Correction of General Deformity with The Taylor Spatial Frame Fixator™

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Abstract

The Taylor Spatial Frame™, a unique external fixation system, can treat a variety of fractures, nonunions, and malunions. In conjunction with a software program, the Spatial Frame can correct the simplest to the most complex skeletal deformity utilizing the same frame. Different methods of correction may be utilized.

1 - Acute fractures may be stabilized with the Spatial Frame using traditional methods of traction and arched olive wires for direct reduction.

2 - Alternatively, fracture fragments can be attached to Spatial rings with interconnecting FastFx™ struts. After fragment fixation the fragments are reduced manually and the FastFx™ struts are locked in position.

3 - Malunions and congenital deformities may be treated by adjusting a frame to exactly mimic a deformity prior to mounting. As the frame is returned to its neutral position the deformity is corrected.

4 - Rings may be attached to each fragment prior to conventional strut attachments (or utilizing FastFx™ struts in the unlocked position) for fractures or chronic deformities. As the struts are brought back to their neutral position the fracture or malunion will be reduced.

After any of these four primary methods fragments may be further reduced by one of the two secondary methods, either the original Residual Deformity Correction or the more recently developed Total Residual Deformity Correction.

Introduction

The Ilizarov system utilizes hinge and translation mechanisms which are specifically oriented for a given case. Complex deformities are addressed by frames which include hinge (rotation) and translation mechanisms in series or stages.

The Taylor Spatial Frame fixator consists of two rings or partial rings connected by 6 telescopic struts at special universal joints. **(Fig. 1)** By adjusting only strut lengths, one ring can be repositioned with respect to the other. 'Simple' or complex deformities are treated with the same frame. The multiple angles and translations of a given deformity are addressed by adjusting lengths of struts only. The Taylor Spatial Frame fixator is capable of correcting a six axes deformity.

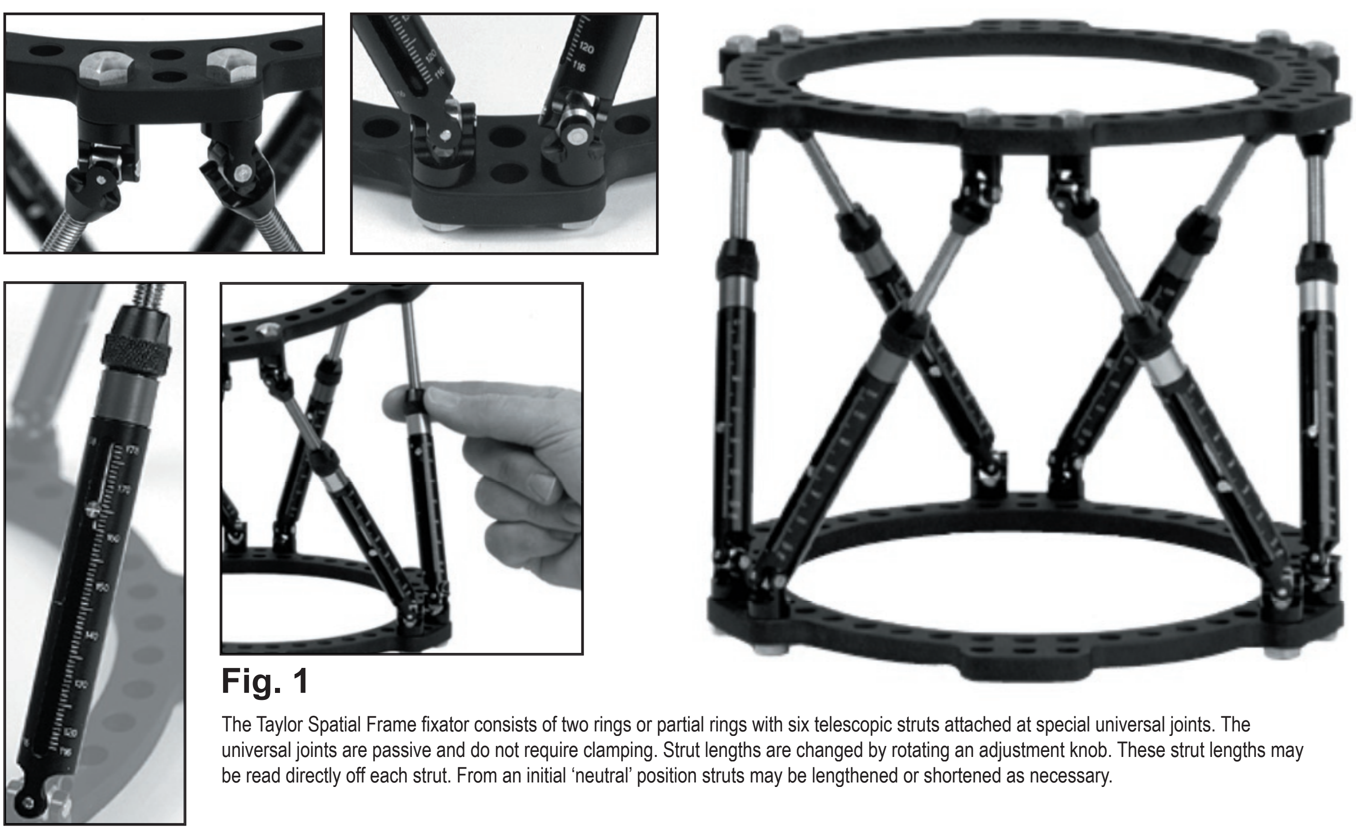


Fig. 1

The Taylor Spatial Frame fixator consists of two rings or partial rings with six telescopic struts attached at special universal joints. The universal joints are passive and do not require clamping. Strut lengths are changed by rotating an adjustment knob. These strut lengths may be read directly off each strut. From an initial 'neutral' position struts may be lengthened or shortened as necessary.

Primary Methods of Deformity Correction

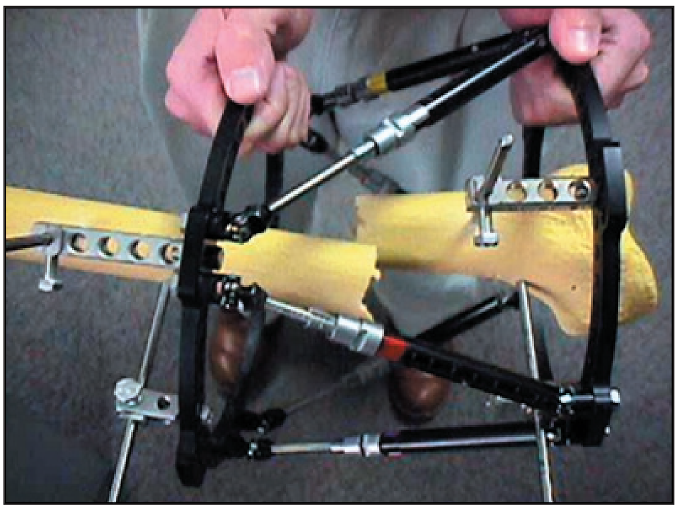
Acute Fracture Reduction — Conventional

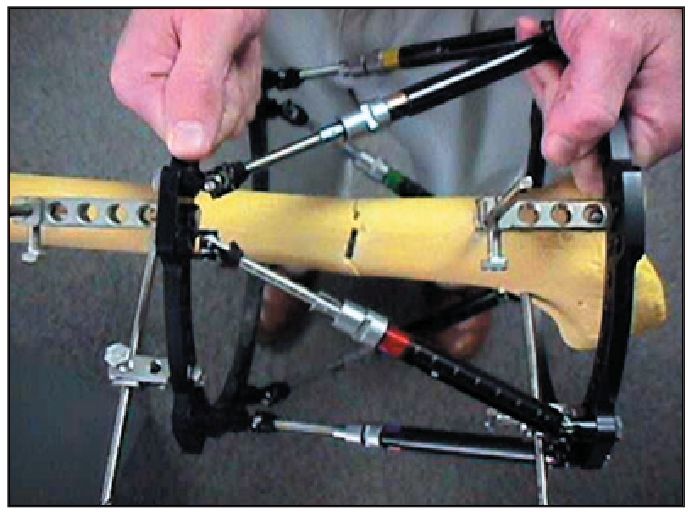
Acute fractures can be reduced with conventional technique using the Taylor Spatial Frame applied in its neutral state, moving fragments with olive wires, half-pins, and traction.

Acute Fracture Reduction — FastFx™ Struts

First a frame is mounted. (See illustration series below: **Fig. 2** - foam bone, **Fig. 3** - in surgery.)

With the struts in their sliding mode the fracture is acutely reduced under direct vision or C-arm control and the strut slides locked. The frame is first fixed to the bone without worrying about reduction. The bone is then reduced without worrying about fixation. If the manual reduction is perfect, no further fine adjustment is necessary. In the postoperative period any additional adjustment may be gradually performed without repeat anesthesia utilizing the Total Residual Deformity Correction Program.





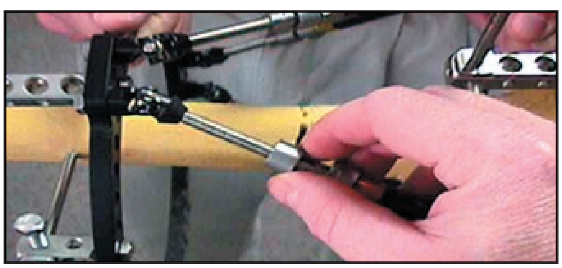
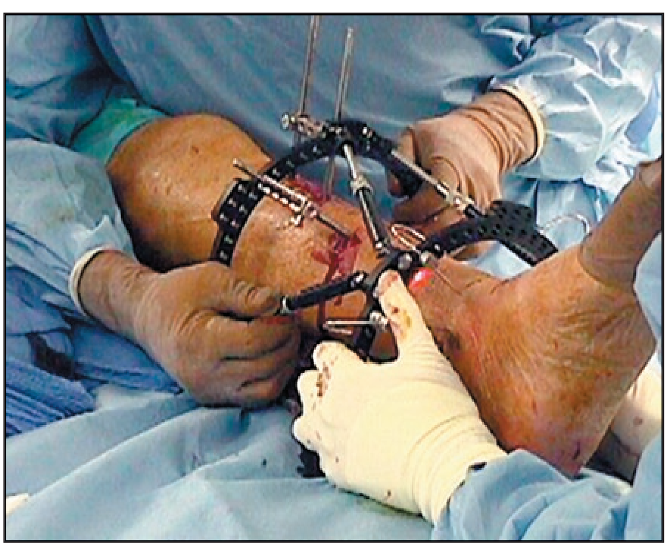
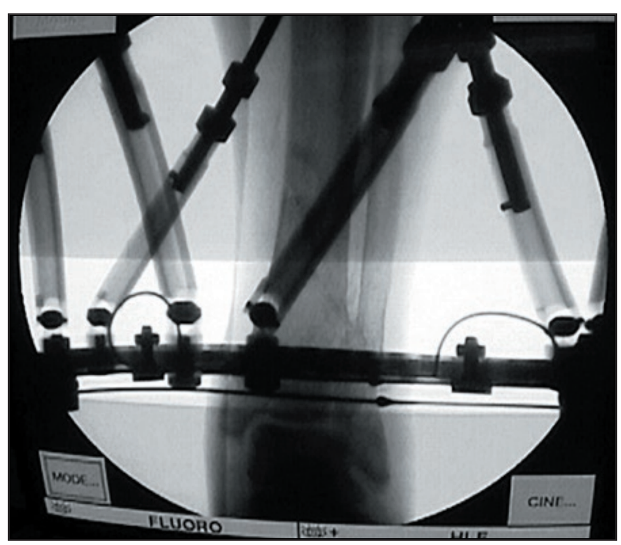


Fig. 2

Fig. 3





Chronic Deformity Correction

Chronic Deformity applies to congenital deformity, malunions, and stiff nonunions that can be measured fairly accurately by radiographs. The deformity should not change on a minute to minute basis, but allow accurate orthogonal radiographs to be taken. Based on these radiographs and a clinical exam, a Spatial frame can be adjusted from its neutral or home position (at which all struts are equal length) to a deformed position that exactly matches the skeletal deformity. The Spatial Frame is then fixed to the skeleton. As the frame is returned to its neutral or home position, the fragments are restored to their anatomic positions. This process is called Chronic Deformity Correction. A structure at risk and a safe velocity of correction may be decided and a daily adjustment schedule is generated by the program **(Fig. 4)**

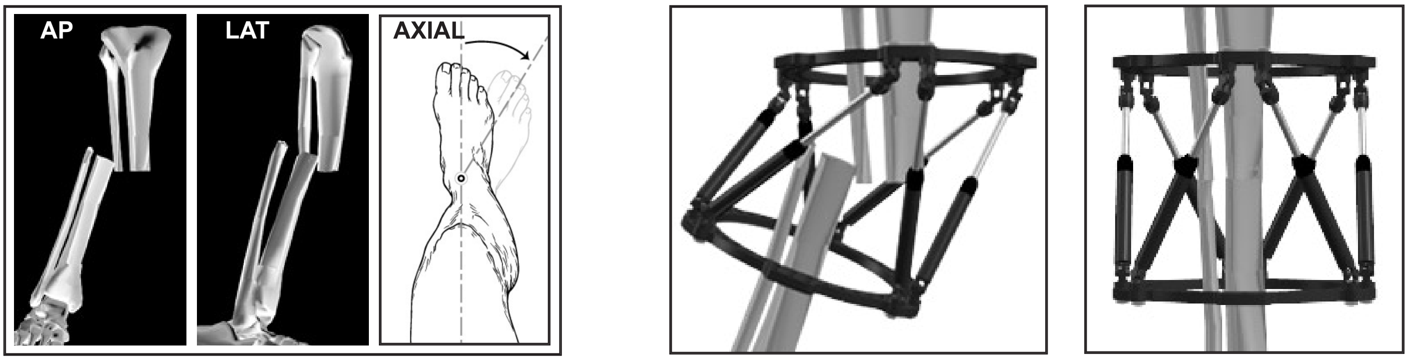
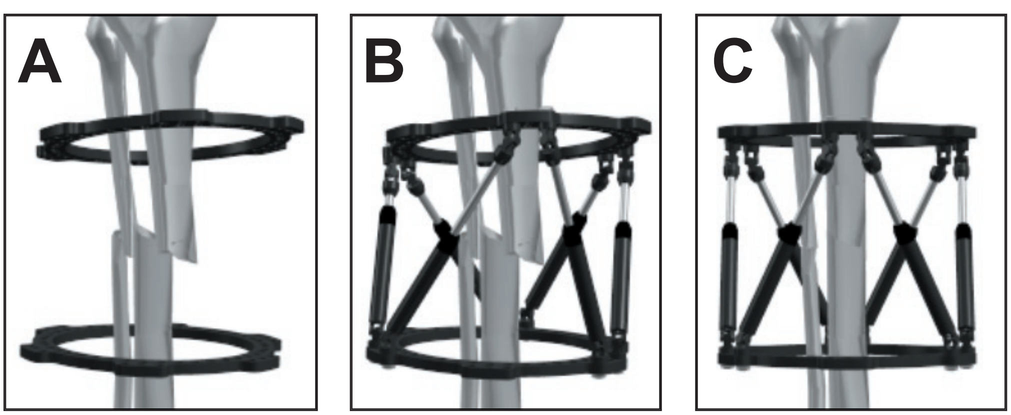


Fig. 4 A B C

Chronic Deformity - For deformity correction, the surgeon measures AP and lateral radiographs and performs a clinical exam which yield the six deformity parameters (A, above left). Clinical exam determines which ring diameters to use and whether longer or shorter struts are required - the three frame parameters. The surgeon anticipates the position of the frame with respect to the origin (usually the interior end of the reference fragment), thus providing the four mounting parameters. These 13 parameters are input to a Chronic Deformity Correction Program which returns 6 specific strut lengths to adjust the Taylor Spatial Frame fixator to exactly mimic the deformity (B, above center). The frame is then attached to the skeleton. The deformity will be fully corrected when the struts are restored to their neutral length (C, above right).

