CHAPTER **31**

BIOTRIGONOMETRIC ANALYSIS AND PRACTICAL APPLICATIONS TO RUCH'S CLOSING WEDGE METATARSAL OSTEOTOMY

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INTRODUCTION

Angular osteotomy constructs are an extremely useful part of the reconstructive foot and ankle surgeon's repertoire. Wedge resection is used in angular deformities where a significant amount of correction is required to achieve the desired surgical outcome, such as in Ruch's closing abductory wedge osteotomy at the base of the metatarsal.[1] This osteotomy is designed for correction of large intermetatarsal angles associated with hallux valgus deformity. In general, the construction of an appropriate triangular osteotomy at the base of the first metatarsal is extremely effective at reducing the deformity and can provide a stable construct for placement of fixation. Preoperative planning allows the surgeon to determine the appropriate axis of correctional angulation. Trigonometric analysis provides information on the degree of correction required and that which is achievable through wedge resection. An understanding of the angular relationship between the first ray and longitudinal axis of the foot, implementation of a set of trigonometric functions, and utilization of templates or osteotomy guides will result in reproducible surgical methods.

BACKGROUND

Hallux valgus is a very common pathology of the forefoot. It is frequently associated with a medial splaying of the first metatarsal (metatarsus primus adductus). The amount of adductus is often minimal and can be corrected via distal metatarsal osteotomy. Capital osteotomies function more to realign the metatarsophalangeal joint, however large shifts of the head of the metatarsal when combined with slight rotation allows for some mild reduction of the angle between the first and second metatarsals. The indication for a closing wedge osteotomy of the first metatarsal includes a large first intermetatarsal angle where a distal osteotomy could not achieve complete deformity correction or would not be appropriate for the patient. Ultimately, the construct is oriented along an axis that will provide for adequate resection of bone to completely reduce the angular deformity, allow for placement of rigid internal compressive fixation, and not violate the sesamoid-metatarsal articulation or the first metatarsophalangeal joint.

Classically the osteotomy is arranged so that the arms converge on an apex that is located in the proximal medial aspect of the first metatarsal, approximately 1.0 – 1.5 centimeters from the metatarsal-cuneiform articulation. The proximity of the hinge to the metatarsal base increases the effective radius arm of the osteotomy, which translates into greater correction for each degree of wedge removed. The more proximal hinge also permits correction while minimizing the possibility for creating a negative intermetatarsal angle as the distal segment is rotated towards the second metatarsal. The direction of the osteotomy is oriented from proximal-medial to distal-lateral. The angle of the osteotomy is based on the proximal arm of the construct. The length of this arm must permit placement of rigid internal fixation. Ruch states that this arm should be approximately 40 degrees from the long axis of the distal metatarsal segment.[1] Successful internal fixation of the osteotomy can be achieved with screws placed in a compressive fashion to maintain alignment of the metatarsal, maintain apposition and compression across the osteotomy, and provide protection for the delicate cortical hinge.

Despite the demonstrated efficacy of the procedure, Ruch's osteotomy is probably underutilized in foot and ankle surgery. This may be associated with the technical nature of creating a precise angular osteotomy, achieving a successful internal fixation construct, or the nature of the postoperative course. The design of this osteotomy demands the ability to perform an exact wedge resection with both osteotomy arms on plane, converging on a common apex, and with removal of an exact amount of bone to reduce the intermetatarsal angle without overcorrecting or excessively shortening the metatarsal. It is critical in this circumstance to understand the angular nature of the deformity in order to understand the deformity correction. With this understanding, careful preoperative analysis will permit visualization of the intended wedge resection, which will translate into ease of execution of the osteotomy in the operating room.

ANGULAR CORRECTION OF THE FIRST METATARSAL

Triangles are used to measure both angles and distances in relation to each other. One of the most commonly measured angles in the foot is the first-second intermetatarsal angle, hereinafter referred to as the IMA (Figure 1). By definition, this angle is the magnitude of separation of the bisectors of the first metatarsal in relation to the second metatarsal along an arc. The longitudinal axis of the second ray is representative of the long bisector of the foot. Generally speaking, the object of the closing wedge osteotomy in metatarsus primus varus repair is to reduce the IMA to zero or near zero and bring the first metatarsal back in line with the foot. Therefore, in creating our osteotomy it would be necessary to remove a wedge from the first metatarsal such that the final position of this metatarsal axis would be parallel or near parallel to the second metatarsal; that is, closure of the IMA.

