Mechanical Axis Deviation of the Lower Limbs
Preoperative Planning of Uniapical Angular Deformities of the Tibia or Femur

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Angular deformities of the tibia or femur in the frontal plane lead to mechanical axis deviation of the lower limb and malorientation of the joints above and below the level of deformity. Accurate correction of the malalignment and of the joint orientation is important for function and to prevent joint degeneration. An accurate yet simple method to determine the apex of deformity and the type of correction required is based on the joint reference lines of the hip, knee, and ankle, and the individual mechanical axis lines of each bone segment. If the osteotomy is performed at the level of the apex of the deformity, then the only correction needed is angulation. If the osteotomy is performed at a level proximal or distal to the apex, then translation in addition to angulation is necessary to accurately correct the deformity.

There are two considerations in evaluating the frontal plane mechanical axis of the lower extremity: (1) joint alignment and (2) joint orientation (Fig. 1). The normal alignment of the hip, knee, and ankle joint centers is collinear. Frontal plane deformities lead to mechanical axis deviation (MAD), which primarily affects the knee but also has an effect on the hip, ankle, and subtalar joints. Normally, the line of weight-bearing force in the frontal plane from the ankle to the hip joint passes immediately medial to the center of the knee near the medial tibial spine. In situations with MAD, it passes medial or lateral to the center of the knee.

Each joint has a normal anatomic inclination to the mechanical and anatomic axes of the limb segment. In the tibia, the mechanical and anatomic axes are the same, but in the femur, they are different. The mechanical axis of the femur is defined as the line from the center of the hip to the center of the knee. This usually subtends a 5°–7° angle to the anatomic axis of the femur that runs from the piriform fossa to the center of the knee joint. The knee joint line has been measured to be approximately 3° off the perpendicular such that the distal femur is in slight valgus and the tibial diaphysis is in slight varus to the knee-joint line. The ankle-joint reference line is the tibial plafond. The tibial plafond is normally perpendicular to the mechanical axis of the tibia.

The hip joint does not initially appear to have an obvious reference line in the frontal plane. Some authors have characterized the hip orientation by the neck shaft angle. However, the normal neck shaft angle ranges from 125° to 131° and varies significantly with hip rotation. Alternatively, the line drawn from the tip of the greater trochanter to the center of the femoral head defines the joint orientation of the hip to the mechanical axis. The normal relationship is 90° ± 6° and changes little with rotation. These reference lines and angles are useful in preoperative planning to determine the level of the apex of the deformity.
cause of the different considerations for osteotomy and fixation at these levels. Deformities that occur between the physis, or physeal scar in adults, and the joint surface have been termed juxtaarticular.

Angular deformities may be obvious or subtle. The level of the apex of diaphyseal deformities is usually obvious, whereas the level of the apex of metaphyseal and, particularly, juxtaarticular deformities is usually subtle and may be occult. The first step is to determine the level of the apex of the angular deformity. This assumes one knows which bone(s) is deformed. For obvious diaphyseal deformities, a line can be drawn down the convex cortex proximal and distal to the apex. The level of intersection of these two cortical lines is the level of the true apex of deformity. When the line of the cortex has been altered by the presence of callus, defects, or bone fragment displacement, then this simple method of deformity preoperative planning becomes less accurate. For juxtaarticular and metaphyseal deformities, there is no cortex on which to draw lines. A more complex system is necessary to accurately determine the apical level. The first step is to determine which bone(s) contributes to the MAD. There are three sources for lower-extremity MAD: (1) femoral deformity, (2) tibial deformity, and (3) knee-joint laxity or deformity.

MALALIGNMENT TEST

The Malalignment Test is used to determine if there is a component of angular deformity in the femur, tibia, or knee-joint space that is contributing to MAD. To perform the Malalignment Test, one needs a standing roentgenograph from the hip to the ankle including both lower limbs. Both knees should be in extension with the patellae pointing forward. The patella should be seen centered between the femoral condyles. If the patella points laterally or medially (external and internal rotation, respectively), long roentgenograms cannot be used for accurate preoperative planning and should be repeated. If there
is true subluxation or dislocation of the patella, the tibial tuberosity should be used as a landmark instead. In cases with torsional deformities of the femur or tibia, the same positioning with the patella forward is maintained. The X-ray technician should be instructed to orient the patella forward, not the foot forward, irrespective of the foot position. One also needs an X-ray marking pencil, long ruler, and goniometer.

