by more than 10 degrees in 14 hips. They also concluded that the application of the TPAT is restricted by variable anatomy and soft tissue, especially in patients who

are obese. As noted previously, for the TPAT to be accurate, the tangent to the most prominent portion of the greater trochanter must be perpendicular to the axis of the femoral neck; however, Davids et al rarely found this to be true and noted considerable variability in the children with cerebral palsy they studied (Tab. 3). With only 2 studies performed on the TPAT, additional research is needed to determine whether this test can accurately predict the FNA angle. Because physical therapists do not need a precise FNA angle measurement, I believe either the TPAT or passive hip rotation values can be used to help predict FNA.

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Table 3.

Data From the Study by Davids et al38 on the Trochanteric Prominence Angle Test (TPAT)a

Previous SectionNext Section

The Clinical Importance of Increased or Decreased FNA

An increased or decreased FNA angle has been associated with a variety of lower-extremity problems in newborns, children, and adults. The interest in determining the precise FNA angle began in the early 20th century with the observation that newborns with congenital hip dislocation often had an increased FNA angle.1,3,5,6,8 Soon after, children with an in-toeing or out-toeing gait were noted to have an increased or decreased FNA angle.1&ndash;7,9 Excessive in-toeing or out-toeing has been shown to be related to many different compensatory problems of the lower extremities, including tibial torsion, genu valgum, genu valgus, pes planus, pes equinus, and metatarsus varus.1&ndash;6,8,23 Many other studies1,3&ndash;8,14,23,25,28,29,31,41&ndash;49 have shown the relationship between an increased or decreased FNA angle and other orthopedic problems of the lower extremity.

Gelberman et al29 showed that a diminished FNA angle in adolescents is often associated
with slipped capital femoral epiphysis of the hip. The FNA angle in patients with slipped capital femoral epiphysis was 1 degree (normal FNA angle=15°–20°) in the worst cases and 2.5 degrees in more moderate cases.29 Alterations in the alignment of the proximal part of the femur have been considered capable of redistributing the forces that are applied across the proximal femoral epiphysis. Gelberman and colleagues29 suggested that the forces that tend to cause a slipped capital femoral epiphysis act in the same direction as the forces that are responsible for the physiological decrease in the angle of anteversion during growth. Decreased FNA or hip retroversion can create unequal force distribution on the proximal femoral epiphysis. Some adolescents may be unable to resist the physiological shearing forces across the epiphysis resulting in a slipped capital femoral epiphysis. A decreased FNA, therefore, has been proposed to be a factor in developing slipped capital femoral epiphysis.29 More research is needed.

Studies7,25,46,47 also have shown that an increased or decreased FNA angle is associated with degenerative hip joint disease. Tonnis and Heinecke7,25 have shown the relationship between reduced FNA (femoral neck retroversion) and degenerative disease of the hip. They defined abnormal FNA using 4 grades, assuming that a normal FNA angle is between 15 and 20 degrees. Moderately decreased FNA was defined as an angle between 10 and 14 degrees. Severely decreased FNA was defined as an angle less than 10 degrees. Moderately increased FNA was defined as an angle between 21 and 25 degrees. Severely increased FNA was defined as an FNA angle greater than 25 degrees.25 Tonnis and Heinecke25 looked at the FNA angle in 118 patients who had arthritis of the hip. Passive hip rotation also was measured. They found decreased hip medial rotation and increased lateral rotation were related to diminished FNA. For example, patients who had a severely decreased FNA angle (less than 10°) had an average range of 17 degrees of medial rotation and an average external rotation of 40 degrees. Tonnis and Heinecke25 found that patients who had decreased FNA angles also were more likely to have osteoarthritis of the hip.

Changes in femoral anteversion that result in an increased or decreased FNA angle can alter the congruence of the hip joint.25 A change in acetabular anteversion also can alter the congruence of the hip joint.50 Hip joint incongruence is the most commonly cited cause of osteoarthritis in the hip joint.25,48,50 The congruity of the hip joint depends on the relationship between FNA and anteversion of the acetabulum.25 A change in hip anteversion requires a similar adjustment in the acetabulum to keep hip joint congruity.

A diminished FNA angle has been associated with a torn acetabular labrum of the hip.49 Ito and colleagues49 studied 24 patients with hip pain and evidence of a labral tear of the hip, and they showed that the patients with labral tears had a mean reduction in the FNA angle. Their data showed the mean FNA angle in patients with labral tears was 9.7 degrees compared with 15.7 degrees in patients without impairments.49 Hip rotation was not measured in this study. Ito and colleagues49 suggested that repetitive impingement of the acetabulum can injure the labrum when a hip with decreased femoral joint anteversion changes the head and neck angle of the femur. Reduced surface area in the hip results in increased force on the acetabular labrum, which may predispose the labrum to injury. Moreover, a torn acetabular labrum is thought to be a precursor to degenerative hip joint disease.49 Thus, an increase or decrease in the FNA angle that may alter the hip’s congruity will place abnormal stress on the acetabular labrum and possibly lead to injury.
Assessing passive hip medial and lateral rotation can be a useful guide in determining if an increased or decreased FNA angle exists. An increased or a decreased FNA angle has been linked to many different lower-extremity problems, including osteoarthritis of the hip, coxa plana, slipped capital femoral epiphysis, congenital hip dysplasia, acetabular labral tears, and in-toeing and out-toeing of the lower extremities.1,3–8,14,23,25,28,29,31,42–49

Identifying when an increased or decreased FNA angle is present may help physical therapists recognize patients who may be at risk for developing hip or other problems associated with in-toeing or out-toeing. Moreover, asymmetries in hip joint rotation also have been associated with low back and regional pain in the sacroiliac joint.43,51

Because the difference between medial and lateral rotation of the hip are related to the FNA angle, I believe that physical therapy interventions aimed at restoring symmetry in hip motion is a reasonable approach in trying to manage hip problems. Differences greater than 16 degrees between the left and right sides for a specific movement or differences of more than 30 degrees between hip medial and lateral rotation on one side may help physical therapists identify patients who may develop future hip or lower-extremity problems associated with in-toeing or out-toeing. Physical therapists also should consider factors that may contribute to differences in hip medial and lateral rotation. For example, sitting or sleeping postures where the hip is habitually placed in extreme hip rotation may change muscle and joint capsule length (Figs. 2 and 3). Although there are no studies on restoring hip motion symmetry and the FNA angle, I believe these studies would be beneficial, because restoring motion and muscle force is an important part of physical therapist practice.

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