Proper preoperative planning for the base wedge osteotomy procedure includes accurate determination of the angle of correction based on radiographic evaluation. However, intraoperatively, it is difficult to "see" an angle in the metatarsal for proper wedge resection. Linear dimensions are more practical to measure and utilize for osteotomy planning in the surgical setting since a ruler is readily available intraoperatively and linear dimensions are less sensitive to radiographic technique aberration when compared to angular values in standard foot x-rays. Therefore, it would be extremely helpful to convert our angular deformity to linear values for use in surgery. Deformity analysis thus has two parts; first to determine the angular correction required to reduce the deformity by a specified number of degrees, and second to convert angular measurements to linear values to facilitate execution of an exact osteotomy.

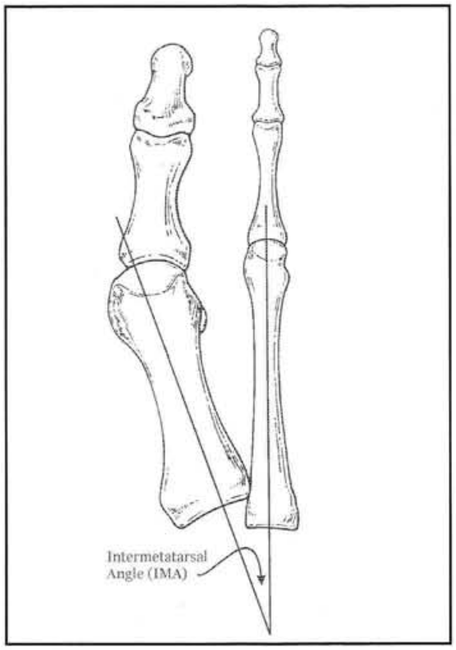


Figure 1. The true intermetarsal angle is defined by the bisectors of the first and second metatarsals. This places the level of metatarsus primus adductus deformity in the midfoot. However, since correction is performed in the metatarsal, the deformity must be evaluated at this level.

To understand the degree of angular correction upon bone wedge resection, we can use the Pythagorean theorem and properties of sines, cosines, and tangents to solve for a triangle, that is, to find unknown parts in terms of known parts (Figure 2).

For Triangle ABC:

- Pythagorean theorem: a2 + b2 =c2.
- Sines: sin A=a/c, sin B =b/c.
- Cosines: cos A=b/c, cos B=a/c.
- Tangents: tan A=a/b, tan B=b/a.

Empirically, the angle of the closing wedge to be ressected is the angle of medial deviation of the first metatarsal away from the mid-axis of the foot. As stated above, the mid-axis of the foot can be equated to a bisector of the second ray. This medial deviation angle (MDA) equates to the traditional intermetatarsal angle, IMA, preoperatively. Correction of the angular deformity via wedge osteotomy is more accurately described by the MDA since the entire metatarsal is not shifted or angulated surgically in angular osteotomies of the first metatarsal. The goal then is to reduce the MDA to zero or near zero when compared with the preoperative IMA (Figure 3).

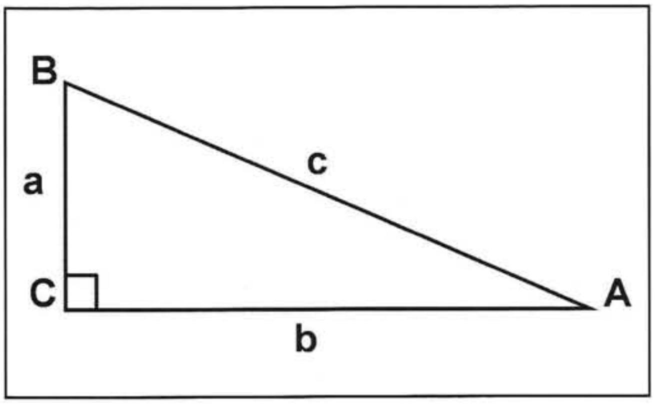


Figure 2.

