Treatment of Tibial Malunions: Characterization by a Graphical Method

Introduction

If ever an ounce of prevention was worth a pound of cure, it would be in achieving and maintaining accurate fracture reduction. Remembering the trauma of the original fracture, there is usually a significant problem with pain, function or cosmesis before a patient would present for consideration of malunion correction.

Whereas the need to treat a tibial nonunion is usually clear, the decisions of whether to divide the tibia and how to stabilize the fragments in the name of improving the anatomic elements of alignment, length and rotation are usually more difficult. Historical guidelines suggest 5 degrees in the coronal plane and 10 degrees in the sagittal plane as upper limits of malalignment. Some mild deformities seem to be better tolerated than others. External rotation of the tibia does not pose the same immediate problem with ambulation as internal rotation. The increased varus play in the subtalar joint can partially ameliorate a supramalleolar valgus deformity. Although as surgeons we strive to reduce and maintain fractures within these limits, there must be very careful consideration before surgically correcting an established malunion at these threshold values. The symptoms, age, activity level, general medical condition of the patient, and condition of the tibia must be considered. In some cases, protracted healing as a result of multiple comorbidities led to the original malunion. Serious initial problems with soft tissue coverage and/or infection may have also contributed to the malunion by limiting the type and zone of fixation. What will be different the second time around after the fracture is recreated? The best healing time in adults is 3-4.5 months. Are the benefits of improved alignment worth this second period of healing following general anesthetic?

Compensated Deformities

In the nondisplaced or anatomic position the mechanical axis passes thru the center of the ankle. **(Fig. 1 A)** In **figures 1 B** and **C** the distal fragment is in 20° varus. In **figure 1 B** the mechanical axis still passes thru the center of the ankle and is compensated. Although the angular deformity in **figure 1 C** is the same, it will be more cosmetically apparent and result in mechanical axis deviation.

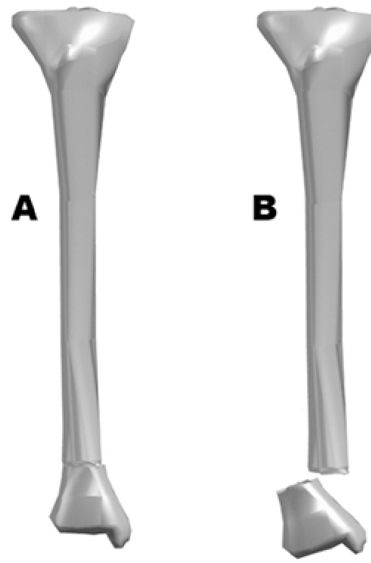

FIGURE 1

A. Normal tibia in which the mechanical axis passes thru the center of knee and ankle.
B. Compensated angular deformity in which the mechanical axis still passes thru the center of knee and ankle.
C. Uncompensated deformity is more apparent clinically and will result in mechanical axis deviation at the knee.

Three Dimensional Deformity

The French geometer Charles Chasles was the first to show that one object can be moved to any 'deformed position' with respect to a reference object by a rotation about a doubly oblique axis. As surgeons we tend to split this true 3-dimensional rotation into the three orthogonal components and talk about a threshold in each. Probably the patient's symptoms are proportional to the true 3-dimensional rotation. The equation is expressed as follows where σ equals the 3-dimensional angle:

$$\sigma = \arctan\sqrt{\tan^2 \text{AP angle} + \tan^2 \text{LAT angle} + \tan^2 \text{AXIAL angle}}$$

Hidden Contractures

Long standing malunions may have associated soft tissue contracture or even bony block preventing normal range of motion of the ankle or knee. A full extension lateral x-ray of the knee and a full dorsiflexion lateral of the ankle should be part of the preoperative evaluation. An equinus contracture of the ankle is often associated with a recurvatum deformity of the distal tibia. It may be necessary to treat the equinus contracture with a hinged frame from distal tibia to foot with or without tendoachilles lengthening. Similarly, a recurvatum deformity with a flexion contracture of the knee might be addressed by less than full correction of the usual 10° posterior slope of the plateau.