The Rings First Method of Deformity Correction

The Rings First Method of Deformity Correction, in which the rings are mounted to corresponding fragments first and struts are applied subsequently, may be applied to fractures or chronic deformities. After struts are applied, the fragments will be reduced as the struts are adjusted to their neutral or home length. **(Fig. 5)** (With the new FastFx™ struts a complete frame may be similarly applied with the struts in the unlocked position. After application the struts are then locked. Using the fine adjustment mode, the struts are returned to neutral.)



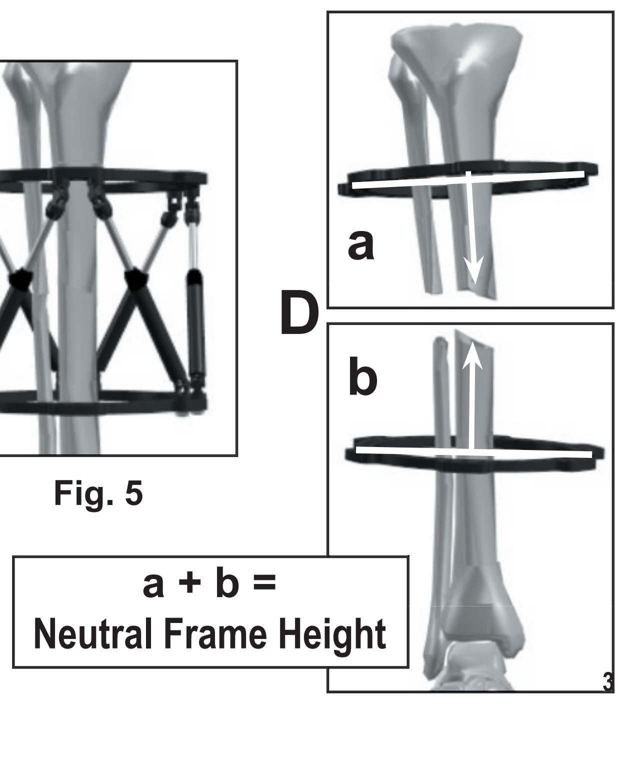


Fig. 5

The Rings First Method may be applied to chronic deformities and acute fractures. A ring is attached orthogonal to each major fragment (A, above left).
Six struts are attached between rings in the Spatial Frame configuration (B, above center).
As the struts are returned to their neutral length, the fragments are reduced (C, above right).
Neutral strut length is determined by measuring the distance from a ring to the interior end of its fragment for each fragment. The sum of these distances is by definition the neutral frame height (D, far right). Knowing the neutral frame height, the neutral strut length can easily be determined with the software or table.

Secondary Methods of Deformity Correction

Residual Deformity Correction

This applies to any situation with persistent skeletal deformity in a Spatial Frame in a neutral position. This may occur because of incomplete reduction of fractures, inaccurate initial assessment of chronic deformity, or excessive load on pins or wires. Based on AP and Lateral radiographs and a clinical exam for rotation, the Spatial Frame can be adjusted from its neutral position to a deformed position to compensate and therefore correct the skeletal deformity. This process is called Residual Deformity Correction. **(Fig. 6)**

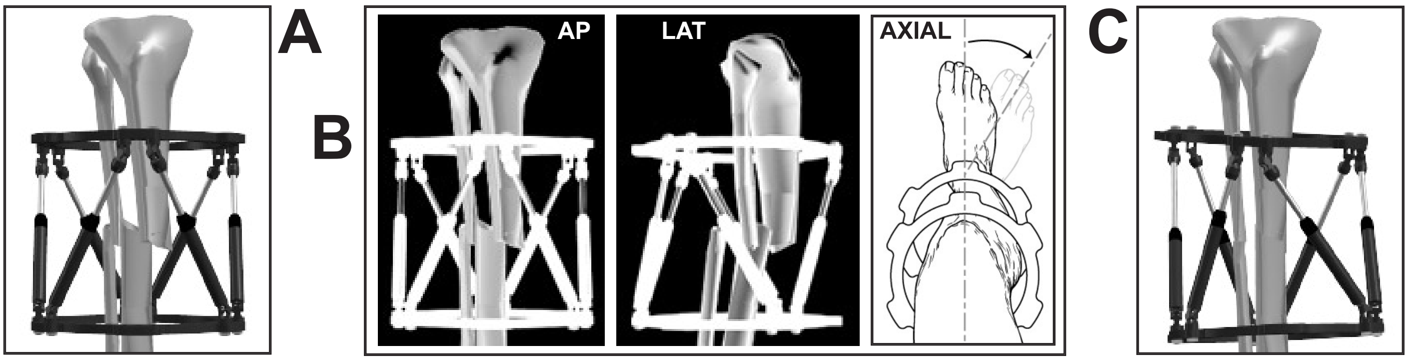


Fig. 6

For standard acute fracture treatment, the surgeon applies an appropriately sized frame with the struts at neutral length - frame parameters (A, above left). Utilize standard reduction techniques as the neutral frame is applied. Postoperatively, AP and lateral radiographs are obtained and a clinical exam is performed (B, above center). From these radiographs the six fracture deformity parameters and the four mounting parameters are measured. These 13 parameters are input to a Residual Deformity Correction Program which returns 6 specific strut lengths to adjust the Spatial Frame to exactly correct the deformity. The deformity will be fully corrected when the struts are moved to their specified lengths (C, above right). ***Residual deformity correction may be used to further improve a chronic deformity correction or the rings first method as well as acute fractures.***

Total Residual Deformity Correction

A more recently developed software program allows the surgeon to correct or compensate a residual skeletal deformity mounted to a Spatial Frame with unequal strut lengths, sometimes referred to as the problem of a ***crooked bone in a differently crooked frame***. As in the chronic deformity correction program and the residual deformity correction program a structure at risk and a safe velocity may be selected to precisely control the correction. **(Fig. 7)**

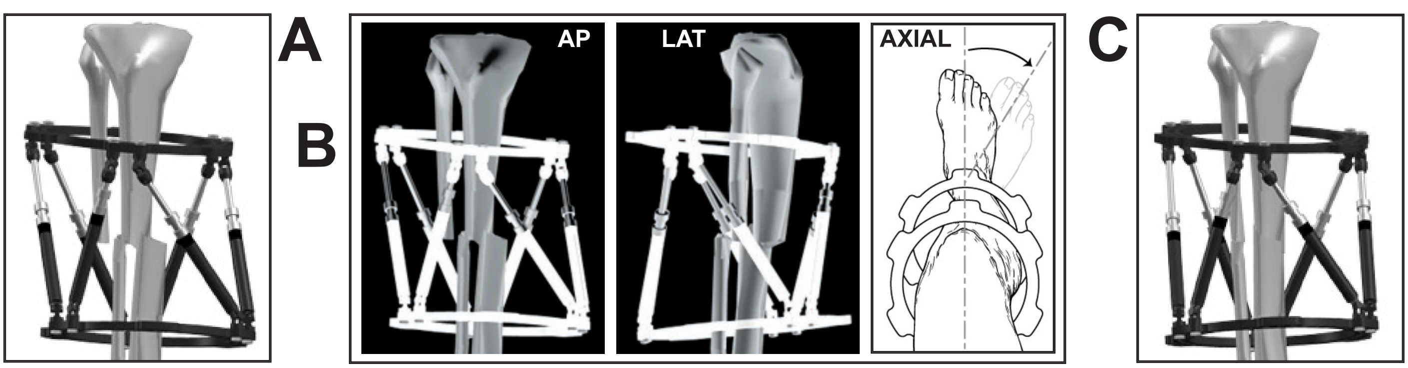


Fig. 7

Total Residual Deformity Correction is similar to Residual Deformity Correction. Both will fully correct any remaining skeletal deformity already mounted to a Spatial Frame. However, the Total Residual Deformity Correction can be undertaken at anytime and not just in a neutral frame position. This method requires the surgeon to record each of the current 6 strut lengths for the computer program.

At anytime with a frame mounted to the bone (A, above left), AP and lateral radiographs are obtained, 6 current strut settings are recorded, and a clinical exam is performed (B, above center). From the radiographs the six skeletal deformity parameters and the four mounting parameters are measured. These 13 parameters and the current strut settings are input to a Total Residual Deformity Correction Program which returns 6 specific strut lengths to adjust the Spatial Frame to exactly correct the deformity. The deformity will be fully corrected when the struts are moved from their current settings to their specified lengths (C, above right).

Fig. 8

Like the Ilizarov, the Taylor Spatial Frame fixator may be used to lengthen or shorten a limb by adjusting all struts the same increment. Unlike the Ilizarov, there is no preload on the frame as adjustments to the struts are made. Since the universal joints are free to rotate, any combination of six strut lengths is a valid frame.

Fig. 9

Regardless of the complexity of the case, essentially the same Taylor Spatial Frame fixator is used. In this case of juxtaarticular deformity, a Taylor Spatial Frame can accomplish the same rotation and translation as Ilizarov frames.

Choosing a *Reference Fragment* and the *Origin*

Orthopedic convention characterizes the deformity of the distal fragment with respect to the proximal fragment. (The proximal fragment is the reference fragment, the distal fragment is the moving fragment.)

Deformities could also be measured where the proximal fragment is characterized with respect to a reference distal fragment. This characterization of the deformity by describing abnormal position of the proximal fragment is especially useful in distal nonunions or malunions with a short distal fragment. The location of the attachment of the distal ring (using the joint surface as a landmark) will be more exactly determined in preoperative planning and in surgery than the level of attachment of the proximal ring on the longer proximal fragment. It also allows the surgeon to fully characterize the deformity even though the radiographs are too short to include the level of attachment of the proximal ring. (The distal fragment is the reference fragment, the proximal fragment is the moving fragment.)

Either fragment could be the Reference Fragment. Ideally, the reference fragment should satisfy two criteria:

1) that fragment whose anatomic planes most closely match the planes of the AP and Lateral radiographs;

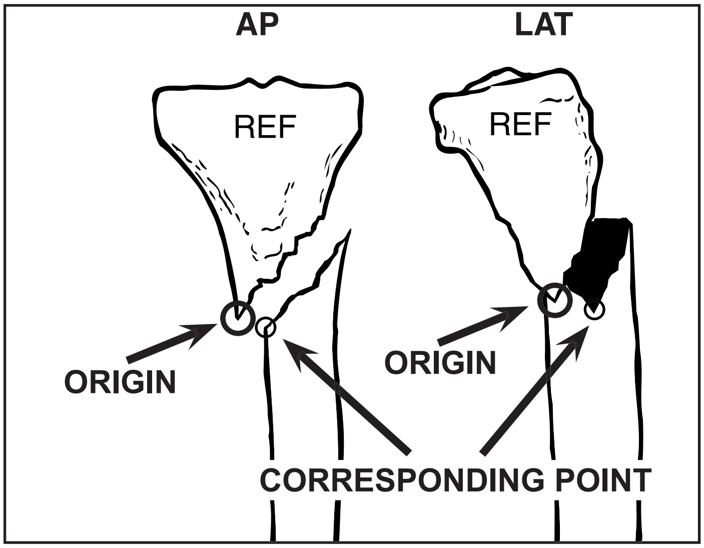
2) AP and Lateral radiographs include the actual or anticipated level of attachment of a ring to the reference fragment.

The patella provides a prominent landmark for distal femoral or proximal tibial deformities. The foot provides a prominent landmark for distal tibial, ankle, and subtalar deformities. Frequently, the best choice for the reference fragment is the short fragment in conjunction with the prominent landmark. The x-ray technician is more likely to successfully align with the landmark (criteria 1) and if the joint line is included in the radiographs (as it should!) then the level of attachment of a ring to that fragment is also included (criteria 2).

Obviously, the actual deformity is the same whether the physician characterizes the distal fragment with respect to the proximal fragment or alternatively characterizes the proximal fragment with respect to the distal fragment. However, the working measurements of even an oblique plane angular deformity will be different depending upon which fragment is chosen for the reference fragment. Strangely enough the final external fixation frames for these different deformity characterizations (based on alternative reference fragments) are identical and will effect the same complete correction. It is important that the same fragment be maintained as reference fragment for AP and Lateral radiographs as well as clinical exam for malrotation.

Translation between fragments is measured from an Origin on the reference fragment to its Corresponding Point on the moving fragment. The best choices for Origin and Corresponding Point are points that are coincident in the anatomic (reduced) state. The tip of a spike on the reference fragment and the matching ‘notch’ on the moving fragment would be reasonable choices in posttraumatic deformity if these points are easily discerned on AP and Lateral radiographs. **(Fig. 10)**

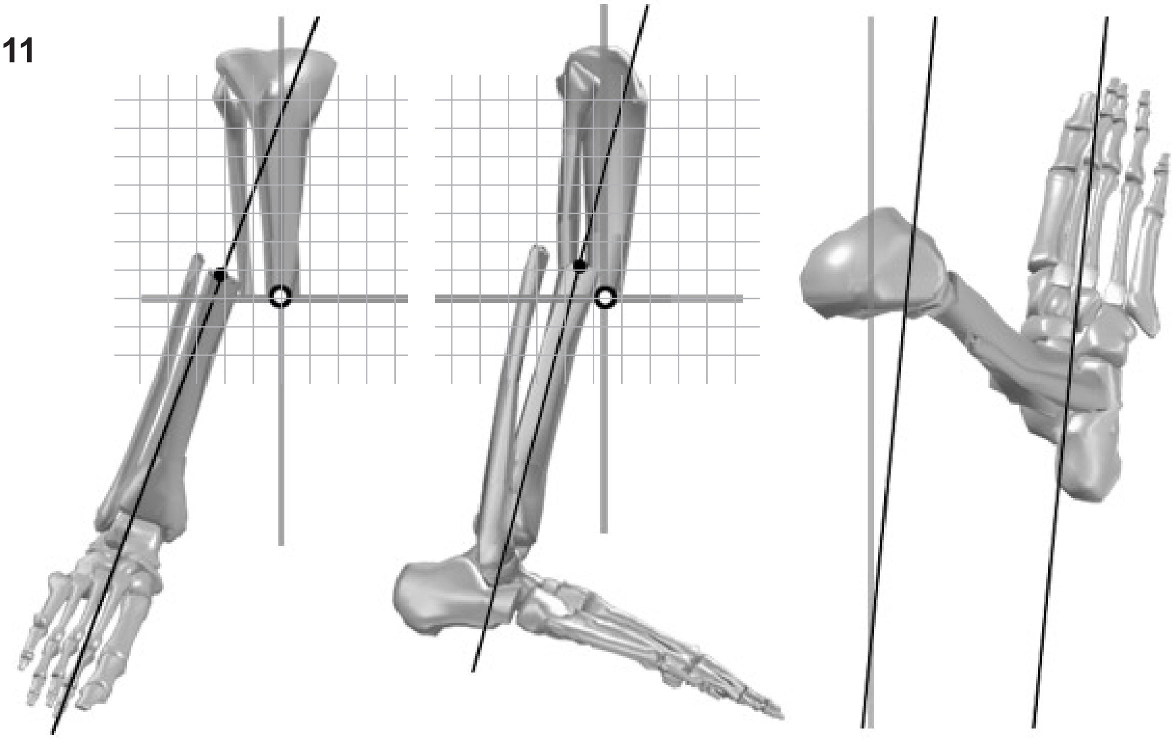
Fig. 10



However, the mechanical axis at the fracture site of the reference fragment and the mechanical axis at the fracture site on the moving fragment are the most commonly used choices for Origin and Corresponding Point, respectively. **(Fig. 11)** The implied coordinate system on which these translational and rotational measurements are made is the coordinate system of the reference fragment. Thus, imagine a grid aligned with the mechanical axes of the reference fragment. The AP View translation, Lateral View translation, and Axial translation are measured along these grid lines.