To convert a measured IMA to a linear dimension for closing wedge osteotomy, it must first be proven that the angle of the ressected wedge to bring the MDA to zero is the same as the IMA. It is then necessary to prepare a trigonometric function and use this angle in determination of a linear value for use in the operative setting.

MATHEMATICAL ANALYSIS

As stated above, the IMA is the measured angular deviation of the long axis of the first metatarsal to the long axis of the second metatarsal. This angle is determined from measurements on the DP radiograph using standard techniques. If the first metatarsal is to be cut at the base, there will be a distal mobile segment and a stable proximal segment. The hinge axis of rotation of the distal segment is the Axis of Correctional Angulation (ACA) and along this axis we can define a Center of Rotation of Angulation, CORA. This is the point of convergence of the distal and proximal segments. The hinge axis in a closing base wedge osteotomy of the first metatarsal is often in the DP plane, although occasionally it is angled to accommodate oblique plane deformity such as a dorsiflexed metatarsal.

In a simplified line diagram depicted in Figure 4, line AB represents the long axis of the first metatarsal, and line AC is the long axis of the second metatarsal. The angle formed at the convergence of AB and AC is angle 2, and completing the right angle with line BC closes triangle ABC.

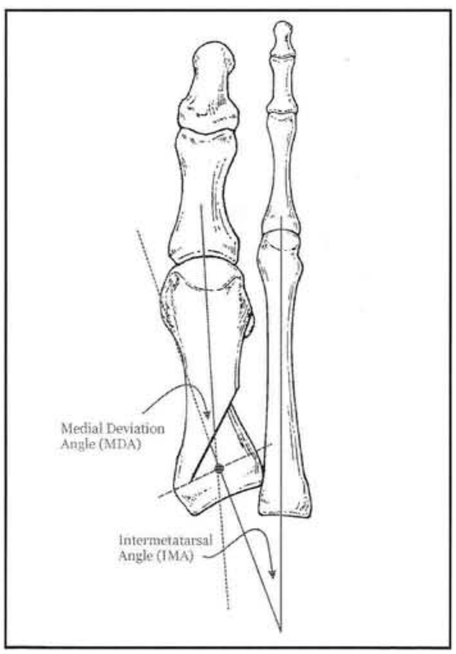


Figure 3. After closure of the base wedge osteotomy, the Medial Deviation Angle (MDA) is revealed. The actual intermetatarsal angle does not change with this procedure, however it is effectively reduced. Pre and postoperative angular analysis is more appropriately performed at the level of the osteotomy.

A triangular wedge with equivalent angle 2 along the acute corner is plotted along the long axis AB. This triangle, DEF, converges on a point across line AB, which will be the axis of rotation of the distal segment. The angular correction will be defined by the movement of line BD from line AD at point D. When triangle DEF is removed from the diagram, and parallelogram BCED is rotated by 2 degrees, line BD becomes parallel to line AC.

In Figure 4, introduction of axis of rotation D produces a mobile segment and stationary segment for line AB. These are lines BD and AD respectively. Prior to rotation, the angle of convergence of lines AB and AC is the IMA. After removal of the wedge and rotation of the distal segment, Angle 2 remains as the true IMA, however the new angle between lines BD and old line AC is the MDA. These diagrams demonstrate how the MDA can be reduced to zero by removal of a wedge of equivalent angle as the IMA. The MDA cannot be revealed until the level of the osteotomy is defined.

Since IMA = 2 = angle of wedge resection, we can now solve for the dimensions of the wedge osteotomy of the first metatarsal. There are two scenarios that have been employed for this type of procedure, that of a shallow wedge (transverse type) originally described by Loison,[2] and that of a more oblique wedge, described and refined by Ruch.[1] For our purposes transverse wedge osteotomies are performed at angles less than 45 degrees to the long axis of the metatarsal, while oblique osteotomies are performed at angles greater than 45 degrees to the metatarsal axis. The transverse osteotomy is not frequently performed due to difficulty in fixation, and this method has more or less been replaced by crescentic osteotomy constructs. Therefore, we will limit this analysis to the more commonly performed Ruch-type osteotomy (Figures 5-8).