Identify if there is MAD by drawing a line from the center of the hip to the center of the ankle. This line should normally pass through the medial tibial spine or between the tibial spines (Fig. 2, Step 0). Medial or lateral deviation indicates varus or valgus malalignment, respectively.

Draw the joint orientation line of the distal femur (line FC) (Fig. 2, Step 1).

Draw the mechanical axis of the femur from the center of the femoral head (H) to the center of the knee (K) (Fig. 2, Step 2).

Measure the lateral angle of the mechanical axis line to the knee-joint line (angle HKF) (Fig. 2, Step 3). If the distal femur is normal, this angle will measure 87° with a range from 86° to 89°. If the femur contributes to the MAD, this angle will fall outside this range.

Draw the line across the top of the tibial plateaus (TP) (Fig. 2, Step 4). Lines FC and TP should be parallel. If there is joint laxity or subluxation, or if the tibial plateaus are not colinear (as in Blount's disease), they will not be parallel. If they are not parallel, the joint space contributes to the MAD.

Draw the mechanical axis of the tibia from the center of the ankle (A) to the center of the knee (K) (line AK) (Fig. 2, Step 5).

Measure the medial angle of the mechanical axis line to the tibial plateau line (angle AKP) (Fig. 2, Step 6). Normally, this angle measures 87° with a range of 86° to 89°. Deviations in angle AKP demonstrate that the tibia contributes to malalignment.

After the deformity has been localized to one and or both bones, preoperative planning of the level of the apex of deformity can be performed. The preoperative planning of uniaxial angular deformities leading to MAD is presented for two types of tibial and two types of femoral deformities: (1) tibial diaphyseal angular deformity with a normal femur; (2) tibial juxtaarticular angular deformity with a normal femur; (3) femoral diaphyseal angular deformity with a normal tibia; (4) femoral juxtaarticular angular deformity with a normal tibia. Metaphyseal deformities are preoperatively planned in the same manner as juxtaarticular deformities.

**TIBIAL DIAPHYSEAL ANGULAR DEFORMITY WITH NORMAL FEMUR**

The mechanical axis line from the center of the hip to the center of the ankle is drawn to demonstrate the MAD (Fig. 3, Step 0). The Malalignment Test was performed to demonstrate the femur is normal and does not contribute to the MAD.

Draw the joint orientation lines of the knee and ankle (Fig. 3A, Step 1). Note if the line across the tibial plafond is perpendicular to
Figs. 3A and 3B. (A) Tibial diaphyseal angular deformity with normal femur. The preoperative planning of a tibial malunion, as described in the text (Steps 0-4), is carried out. The Malalignment Test demonstrates that the femur and joint do not contribute to the valgus mechanical axis malalignment. The apex of the deformity is identified by the mechanical axis method in Step 3A and by the convex cortex method in Step 3B. Both methods demonstrate a 26° valgus deformity at the same level. A 26° opening or closing wedge osteotomy at this level realigns the mechanical axis. (B) The Ilizarov circular fixator is applied with its hinge at the level of the apex of the deformity. The pair of rings above and below the deformity are perpendicular to the tibial diaphysis. The hinge is set at 26° (left). At the end of a 26° opening wedge correction, all of the rings are parallel. The correction is that of angulation only (right).

the distal tibial diaphysis. If not, instead use a line perpendicular to the distal tibial diaphysis as the joint orientation line of the ankle. Because the femur is normal, draw the line from the center of the hip through the center of the knee and extend it distally (Fig. 3A, Step 2). This line represents the mechanical axis of the tibia proximal to the apex of the deformity. The center of the ankle will come to lie on this line at the end of the correction.

Draw a line from the center of the tibial plafond extending proximal parallel to the distal tibial diaphysis. Because the anatomic and mechanical axis of the tibia are the same, this line represents the mechanical axis line of the distal tibia. Alternatively, if the plafond is 90° to the tibial diaphysis, one can draw the perpendicular to the ankle reference line from the center of the ankle joint and extend it proximally. Note the level of intersection of the two mechanical axis lines (Fig. 3A, Step 3A). This is the center of rotation of the angu-
lar deformity (apex). Measure the angle between the mechanical axis lines at the apex.

The alternative method is to draw a line down the convex cortices of the deformity (Fig. 3A, Step 3B). These lines should intersect at approximately the same level as the mechanical axis lines. Measure the angle between these cortical lines.

