Quantitative Geometry of the Distal First Metatarsal Axis Guide Concept

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The axis guide concept was introduced as an intra-operative tool to assist the surgeon in estimating the transverse and sagittal plane motion of the capital fragment during lateral transposition of a distal first metatarsal osteotomy for the surgical correction of the hallux abductovalgus deformity. The intention of this investigation was an attempt to provide a quantitative estimate to the previously qualitative axis guide concept. The Law of Cosines was applied to the morphologic characteristics of a sawbone first metatarsal model. Measurements were calculated based on 1/4, 1/3, and 1/2 lateral transpositions of the capital fragment of the first metatarsal. An average of all measurements resulted in a change of the absolute first metatarsal position of 1mm for every 10° change in axis guide orientation in both the transverse and sagittal planes. It is the authors' hope that this data can be used to further understanding of the perioperative evaluation and surgical correction of the hallux abductovalgus deformity.

Key words: Distal first metatarsal osteotomy, hallux abductovalgus, axis guide, geometry

The axis guide concept was first introduced as an intra-operative tool to assist the surgeon in estimating the transverse and sagittal plane motion of the capital fragment during lateral transposition of a distal first metatarsal osteotomy for the surgical correction of the hallux abductovalgus deformity.[1,2]

A temporary Kirschner wire (K-wire) is inserted in a medial to lateral direction through the center of the first metatarsal head and aimed distally or proximally (to achieve lengthening or shortening of the capital fragment respectively), and dorsally or plantarly (to achieve dorsiflexion or plantarflexion of the capital fragment respectively). An osteotomy is then performed with the saw blade orientated parallel to the axis guide.

Previous works have established the importance of appreciating a long[3-12] , short[3,4,8,13,14], or elevated[13,6,8,9,15] first metatarsal as a contributing deformity in the pre-operative evaluation of hallux abductovalgus.

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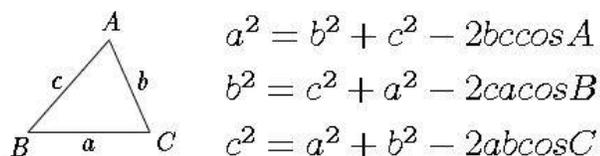[2] Private Practice, Vienna, Virginia, USA

$$a^2 = b^2 + c^2 - 2bc\cos A$$
$$b^2 = c^2 + a^2 - 2ca\cos B$$
$$c^2 = a^2 + b^2 - 2ab\cos C$$

Figure 1 Law of Cosines.

Specific measurements, such as Hardy and Clapham's tangential lines[16] and the Seiberg index[17], have been introduced to quantify how "long", "short" or "elevated" the first metatarsal is relative to the remainder of the lesser metatarsal parabola.[18,19] However, the axis guide concept is a qualitative estimate, with the relative position of the temporary K-wire allowing the surgeon to generally correct for lengthening, shortening, dorsiflexion, or plantarflexion of the first metatarsal. It does not provide a quantitative measurement for correction.

Geometric principles have been applied to distal first metatarsal and general forefoot surgeries in the past[20-31], but the intended emphasis of this investigation is an attempt to provide a quantitative estimate to the previously qualitative axis guide concept.