Choosing the origin and corresponding points for congenital and remodeled deformities will be presented in a later section.

Fig. 11



Once a reference fragment is selected, in this case the proximal fragment, translational and rotational deformity parameters are measured on an X, Y, Z grid aligned to the mechanical axes of the reference fragment,

Parameters

By fully characterizing skeletal deformity, determining the appropriate frame size, and establishing the position of the frame on the limb, the surgeon can correct complex deformity and reduce fractures utilizing the Chronic Deformity Correction Method or the Residual Deformity Correction Method.

Skeletal deformity is completely characterized by measuring six deformity parameters: the three projected angles (rotations) and three projected translations between major fragments.

The three frame parameters consist of proximal and distal ring diameters and neutral strut length or neutral frame height.

Four mounting parameters are anticipated before surgery for chronic situations and measured radiographically and clinically after surgery for acute fractures. They are AP View, Lateral View, Axial, and Rotary Frame Offsets.

These parameters are input to a computer program which determines the strut lengths for the Taylor Spatial Frame Fixator.

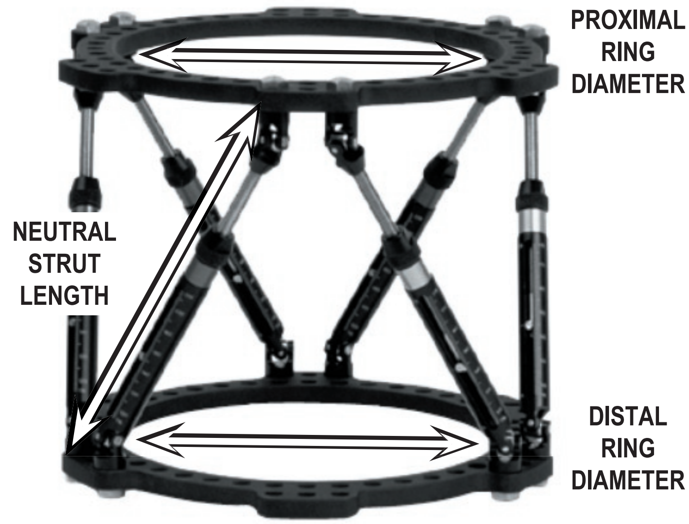
Frame Parameters

Three dimensions, or parameters, are required to fully describe a particular Spatial Frame: proximal ring internal diameter; distal ring internal diameter; and neutral frame height or neutral strut length.

Proximal and Distal Ring Internal Diameters

Complete rings range in size from 105-300 mm internal diameter in 25 mm increments. Two-third rings range from 155-275 mm. Different size rings may be used on one frame. Tapered frames allow a lower profile mounting. A two-thirds ring permits more proximal fixation of the femur and humerus. Accessory rings and partial rings may be attached to extend the levels of fixation. Short and long foot plates are available in 155 and 180 mm internal diameters. The internal diameter is printed on each ring, partial ring, or foot plate.

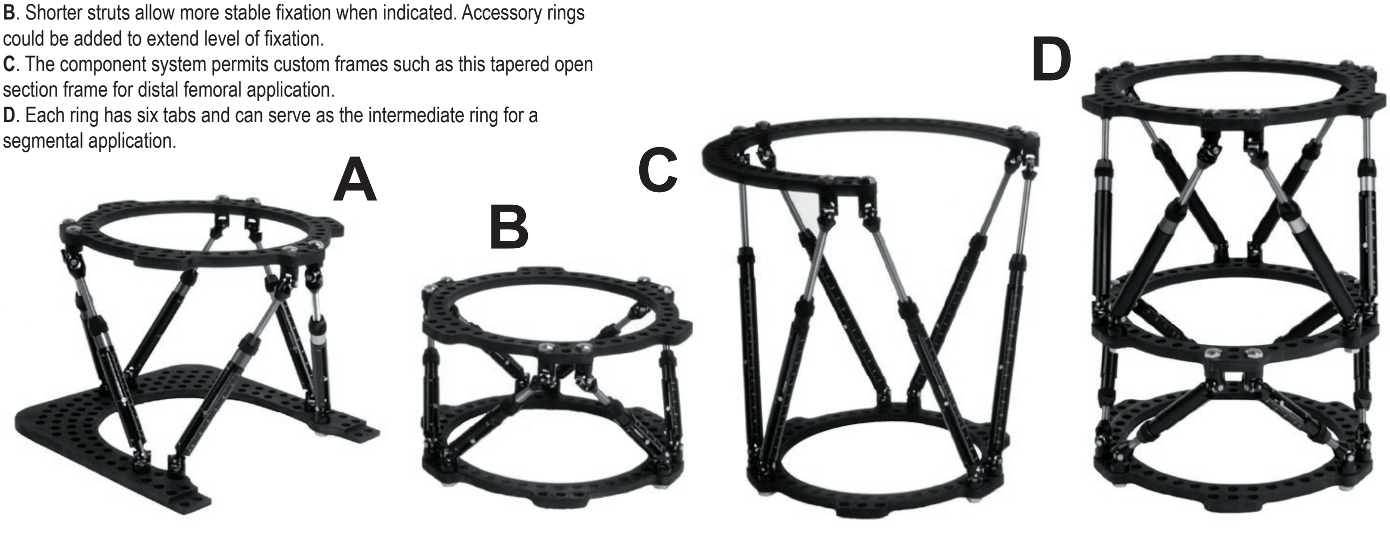
Fig. 12



Neutral frame with medium struts in mid-position.

Fig. 13

A. Spatial Frame with short foot plate and medium struts in mid-position. The short foot plate would allow independent treatment of the forefoot.
B. Shorter struts allow more stable fixation when indicated. Accessory rings could be added to extend level of fixation.
C. The component system permits custom frames such as this tapered open section frame for distal femoral application.
D. Each ring has six tabs and can serve as the intermediate ring for a segmental application.



Neutral Frame Height and Neutral Strut Length

Standard telescopic struts are available in x-short, short, medium, and long sizes ranging in functional length from 75-284 mm (**Fig. 14**). For a given size, the strut has a specific range from its shortest to longest length and a mid-position marked on each strut. Struts are marked with millimeter graduations with actual strut length printed every 10 mm. The strut length is read at the indicator **(Fig. 15).**

FastFx™ struts likewise are available in x-short, short, medium, and long sizes ranging in functional length from 91-311 mm.

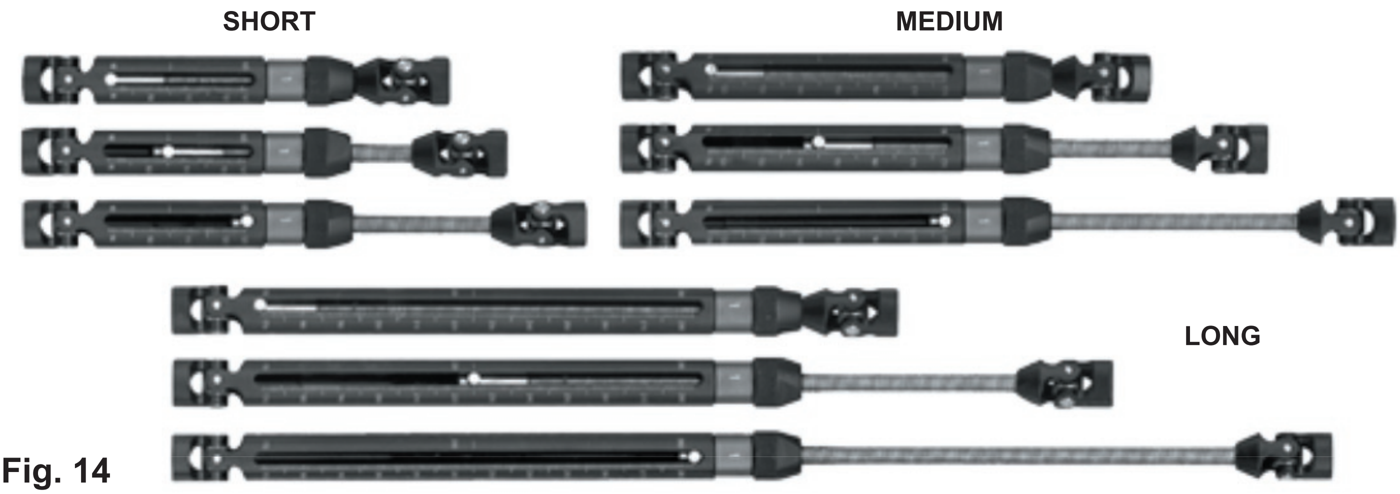


Fig. 14

Several strut sizes are shown above in various positions: fully shortened, mid-position, and fully lengthened.

Struts are attached to the rings in a specific pattern with special shoulder bolts. The holes in the rings for attaching the struts are apparent. Mounting holes in the foot plates are highlighted by a shallow groove. When a strut runs out of travel or excursion it can be exchanged for the next size strut. Before the exchange simply apply an additional telescopic strut or threaded rod temporarily between rings. Any available holes may be used for this temporary seventh strut. After the exchange remove the temporary strut. The short strut in its fully lengthened position overlaps the medium strut in its fully shortened position by several millimeters. Likewise, the medium strut in its fully lengthened position overlaps the long strut in its fully shortened position by several millimeters. Thus, the surgeon has some choice when the struts are exchanged. At the time of exchange simply set the strut to be inserted at the same length as the strut being replaced **(Fig. 16)**.

Fig. 15

At right, a close-up of a short strut shows the indicator at mid-position.

Fig. 16

A. A short strut and a medium strut both set to 120 mm.
B. A medium strut and a long strut both set to 175 mm.
There is an overlap between fully lengthened and fully shortened struts.

The neutral frame height is the distance from the center of one ring to the center of the other ring with all struts at their neutral length. The neutral frame height or the neutral strut length is chosen by the surgeon preoperatively for chronic deformity correction. This neutral frame height will be the target or final destination that will be achieved at full correction **(Fig. 17)**.

However, the neutral frame height is the starting point for residual corrections. From this neutral position the frame will subsequently be adjusted to compensate for residual deformity. The surgeon must make sure all struts are equal during a conventional fracture application. This strut length is the neutral strut length for calculation if a residual deformity correction should be necessary.

Finally, the neutral frame height is measured by radiograph or image intensifier when utilizing the rings first method for fractures or malunion/nonunions. The distance from one ring to the interior end of its fragment is added to the distance from the other ring to the interior end of its fragment. This sum is the neutral frame height, and similar to the chronic deformity correction becomes the target or final destination **(Fig. 18)**.

Fig. 17

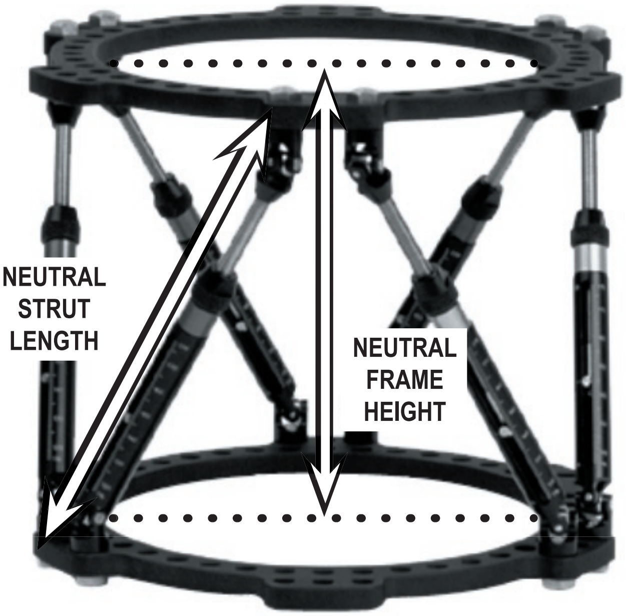
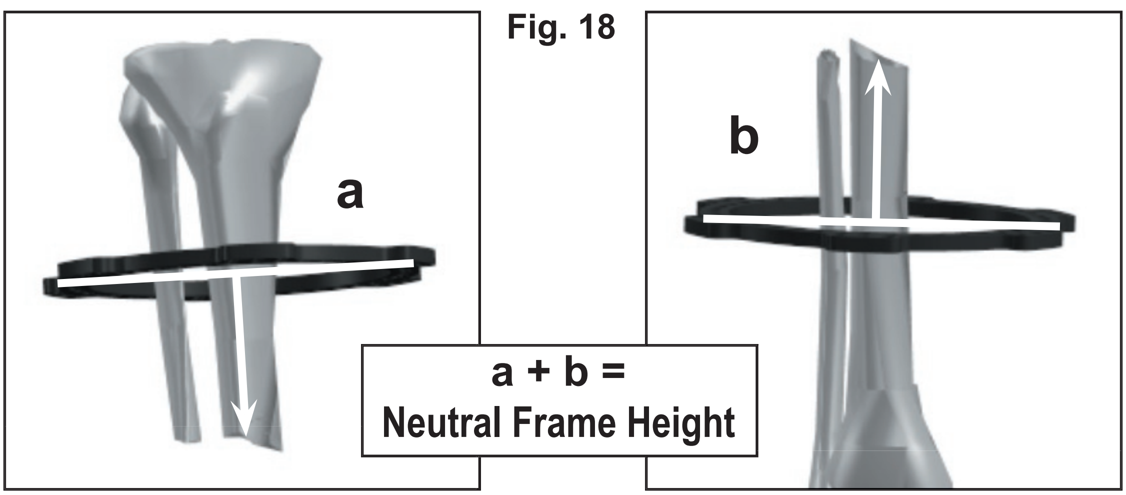


Fig. 18



Neutral strut length is determined by measuring the distance from a ring to the interior end of its fragment for each fragment. The sum of these distances is by definition the neutral frame height. Knowing the neutral frame height, the neutral strut length can easily be determined with the software or chart.