Nail, Plate, Ex-Fix

Intramedullary nails tend to be self-proving for diaphyseal fractures and malunions, in that simply inserting a nail that practically fills the canal automatically realigns the fragments, however it does not guarantee correct rotation and cannot address significant length discrepancy. In fact malunions are seen with IM nailing of relatively proximal and distal fractures which are technically more demanding and not self-proving. Recent reports site significant numbers of rotational malunions with nailing of even diaphyseal fractures. IM nailing's role in the treatment of malunions should be confined to diaphyseal deformity in which there is no significant length discrepancy, no history of osteomyelitis, and a sufficient or restorable canal. The surgeon must be able to accurately assess rotation intraoperatively. Some patients have postoperative and occasionally chronic anterior knee pain following IM nailing of the tibia.

Plates may be used for malunions at all levels of the tibia. Like IM nailing all correction is achieved in surgery. Sliding oblique osteotomies fixed with plates can correct some length in addition to correcting alignment, but there are limitations to how much length can be acutely and safely gained at the expense of fragment apposition. The soft tissues and bone must be able to tolerate the exposure necessary for precise osteotomy and plate fixation. The surgeon must be able to assess the mechanical axis as well as the rotation in surgery. A history of prior infection is a relative contraindication to plate synthesis.

External fixation has proven to be a powerful method for correcting all anatomic elements of a malunion and providing skeletal stability while the osteotomy heals. It is also used as a reduction tool to achieve a more anatomic realignment which is then fixed in situ by a plate or IM nail, and the fixator removed. As thoroughly shown by Ilizarov, an osteotomy stabilized by external fixation and gradually distracted is capable of creating regenerate bone filling in an opening wedge correction of the angular deformity. Also, additional length to correct any inequality in the limbs is achieved by continuing to gradually lengthen through the osteotomy to correct the angular deformity or a second osteotomy in more metaphyseal bone for more extensive lengthenings. Present day external fixation allows the surgeon to build an external fixator that exactly mimics the deformity. After the fixator is fixed to the tibia and the osteotomy performed, the fixator is gradually adjusted to a home position thereby correcting the malunion. Since 2002 the Total Residual Method has been possible with the Spatial Frame allowing the surgeon to fix the rings of the frame to the skeleton first and create an accurate adjustment schedule for the malunion even after surgery. The Spatial Frame is a 6 axis manipulator and is able to address all components of a deformity including rotation with essentially the same frame. The goals in surgery for correction of malunions with external fixators is different from IM nail or plate fixation. The surgeon has only to provide stable fixation of each bone segment and perform an osteotomy. The gradual highly accurate reduction is achieved after surgery. Further adjustments can be made for weeks until the patient and surgeon are satisfied. External fixation is relatively indicated in cases of prior infection or with poor soft-tissue coverage.

Because of the simpler surgical goals, applicability to the entire shaft of the tibia, use in cases with prior infection, late adjustability, extreme accuracy, and high success rate, the external fixator is a powerful tool for the treatment of malunions.

The remainder of this chapter will address the topics of characterizing the skeletal deformity, determining the level of osteotomy, and locating the external fixator.

Overcorrection/Undercorrection – In the case of varus deformity of the proximal tibia in conjunction with arthritis of the medial compartment of the knee, it is advisable to slightly overcorrect the skeletal deformity to have the mechanical axis passing lateral to the center of the knee up to the Fujisawa Point for bone on bone arthritis, or slightly short of the Fujisawa Point for articular cartilage thinning.

Definitions and Measurements

The opposite normal side is a convenient standard when characterizing tibial malunion. Good standard measurements have been published by Paley and Herzenberg as well as others. The mechanical axis in the sagittal plane passes from the center of the femoral head, thru the center of the knee joint, and on thru the center of the ankle. In the coronal plane the mechanical axis passes thru the junction of the anterior 1/5th of the joint in the knee and the center of the ankle. The knee slopes 3° on AP view, the ankle is essentially 90° on AP view. The knee slopes 9° posterior on lateral view. The ankle opens 10° anteriorly on lateral view.