Methods

The Law of Cosines was applied to the morphologic characteristics of a sawbone first metatarsal model. (Figs. 1 and 2) Several variables and limitations affect the mathematics when utilizing this technique. The variables include only the relative transverse plane position of the axis guide, the relative sagittal plane position of the axis guide, and the extent of lateral translation of the capital fragment. In terms of limitations, it is important to appreciate that all measurements represent absolute changes to the first metatarsal, and are not measured directly relative to the remainder of the lesser metatarsal parabola.
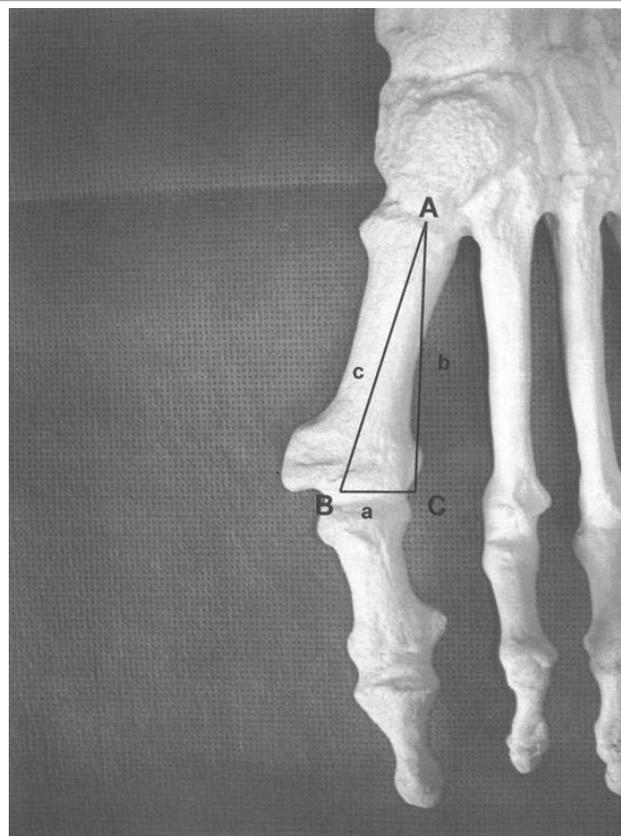

Figure 2 The law of cosines applied to a sawbones model. In this model, *c* represents the initial first metatarsal length, *b* represents the post-transposition first metatarsal length, and *a* represents a parallel to the axis of translation (axis guide).

Absolute axis guide positions relative to the first metatarsal in the transverse and sagittal planes can be correctly measured and effectively generalized to all hallux abductovalgus deformities. (Fig. 3)

However, relative axis guide positions, such as an axis guide that is perpendicular to the second metatarsal shaft (Figure 4A) or aimed at the third metatarsal head (Figure 4B), are additionally dependant on the intermetatarsal angle and metatarsal length pattern. Therefore, while it can be correctly measured in this sawbones model, the results cannot be generalized to all hallux abductovalgus deformities.
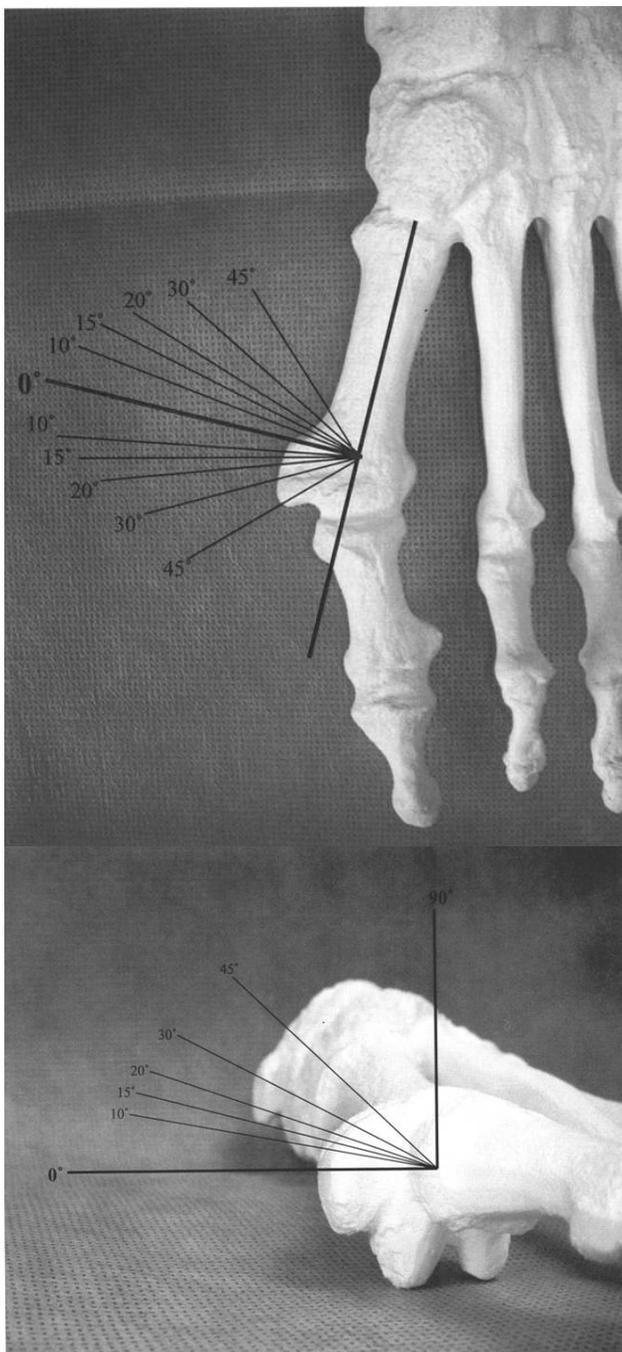
Figure 3   Absolute axis guide orientations measured directly from the first metatarsal represent absolute changes to the first metatarsal length and declination. The only variables in this situation are the transverse plane position of the axis guide, the sagittal plane position of the axis guide, and the extent of lateral translation of the capital fragment. These measurements can be correctly determined and effectively generalized to all hallux abductovalgus deformities.