The osteotomy is performed at the level of the apex of the deformity (Fig. 3A, Step 4A and Fig. 3B). This can be carried out as an opening or closing wedge correction of pure angulation. This realigns and overlaps the mechanical axis lines and reestablishes the colinearity of the hip, knee, and ankle.

This same osteotomy realigns the diaphyseal line of the convex cortex so that it is colinear (Fig. 3A, Step 4B).

**JUXTAARTICULAR TIBIAL DEFORMITY WITH A NORMAL FEMUR**

The mechanical axis line is drawn from the center of the femoral head to the center of the ankle to demonstrate the magnitude and direction of mechanical axis deviation created by the tibial deformity (Fig. 4A, Step 0). The Malalignment Test was performed to confirm that the femur does not contribute to the mechanical axis deviation.

Draw the joint orientation lines of the knee and ankle (Fig. 4A, Step 1).

Draw the mechanical axis line of the femur from the center of the femoral head through the center of the knee and extend it distally (Fig. 4A, Step 2). This represents the mechanical axis of the tibia proximal to the apex of deformity. The center of the ankle will come to lie on this line after the correction.

Draw a line from the center of the tibial plafond extending proximal parallel to the distal tibial diaphysis. Draw the perpendicular to the ankle orientation line starting at the center of the ankle joint and extend this line proximally. The level of intersection of the two mechanical axis lines is the apex of the deformity. Measure the amount of angular deformity between the two mechanical axis lines. With a juxtaarticular deformity, the intersection of these lines lies between the growth plate and the joint. With a metaphyseal deformity, the intersection lies between the metaphyseal–diaphyseal junction and the growth plate.

The deformity may be corrected using an opening or closing wedge in the epiphyseal region of the bone (Fig. 4A, Step 4A). This leaves little room for fixation of the juxtaarticular fragment. In children, one is limited by the growth plate, and corrections at this level can only be performed by physeal distraction.

The preferred alternative is to perform the osteotomy correction at the level of the metaphysis distal to the apex of deformity (Fig. 4A, Step 4B and Fig. 4B). If a pure angular correction via an opening or closing wedge osteotomy is performed at this nonapical level, overcorrection is necessary to realign the mechanical axis. Although alignment is restored to normal, the joint orientation of the knee and ankle is not corrected.

If only the amount of measured angular deformity is corrected, the knee and ankle will be properly oriented to one another, but the MAD will not be completely corrected (Fig. 4A, Step 4C). There will be a persistent residual translational deformity (T), producing the so-called dog-leg deformity (Fig. 5).

To realign the mechanical axis and the joint orientation through a metaphyseal osteotomy for a juxtaarticular deformity requires a combination of angulation and translation (Fig. 4A, Step 4D and Fig. 4C). The true amount of angular deformity is combined with the amount of previously measured translation to correct the mechanical axis and joint orientation. The magnitude of T increases as the level of the osteotomy moves farther from the apex of the deformity. This correction of deformity is performed by pivoting the distal fragment around the true apex of deformity. The osteotomy is distal to the apex of deformity and, therefore, the distal fragment will translate medially when
Figs. 4A–4C, (A) Juxtaarticular tibial deformity with a normal femur. Preoperative planning for a case of severe Blount’s disease is illustrated. The Malalignment Test demonstrates that the femur and joint do not contribute to the varus MAD. Steps 0 through 4 are carried out. The apex of the deformity is found to be at the level of the proximal tibial physis and the magnitude of the deformity is 37° varus. Correction by physeal distraction at the level of the deformity is illustrated (Step 4A). This can be performed as a simple opening wedge correction. Correction by a metaphyseal osteotomy is illustrated in Steps 4B, C, and D. Because the osteotomy is distal to the apex of the deformity, an opening or closing wedge at this level without translation (Step 4B and 4C) cannot realign the mechanical axis and correct the joint orientation. The tibia needs to be translated laterally in addition to the 37° of angular correction (Step 4D). (B) An Ilizarov fixator is shown applied to the tibia with its hinge at the level of the osteotomy (left). Over-correction is required to realign the mechanical axis (right). The preferred correction is as shown in Figure 4C. (C) The Ilizarov circular fixator is shown applied to this tibial deformity with its hinge located over the proximal tibial physis at the apex of the deformity (left). The osteotomy is performed at the same level as in the previous example, distal to the hinge. The hinge is set at 37°. After correction, the rings are parallel and the tibia has translated laterally in addition to the angular correction of 37°. The mechanical axis and joint orientation are restored to normal (right).

correcting valgus and laterally when correcting varus deformities.