The Taylor Spatial Frame software can use either neutral frame height or neutral strut length to calculate adjustments to the frame. Also, given one of these values the software will immediately return the other, which may be useful in frame planning and is essential when performing the rings first method.

When performing a chronic deformity correction with primarily angular and transverse plane translational deformity, choose the neutral strut length equal to the mid-length of one of the strut sizes. This permits some struts to shorten and some to lengthen without needing to exchange struts. If performing primarily a lengthening, choose a neutral strut length toward the lengthened end of the particular strut size. This better utilizes the available excursion and may decrease the need to exchange struts.

Deformity Parameters

The orthopedic surgeon must assess the patient for fixed pelvic obliquity. Long films (including hip, knee, and ankle) with a radiographic ruler are helpful to assess mechanical and anatomic axes and identify all deformities. Weight bearing films identify ligamentous laxity which may mimic skeletal deformity.

Imagine a limb segment in anatomic position as in **figure 19**. The two fragments adjoin at the origin. With fracture or deformity, the two fragments are angulated and translated. The translations are measured as the separation of the adjacent (or corresponding) point from the origin. Translations are measured along the coordinate axes of the reference fragment (actually the reference ring). **(Fig. 20)**

Determine whether a conventional distal characterization or a proximal characterization is to be used. Angulations are determined by measuring the divergence of centerlines drawn in each fragment, as with traditional methods. Axial malrotation (internal or external rotation) is assessed clinically or with special films. **(Fig. 21)**

Translation (displacement) is the perpendicular distance from the reference fragment to its corresponding point on the moving fragment.

To measure translations determine where the corresponding point is with respect to the origin. *(If a distal reference is chosen the AP view and Lateral view translations will generally be opposite those if a proximal reference is chosen.)*

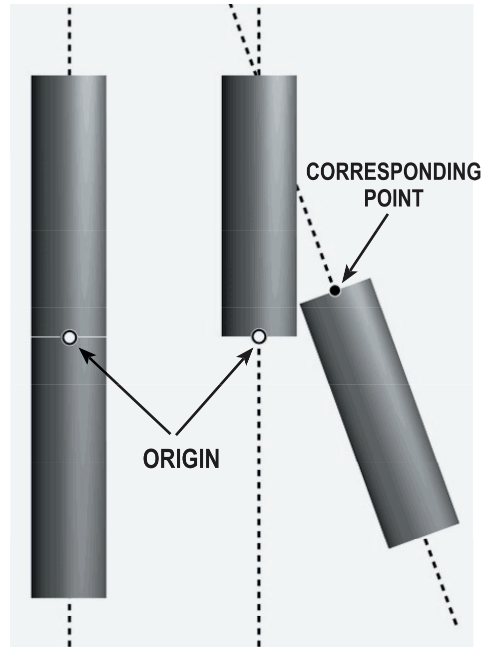


Fig. 19 Fig. 20

NOTE. Angulation and rotation are determined by the reference fragment's view of the deformity in a traditional sense. For example, if a proximal reference is chosen and the AP view along the reference fragment shows a varus deformity, then it is a varus deformity.

If a distal reference is chosen and an axial view is taken along the axis of the distal fragment (usually clinical exam) which shows the distal fragment internally rotated with respect to the proximal fragment it is an internal rotation deformity.

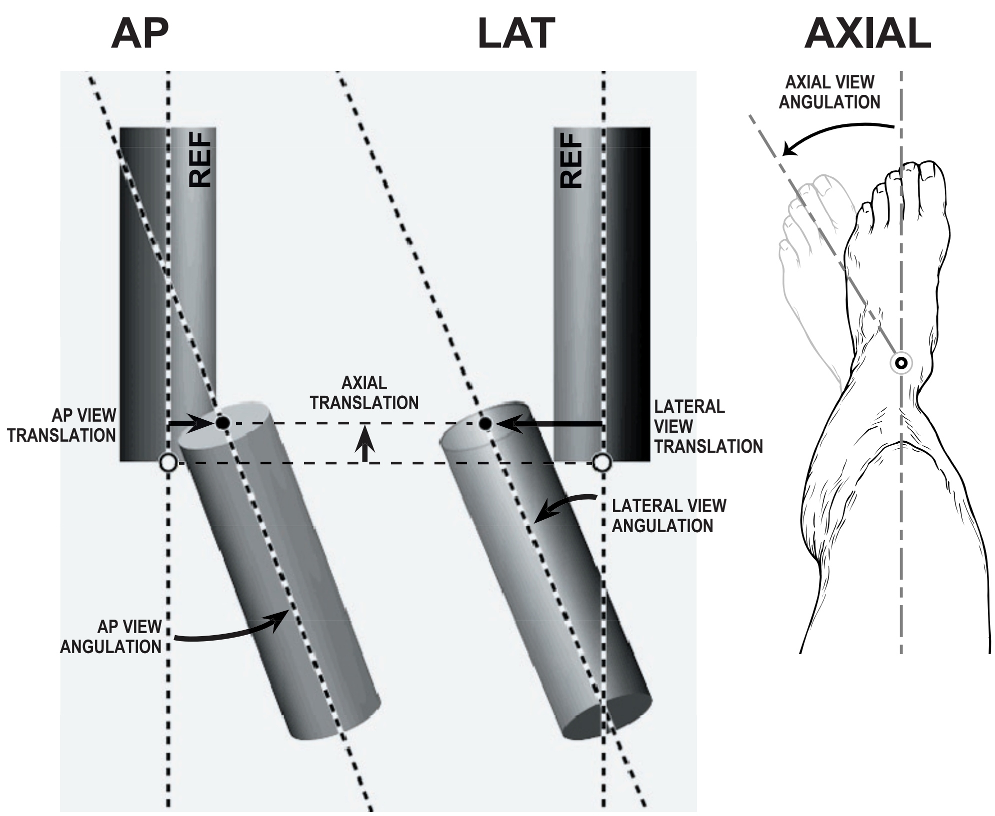


Fig. 21 Select one fragment as the reference fragment. Translation is measured between the origin and its corresponding point on AP and Lateral views. Axial translation can be measured on either radiograph as the distance between the interior ends of fragments measured along the reference fragment centerline. AP and Lateral angulations are measured as the angles between respective centerlines; the axial angle is measured clinically.

Mounting Parameters

Axial Frame Offset

Axial frame offset is the measurement of length parallel to the frame centerline from the origin to the reference ring. **(Fig. 22)** This can generally be measured on AP or Lateral films. This measurement in millimeters partially specifies the orientation of the frame with respect to the origin.

AP View and Lateral View Frame Offset

In most tibial mountings with circular fixators, the tibia is located anterior to the geometric center of the ring. Measure the distance from the origin to the centerline of the frame. This distance in millimeters is Lateral view frame offset. **(Fig. 23, 25)** If the tibia is significantly shifted from centered on AP view, measure the distance from the origin to the centerline of the rings. This distance is AP view frame offset. **(Fig. 24, 25)**

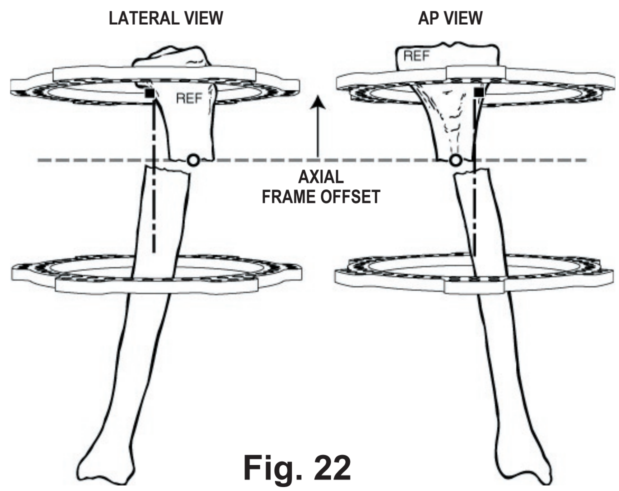


Fig. 22

Axial Frame Offset - One of the four parameters characterizing how the frame is positioned with respect to the origin (fragment). Measured from the origin to the reference ring parallel to the axis of the frame.

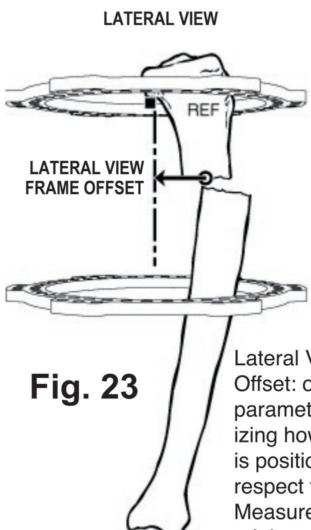


Fig. 23

Lateral View Frame Offset: one of the four parameters characterizing how the frame is positioned with respect to the limb. Measured from the origin to the centerline of the frame.

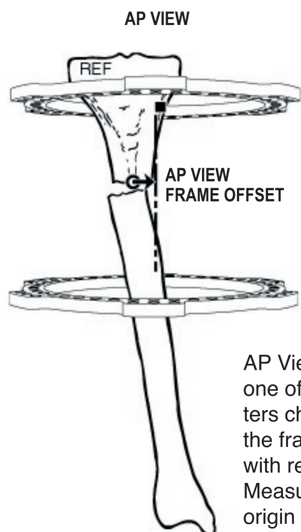
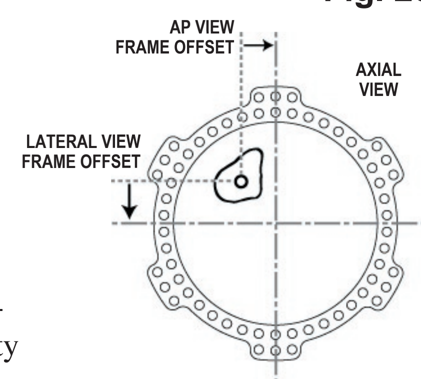


Fig. 24

AP View Frame Offset: one of the four parameters characterizing how the frame is positioned with respect to the limb. Measured from the origin to the centerline of the frame.

Fig. 25



AP View Frame Offset is measured from the origin to the centerline of the reference ring as seen on the AP radiograph. Lateral View Frame Offset is measured from the origin to the centerline of the frame.

The surgeon can choose the exact virtual center of rotation of the correction. This virtual center of rotation, the origin, can be placed at the convexity of the deformity rather than the center of the interior end of the moving fragment. Rotation at the convex cortex will be necessary especially for correction of congenital deformities, malunions, and stiff nonunions which require minimal or no lengthening. Otherwise, too much impaction and overconstraint at the convex cortex may result in excessive preload on pins and wires and under-correction of the deformity.

When treating stiff nonunions, malunions, and congenital deformities, the position of the frame with respect to the origin can be anticipated. Corresponding values for Axial frame offset, Lateral view frame offset, and AP view frame offset are entered into the Chronic Deformity Correction Program to determine exact strut lengths for the Taylor Spatial Frame to ***mimic*** the given deformity, maintaining the anticipated relative position of frame and bone.

When treating fresh fractures, Axial frame offset, Lateral view frame offset, and AP view frame offset are measured on postoperative films. These values are entered into the Residual Deformity Correction Program to determine exact strut lengths for the Spatial Frame to compensate for or ***mirror*** the residual deformity.

Rotary Frame Offset

The preferred (reference) rotational orientation of the Taylor Spatial Frame is with the proximal ring universal joints (master universal joints) for Strut 1 and Strut 2 located exactly anterior on the proximal fragment. **(Fig. 26)**

When using 2/3 rings for mid-femur or humerus, the surgeon may place the master universal joints directly lateral by selecting 90 degrees of external rotation for some femoral and humeral applications. **(Fig. 27, 28)** When treating stiff nonunions, malunions, and congenital deformities, the position of the frame with respect to the bone can be anticipated, and corresponding values for Rotary frame offset **(Fig. 29)** are entered into the Chronic Deformity Correction Program to determine exact strut lengths for the Spatial Frame to mimic the given deformity maintaining the anticipated relative position of bone and frame.

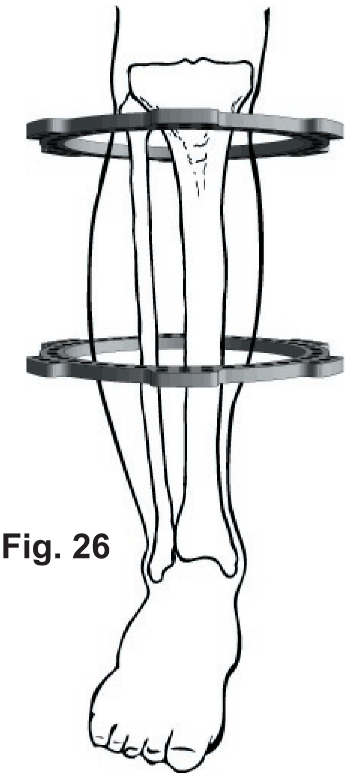


Fig. 26

The preferred (reference) rotational orientation of the Taylor Spatial Frame is with the proximal ring universal joints (master universal joints) for Strut 1 and Strut 2 located exactly anterior on the proximal fragment.

Fig. 27

To improve trunk and opposite thigh clearance, the Spatial Frame may be externally rotated 90 degrees for right humeral or femoral applications.

Fig. 28

To improve trunk and opposite thigh clearance, the Spatial Frame may be externally rotated 90 degrees for left humeral or femoral applications.

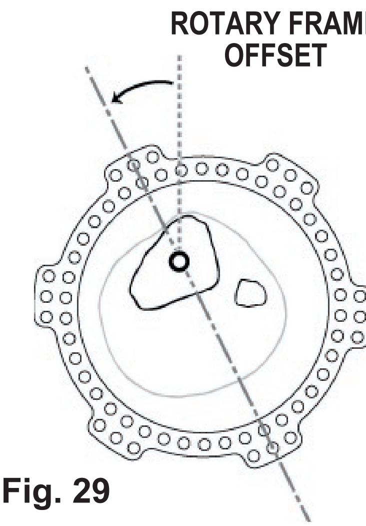


Fig. 29

Rotary Frame Offset: one of the four parameters characterizing how the frame is positioned with respect to the bone. Measured clinically as rotation of the sagittal plane of the reference ring with respect to the sagittal plane of the reference fragment.

When used for fractures, the frame may be inadvertently malrotated when applied. Simply enter the angular position of the sagittal plane of the reference ring with respect to the reference fragment in rotary frame offset.

Structure at Risk and Rate of Correction

It is incumbent upon the surgeon to be aware of the structures at risk on the concavity of the deformity. When dealing with rotation about the longitudinal axis in addition to conventional angular correction, the risks may be less or greater depending on direction of axial rotation. For example, when correcting a flexion/valgus/external rotation deformity of the proximal tibia, the peroneal nerve is at increased risk. However, when correcting a flexion/valgus/internal rotation deformity, the axial rotation will tend to offset the stretch on the peroneal nerve created during the correction of flexion/valgus.