Compared to congenital deformities, more malunions have additional translation in a plane perpendicular to the oblique plane of angulation and thus require more than just an angular correction to reestablish the mechanical axis.

The information needed to completely characterize a skeletal deformity is present in orthogonal radiographs, AP and Lateral, and an assessment of rotation, which may be clinical or based on CT landmarks. From a practical standpoint the amount of additional length needed during skeletal correction will depend upon the cross sectional shape of the bone at the level of osteotomy and conceivably extrinsic information such as scanograms or growth charts. Most external fixation systems have a means of lengthening along the axis of the fixator, although most do not have a convenient means of gradually derotating the deformed fragment about its mechanical or anatomic axis.

The Importance of the Reference Fragment

If both radiographs are taken orthogonal to the reference fragment and the magnification is taken into account, then the axis of the reference fragment is like a scale which can be used to measure the position of the deformed fragment. The only foreshortening is in the deformed fragment as expected. The mechanical axis of a short periarticular fragment is usually most accurately represented as a line with a given relation to the joint line, such as a 90° with respect to the AP ankle line or an 87° line with respect to the AP knee line. Since it is difficult to draw the joint lines accurately in oblique views, the short periarticular fragment often is the best choice for Reference Fragment. Also, the x-ray technician can usually do a better job aligning to the patella for distal femoral or proximal tibial deformities and the foot for distal tibial deformities and the elbow or hand for upper extremity deformities.

Synthesis of the Axial View

Like a mechanical drawing where the information on the front and side view can be used to create a top view, the AP and Lateral projections contain the information to create an Axial view. On AP and Lateral radiographs draw extended mechanical axes. (**Fig. 2**)

On a piece of graph paper begin the Axial View by placing a small circle at the intersection of the sagittal and coronal planes. This is the Reference Fragment. Label anterior, posterior, medial, and lateral. (**Fig. 3**)

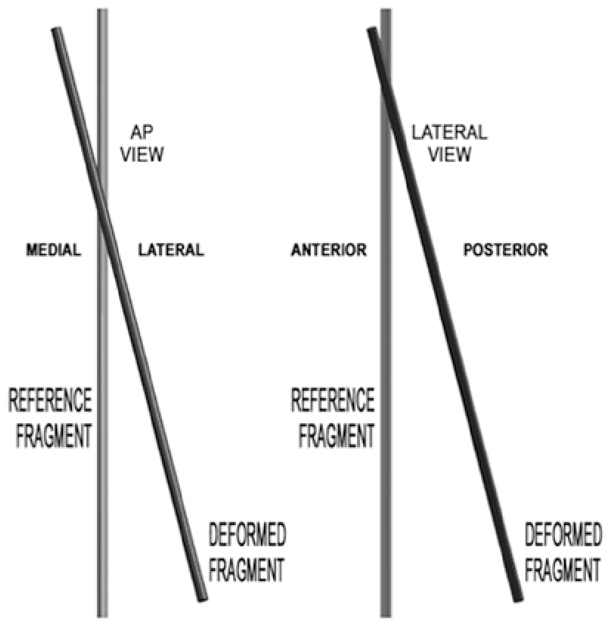

FIGURE 2

On AP and Lateral radiographs or tracings made to the same scale, extend the centerlines or mechanical axis of each fragment and label the anterior, posterior, medial , and lateral directions. This is the first step to creating an axial view and locating the LOCA.

