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Basilar Crescentic Osteotomy
A Three-Dimensional Computer Simulation

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Treatment of the symptomatic bunion deformity is a controversial and complex subject. There are more than 130 various surgical procedures that have been described to treat this common foot deformity. These procedures generally fall into one of two categories. There are those procedures that rely solely upon soft-tissue releases and then there are those that combine the soft-tissue releases with an osteotomy. Osteotomies have been described at the base of the first metatarsal,[9,11,16] the diaphysis, the distal portion of the first metatarsal,[5,7,21,23-25] and the proximal phalanx.[8,28] The basilar crescentic osteotomy of the first metatarsal combined with the appropriate soft-tissue surgery, is advocated as an excellent method for correcting wide metatarsus primus varus that often is associated with hallux valgus.[19,20]

There is little guidance for the operating surgeon in the exacting method needed for performing this osteotomy (Table 1).[15,20] The current recommendations are to perform the osteotomy in the metaphysis, the saw blade should be concave distal and at right angles to the metatarsal shaft, with no medial or lateral deviation. The diaphysis should be predrilled and the osteotomy should be fixed with either Steinmann pins, Kirschner wires, staples, or an interfragmentary screw. When the osteotomy is performed in the oblique plane, there is little to guide the surgeon as to the final three-dimensional orientation of the first metatarsal head.[19,20,26]

The literature has been addressed to the varus position of the first metatarsal and very exact methods.[27] The weight-bearing anterior-posterior roentgenogram is the standard by which many of the decisions are based when selecting bunionectomy procedure. There has been mention of hypermobility of the first metatarsal and pronation of the great toe, although little has been done to quantify these deformities. When an osteotomy has been performed that elevates the metatarsal head, transfer metatarsalgia will occur.[1,3,4,10] If rotation should occur that increases the pronation of the metatarsal head, then the deformity will be worsened. This study will provide the surgeon with an understanding of the flexibility that is afforded by the crescentic osteotomy in correcting this multiplanar deformity.

There has been much interest in using computer simulation to visualize deformities and fractures about the pelvis. There also has been a great deal of interest in the three-dimensional anatomy of the clubfoot. These three-dimensional computer simulations are performed on large, mainframe computers, which involve extensive software development. Also, these simulations generally are used to view the deformity. The computer simulations may be used in fabrication of custom implants or in modification of existing allografts. There has been little data published on three-dimensional simulations and osteotomies. The computer simulations on which this study has been based have all been performed on a microcomputer. A microcomputer is readily available to many practicing orthopedic surgeons.

METHODS

A model of the normal foot was constructed from serial CT sections spaced 3 mm apart. Serial sections were oriented normal to the plantar surface of the weight-bearing foot. An image analysis system (Data Translations, Marlborough, Massachu-

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Table 1. *Specific Guidelines for Performing the Crescentic Osteotomy**

1. Biplanar radiographic evaluation using weight-bearing anterior or posterior and sesamoid roentgenograms.
2. Distal soft-tissue reconstruction.
3. Excision of the medial eminence *following correction* of the intermetatarsal angle by the basilar osteotomy.
4. Directing the saw blade in a proximal to distal direction.
5. Directing the saw blade in a lateral to medial direction.
6. Distal translation of the metatarsal when there is significant shortening.

*New recommendations for performing the basilar crescentic osteotomy.

setts) using 256 gray levels was used to digitize the CT images. Bony surface contours were constructed from enhanced boundary gray level gradients. From the resulting cross-sectional areas, centroids were calculated, and the centroidal axes of the first and second metatarsal were determined by three-dimensional linear regression. An orthogonal, global-coordinate system, with the origin at the head of the first metatarsal (Fig. 1) was constructed, incorporating all serial sections. Subsequent computer-generated images of the foot (Fig. 2) were constructed using a three-dimensional computer-assisted design (CAD; Generic 3D, CA, Bothell, Washington) software package.

The crescentic osteotomy blade was modeled as a hemicylinder 2 cm in diameter. All osteotomies were simulated with a length of the first metatarsal as 66 mm, and the apex of the cutter oriented proximal and intersecting the X axis 1.5 cm distal to the first metatarsal head. Surgical corrections were such that the intermetatarsal angle was closed to 8 degrees.

The equations describing the crescentic osteotomy were determined as follows:

—A crescentic surface cut at a given orientation in the X-Y plane was modeled in the first metatarsal as described previously
—The distal segment of the first metatarsal then was rotated about the Y axis to obtain the desired surgical correction
—Rotations and translations then were made with respect to the X and Z axes such that the contact surfaces were maximized and the gap was minimized between the distal and proximal osteotomy surfaces

A saw kerf of zero (that is, identical radius of the curvature for the distal and proximal sections) was employed in this study, which resulted in a perfect mate between the osteotomy surfaces. This procedure resulted in a series of distal first metatarsal