The chronic, residual, and total residual programs allow the surgeon to input the coordinates of the structure at risk with respect to the origin and the maximum daily displacement of the structure at risk. The program creates a daily adjusment schedule moving the structure at risk the prescribed amount each day until the deformity is eliminated.

Chronic Deformity - A Second Chance for Correction

Because of nonorthogonal initial radiographs, error in measuring radiographs, or excessive preload and bending of wires and pins, there may be residual skeletal deformity when the struts have reached their neutral lengths at the completion of a chronic deformity correction. This situation is analogous to the residual deformity after fracture stabilization. Simply measure the radiographs to determine deformity parameters and mounting parameters, and make a clinical exam for malrotation. Use the Residual Deformity Correction Program to determine new strut lengths to correct the residual deformity.

Alternatively, during any gradual correction a total residual deformity correction may be undertaken by measuring current parameters and noting current strut settings.

Rings First Method - Further Considerations

The neutral strut length is determined by directly measuring the components of neutral frame height from the radiographs and using the program to calculate corresponding neutral strut length. After the rings and struts have been applied, a separate radiograph is taken perpendicular to each fragment(the exact orientation of the radiograph is not important, only that it is taken perpendicular to the fragment). The distance from the interior end of the fragment to the level of that fragment's ring is measured. The sum of these two distances is the neutral frame height. Knowing the proximal ring diameter and the distal ring diameter, the software program can calculate the neutral strut length to restore the frame to neutral frame height. The neutral strut length can also be obtained from a simple chart.

The Rings First method would enable the surgeon to correct complex deformity without measuring the deformity. It is only essential to mount each ring orthogonal to its corresponding fragment and maintain the same bone to frame position.

Requirements of the Rings First Method

The surgeon should maintain the same AP view, Lateral view, and Rotary frame offsets for each ring. Each ring should be orthogonal to the mechanical axis and similarly positioned about its fragment.

Advantages of the Rings First Method

This method can be applied to fractures and chronic deformities.

After mounting the rings for acute fractures, the surgeon may desire to position the fragments malreduced, even overlapped, which may eliminate a soft tissue gap or allow vascular repair without tension. After soft tissue healing the fragments can then be reduced. The Rings First method allows the surgeon to quickly fit the struts to these malpositioned rings while an assistant holds the rings. It is not necessary to characterize the deformity parameters of this malposition as in the chronic deformity correction method and ,thus, can be applied emergently without software assistance.

Rings First allows a more spontaneous surgical procedure with full access to the limb for osteotomy, debridement, and plastic procedures.

Any residual deformity (after the struts are brought to their neutral length) can be corrected with a Residual Deformity Correction.

Disadvantages of the Rings First Method

In general, when utilizing the Rings First Method only, the software can not utilize the coordinates of the structure at risk to calculate the number of days for safe correction. It will be up to the surgeon to decide how many days will be necessary for a safe correction. Given that number of days for safe correction, the software can, however, determine a precise adjustment schedule to bring the struts to their neutral length.

Any error in maintaining the same AP view, Lateral view, and Rotary offsets for each fragment will effect the final reduction. However, any error can be corrected with a Residual Deformity Correction once the struts reach neutral length.

Choosing the *Origin* and *Corresponding Point* for Congenital and Remodeled Deformities - Additional Considerations

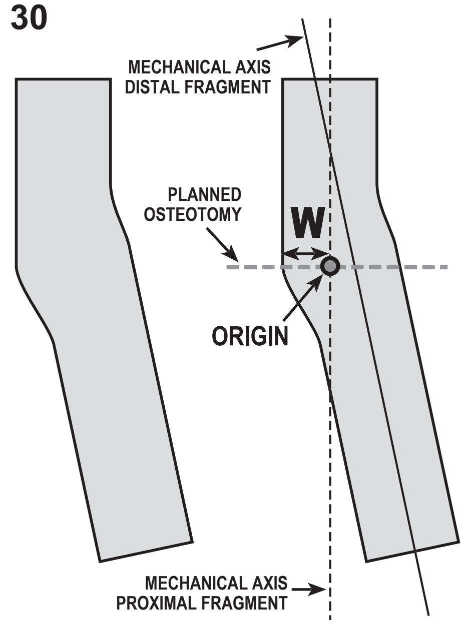
Congenital deformities, old remodeled malunions, and two bone deformities (tibia-fibula, radius-ulna) require additional considerations. The level of the Origin (transverse plane) could be arbitrarily chosen provided the Corresponding Point could be determined. However, the most useful levels for establishing the Origin has been the knee joint line for distal femoral deformity; proximal tibia-fibula joint for proximal tibial deformities; the ankle joint line for distal tibial deformities; and the subtalar joint for ankle and hindfoot deformities. The level of the anatomic center of rotation of the knee is a convenient level for the Origin in correction of knee contracture.

Remodeled shaft deformities should have the level of the Origin set at the intended osteotomy or a nearby anatomic landmark such as a boney prominence or broken screw. It is essential that the level of the Origin can be accurately determined on both AP and Lateral radiographs.

In general the Corresponding Point will not reside at the level of the Origin in the deformed position except for pure rotational or pure translational deformities. Even if the true Corresponding Point resided at the level of the Origin in a pure remodeled varus tibial deformity the best choice for determining the level of the Corresponding Point would reflect that the tibia is functionally short. Then, after the tibia is osteotomized and the angular deformity corrected, sufficient length is gained to prevent the remodeled bone on the convexity from impinging. This is equivalent to positioning the Ilizarov hinge axis to pass along the convexity of a deformity to prevent impaction. For each case of congenital deformity or remodeled malunion a simple geometric local analysis is performed to determine the best choice of corresponding point to fully correct the deformity and prevent impaction at the osteotomy or to match the length of the other bone on the convexity in a two bone system.

The mechanical axes are drawn for each of the fragments. **(Fig. 30)** The Origin is the intersection of the mechanical axis of the reference fragment and the specific level (transverse plane) which the surgeon has chosen. Generally, the surgeon wants to bring the mechanical axis of the deformed fragment to coincide with the mechanical axis of the reference fragment. The difficulty is determining which point along the mechanical axis of the deformed fragment corresponds to a particular point on the mechanical axis of the reference fragment, which has been chosen as Origin.

Fig. 30



Geometric Local Analysis of Extra Length to Prevent Impaction

Measure the distance from the origin to the convex cortex of the reference fragment ‘W’ **(see Fig. 30)**. Reproduce a line segment ‘T’ of length ‘W’ with one end touching the plane passing through the origin and the other end touching and perpendicular to the mechanical axis of the deformed fragment. The point of contact of this line segment with the axis of the deformed fragment is the corresponding point. **(Fig. 31)** When this corresponding point is reduced to the origin the deformity will have been reduced with enough length gained to prevent impaction.

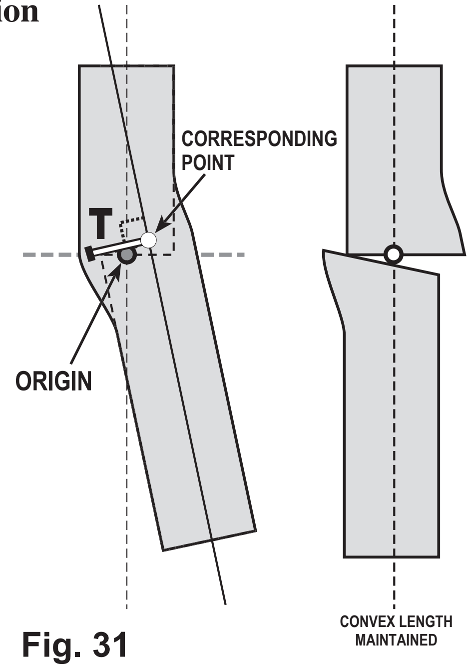


Fig. 31

Similarly, in a two bone system, draw the mechanical axes of each fragment. Determine the plane of the origin. **(Fig. 32)** Measure the distance from the origin to the convex cortex of the second bone ‘W’. Reproduce a line segment ‘T’ of length ‘W’ with one end touching the plane passing through the origin and the other end touching and perpendicular to the mechanical axis of the deformed fragment. The point of contact of this line segment with the axis of the deformed fragment is the corresponding point. **(Fig. 33)**

When this corresponding point is reduced to the origin the deformity will have been reduced with enough length gained to prevent impaction at the second bone at the convexity.

Fig. 32

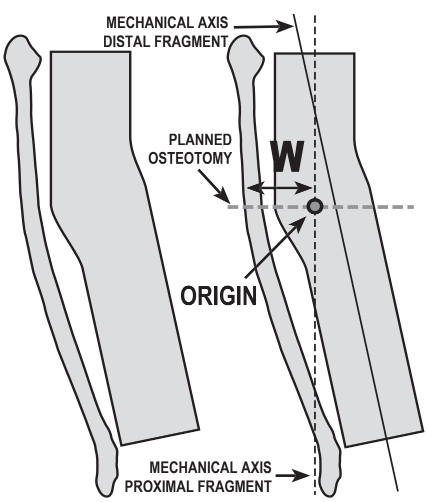
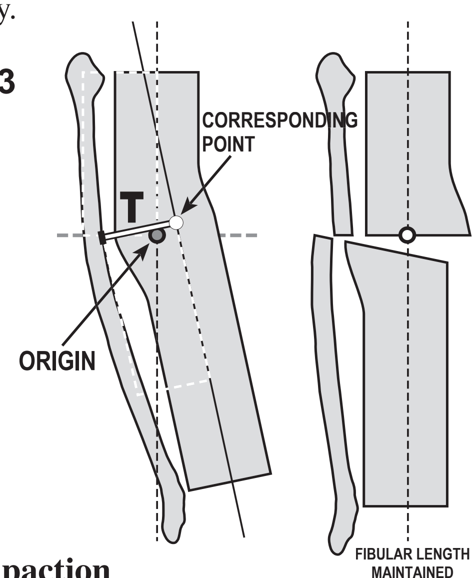


Fig. 33



Trigonometric Local Analysis of Extra Length to Prevent Impaction

Similarly, a trigonometric analysis may be performed to find the most appropriate Corresponding Point, so that when the angular deformity is corrected the convex cortices will just clear one another. If ‘W’ is the distance from the Origin to the convex cortex and θ is the angle between the mechanical axis of the reference fragment and the mechanical axis of the deformed fragment, then the amount of shortening ‘S’ of the Corresponding Point is: $\mathbf{S} = \mathbf{W} \sin\theta$

Thus, if a line is drawn distance S (shortened) from the origin, the Corresponding Point is located at the intersection of this new line and the mechanical axis of the deformed fragment. **(Fig.34)**

Sometimes it is more useful to utilize the anatomic axes for femoral cases rather than mechanical axes.

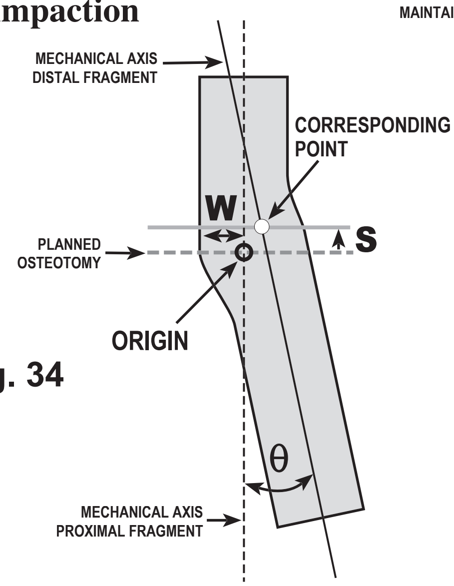


Fig. 34

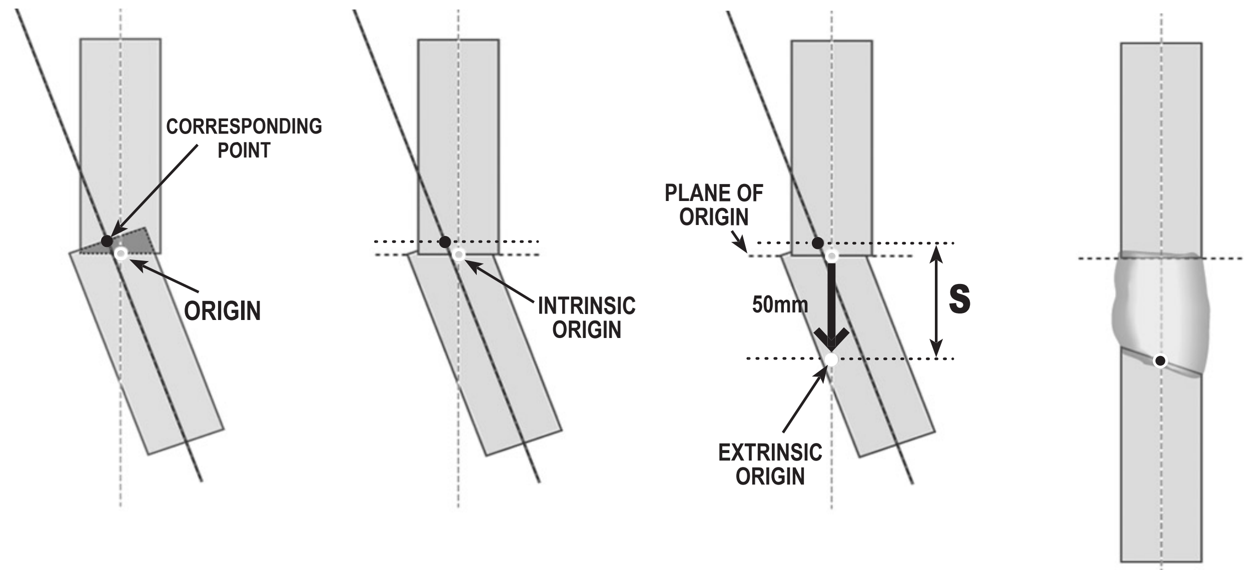
Intrinsic vs Extrinsic Deformity

In the previous example the origin and corresponding point chosen will characterize and thus serve to correct the inherent or intrinsic deformity. The origin selected is the intrinsic origin . When the corresponding point is restored to the intrinsic origin, the angular and translational deformity will be corrected with the corresponding point gaining just enough length through the local analysis to maintain a constant lateral cortical length.

In other situations the surgeon may have other additional or extrinsic information to take into account for a deformity correction. For instance, the physician may know by scanogram that the deformed limb is also 50 mm short or that based on growth charts there will be a 50 mm limb length discrepancy. **(Fig. 35)** This additional shortening deformity is an extrinsic deformity. If the physician wants to correct the intrinsic plus extrinsic deformity an extrinsic origin is selected 50 mm along the mechanical axis of the reference fragment from the intrinsic origin. The deformity parameters are measured from the extrinsic origin to the corresponding point. For the tibia, humerus and forearm the only change is in the axial shortening. The AP and Lateral view translations and all rotation and angulations remain the same for an intrinsic or extrinsic correction. If there is a particular level of attachment of the reference ring that is to be used for intrinsic or extrinsic correction (as is usually the case) the surgeon must also add 50 mm to axial frame offset under the mounting parameters for the extrinsic correction.