Evaluation of the preoperative dorso-plantar radiograph will produce the IMA, the same angle as our

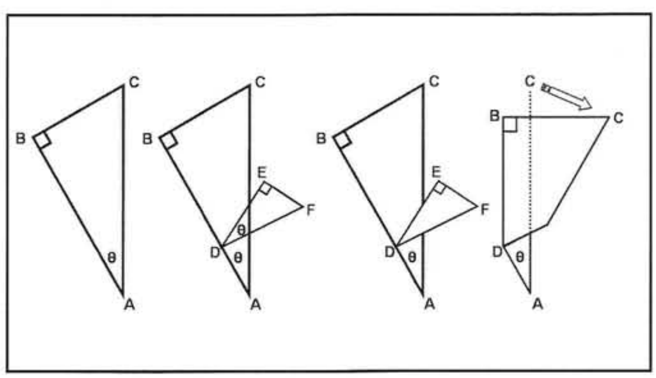


Figure 4.

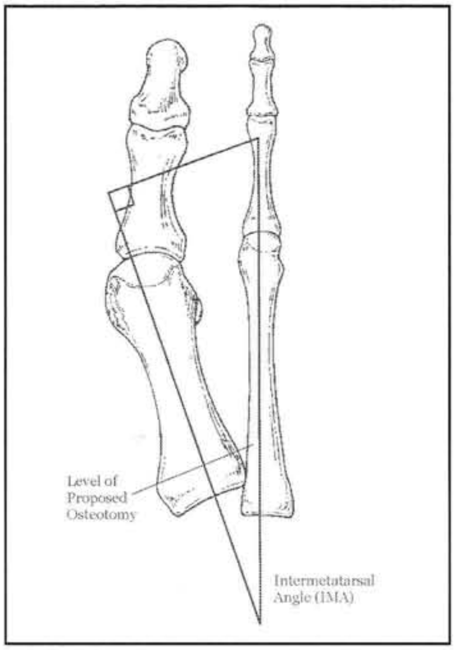


Figure 5. The intermetatarsal angle (IMA) is defined as the angle between the bissectors of the first and second metatarsals. In Ruch's closing base wedge osteotomy, the level for placement of the axis guide for correctional angulation is approximately at the waist of the first metatarsal.

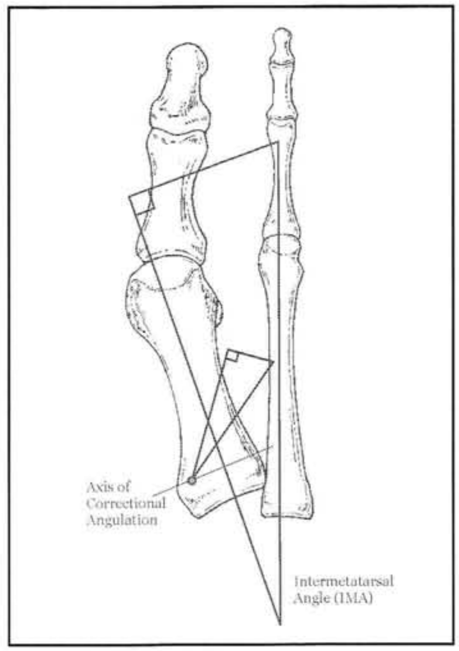


Figure 6. A right triangle with an acute angle of exactly the IMA is plotted to intersect along the axis of correctional angulation (ACA). Removal of this wedge of bone will result in complete closure of the intermetatarsal angle. The center of rotation and angulation (CORA) is the location of the intersection of the proximal and distal metatarsal bissectors.