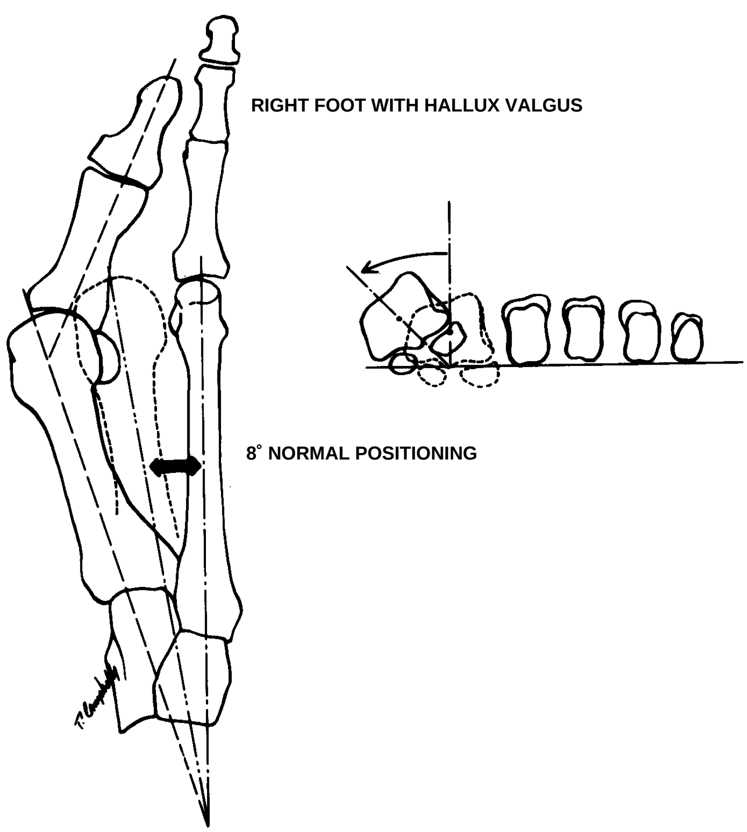

Figure 1. Representation of hallux valgus with a wide intermetatarsal angle and elevation and pronation of the first metatarsal head. The ghosted images demonstrate three dimensional final correction.

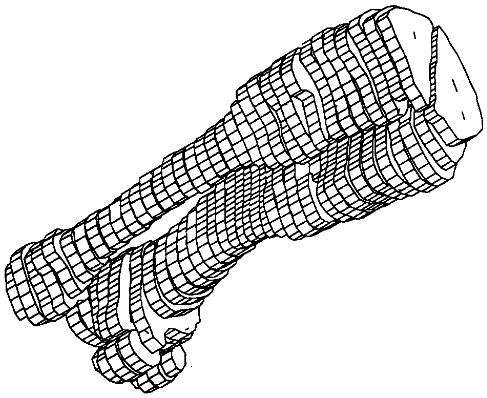

Figure 2. Three-dimensional reconstruction of the foot, generated from computerized tomographic images, obtained at 3-mm intervals.

orientations that varied as a function of the proximal - distal cutter angulation and surgical closure angle. Series approximation then was computed of the coupled rotations and translations. The resulting equations that were determined are as follows:

$$R(x) = {}^{1}/_{4}\,Cos(TR)\,{}^{1}/_{2} * {}^{1}/_{4}\,Tan(TC)\,{}^{1}/_{2} * {}^{1}/_{4} - TR\,{}^{1}/_{2}$$

$$R(z) = {}^{1}/_{4}\,Sin(TR) * Tan(TC) * \frac{TR\,{}^{1}/_{2}}{2}$$

$$T(x) = {}^{1}/_{4}\,Tan\,[R(z)] * \frac{Sin(TC)\,{}^{1}/_{2}}{{}^{1}/_{4}\,Cos[R(z)]}\;{}^{1}/_{2}$$

$$T(z) = -{}^{1}/_{4}\,Tan[R(x)] * \frac{Sin(TC)\,{}^{1}/_{2}}{({}^{1}/_{4})(2) * Cos[R(x)]\,{}^{1}/_{2}}$$

Where TR = the surgical base closure, TC = the cutter angulation relative to the Z axis, R(x) = the coupled X-axis rotation (pronation-supination), R(z) = the coupled Z-axis rotation (elevation-depression) T(x) = the coupled X-axis translation of the osteotomy centroid, T(z) = the coupled Z-axis translation of the osteotomy centroid

Medial and lateral deviations of the cutter were modeled by transforming the above equations from the cutter—X plane to the global X- Y plane.