**DIAPHYSEAL ANGULAR DEFORMITY OF THE FEMUR WITH A NORMAL TIBIA**

The mechanical axis line from the center of the hip to the center of the ankle is drawn to demonstrate the magnitude and direction of MAD (Fig. 6, Step 0). The Malalignment Test was performed to confirm that the tibia does not contribute to the mechanical axis deviation and is, therefore, considered normal.

Draw the joint orientation lines of the hip and knee (Fig. 6A, Step 1). The hip joint orientation line is drawn from the tip of the trochanter to the center of the femoral head.

Draw the mechanical axis line of the tibia from the center of the ankle to the center of the knee and extend it proximally (Fig. 6A, Step 2). This is the mechanical axis line of the segment of femur distal to the apex of deformity. The center of the hip will come to lie on this line after the correction.

Draw the mechanical axis line of the contralateral femur from the center of the femoral head to the center of the knee as well as the hip orientation line from the center of the femoral head to the tip of the greater trochanter (Fig. 6A, Step 3A1). Measure the angle subtended by these two lines. If the contralateral hip is identical, this angle is this patient’s normal orientation of the mechanical axis of the femur to the hip-joint reference line. Use this angle on the deformed side. The extension of this angle is the mechanical axis line of the proximal femur. For example, if the angle on the unaffected side measures 88°, then draw an 88° line to the hip orientation line on the deformed side. Extend this line from the center of the femoral head distally. The point that intersects the tibial mechanical axis line is the apex of the deformity. Measure the degree of angulation at this level. If the opposite hip is deformed or significantly different than the hip in the malaligned side, an alternative method to define the proximal femoral mechanical axis is used. Because the femoral diaphysis is not parallel to the anatomic axis of the femur, a line cannot simply be drawn from the center of the femur at the head parallel to the diaphysis as was done in the tibia. However, the anatomic axis of the femur does maintain a fixed relationship to the mechanical axis. This varies from individual to individual but is approximately 5°–7°. When the malaligned side has a different neck-shaft angle or trochanteric level than the normal side and when no correction of this hip variation or deformity is clinically merited, then the...
proximal femoral lateral cortex is used as the reference to locate the mechanical axis of the proximal segment of femur. Draw the line down this cortex on the normal side (Fig. 6, Step 3A2). Measure the angle "α" between this line and the mechanical axis of the normal femur. Draw a line down the lateral cortex of the proximal femur on the malaligned side. Draw a line parallel to this line starting at the center of the femoral head extending distally. Draw a second line of angle "α" to the first line. This last line represents the mechanical axis of the proximal segment of femur. When the hip deformity is significant and merits correction, then the method outlined for multipical angular deformities is used.\textsuperscript{12} For diaphyseal deformities, an alternative method is to use the convex diaphyseal cortex (Fig. 6A, Step 3B). The intersection for the two cortical lines should be at the same level and of equal magnitude. The angular deformity can be corrected by an opening or closing wedge osteotomy at the level of the apex of the deformity (Fig. 6A, Step 4A and Fig. 6B). The same angular correction should realign the anatomic axis and the convex cortices of the bone (Fig. 6, Step 4B).

**JUXTAARTICULAR ANGULAR DEFORMITY OF THE FEMUR WITH NORMAL TIBIA**

The mechanical axis line from the center of the femoral head to the center of the ankle is drawn to demonstrate the magnitude and direction of MAD (Fig. 7A, Step 0). The Malalignment Test has already been performed, confirming the tibia does not contribute to MAD and is, therefore, normal.

Draw the joint orientation line of the hip and knee, as in the previous example (Fig. 7A, Step 1).

Draw the mechanical axis line from the center of the ankle through the center of the knee and extend it proximally (Fig. 7A, Step 2). The center of the hip joint will come to lie on this line after correction. This represents the mechanical axis of the segment of femur distal to the apex of the deformity.