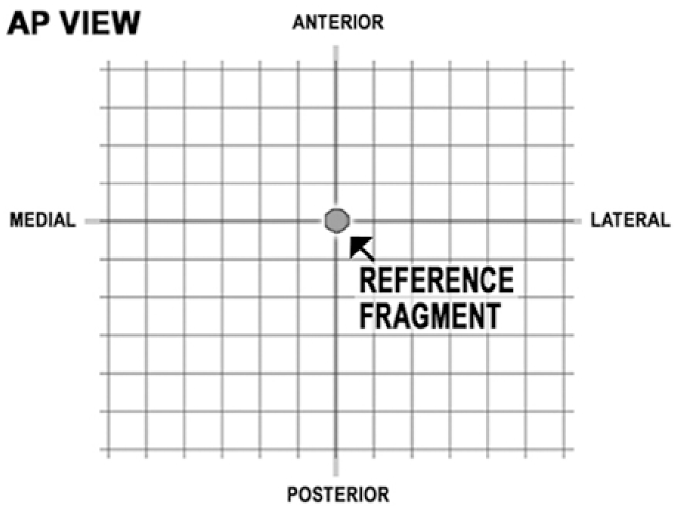

FIGURE 3

Creating an axial view of the reference fragment with directions labeled.

The position of the deformed fragment mechanical axis relative to the mechanical axis of the reference fragment must be measured at two levels 15-20 cm apart. Level 1 might be the level of the knee joint or other good landmark easily discerned on AP and Lateral views. Level 2 is located on both AP and Lat views by measuring the same distance from Level 1. (**Fig. 4**)

At level 1 on AP and Lateral measure the position of the deformed axis with respect to the reference axis. Represent this as a small circle, point 1, on the Axial View. (**Fig. 5**)

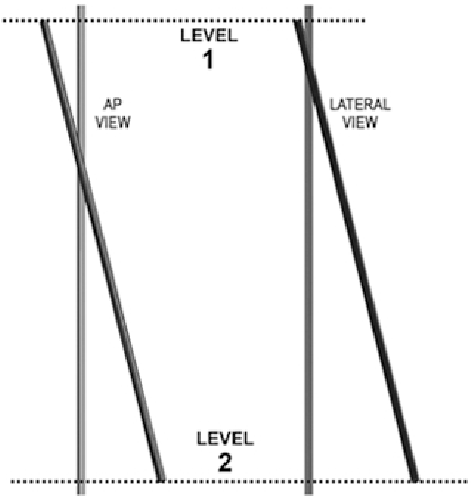

FIGURE 4

Establish two levels at least 20 cms apart at which to measure the relative position of the deformed fragment centerline to the reference fragment centerline.

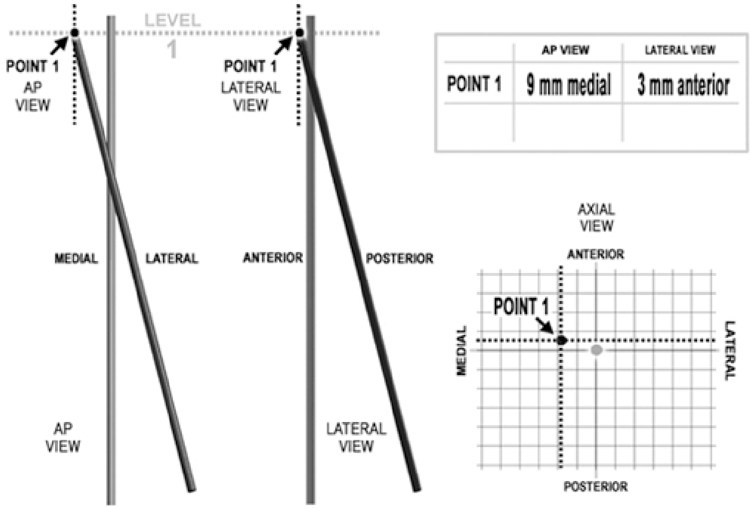

FIGURE 5

Measure the position of the deformed fragment centerline at level 1 on AP and Lateral views. Place this point 1 on the axial view.