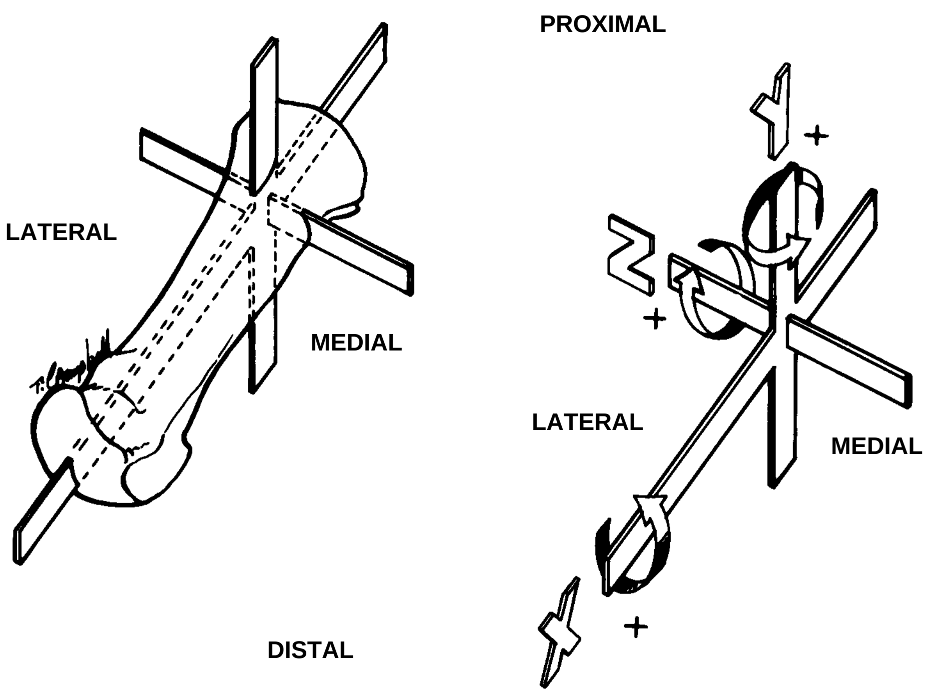

Figure 3. Demonstrates the axis system with the X axis being the long axis of the first metatarsal, the Y axis being the anterior to posterior axis, and the Z axis being the medial to lateral axis. Note that rotation about these axes may be positive or negative.

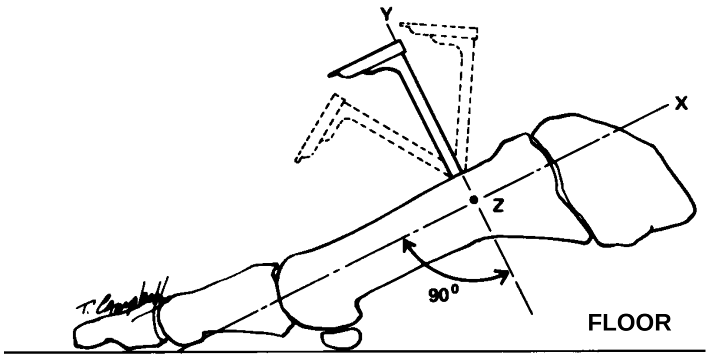

Figure 4. Demonstration that the saw blade may be directed at 90 degrees to the shaft of the first metatarsal or directed proximally or distally.

RESULTS

There are an infinite number of possible osteotomy simulations. Three basic types of simulations will be presented with accompanying graphs (Figs. 1 , 3 to 5).

When the saw blade is oriented at a right angle to the long axis with no medial or lateral deviation, only shortening of the metatarsal occurs as the intermetatarsal angle is closed (Fig. 6). The greater the correction, the more the shortening.

By directing the saw blade proximally or distally, and keeping the blade at 90 degrees to the long axis, the metatarsal head will pronate or supinate as the intermetatarsal angle is closed (Figs. 7 and 8 and Table 2).

Anterior or posterior, metatarsal head deflection occurs with medial or lateral directioning of the saw blade (Figs. 9 and 10 and Table 3). As in the other simulations, the length of the metatarsal will decrease proportionately with the amount of closure of the intermetatarsal angle.

Multiplanar changes will create dramatic changes in the metatarsal head's final position. An exaggerated scenario would be as follows: the saw blade is oriented 45 degrees proximally and 45 degrees laterally (Fig. 11). When a 15-degree closure is accomplished, the metatarsal shaft shortens by 4.3 mm, the head elevates 15.4 mm and pronates 26 degrees. This is an unlikely surgical event, but it dramatizes the potential alterations that would not be apparent on an anterior-posterior roentgenogram.

DISCUSSION

Treatment of the bunion deformity is a complex and controversial subject. Medial deviation and elevation of the first metatarsal head are commonly associated with hallux valgus. Clinically, these are evidenced by a widened forefoot and marked callus formation under the lesser metatarsal heads. This increased callusing is a result of decreased weight bearing of the first ray and increased weight bearing by the lesser metatarsals. As the first metatarsal deviates medially, it will also elevate. This occurs because of the shape of the

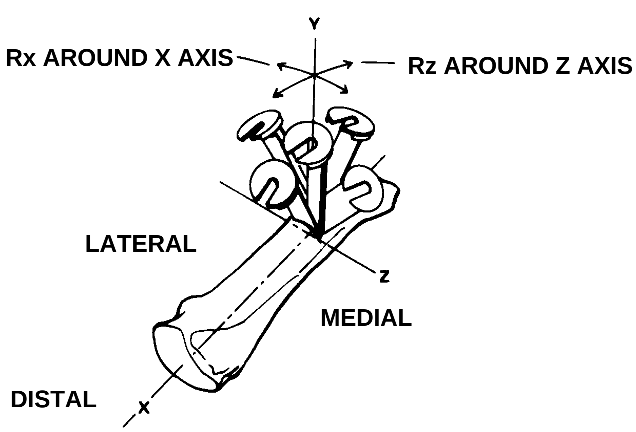

Figure 5. Multiplanar changes may occur with directing the saw blade either medial to lateral or distal to proximal directions.