Draw the mechanical axis line of the proximal femur taking into consideration the various factors and steps outline in the previous example (Fig. 6 and Fig. 7A, Step 3).
Figs. 6A and 6B. (A) Diaphyseal angular deformity of the femur with a normal tibia. Preoperative planning of a valgus diaphyseal femoral deformity is carried out (Steps 0–4), as described in the text. The Malalignment Test was performed, demonstrating that the tibia and joint do not contribute to the valgus mechanical axis deviation. The convex cortex method and the mechanical axis method demonstrate an angular deformity of 15° at the same level in the diaphysis. This can be corrected by angulation using an opening or closing wedge at the level of the apex. (B) The Ilizarov apparatus is shown applied to this femoral deformity. The hinges are preset at 15°. The rings are all oriented perpendicular to the mechanical axes. The hinge is placed at the same level as the apex of the deformity. The osteotomy is performed at this level (left). At the end of the 15° open wedge correction, the rings are all parallel (right).

This line intersects the distal mechanical axis line at the apex of deformity. If the intersection is between the knee joint and growth plate, it is a juxtaarticular deformity. If the apex is between the metaphyseal-diaphyseal junction and the physis, it is a metaphyseal-level deformity. Measure the amount of angular deformity.

To perform a purely angular correction for a juxtaarticular deformity, an opening or closing wedge osteotomy would be intraarticular or transarticular or through the growth plate. This is not practical or safe in most situations, and the osteotomy is instead performed at the level of the adjacent metaphysis, proximal to the apex of deformity (Fig. 7A, Step 4, and Fig. 7B). To realign the mechanical axis with an opening- or closing-wedge angular correction at the metaphyseal level requires overcorrection. As in the previous example of a tibial juxtaarticular deformity, this produces a normal mechanical axis alignment and malorientation of the relationship of the hip to knee. Although this may be insignificant with small deformities, with larger angular deformities this produces the so-called golf club deformity of the distal femur (Fig. 8).
FIGS. 7A AND 7B. Juxtaarticular angular deformity of the femur with normal tibia. Preoperative planning is shown for a distal femoral valgus deformity. Steps 0–4, as described in the text, are carried out. The Malalignment Test demonstrates that the tibia and joint do not contribute to the valgus mechanical axis deviation. The apex of the deformity is identified at the level of the joint. The magnitude of the deformity is 11° valgus. The osteotomy is performed in the supracondylar region, as shown in Steps 4A–4C. Complete realignment through an opening or closing wedge at this level requires overcorrection (14°) because the osteotomy is proximal to the apex (Step 4A). Alternatively, one could correct only the measured deformity, 11°, but with a slight residual valgus malalignment (Step 4B). This produces a translational deformity between the mechanical axes of the proximal and distal femur. However, if the distal femur translates laterally, normal alignment and joint orientation are restored (Step 4C). Therefore, the correct realignment through a supracondylar osteotomy for a juxtaarticular deformity includes angulation and translation around the center of rotation at the level of the apex. (B) The Ilizarov apparatus is constructed with the hinge located over the apex of the deformity. The rings subtend an angle of 11° through this hinge (left). After correction of the deformity through a supracondylar osteotomy, there is angulation and translation of the bone ends. The rings are now all parallel (right).

There will be a residual translation deformity if the correction is limited to the amount of angular deformity measured in preoperative planning (Fig. 7A, Step 4B). Although the hip- and knee-joint orientation is corrected, there is a persistent malalignment of the mechanical axis.

Therefore, the most accurate correction through a metaphyseal osteotomy at a different level than the apex of a juxtaarticular deformity includes angulation (as measured in preoperative planning) and translation of the amount T (Fig. 7A, Step 4C). The amount T increases as the distance of the osteotomy from the apex of the deformity increases.

ANGULAR DEFORMITIES OF BOTH TIBIA AND FEMUR

When the Malalignment Test demonstrates that both bones contribute to the malalignment, then preoperative planning is used to locate the apex of the femoral and the tibial deformities.

A line is drawn from the center of the femoral head to the center of the ankle, demon-
Fig. 8. Golf club deformity of the distal femur after closing wedge osteotomy for the correction of valgus deformity. Although the angular deformity has been eliminated, there is a persistent medial translational deformity when the osteotomy was performed proximal to the apex of the deformity.