Specific for this study, measurements were calculated based on 1/4, 1/3, and 1/2 lateral transpositions of the capital fragment of the first metatarsal.

Results

Tables 1 and 2 provide data based on a 1/4 capital fragment lateral transposition. The average change in transverse plane axis guide orientation is 15.5° for every 1mm change in absolute first metatarsal length based on the measured calculations (or 0.6mm for each 10° change).   The average change in sagittal plane axis guide orientation is 11.4° for every 1mm change in absolute first metatarsal sagittal plane position based on the measured calculations (or 0.9mm for each 10° change).

Tables 3 and 4 provide data based on a 1/3 capital fragment lateral transposition. The average change in transverse plane axis guide orientation is 13.2° for every 1mm change in absolute first metatarsal length based on the measured calculations (or 0.8mm for each 10° change).   The average change in sagittal plane axis guide orientation is 8.7° for every 1mm change in absolute first metatarsal sagittal plane position based on the measured calculations (or 1.2mm for each 10° change).

Tables 5 and 6 provide data based on a 1/2 capital fragment lateral transposition. The average change in transverse plane axis guide orientation is 10.7° for every 1mm change in absolute first metatarsal length based on the measured calculations (or 1.1mm for each 10° change).   The average change in sagittal plane axis guide orientation is 6.0° for every 1mm change in absolute first metatarsal sagittal plane position based on the measured calculations (or 0.9mm for each 10° change).
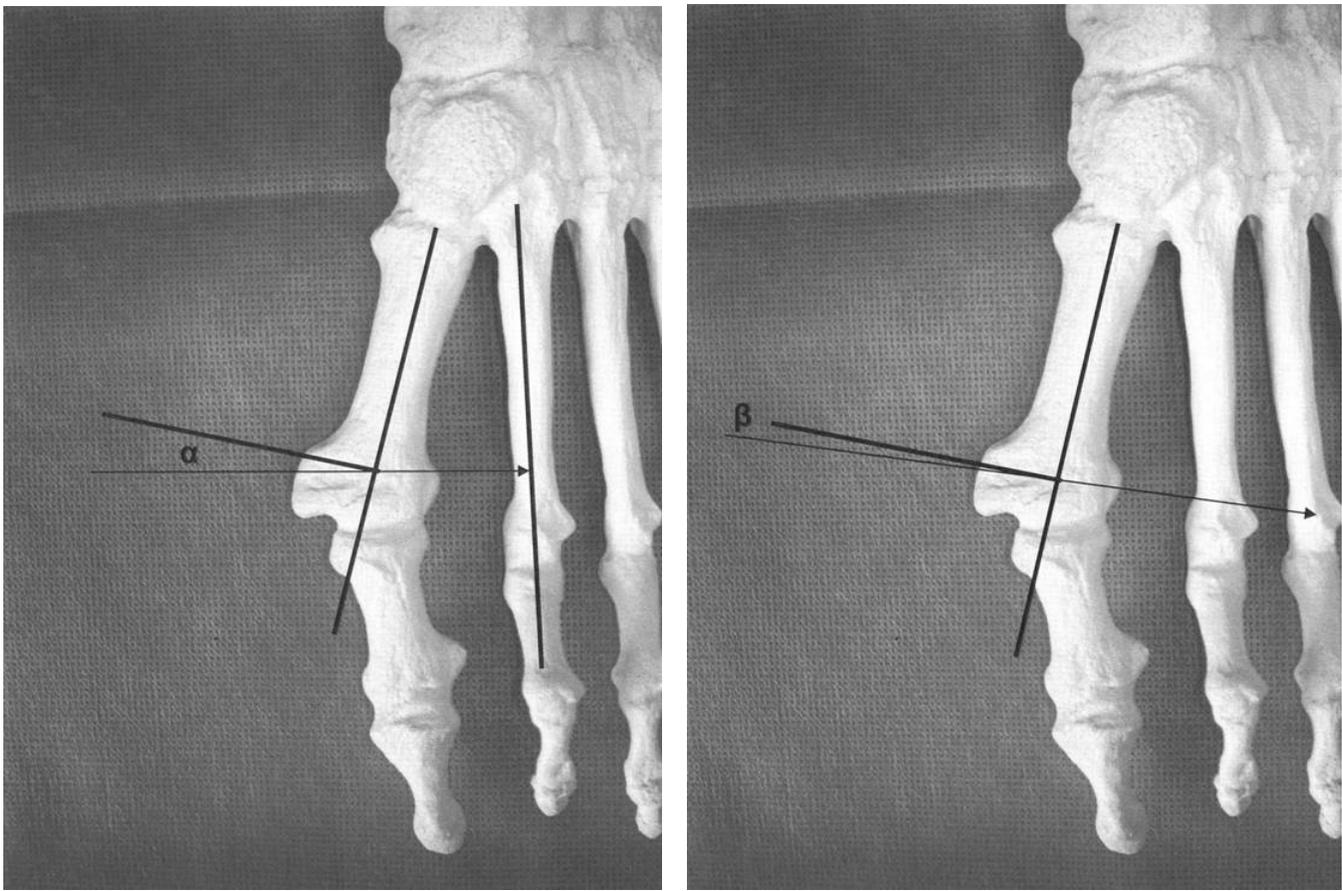
Figure 4AB   Relative axis guide orientations, here demonstrated as perpendicular to the 2nd metatarsal shaft (A) and aimed at the third metatarsal head (B), are dependant on the intermetatarsal angle and metatarsal length pattern in addition to the transverse plane position of the axis guide and the extent of lateral translation of the capital fragment. Although these measurements can be correctly determined in this model (α=12°; β=4°), the results cannot be generalized to all hallux abductovalgus deformities.