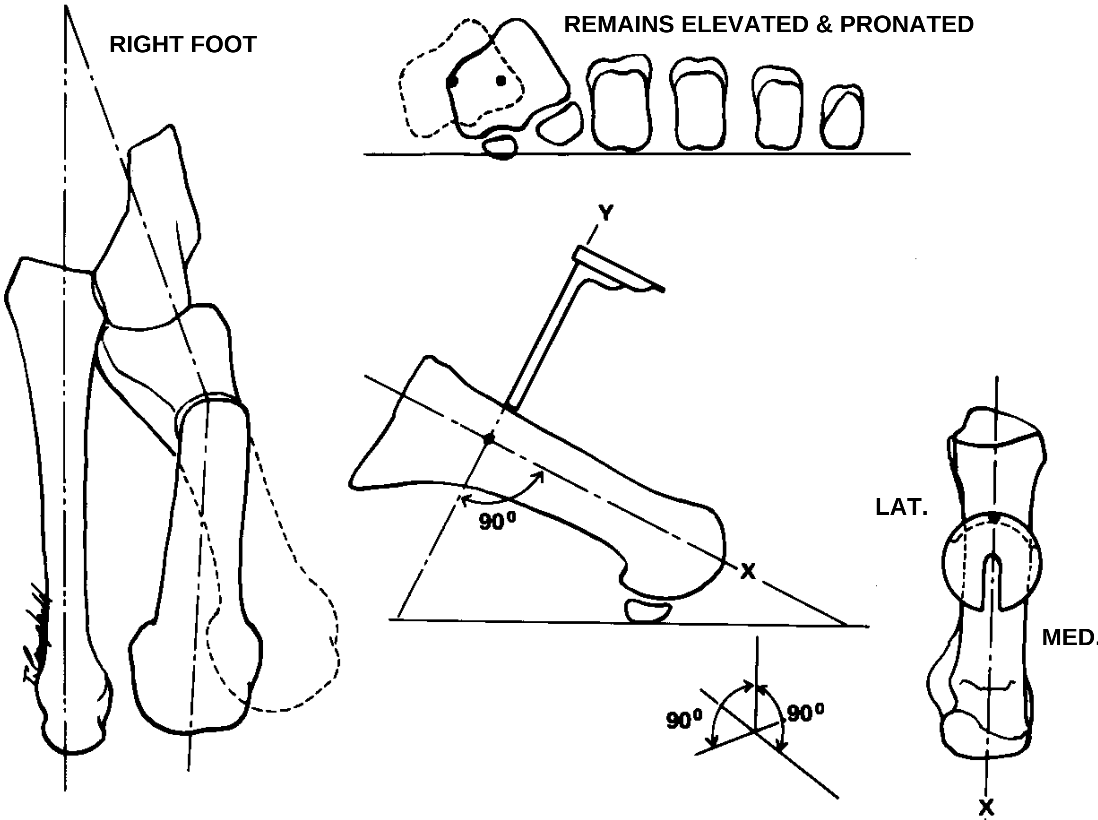

Figure 6. Graphic demonstration of Simulation 1. When the osteotomy is 90 degrees in both the proximal to distal direction and medial to lateral direction, then when closure of the intermetatarsal angle occurs, the head will remain at the same anterior-posterior level and no rotational changes will occur.

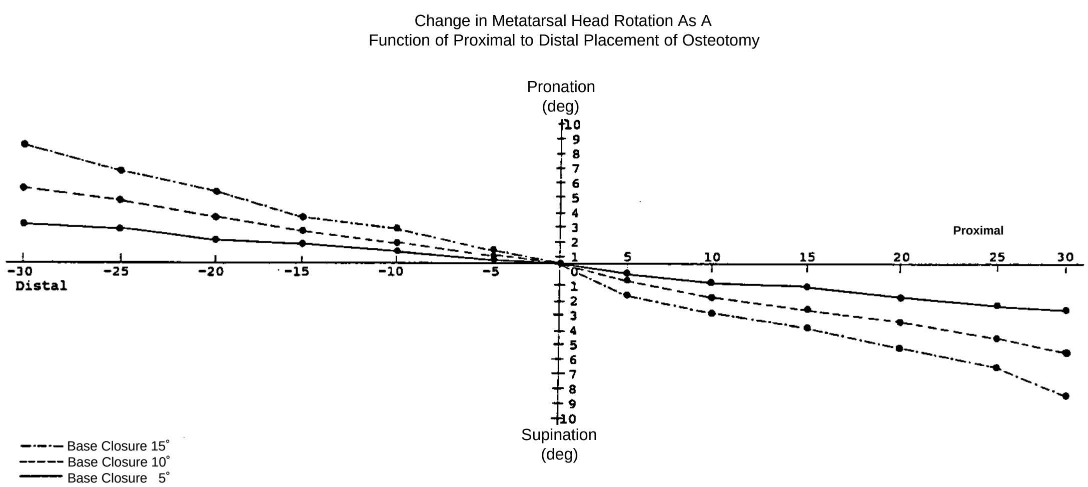

Figure 7. This is a graphic representation of Table 2. When the saw blade is directed proximally to distally, supination of the metatarsal head occurs. When the saw blade is directed distally to proximally, pronation of the metatarsal head occurs when the intermetatarsal angle is closed.