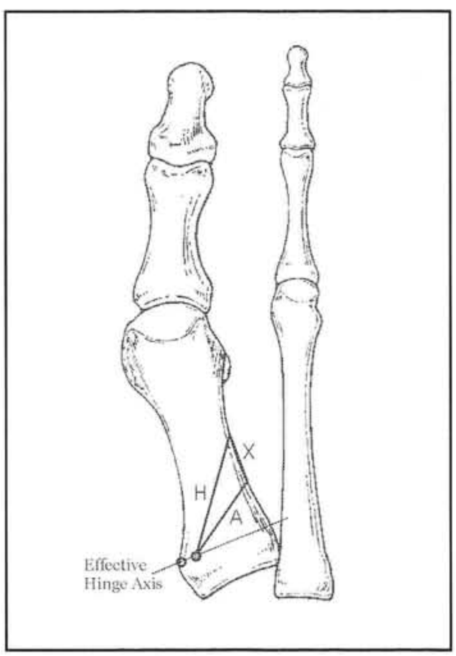


Figure 7. The arms of the triangle are formed by the proposed oblique osteotomy arms (Adjacent side 'A' and Hypotenuse 'H') and the lateral cortex of the first metatarsal which will be removed. The length of lateral cortex (X) to be removed is an unknown linear value with special importance since it can be measured intraoperatively. The effective hinge axis (white circle) is the extreme medial aspect of the first metatarsal at the level of the osteotomy since the distal metatarsal segment rotates around an intact medial cortical hinge.

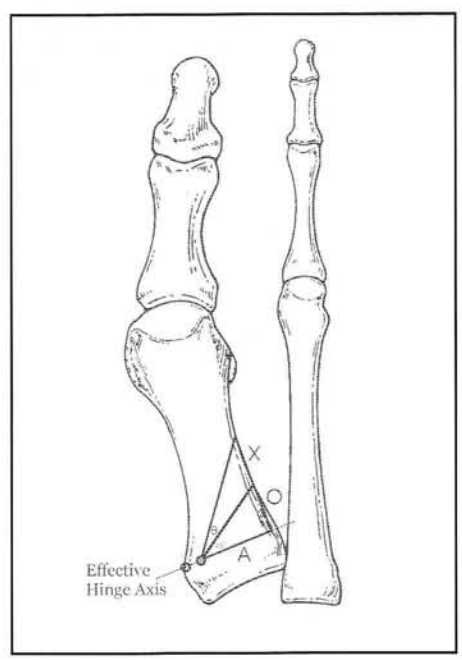


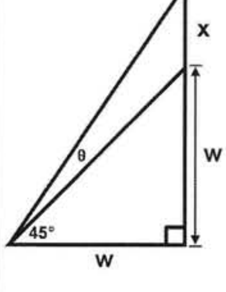
Figure 8. To determine the length of unknown dimension 'X' a complete right triangle is created. This allows us to use the width of the metatarsal and the known angle of the osteotomy along with the law of tangents to determine the length of lateral metatarsal cortex to be removed. The opposite arm of the osteotomy is labelled 'O.' The complete right triangle is then essentially a function of the tangent of the combined angle (IMA + 45) and the metatarsal width since the effective hinge is at the most medial aspect of the metatarsal.

wedge osteotomy. We can also measure the width of the metatarsal at the level of our planned axis of correction which will be one of the arms of our theoretical triangle. Since the law of tangents is tan (angle 2) = opposite/adjacent, we can solve for the unknown side (opposite to the angle 2), which in both osteotomy situations (oblique and transverse) is the dimension of the lateral metatarsal cortex which would complete the base of a triangular osteotomy construct.

In our oblique osteotomy scenario, a triangle with sides that are equivalent will be used as a reference because of the rule of right triangles. The width of the metatarsal at the level of the planned osteotomy serves as the dimension for the opposite (O) and adjacent (A) sides, while the hypotenuse (H) is the dimension of the shorter of the two arms of the wedge osteotomy. Since we are solving for the unknown linear dimension of lateral cortex to be removed (X), first we must realize that part of the opposite arm of our theoretical triangle is defined as the same as the width dimension (adjacent arm), and the unknown will be some function of this dimension. In other words, in a right triangle, O = A, and O and A oppose at a 90 degree angle. Because our construct is oblique to the long metatarsal axis and our planned osteotomy is off of the tangential (90 degree) axis, the adjacent and opposite arms will vary in length. The opposite arm will be some length greater than the width of the metatarsal at the level of the planned osteotomy if we use our reference triangle. The angle to solve for (the MDA) is added to 45 degrees to create a larger triangle and allow us to use a known linear dimension, the width at the ACA (Figure 9).