At level 2 (approximately 20 cm away) on AP and Lateral measure the position of the deformed axis with respect to the reference axis and represent this as another small circle, point 2, on the Axial View. (**Fig. 6**)

Connect the two circles corresponding to the deformed axis at level 1 and level 2. This new line is the axial view of the deformed fragment mechanical axis between level 1 and level 2. (**Fig. 7**)

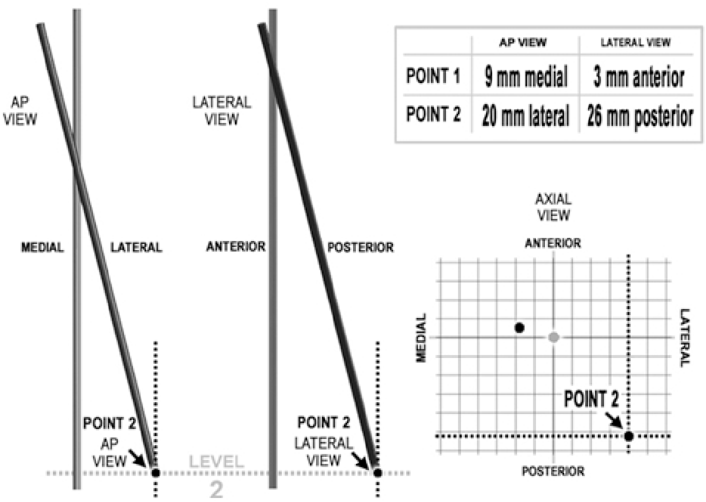

FIGURE 6

Measure the position of the deformed fragment centerline at level 1 on AP and Lateral views. Place this point 2 on the axial view.

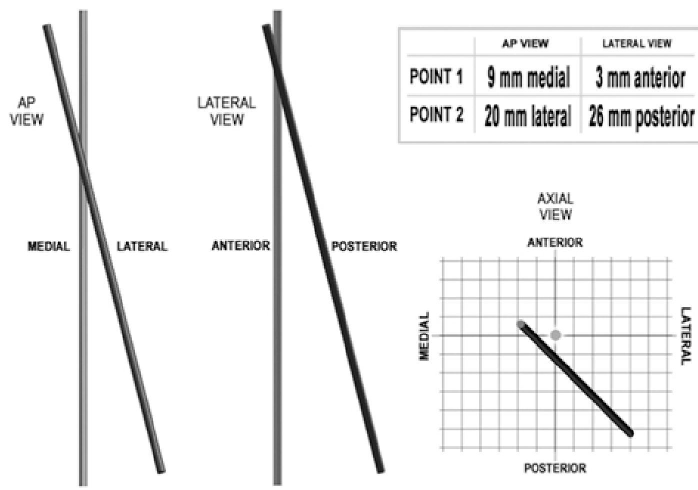

FIGURE 7

Connect point 1 and point 2 with a line. This line is the axial view of the deformed fragment between levels 1 and 2.

Line of Closest Approach - The Key to Characterizing and Correcting Deformity

Given two lines, one arbitrarily oblique to a reference line, analytic geometry shows there is only one line that is perpendicular to both. This line is also the shortest distance between the two lines and is the line of closest approach or **LOCA**.

On the Axial View draw a line that is perpendicular to the deformed axis and passes through the reference axis. This is the LOCA. (**Fig. 8**)

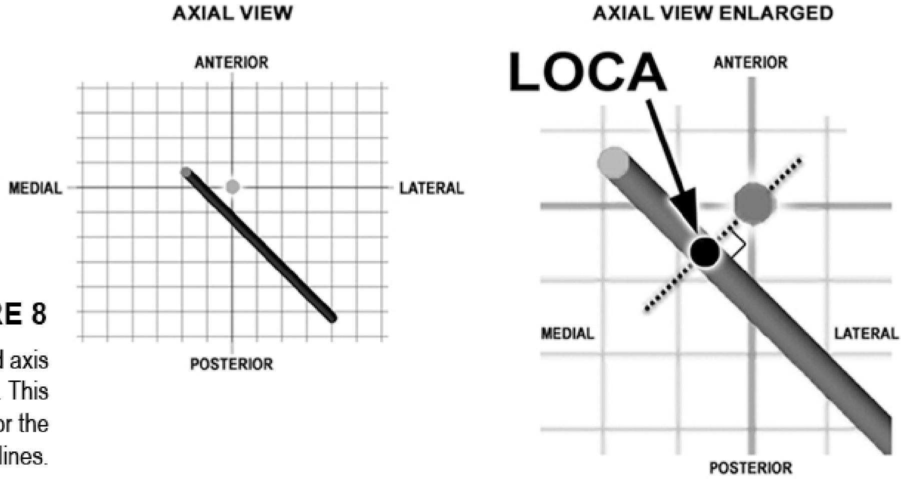

FIGURE 8

Draw the line perpendicular to the deformed axis and passing through the reference fragment. This line is the line of closest approach, LOCA, for the two fragment centerlines.