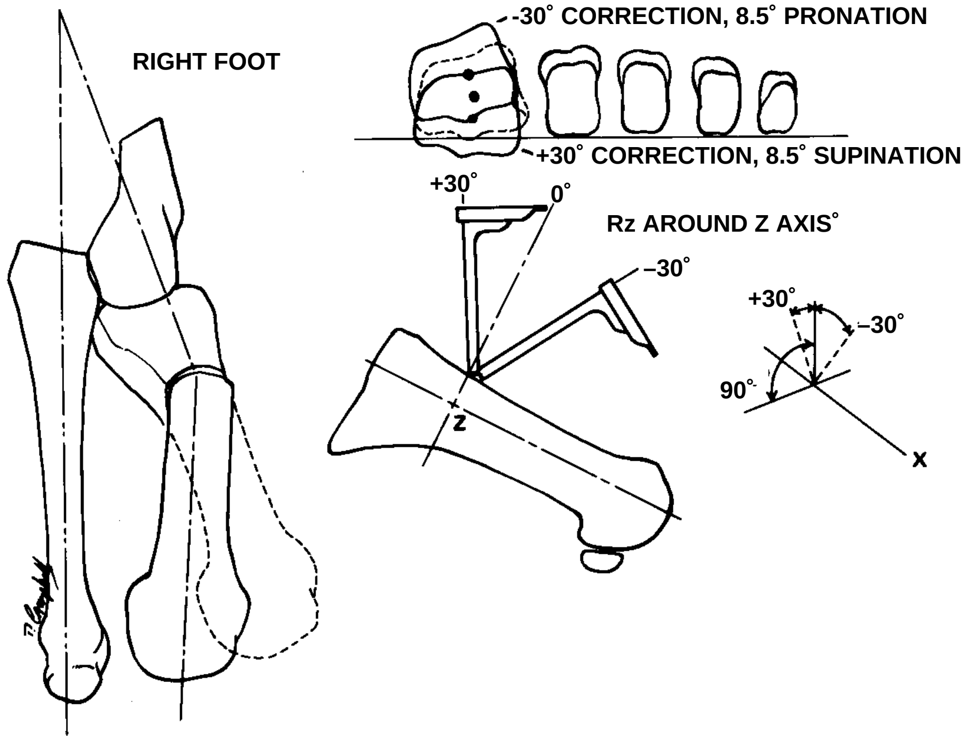

Figure 8. When the saw blade is directed distally to proximally then as the inter-metatarsal angle is corrected pronation will occur. When the saw blade is directed proximally to distally then supination of the metatarsal head occurs. Therefore, it would be most desirable to correct the pronated metatarsal head by directing the saw blade in a proximal to distal direction.

first metatarsocuneiform joint. The second metatarsocuneiform joint is a stable articulation and has little motion in the dorsoplantar or anterior-posterior planes. When sufficient forces are transferred away from the first metatarsal head, a symptom complex occurs. There is pain that is secondary to bursitis, synovitis, interdigital neuritis, or possibly stress fracture. One of the most important aspects of bunion correction is the return of normal weight bearing to the first ray. The pronation of the toe is secondary to the tethering of the proximal phalanx by the conjoined tendon and by rotation of the metatarsal head as it elevates The pronation may be quantified by measuring the plane of a nail plate . The plane of the lesser toenails would serve as the reference point. The weight-bearing, sesamoid roentgenogram is used to determine the elevation of the metatarsal head. This roentgenogram is simple to obtain with a commercially available stand.[17]

A well-recognized cause of failure after bunion surgery is elevation of the first metatarsal head such that it no longer will participate in normal weight-bearing function. Therefore, it is important to determine the preoperative head elevation. If the osteotomy is performed in such a fashion that an already-existing metatarsal head is elevated further, then failure will result. The anterior-posterior roentgenogram will not demonstrate this position of the metatarsal head. In fact, an excellent correction often is assumed when this roentgenogram is relied on solely. The weight-bearing lateral roentgenogram of the foot is not used to determine the head position because the overlap of the metatarsal heads makes it difficult to discern exact points. We would recommend using a weight-bearing, sesamoid roentgenogram in addition to the weight-bearing anterior - posterior roentgenogram as the standard radiographic evaluation of those undergoing surgical correction of the bunion deformity.

The ideal bunionectomy will not create mechanical imbalances in the foot secondary to a change in length of the first metatarsal following an osteotomy. When shortening of the first metatarsal occurs, it does not effectively participate in weight bearing. This is a well-known cause of transfer metatarsalgia and is seen in its most severe form

*Table 4. Changes in Metatarsal Length and Head Position as a Function of Proximal to Distal Placement of Osteotomy**