Performing an extrinsic correction is similar to performing an initial deformity correction followed by a residual deformity correction consisting of length only. The intrinsic origin is essentially a way point as the corresponding point moves to the extrinsic origin.

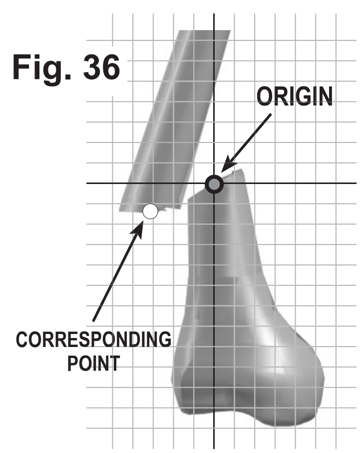
Fig. 35



The following examples demonstrate typical choices for Origin and Corresponding Point.

• Post-traumatic femoral shaft deformity. In this deformity the bone ends are still discernable. The Origin is established at the anatomic axis at the interior end of the reference fragment. The Corresponding Point is at the anatomic axis of the deformed fragment at its interior end. The points will be coincident when the deformity is corrected. **(Fig. 36)**

Fig. 36



• Remodeled or congenital femoral shaft deformity. In this deformity bone ends may not be discernable or new bone may be interposed. Set the level of the Origin at the osteotomy site. Local analysis is used to determine a level of corresponding point that will allow full correction of the angular deformity without creating impaction of the convex cortex.

• Proximal tibial varus. Set the level of the Origin at the proximal tibia-fibula joint. The Origin is the intersection of the mechanical axis of the proximal tibia with the plane passing through the tibia-fibula joint. The distance 'W' from the mechanical axis to the tibia-fibula joint is measured and a second line 'T' of length 'W' is constructed so that one end lies on the proximal tibia-fibula joint plane and the other end rests on and is perpendicular to the mechanical axis of the distal fragment. **(Fig. 37)** The Corresponding Point is the intersection of this constructed line segment with the mechanical axis of the distal fragment. This choice of Origin and Corresponding Point will allow full correction of angular and translational deformity without changing fibular length. Fibular osteotomy is generally unnecessary. **(Fig. 38)**

Fig. 37

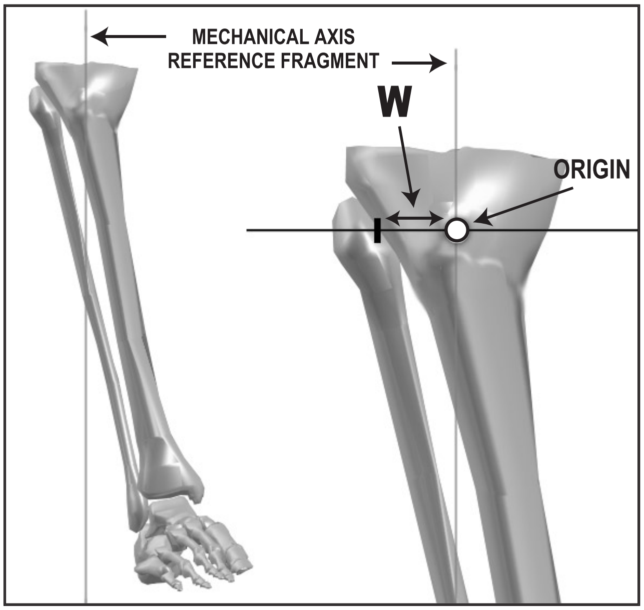
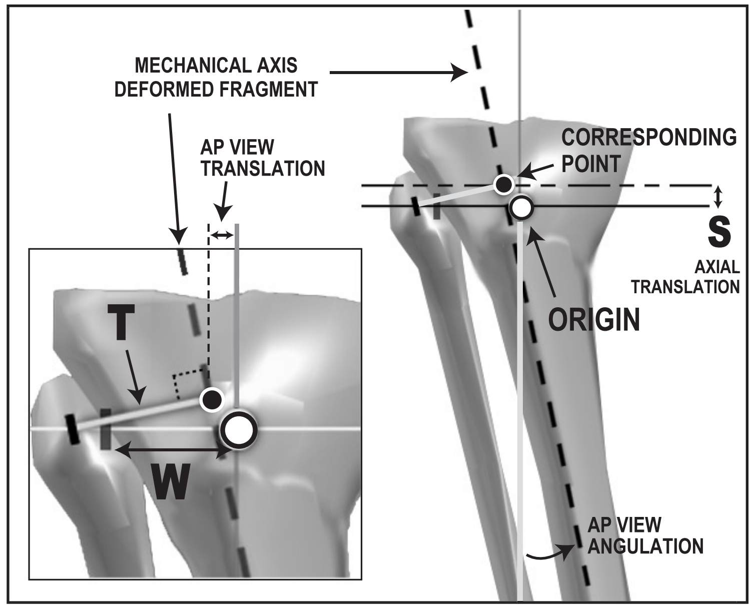
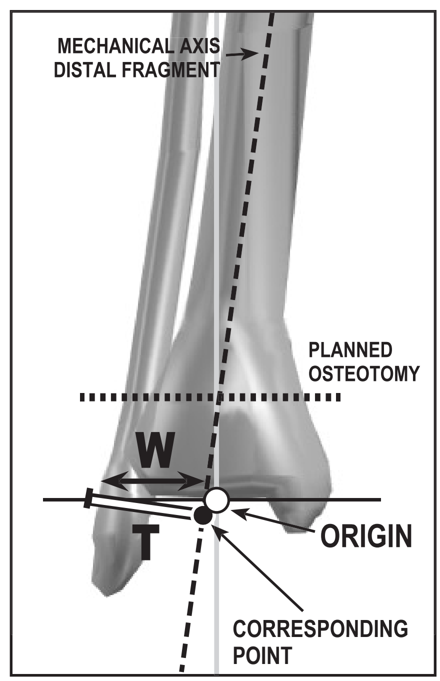


Fig. 38



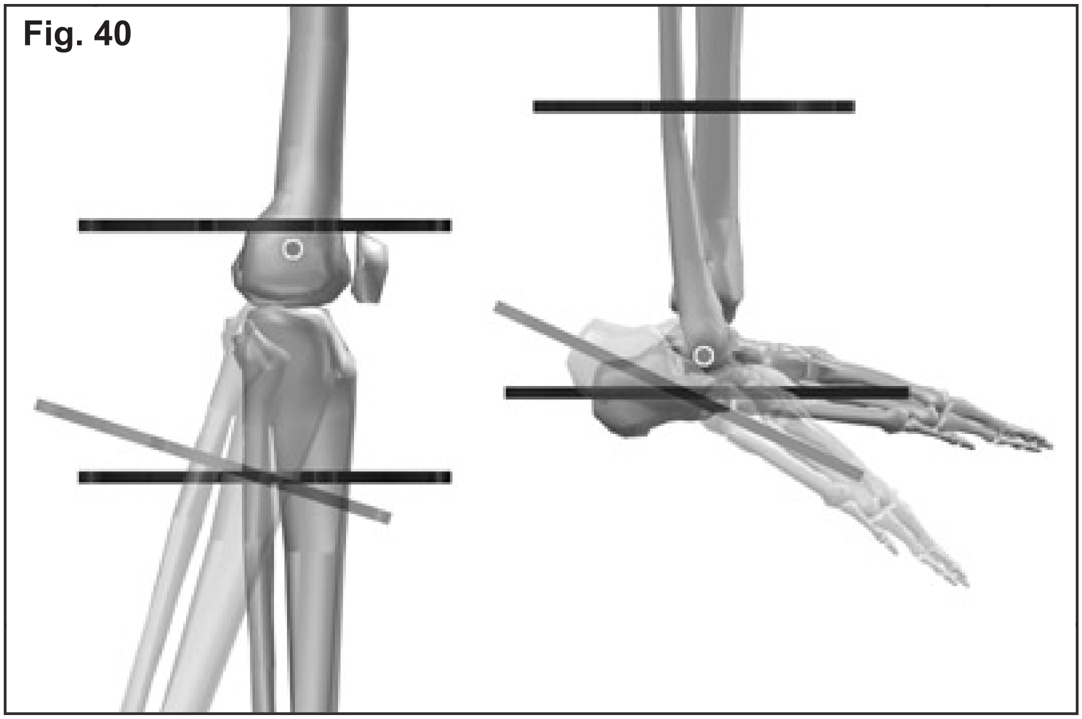
• Distal tibial varus. Set the level of the Origin at the ankle joint. The Origin is the intersection of the mechanical axis of the distal tibia at the ankle joint. The distance 'W' from the mechanical axis to the tibia-fibula joint is measured and a second line of length 'W' is constructed so that one end lies on the ankle joint plane and the other end rests on and is perpendicular to the mechanical axis of the proximal fragment. The Corresponding Point is the intersection of this constructed line segment with the mechanical axis of the proximal fragment. This choice of Origin and Corresponding Point will allow full correction of angular and translational deformity without changing fibular length. Fibular osteotomy may only be necessary if there is significant distal fibular deformity. **(Fig. 39)**

Fig. 39



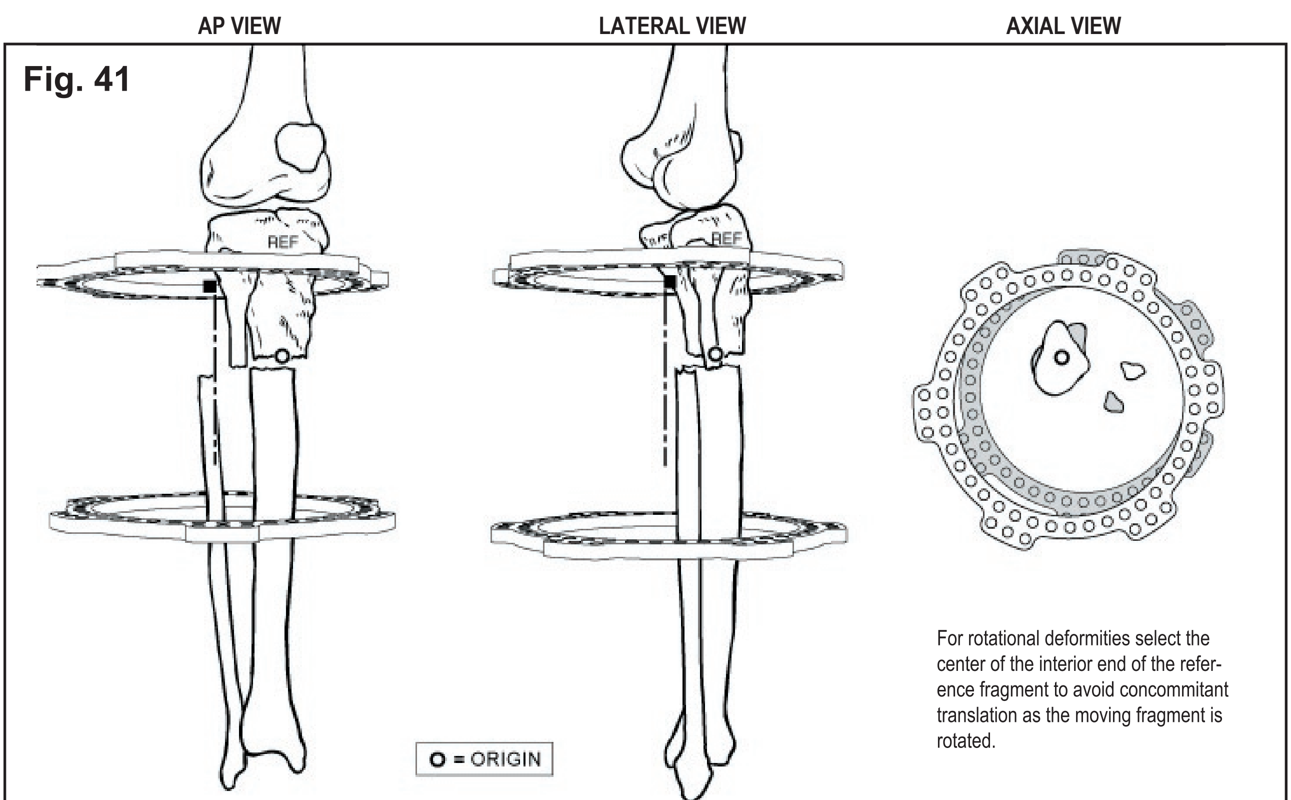
When using the Spatial Frame to correct joint contracture (joint reduced), choose the anatomic center of joint rotation as the Origin. By definition the fragment centerlines intersect at this point, thus there are no translations to measure. The deformity will consist only of rotational deformities. **(Fig. 40)**

Fig. 40



In deformities with significant malrotation, it is especially important to have the origin at the center of the reference fragment at the level of the interior end of the reference fragment **(Fig. 41)**. In these cases no additional translation is created by rotation about this center. Thus any translation measured at the level of the origin will be fully corrected and no additional translation will be created by correction of the malrotation.

Fig. 41



For rotational deformities select the center of the interior end of the reference fragment to avoid concommitant translation as the moving fragment is rotated.

Frame Orientation and Review of Components

The Taylor Spatial Frame fixator consists of two rings or partial rings connected by 6 telescopic struts at special universal joints. Telescopic struts are available in x-short, short, medium, and long sizes. **(Fig. 42)** For a given size, the strut has a specific range from its shortest to longest length and a mid-position marked on each strut.

Six identifier clips, uniquely colored and numbered 1 through 6, are provided with each frame. Each numbered/colored clip is applied to a strut beginning with strut 1 (which is attached to the designated Master Tab anteriorly) and progressing counterclockwise as viewed from the proximal end of the frame.

The computer program assumes the universal joints connecting strut 1 and strut 2 to the proximal ring are aligned directly anterior with respect to the reference fragment. Different rotational alignments, especially for more proximal femoral and humeral applications, can be accommodated by changing rotary frame offset.