An external fixator hinge placed collinear with the LOCA will correct the angular deformity without creating any additional translation. The Axial View gives the orientation of the LOCA in the transverse plane, but it must also be located at the correct level. To determine the correct level for the LOCA, look at the intersection of the LOCA with the mechanical axis of the deformed axis, point 3, as seen on the Axial View. Measure the amount of medial/lateral translation of point 3 with respect to the reference fragment and find the level on the AP View where the deformed fragment has this same translational relation. This level is the level of the LOCA. Likewise the anterior/posterior translation of this same point and the Lateral View can be used to identify this same level of the LOCA. (**Fig. 9**)

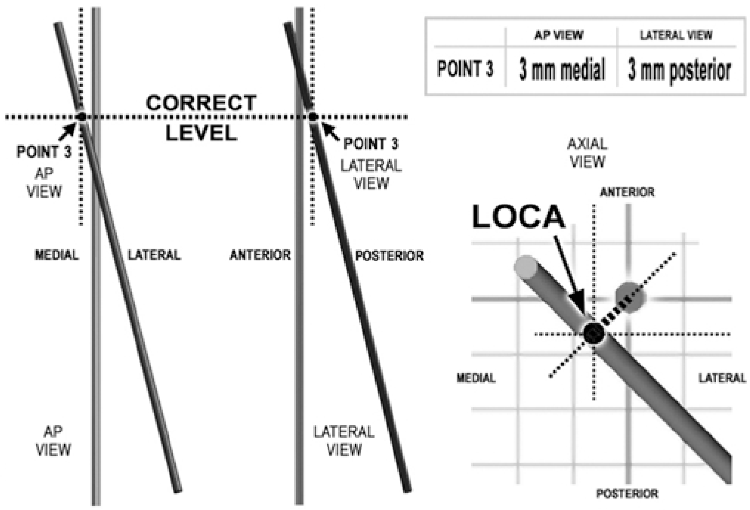

FIGURE 9

On the axial view measure the medial-lateral position of the point of intersection of the LOCA with the deformed fragment centerline. Find the level on the original AP drawing where the deformed fragment centerline has this same medial-lateral position relative to the reference fragment centerline. This level 3 is the real level of the LOCA.

Measuring True Angular Deformity

If the length of the line between point 1 and point 2 is taken as the base of a right triangle and the distance between level 1 and level 2 is taken as the height of the right triangle, the inscribed angle, δ, is the true magnitude of the oblique plane angular deformity. (**Fig. 10**)

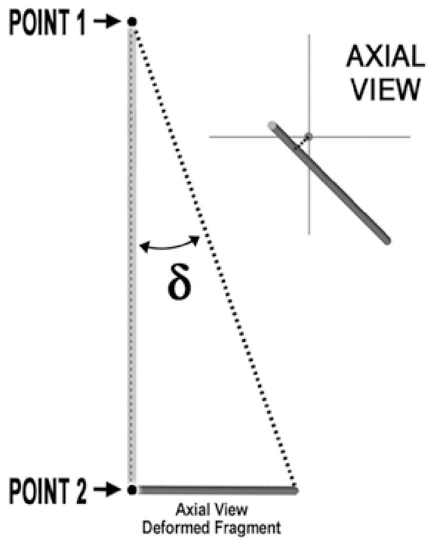

FIGURE 10

Draw a triangle with a base equal to the length of the line from point 1 to point 2 on the axial view. The height of the triangle is equal to the distance from level 1 to level 2. The inscribed angle equals the true magnitude of the oblique plane angular deformity.