Cut Angle Placement	BASE OF [illegible]—15°			BASE OF [illegible]—10°			BASE OF [illegible]—5°		
	Change in Length (mm)	Elevation (+) Depression (−)	Supination (−) Pronation (+)	Change in Length (mm)	Elevation (+) Depression (−)	Supination (−) Pronation (+)	Change in Length (mm)	Elevation (+) Depression (−)	Supination (−) Pronation (+)
+30	−1.57	−0.76 mm	−9.36	−0.62	−0.57 mm	−5.69	−0.16	−0.09 mm	−2.97
+25	−1.59	−0.62 mm	−6.75	−0.62	−0.49 mm	−4.59	−0.16	−0.07 mm	−2.32
+20	−1.59	−0.49 mm	−5.27	−0.62	−0.22 mm	−3.59	−0.16	−0.05 mm	−1.91
+15	−1.59	−0.36 mm	−3.99	−0.63	−0.16 mm	−2.64	−0.16	−0.04 mm	−1.33
+10	−1.40	−0.23 mm	−2.55	−0.63	−0.11 mm	−1.74	−0.16	−0.02 mm	−0.97
+ 5	−1.40	−0.11 mm	−1.26	−0.63	−0.06 mm	−0.96	−0.16	−0.01 mm	−0.45
0	−1.40	0	0	−0.63	0	0	−0.16	0	0
−5	−1.40	+0.11 mm	+1.26	−0.63	−0.06 mm	+0.96	−0.16	+0.01 mm	+0.45
−10	−1.40	+0.23 mm	+2.55	−0.63	−0.11 mm	+1.74	−0.16	+0.02 mm	+0.97
−15	−1.59	+0.36 mm	+3.99	−0.63	−0.16 mm	+2.64	−0.16	+0.04 mm	+1.33
−20	−1.59	+0.49 mm	+5.27	−0.62	−0.22 mm	+3.59	−0.16	+0.05 mm	+1.91
−25	−1.59	+0.62 mm	+6.75	−0.62	−0.49 mm	+4.59	−0.16	+0.07 mm	+2.32
−30	−1.57	+0.76 mm	+9.36	−0.62	−0.57 mm	+5.69	−0.16	+0.09 mm	+2.97

*Computer data from proximal or distal direction of the saw blade. The correction angle corresponds to the amount of closure of the [illegible] angle. For example, [illegible] angle of 4° from a perpendicular 15° [illegible] angle would produce a 15° [illegible] correction angle. A proximal-to-distal direction will [illegible] the head, while distal-to-proximal direction [illegible] the head when the [illegible] angle is closed.

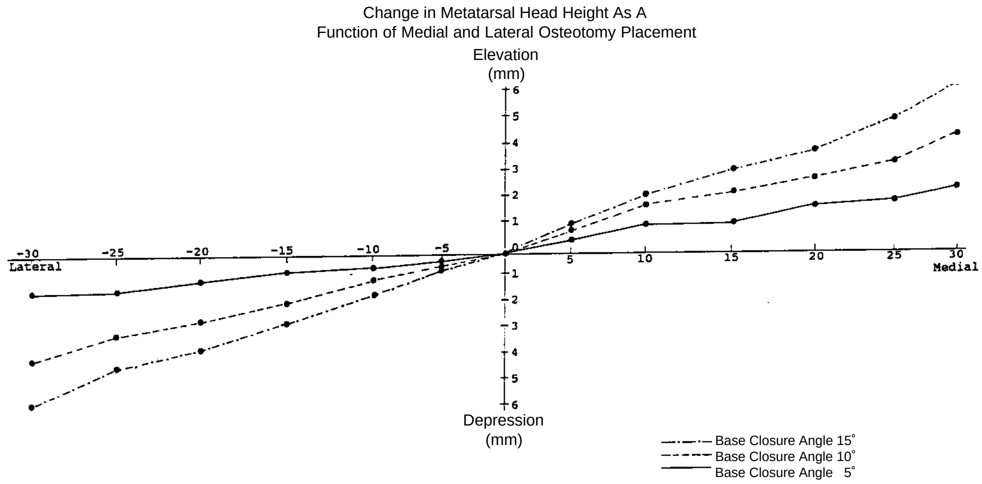

Figure 9. This is a graphic representation of Table 3. When the saw blade is directed in a lateral to medial direction, depression of the metatarsal head occurs. When the saw blade is directed in a medial to lateral direction, elevation of the first metatarsal head occurs.