An average of all transverse plane measurements (with a range from1/4-1/2 capital fragment lateral transposition and 0-63.8° of axis guide orientation) results in a change of the transverse plane axis guide orientation of 13.1° for every 1mm change in absolute first metatarsal length (or 0.8mm for each 10° change). An average of all sagittal plane measurements (with a range from 1/4-1/2 capital fragment lateral transposition and 0-45° of axis guide orientation) results in a change of the sagittal plane axis guide orientation of 8.7° for every 1mm change in first metatarsal sagittal plane position (or 1.3mm for each 10° change).

An average of all measurements (transverse and sagittal planes) results in a change in the axis guide orientation of 11.2° for every 1mm change in first metatarsal position (or 1.0mm for each 10° change).

Results:

Δ in length	Hand Position	Hand Position	Δ in length
1mm	15.1°	0°	+0.2mm
2mm	28.4°	10°	0.6mm
3mm	43.5°	15°	1.0mm
4mm	63.8°	30°	2.1mm
5mm	Undefined	45°	3.1mm
		⊥ to the 2nd metatarsal	-0.8mm
		Directed at the 3rd met head	-0.1mm

Table 1 Transverse Plane Motion Based on a 1/4 Lateral Translation

The average change in transverse plane axis guide orientation is 15.5° for every 1mm change of absolute first metatarsal length based on these specific calculations of a 1/4 capital fragment lateral translation (or 0.6mm for each 10° change).

Δ in height	Hand Position	Hand Position	Δ in height
1mm	12.5°	0°	0.0mm
2mm	24.0°	10°	0.8mm
3mm	33.7°	15°	1.2mm
4mm	41.6°	30°	2.6mm
5mm	48.0°	45°	4.5mm

Table 2 Sagittal Plane Motion Based on a 1/4 Lateral Translation

The average change in sagittal plane axis guide orientation is 11.4° for every 1mm change of absolute first metatarsal sagittal plane position based on these specific calculations of a 1/4 capital fragment lateral translation (or 0.9mm for each 10° change).