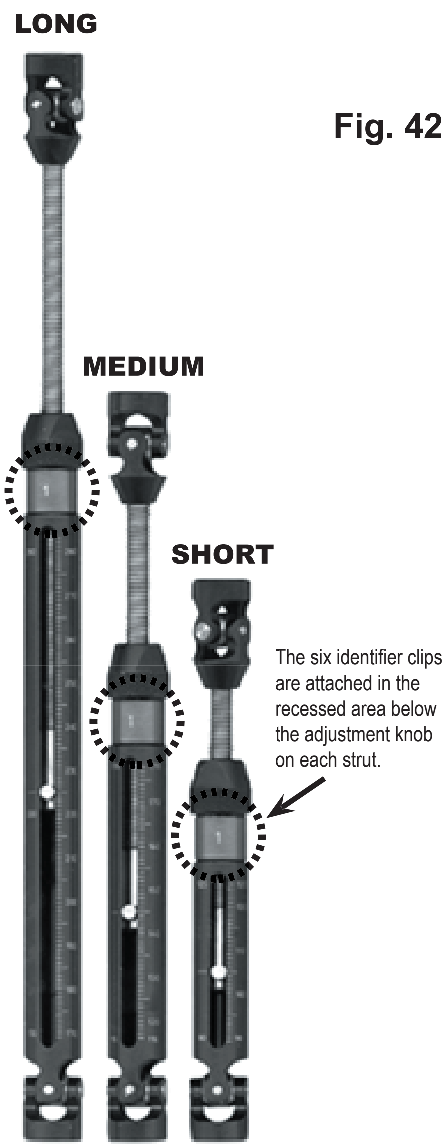
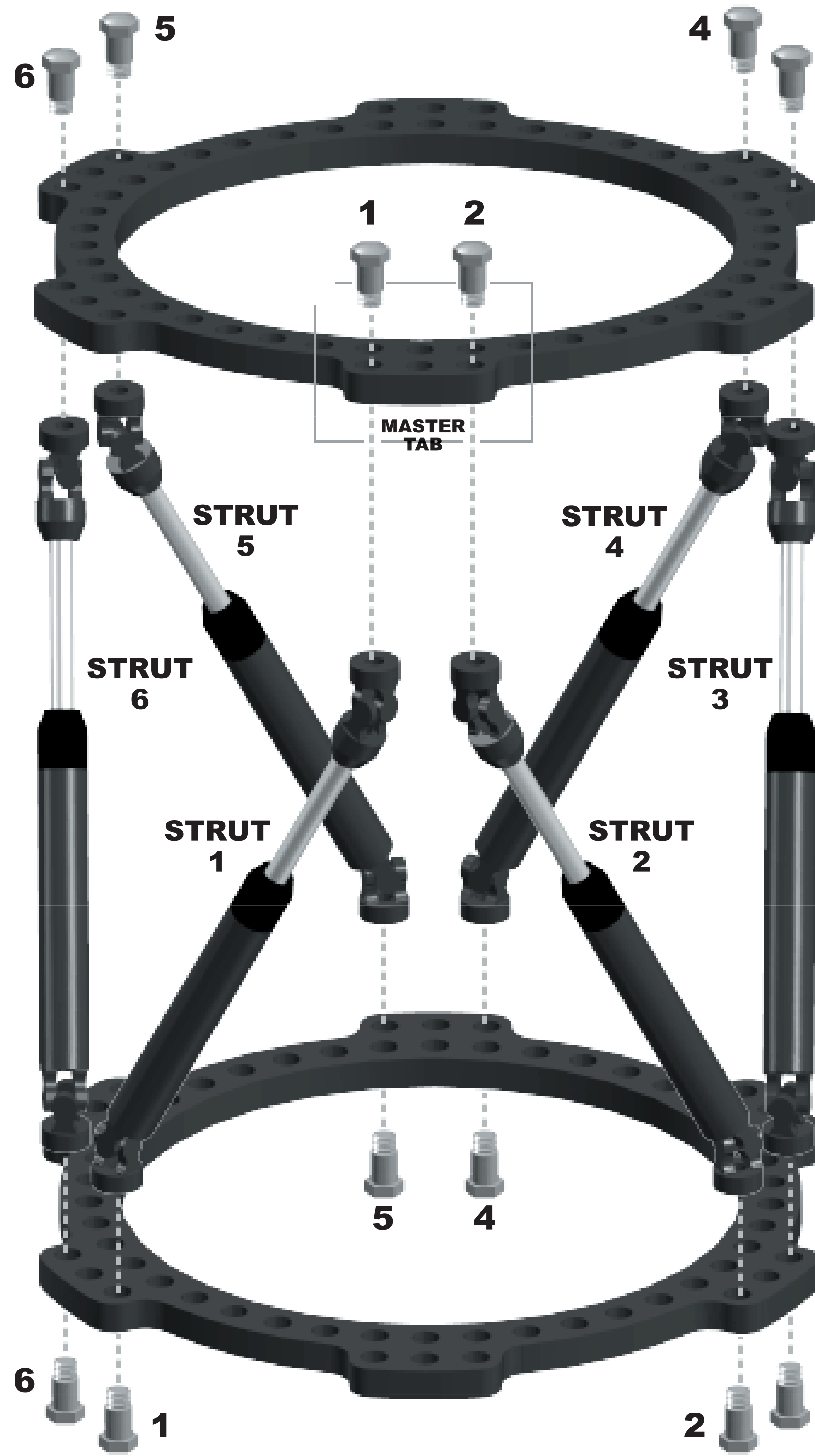


Fig. 42



Acute Fracture Reduction — FastFx™ Struts

Utilizing Fast Fx™ struts, a new primary method has evolved with the Taylor Spatial Frame Fixator™ (**Fig. 43**).

First a frame is mounted. (See illustration series below: **Fig. 44** - foam bone, **Fig. 45** - in surgery.)

With the struts in their sliding mode the fracture is acutely reduced under direct vision or C-arm control and the strut slides locked. Thus, in general, you will be left with a crooked frame on a slightly crooked bone.

The frame is first fixed to the bone without worrying about reduction. The bone is then reduced without worrying about fixation.

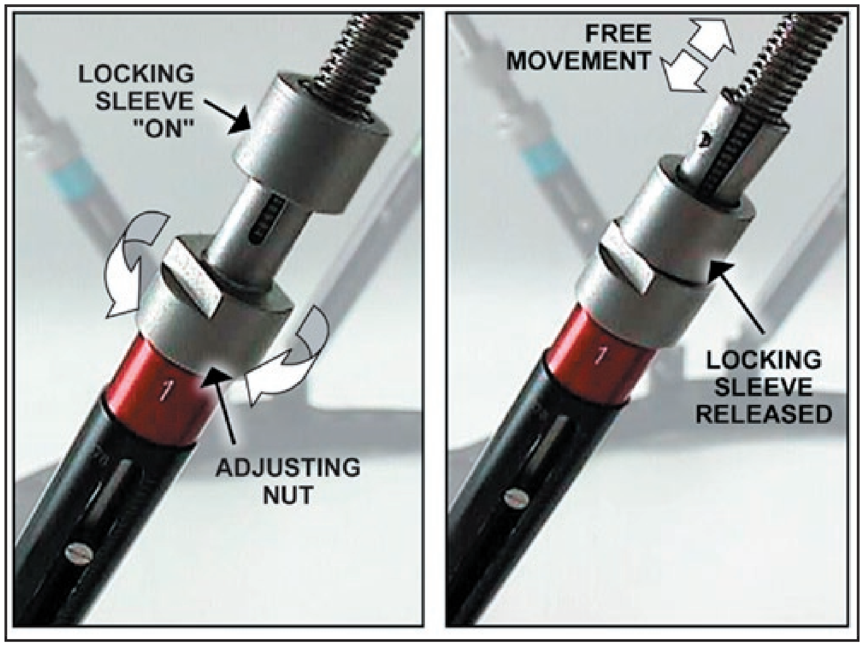
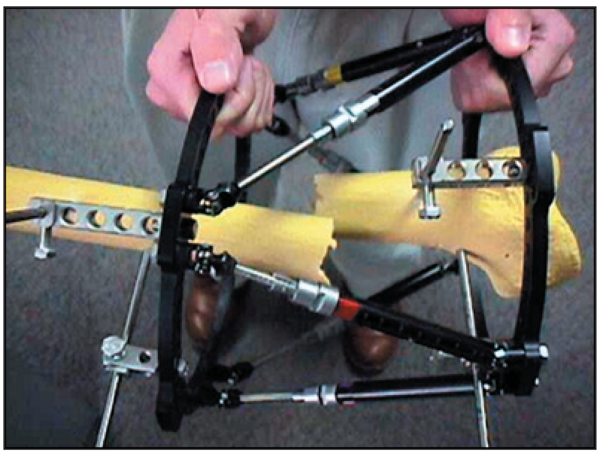
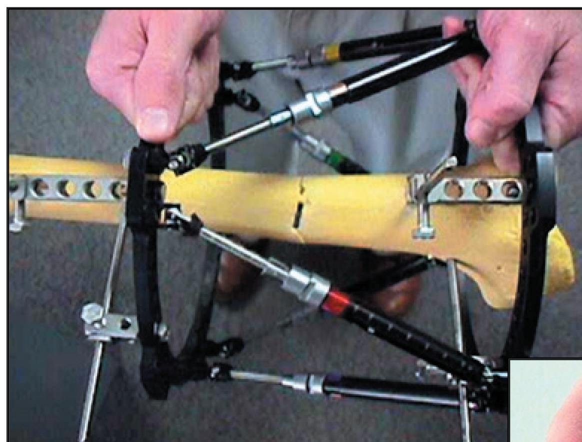
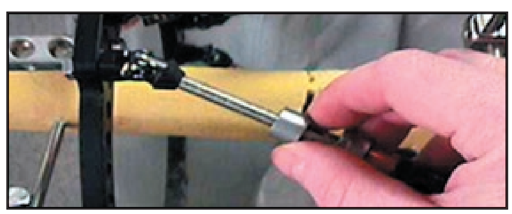


Fig. 43 Fast Fx™ struts have dual actions. With the locking sleeve released the strut length can be easily changed like a trombone slide. If six Fast Fx™ struts are used on a Spatial Frame and all locking sleeves are released the frame can be adjusted through all six degrees of freedom, analogous to an unlocked ball joint frame.







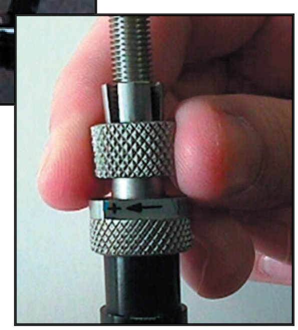
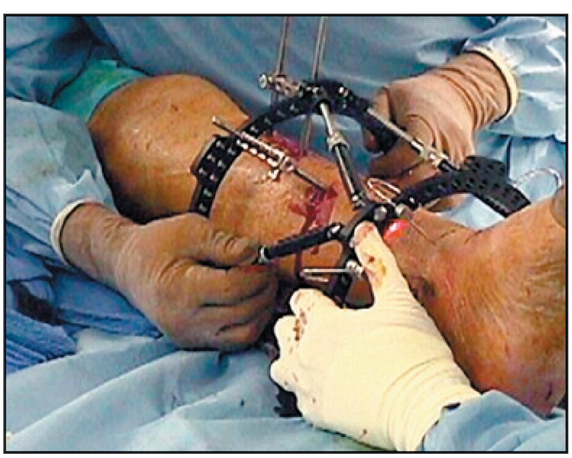
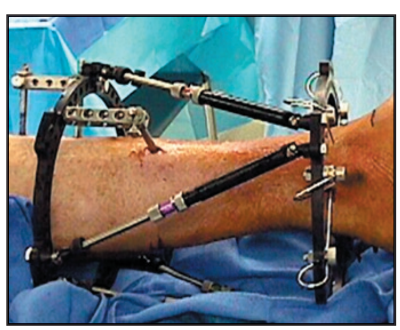


Fig. 44





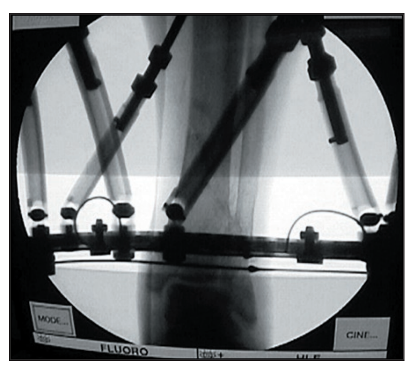


Fig. 45

A powerful new web based program **(Fig. 46)** allows the surgeon to perform a total residual correction of skeletal deformity even though it is mounted to a non-neutral or crooked frame. The only difference in this new program is under the frame parameters where in addition to the ring diameters we now enter each of the 6 specific strut lengths when the x-rays were taken.

Indications

The primary indications will probably be referred patients without documentation, very nonorthogonal mounting for a gradual Rings First method for fractures and chronic deformities, and in support of the Fast Fx™ method.

Method

Patient and file information as well as specific case notes can be saved to the physicians computer. Saved cases can be reopened and modified, then saved again as the same or different case or scenario.

To begin, enter patient information and the side (left or right). **(Fig. 47)**

In the next window **(Fig. 48),** select the proximal or distal reference fragment. Input the six skeletal deformity parameters. When regenerate views is then selected the software provides the surgeon with updated AP, Lateral , and Axial views of the skeletal deformity. The pointed end of the blue rod is the Origin and the pointed end of the green rod is the Corresponding Point.