Fig. 9. Angular deformity of femur and tibia. The Malalignment Test in this example demonstrated that the femur and tibia contribute to the varus malalignment. Therefore, the normal mechanical axis of one bone cannot be used as the mechanical axis of the other bone. Instead, the mechanical axis of the proximal tibia and of the distal femur is defined as a line extending from the center of the knee distally and proximally, respectively, at an 87° angle to the knee joint line. Preoperative planning is carried out (Steps 0-5). The apex of each deformity is identified to be diaphyseal; an opening wedge osteotomy is carried out. An alternative to an opening or closing wedge osteotomy is to perform the osteotomy at a level proximal or distal to the apex and realign the axis with a combination of angulation and translation. This is demonstrated in Step 6B. The advantage of this correction is that it allows the insertion of the corner of one bone into the medullary canal of the other. Metaphyseal bone heals more readily, and this position increases the stability of acute corrections.
ning and extend it proximally (Fig. 9, Step 3). The intersection point of the two mechanical axis lines is the apex of the tibial deformity.

Correct the deformity of the tibia by an osteotomy at the level of the apex with an opening or closing angulation of the amount measured from the mechanical axis lines or by a combination of angulation and translation through an osteotomy proximal or distal to the apex of the deformity (Fig. 9, Step 4).

Because the tibia is now normal and does not contribute further to MAD, additional correction is performed as described above for a femoral deformity with a normal tibia (Fig. 9, Step 5).

There are two frontal plane angular deformities that do not contribute to malalignment. These are juxtaarticular deformities of the hip and ankle because the apex of these deformities is at either end of the frontal plane mechanical axis line, center of the hip, and center of the ankle. It is usually not feasible to perform an osteotomy in the juxtaarticular region of the hip or ankle. Therefore, the osteotomy must be performed proximal and distal to the apex of a juxtaarticular deformity, distal to the apex for the hip. If a simple opening or closing wedge osteotomy is performed without translation, a translational deformity will be created. This will produce a mechanical axis malalignment and a translational malorientation of the hip relative to the knee (for osteotomies of the proximal femur) and of the ankle relative to the knee (for supramalleolar osteotomies). It is, therefore, important to understand the concept of combining angulation with translation when performing osteotomies of the proximal femur or distal tibia if the osteotomy level is not at the level of the apex of the deformity.

TIBIAL PLAFOND (ANKLE)
DEFORMITY IN THE FRONTAL PLANE

The mechanical axis is drawn and demonstrates a normal collinearity between the centers of the hip, knee, and ankle (Fig. 10, Step 0). The joint orientation lines of the hip and knee are normal, but the ankle-joint orientation line is significantly greater or less than 90°, indicating an ankle deformity.

A 90° line is extended proximally from the center of the plafond (Fig. 10, Step 1). Because there is no MAD, the center point of the plafond is also the apex of the deformity. The magnitude of the angular deformity is measured between the perpendicular to the plafond and the mechanical axis. The osteotomy is performed in the supramalleolar region to allow room for fixation.

If the correction is performed with a center of rotation at the level of the osteotomy, overcorrection is needed to completely reorient the ankle. Medial MAD occurs when
correcting valgus and lateral translation when correcting varus (Fig. 10, Step 2A).

If the angular correction is performed through a supramalleolar osteotomy with the center of rotation at the level of the plafond, there will be no disturbance of the mechanical axis and no overcorrection (Fig. 10, Step 2B). The correction is that of angulation together with lateral translation when correcting valgus, or medial translation when correcting varus.

HIP DEFORMITY IN THE FRONTAL PLANE

The mechanical axis is drawn and demonstrates a normal colinearity of the hip, knee, and ankle centers (Fig. 11, Step 0). The joint orientation lines are normal for the ankle and knee, but the hip orientation angle is significantly greater or less than 90°, indicating a hip deformity.

Draw a 90° line to the hip reference line,

**STEP 0  ** **STEP 1  ** **STEP 2A  ** **STEP 2B**

Fig. 11. Varus deformity of the hip in the frontal plane. The mechanical axis is colinear between the hip, knee, and ankle, and the joint orientation of the knee and ankle are normal. The joint orientation line at the hip demonstrates a 23° varus deformity. Preoperative planning is described in Steps 0–2 in the text. The osteotomy is performed in the intertrochanteric or subtrochanteric region, distal to the apex of the deformity. A simple opening or closing wedge correction at the level of the osteotomy produces a lateral translational deformity with valgus mechanical axis malalignment and malorientation of the hip and knee joints (Step 2A). Therefore, a valgus correction of the hip should be combined with lateral translation (Step 2B).
extending distally from the center of the hip joint (Fig. 11, Step 1). The angle measured between this line and the mechanical axis line is the magnitude of the angular deformity. The osteotomy is performed in the subtrochanteric region for practical purposes.