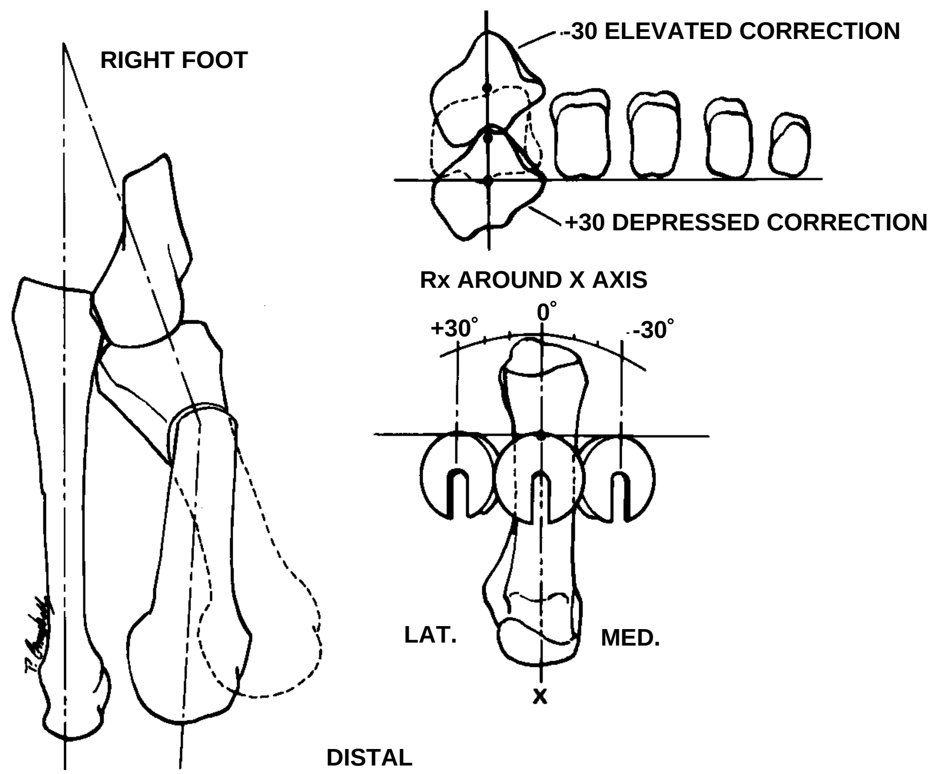

Figure 10. Graphic demonstration of directing the saw blade medially or laterally while maintaining the saw blade at 90 degrees to the long axis of the first metatarsal. When the intermetatarsal angle is corrected, then either elevation will occur when the saw blade is directed medially to laterally or depression of the metatarsal head will occur when directed laterally to medially.

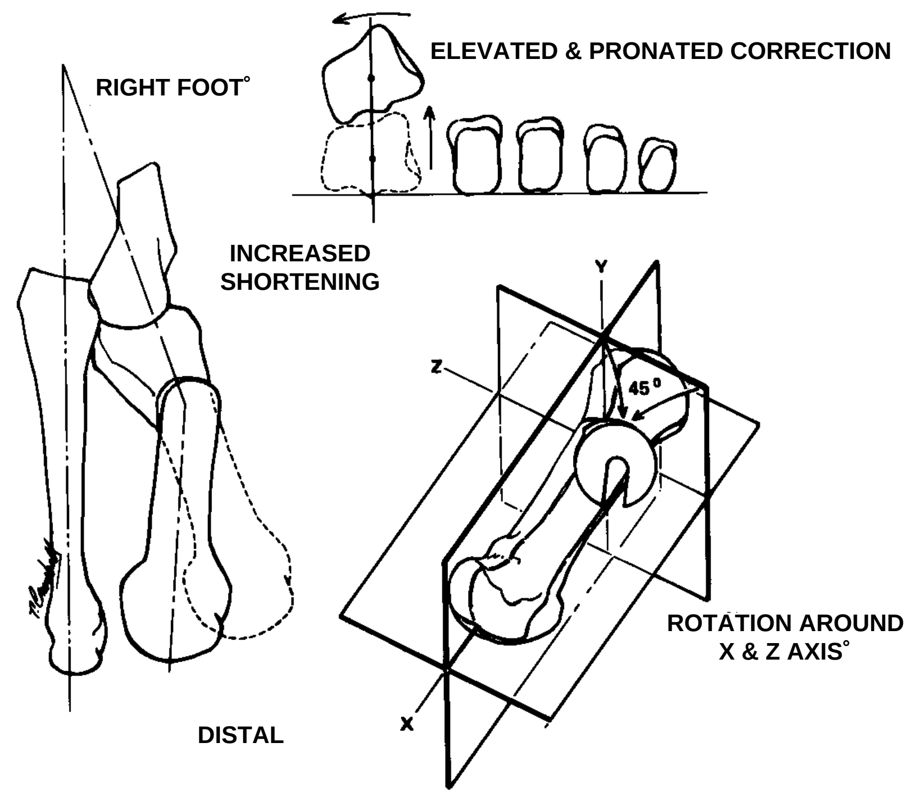

Figure 11 The saw blade is now directed 45 degrees distal to proximal, 45 degrees medial to lateral. When the intermetatarsal angle is closed then severe elevation and pronation of the metatarsal head will occur.

following the Mayo bunionectomy. Another possible sequela following osteotomy of the first metatarsal is lengthening. This can occur with an opening-wedge osteotomy. Two events have been noted following the lengthening of the first metatarsal. The first is that there may be an increase in the joint reaction force at the first metatarsophalangeal joint, leading to hallux rigidus. The second possible event is bowstringing of the soft tissue which may lead to a premature recurrence of the deformity. It is therefore desirable to maintain the neutral length of the first metatarsal. Shortening following the basilar crescentic osteotomy occurs for two reasons. First, there is loss of approximately 2 mm of bone that has been created by the saw blade. Second, shortening occurs with closure of the intermetatarsal angle. If a great deal of correction is needed and the osteotomy has been performed in a severely oblique fashion, then a great deal of shortening can occur. In the exaggerated 45-degree distal-to-proximal and medial-to-lateral saw blade orientation, 6.3 mm of shortening occurs. It is therefore recommended that, if a great deal of shortening is anticipated, then distal translation of the distal fragment may be necessary to return the metatarsal to its original length. This translation creates a decreased amount of bone contact at the osteotomy site that otherwise might have caused instability, delayed union, or nonunion. It also is recommended that the obliquity be made in a proximal-to-distal angle. As previously noted, this orientation would supinate the first metatarsal head as opposed to a distal-to-proximal orientation, which would pronate the first metatarsal head.