Solving for the unknown linear dimension, x, we see that tan θ = opp/adj. The opposite arm equates to x + A, and angle 2 is 45 + IMA. Therefore, tan (45 + IMA) = (x + A)/A. Rearranging the equation, (x + A) = A (tan (45 + IMA)). Subtracting A from both sides, we see that x = A (tan (45 + IMA)) A, and simplification reveals that x = A [tan (45 + IMA) – 1]. This corresponds to the equations proposed by Kempe et al.[3]

We are solving for a linear dimension x, which is the distance in millimeters of lateral cortex of the first metatarsal to be ressected. With this information we can appropriately set an axis guide such as a 0.045" Kirschner wire in the proximal medial first metatarsal and use a ruler to define this dimension on the lateral cortex. Our osteotomy arms would then converge on this dimension, removing an exact wedge of bone and correcting the MDA the appropriate number of degrees. To minimize the need for additional bone removal that can occur when reciprocal planning the osteotomy site on closure, an axis guide should be used (Figure 10).



$$\tan \theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\tan (\theta + 45) = \frac{(x + w)}{w}$$

$$w[\tan (\theta + 45)] = x + w$$

$$w[\tan (\theta + 45)] - w = x$$

$$w[\tan (\theta + 45) - 1] = x$$

Figure 9.

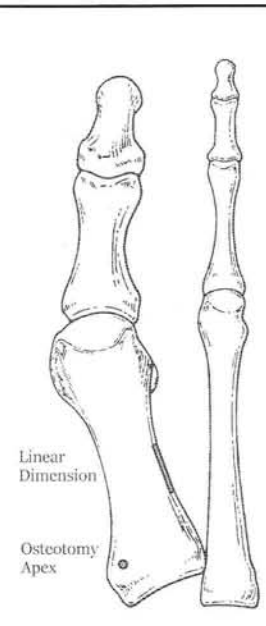


Figure 10. Intraoperatively, angles are not able to be accurately defined, however linear dimensions are easily measured with a ruler. With appropriate preoperative planning, the level of the axis guide can be predetermined and the length of the lateral cortex to be removed can be plotted. The use of an angular osteotomy guide will facilitate accurate bone cuts and creation of an exact osteotomy construct.

DISCUSSION ON CORA AT THE BASE OF THE FIRST METATARSAL

Deviation of the first metatarsal in the transverse plane away from the longitudinal axis of the foot, specifically the second ray, can be plotted on the Cartesian plane and described as angulated by a certain number of degrees. The intersection of the bissectors of both the first metatarsal and the stationary second metetarsal describe a theoretical axis because the point of intersection is somewhere in the midfoot where there is no joint to provide such motion. In general, correction for the MDA using a wedge-type osteotomy is performed at a location distal to the intersection point of the metatarsal bisectors, most commonly at the level of the metatarsal. This results in a bissector of the base of the metatarsal up to the level of the osteotomy, specifically identified as the proximal immobile arm of the osteotomy. Distal to this is a mobile segment, which also is described by a bissector of the metatarsal. The point at which the mobile and stationary bissectors of the first metatarsal intersect in the proximal metetarsal region is the center of rotation and angulation, CORA. The wedge osteotomy which allows for mobility of the distal metatarsal on the proximal metatarsal converges on an axis in the proximal medial first metatarsal. This is the axis of correctional angulation, ACA. Despite using an axis guide placed strategically to avoid cracking in to the metatarsal-cuneiform articulation and permitting placement of internal compression fixation, this axis is effectively the most proximal and medial extent of the first metatarsal. Because CORA's exist along the ACA, the true CORA would be at the metatarsal-cuneiform joint level (Figures 11-13).

CONCLUSION

Medial angulation deformity at the first metatarsal is a common finding in hallux valgus deformity. Ruch's closing base wedge osteotomy can effectively reduce this deformity. Preoperative analysis will reveal the degree of adduction and this value is used to determine the amount of wedge to be removed. In the surgical setting, it is very difficult to visualize an angular deformity. Consequently, the angular deformity can be converted into a linear measurement of lateral metatarsal cortex to be removed to facilitate accurate wedge resection. The use of an angular osteotomy guide is the final element required to perform an exact closing base wedge osteotomy.