Δ in length	Hand Position	Hand Position	Δ in length
1mm	12.6°	0°	+0.3mm
2mm	22.3°	10°	0.7mm
3mm	32.7°	15°	1.3mm
4mm	44.1°	30°	2.8mm
5mm	58.2°	45°	4.1mm
		⊥ to the 2nd metatarsal	-0.9mm
		Directed at the 3rd met head	-0.1mm

Table 3 Transverse Plane Motion Based on a 1/3 Lateral Translation

The average change in transverse plane axis guide orientation is 13.2° for every 1mm change of absolute first metatarsal length based on these specific calculations of a 1/3 capital fragment lateral translation (or 0.8mm for each 10° change).

Δ in length	Hand Position	Hand Position	Δ in length
1mm	9.5°	0°	0.0mm
2mm	18.4°	10°	1.1mm
3mm	26.6°	15°	1.6mm
4mm	33.7°	30°	3.5mm
5mm	39.8°	45°	6.0mm

Table 4 Sagittal Plane Motion Based on a 1/3 Lateral Translation

The average change in sagittal plane axis guide orientation is 8.7° for every 1mm change of absolute first metatarsal sagittal plane position based on these specific calculations of a 1/3 capital fragment lateral translation (or 1.2mm for each 10° change).

Δ in length	Hand Position	Hand Position	Δ in length
1mm	10.9°	0°	+0.7mm
2mm	17.3°	10°	0.9mm
3mm	23.8°	15°	1.6mm
4mm	30.5°	30°	3.9mm
5mm	37.6°	45°	6.0mm
		⊥ to the 2nd metatarsal	-1.2mm
		Directed at the 3rd met head	-0.1mm

Table 5 Transverse Plane Motion Based on a 1/2 Lateral Translation

The average change in transverse plane axis guide orientation is 10.7° for every 1mm change of absolute first metatarsal length based on these specific calculations of a 1/2 capital fragment lateral translation (or 1.1mm for each 10° change).

Δ in length	Hand Position	Hand Position	Δ in length
1mm	6.3°	0°	0.0mm
2mm	12.5°	10°	1.6mm
3mm	18.4°	15°	2.4mm
4mm	24.0°	30°	5.2mm
5mm	29.1°	45°	9.0mm

Table 6 Sagittal Plane Motion Based on a 1/2 Lateral Translation

The average change in sagittal plane axis guide orientation is 6.0° for every 1mm change of absolute first metatarsal sagittal plane position based on these specific calculations of a 1/2 capital fragment lateral translation (or 1.7mm for each 10° change).

Discussion

This is proposed to be a theoretical exercise, rather than a study of functional outcomes. Just as the original axis guide concept was introduced to assist the surgeon in estimating capital fragment movement, this study only intends to add a quantitative measurement to this estimation. Two clinically relevant points may be taken from these findings. The first is that an average of all measurements results in approximately 1mm of metatarsal positional change per 10° of axis guide orientation change.

If a surgeon pre-operatively quantifies how long, short, dorsiflexed or plantarflexed the first metatarsal is relative to the lesser metatarsal parabola, then they may choose to use this quantified estimate during their surgical deformity correction.

The second clinical point is that the analyses indicate that a relatively wide range of hand positions result in relatively small changes to the metatarsal length and sagittal plane position. Put simply, even if a surgeon is not completely satisfied with the axis guide orientation prior to the osteotomy, a small change of the axis guide position is unlikely to result in a significant clinical change to the metatarsal position. While certainly there may be a difference between an axis guide orientated 60° plantar versus one aimed 20° plantar, there probably isn't a difference between one aimed 25° compared to 20°.

It is important to note that the authors make no claims of clinical outcomes based on millimeters of positional change. It is also important to note that the authors make no attempt to correct for shortening that will occur as a result of the osteotomy itself, although this is assumed to be equal and independent of the axis guide position.

It is the authors' hope that this data will be utilized to further understand the perioperative evaluation and surgical correction of the hallux abductovalgus deformity.

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