Currently, it is recommended that the medial eminence of the first metatarsal head be excised before performing the basilar osteotomy. If the osteotomy has been performed at an oblique angle, then head rotation occurs as the intermetatarsal angle is closed. A previously well-trimmed metatarsal head will no longer exist if the rotation is significant. Therefore, trimming of the medial eminence should be performed after the basilar osteotomy has been completed. The osteotomy should be stabilized with either wire or screw fixation. It also is recommended that a motorized saw be used to excise the medial eminence because an osteotome may disrupt the basilar osteotomy's fixation.

The literature on three-dimensional orthopedic reconstructions typically has fallen into these areas: graphic representation of complex anatomic

Table 3. Change in Mandibular Length and Pivot Position as a Function of Medial and Lateral Placement of Osteotomy*

Cutter Position (Medial)	BASIC MANDIBULAR ANGLE—5° Change in Length (mm)	Elevation (+) Depression (−)	Supination (−) Pronation (+)	BASIC MANDIBULAR ANGLE—10° Change in Length (mm)	Elevation (+) Depression (−)	Supination (−) Pronation (+)	BASIC MANDIBULAR ANGLE—5° Change in Length (mm)	Elevation (+) Depression (−)	Supination (−) Pronation (+)
+30	−1.60	+5.29 mm	0	−0.90	+4.05 mm	0	−0.25	+2.14	0
+25	−1.59	+4.77 mm	0	−0.76	+3.30 mm	0	−0.25	+1.91	0
+20	−1.59	+3.96 mm	0	−0.76	+2.57 mm	0	−0.16	+1.62	0
+15	−1.59	+2.92 mm	0	−0.76	+2.02 mm	0	−0.16	+0.92	0
+10	−1.40	+1.94 mm	0	−0.65	+1.21 mm	0	−0.16	+0.62	0
+5	−1.40	+0.96 mm	0	−0.62	+0.62 mm	0	−0.16	+0.31	0
0	−1.40	0	0	−0.65	0	0	−0.16	0	0
−5	−1.40	−0.96 mm	0	−0.65	−0.62 mm	0	−0.16	−0.31	0
−10	−1.40	−1.94 mm	0	−0.65	−1.21 mm	0	−0.16	−0.62	0
−15	−1.59	−2.92 mm	0	−0.76	−2.02 mm	0	−0.16	−0.92	0
−20	−1.59	−3.96 mm	0	−0.76	−2.57 mm	0	−0.16	−1.62	0
−25	−1.59	−4.77 mm	0	−0.76	−3.30 mm	0	−0.25	−1.91	0
−30	−1.60	−5.29 mm	0	−0.90	−4.05 mm	0	−0.25	−2.14	0

*Computer data from medial or lateral direction of the saw blade. When the saw blade direction is medial to lateral, then elevation of the [illegible] head occurs as the [illegible] angle is closed. When the saw blade is directed lateral to medial, then depression of the [illegible] head occurs.

structures, fabrication of complex implants and custom implants, and computer simulation of osteotomies.[2,6,13,14,18,22,29,30,31] Prior to this study, there was little information that was applicable to simulation of osteotomies for the practicing orthopedic surgeon. The computer simulation program that has been formulated can be used on a microcomputer, and is readily available to most orthopedic surgeons. This will allow an added avenue of precision when performing this osteotomy. The basilar crescentic osteotomy of the first metatarsal is a complex osteotomy that requires much in the way of preoperative planning.

SUMMARY

A three-dimensional computer simulation of the basilar crescentic osteotomy has been presented. The bunion deformity consists of hallux valgus, an increased first and second intermetatarsal angle, pronation of the great toe, and elevation of the first metatarsal head. Every foot is different and some may have more or less of each of the above noted components. Because the deformity is multiplanar, at least two roentgenograms are needed to evaluate the deformity. The weight-bearing, anterior-posterior roentgenogram is the principle radiograph used in preoperative planning. The use of a weight-bearing, sesamoid roentgenogram is recommended to quantify the anterior-posterior deflection and rotation of the first metatarsal head. A computer model (based on a cylinder) of the first metatarsal has been formulated.

The osteotomy then was performed in a variety of scenarios in order to simulate the surgical correction. A great deal of flexibility is afforded by this osteotomy. The surgeon needs to be aware of the coupled motions that occur. That is, closure of the intermetatarsal angle may also cause head rotation, depression, or elevation. If the osteotomy is performed in an oblique multiplanar direction, then it is possible for the metatarsal head to elevate, pronate, and significantly shorten as the intermetatarsal angle is closed. If this scenario should occur, a poor surgical outcome will result. Excision of the medial eminence is recommended after the osteotomy has been completed and secured with stable fixation because of these rotational changes. The basilar crescentic osteotomy is an excellent method for correction of a marked metatarsus primus varus. It is important to pay close attention to a variety of anatomic considerations. The osteotomy must not be made in the diaphysis because of potential nonunion. There should be little dissection of the periosteum because of possible delayed union. As in any bunion surgery, it is essential to perform an adequate, distal, soft-tissue repair. Three dimensional preoperative planning is essential in obtaining correction of all components of a bunion. Specific guidelines, based on a three-dimensional computer model, are now available. An interactive computer program also is available to aid the surgeon in preoperative planning. We hope there will be better understanding of this technically difficult but highly versatile osteotomy.

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