If the correction is performed with a center of rotation at the level of the subtrochanteric osteotomy using an opening or closing wedge, correction of varus deformity leads to lateral deviation while correction of valgus leads to medial MAD (Fig. 11, Step 2A).

Because the center of rotation of the deformity is at the level of the center of the hip, rotation of the proximal femoral segment around this apex produces angulation and translation of the osteotomy (Fig. 11, Step 2B). Correction of varus deformity requires lateral translation and correction of valgus requires medial translation.

**SAGITTAL PLANE DEFORMITY
PREOPERATIVE PLANNING**

The same precautions must be taken when correcting juxtaarticular deformities not in the frontal plane. Sagittal plane deformities of the distal femur, proximal tibia, proximal femur, or distal tibia must also be corrected relative to the apex of the deformity. Although there is more tolerance for translational deformity in the sagittal plane because the deformity is corrected in the plane of motion of the hip, knee, or ankle, one should try to avoid producing a new deformity when correcting an existing deformity. The normal alignment in the sagittal plane is from the center of gravity at the level of S2 in the spine, passing posterior to the center of the femoral head and anterior to the center of the knee to a point anterior to the center of the ankle. This alignment becomes especially important in situations with weak or paralytic muscles. Sagittal plane alignment is also important for normal patellofemoral function to minimize joint forces on the patella, and for normal foot function. For example, anterior translation of the distal tibia by a supramalleolar osteotomy can produce a gait disturbance, particularly in a stiff foot, by increasing the length of forefoot to be stepped over.
Joint orientation is also important in sagittal plane deformities (Fig. 12). The proximal femur has an anteversion angle of 5° to 15°.8,13 The distal femur is difficult to characterize by a joint orientation line. The anterior aspect of the distal femur and the anterior tibia should be colinear for the knee to have full extension. This line can be used to judge procurvatum or recurvatum deformities of the distal femur. The tibial plateau has a normal posterior slope, measuring 8°–12°.3 This is important in resisting the forward roll of the femoral condyles on the tibia and also prevents recurvatum of the knee. The tibial plafond has an anterior tilt of approximately 5°–7°. The line from the center of the ankle to the center of the knee is parallel to the diaphysis of the tibia. The sagittal line from the center of the femoral condyles to the center of the femoral head is sloped slightly posterior to the anterior femoral cortex.

Diaphyseal deformities in the sagittal plane can also be measured by the convex cortical line method previously illustrated. Juxtaarticular deformities are planned by using the joint orientation angles of the opposite normal side as a reference. Alternatively, one can use the average of 10° posterior tilt for the tibial plateau and 5° anterior tilt for the ankle (relative to the midline from the center of the ankle to the center of the knee on the lateral view). Because the joint range of motion is in the plane of the deformity, limitations in range affect the amount of possible correction. This is not a limitation in frontal plane deformities of the knee or ankle but is a limitation for juxtaarticular deformities of the hip.

OBLIQUE PLANE ANGULAR DEFORMITIES

The above method for preoperative planning is used to evaluate angular deformity in the frontal and sagittal anatomic planes. Many angular deformities appear to have angulation in the frontal and sagittal planes, as noted on the anteroposterior (AP) and lateral roentgenographs. Although these have been termed planar deformities, they are actually uniaxial angular deformities in an oblique plane between the anatomic sagittal and frontal planes. To determine the true magnitude of the angular deformity, one must know the magnitude of the angular deformity in each of the anatomic planes.10 The apex of the deformity will be at the same level as the apex determined in the frontal and sagittal planes in the absence of traditional deformity or when angulation and translation are in the same plane. The preoperative planning of these deformities is beyond the scope of this paper and is the subject of a future publication. The frontal and sagittal plane preoperative planning method described above is used to evaluate the level of the apex and the magnitude of the frontal and sagittal plane deformities. The latter are then used to determine the plane and the magnitude of the oblique plane deformity, as previously described.10 The considerations for osteotomy are the same as for anatomic plane deformities. Diaphyseal and metaphyseal oblique plane deformities are usually treated by opening or closing wedge osteotomies while juxtaarticular oblique plane deformities are usually treated by angulation and translation.

REFERENCES

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