Determining Translation Perpendicular to the Plane of Angular Deformity

The LOCA by definition is the shortest distance between the reference fragment and deformed fragment. The length of the LOCA as seen on the Axial View is the distance the deformed fragment needs to be translated in a plane perpendicular to the plane of angulation. In the Ilizarov system this is the setting for the translational blocks or the offset in the translational hinge. (**Fig. 11**)

Unless there are other considerations, such as skin and bone condition or fragment size for sufficient fixation, the LOCA is usually the best level for osteotomy. Osteotomy at the level of the LOCA will result in the least possible offset after correction of the translational deformity. Gigli saw osteotomies in the metaphysis and multiple small drill holes followed by osteotome for the diaphysis have both been used.

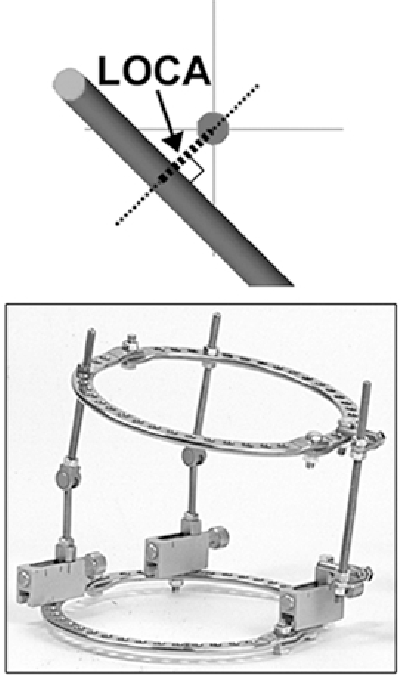

FIGURE 11

The length of LOCA is the distance the deformed fragment must be translated to bring the fragments coplanar. The LOCA is perpendicular to the plane of deformity. In the Ilizarov system this may be accomplished with multiple translation blocks.

Putting It All Together Discussion

The preceding graphical method generates an Axial View and solves for the LOCA. The Axial View yields the plane of angulation, the length of the LOCA, and can be used to plan fixator hinge orientation. (**Fig. 12**)

A hinged fixator placed collinear to the LOCA can correct oblique plane angulation without introducing translation in that oblique plane. The length of LOCA is the amount of translation in a plane perpendicular to the plane of angulation that the deformed fragment must be moved to bring it collinear to the reference fragment. Also, the true magnitude of the angular deformity is determined. In many instances the level of the LOCA represents the best choice for the level of osteotomy. This method is efficient, only an AP and Lateral radiograph are required, and precise.

The six deformity parameters used to control the Spatial Frame may be measured at any level such as level 1, 2, or 3 in the preceding example. It is unnecessary to determine the orientaion of the hinge axis, the true magnitude of angulation, or the magnitude of translation perpendicular to the plane of angulation. The computer program basically establishes a virtual hinge axis and virtual translation device which completely corrects the deformity. It is still advisable to determine the level of the LOCA when using the Spatial Frame on malunions to plan the osteotomy. LOCA type analysis is also required for treatment of nonunions with conventional fixators, but is not necessary for Spatial Frame cases since no osteotomy is required.

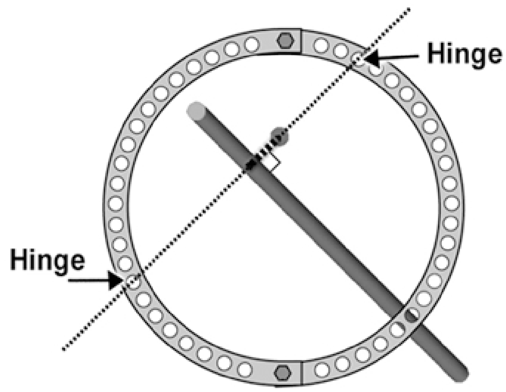

FIGURE 12

To correct a complex deformity the hinge axis of the fixator is made collinear with the LOCA and an angular correction equal to the true magnitude of the angle between the fragments is performed. The deformed fragment is translated along the hinge axis by an amount equal to the length of LOCA.

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