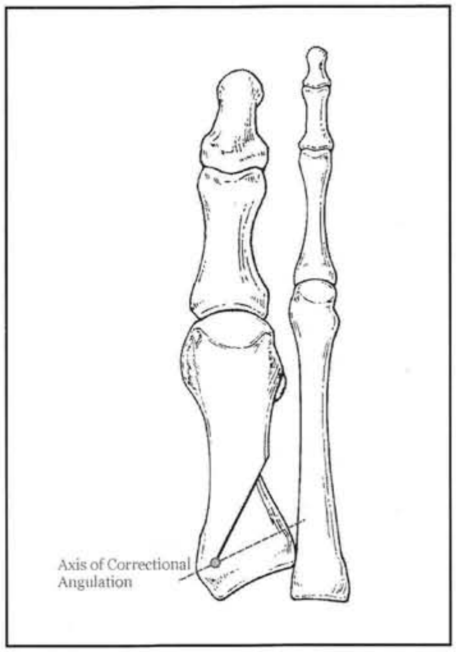


Figure 11. The axis of correctional angulation (ACA) in Ruch's osteotomy is determined to be 1-1.5 cm from the metatarso-cuneiform joint level. This will protect the delicate medial cortical hinge.

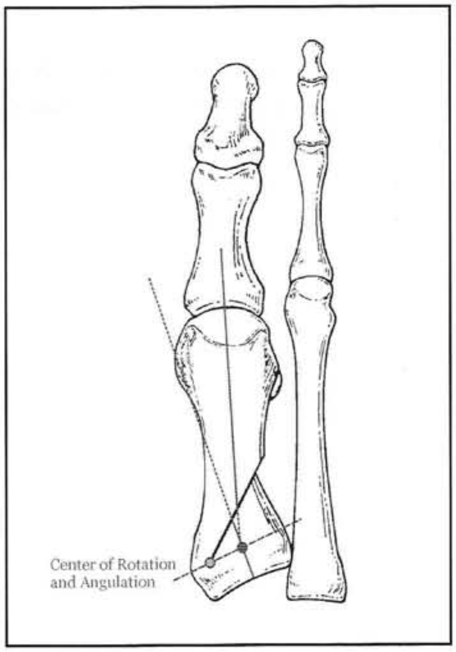


Figure 12. The center of rotation and angulation (CORA) exists at the base of the first metatarsal. This point is at the intersection of the distal and proximal metatarsal bisectors at the level of the planned osteotomy. The true angular deformity exists at the metatarso-cuneiform joint level, however the closing wedge osteotomy is performed distal to the level of deformity. Note that post-rotation the distal and proximal bisectors no longer converge at the level of the osteotomy but rather along the axis of correctional angulation (ACA).

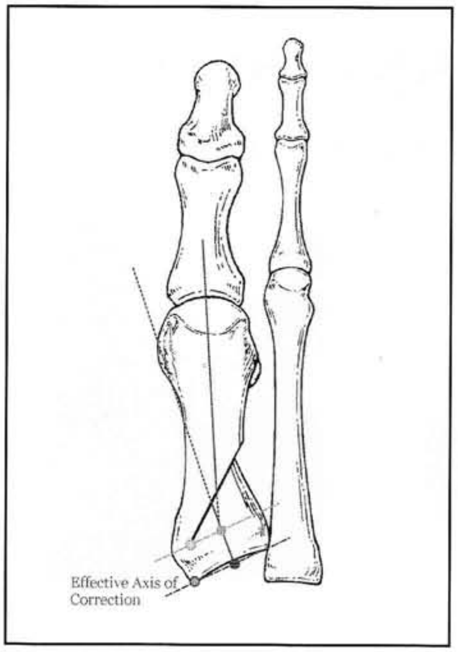


Figure 13. Because the medial cortical hinge is preserved, the effective point of rotation and correction is at the metatarsal base. Preservation of the hinge also prevents translation with rotation, and offers additional stability to the construct.

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3. Kempe SA, Grapel D, Hovanec P. A mathematical approach to the closing base wedge osteotomy. J Am Pod Assoc *1984;74:601-4.*