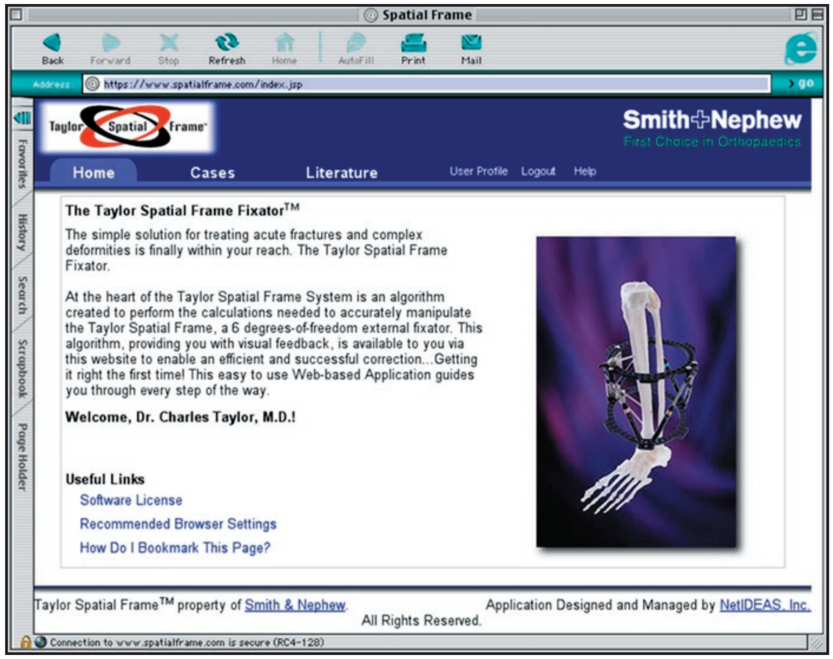


Fig. 46

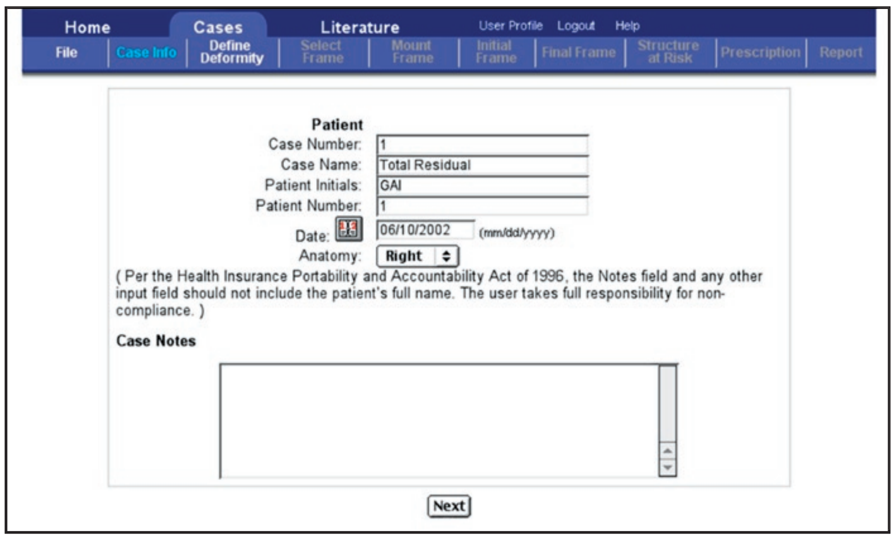


Fig. 47

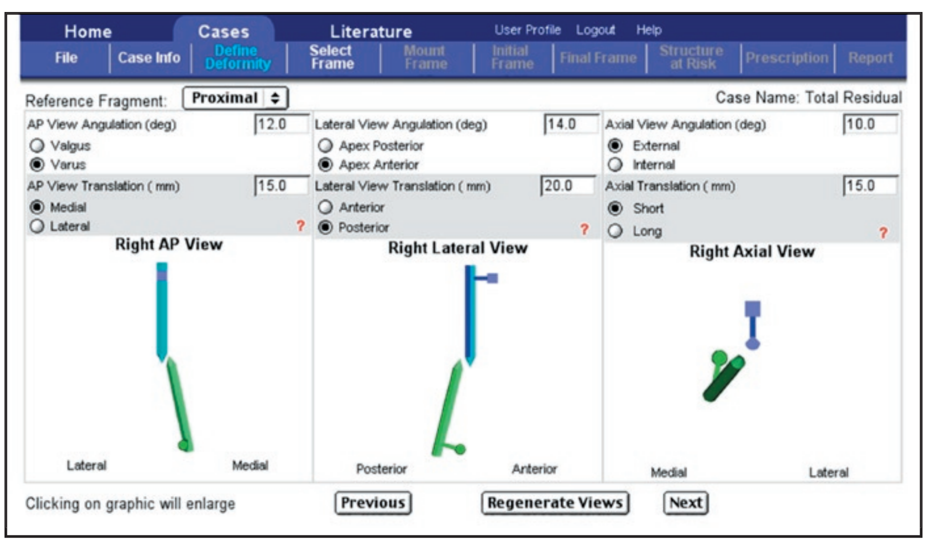


Fig. 48

Using the pull down menu in the next window, select the proximal ring diameter, distal ring diameter, and the strut body type. **(Fig. 49)** Different sized rings may be used to create a tapered frame..

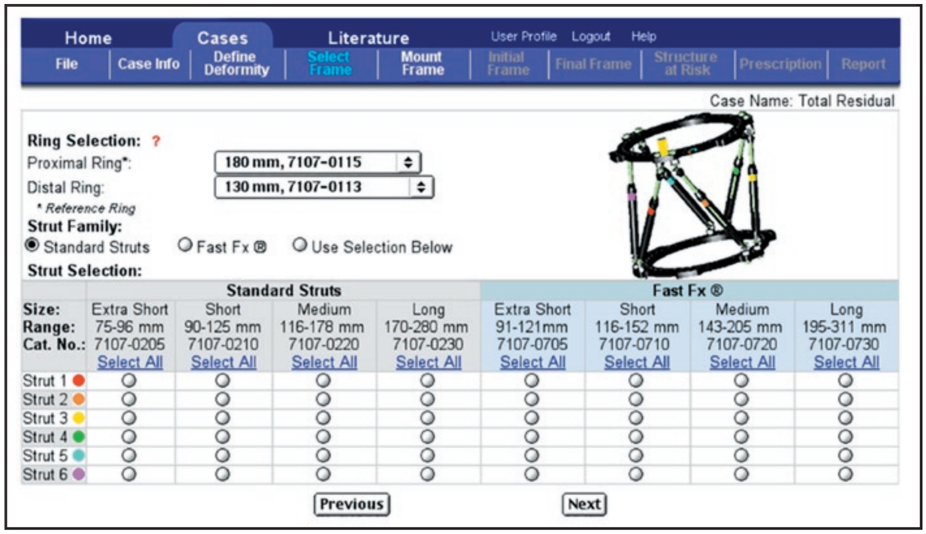


Fig. 49

Next, select the operative mode which in this case is the total residual button. **(Fig. 50)** The position of the reference ring with respect to the Origin is input into the mounting parameters. The regenerated views confirm the relation of the reference ring on the reference fragment.

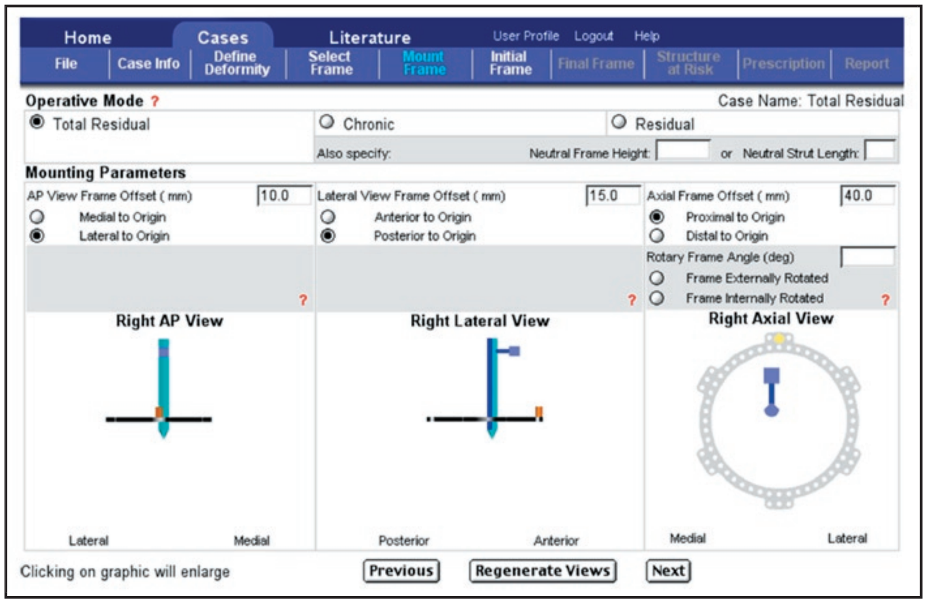


Fig. 50

Each of the six strut lengths is entered in the next window. **(Fig. 51)** The computer then provides a graphical representation of the initial crooked frame on crooked bone.

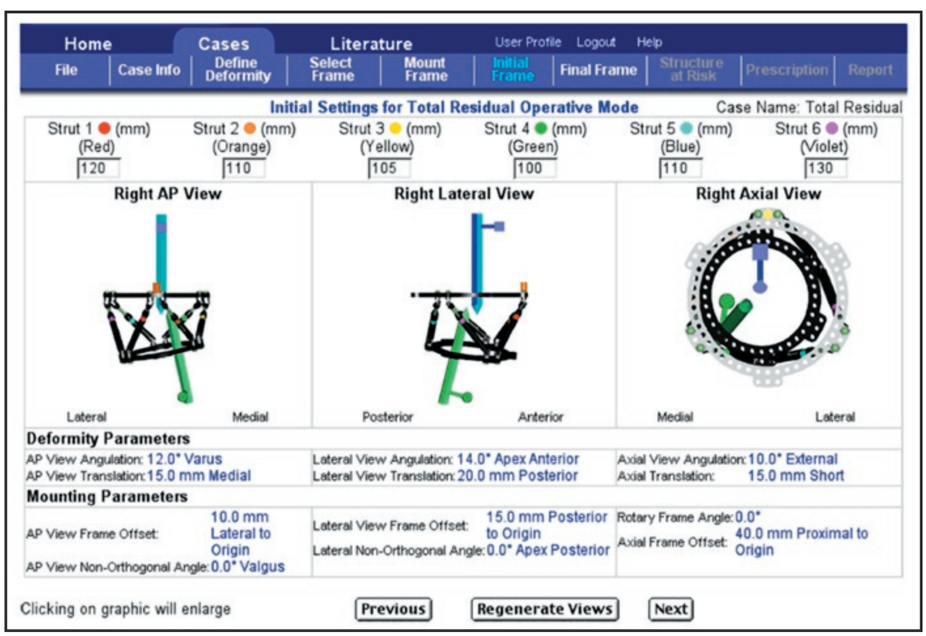


Fig. 51

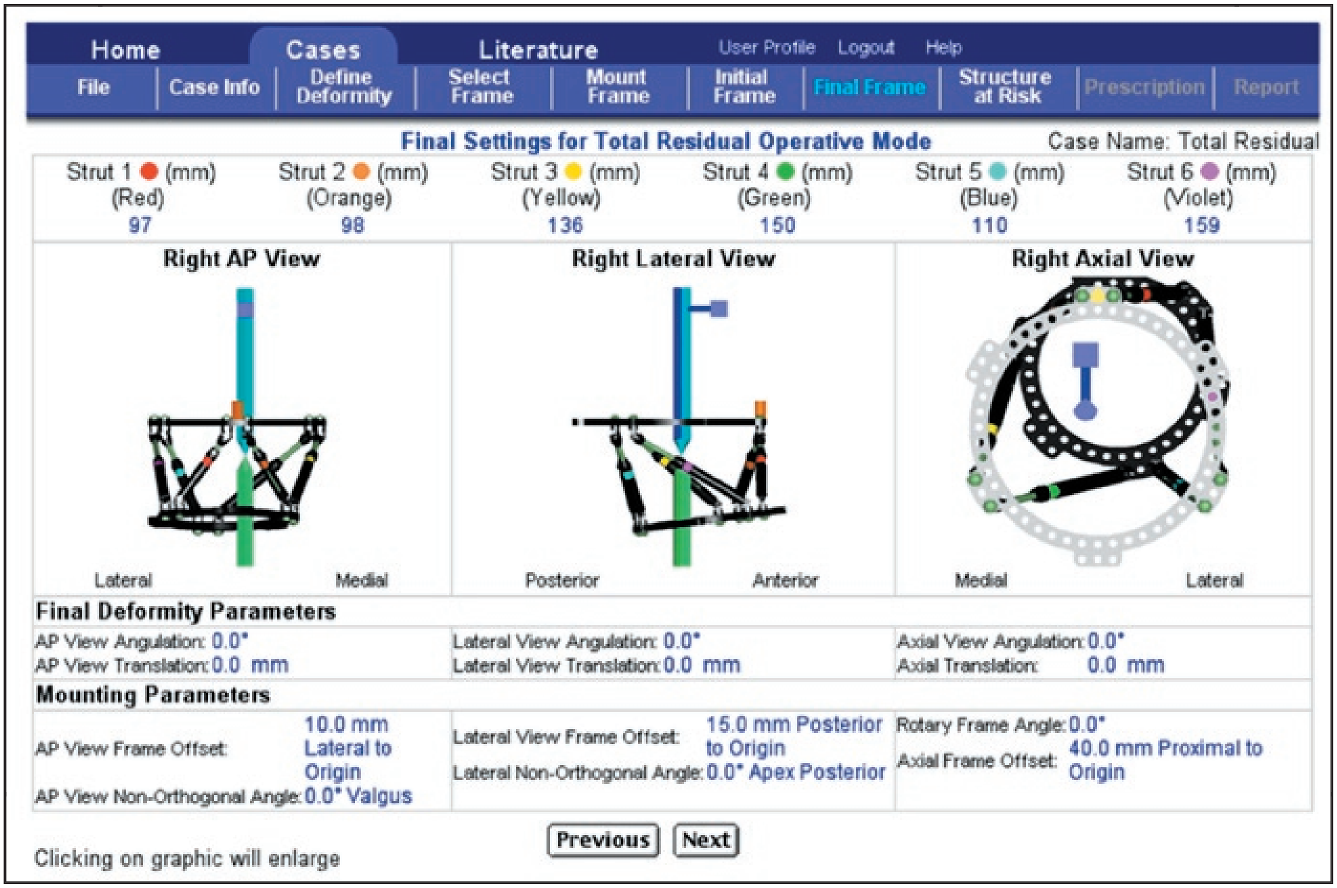


Fig. 52

In the **Final Frame** window, the computer solves for the necessary strut lengths to correct the skeletal deformity and presents it graphically. **(Fig. 52)**

In the next window, the coordinates of the structure at risk and the maximum safe velocity are entered. **(Fig. 53)** The computer determines the number of days required for the correction. The surgeon may also override the number of days.

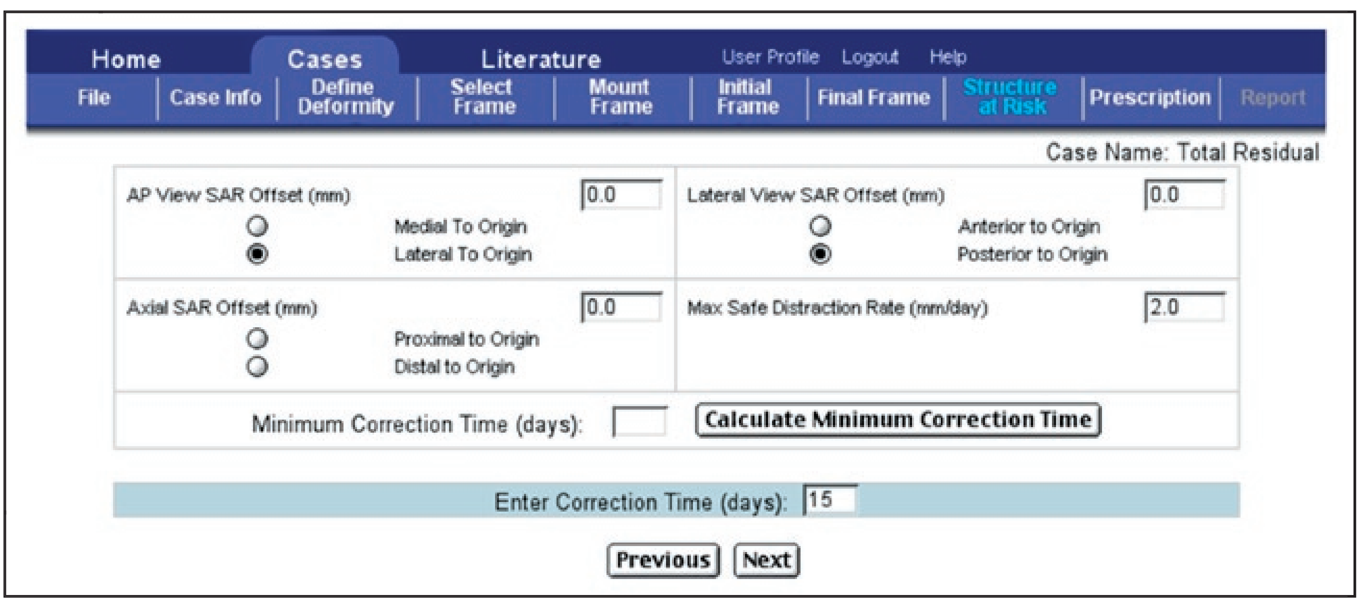
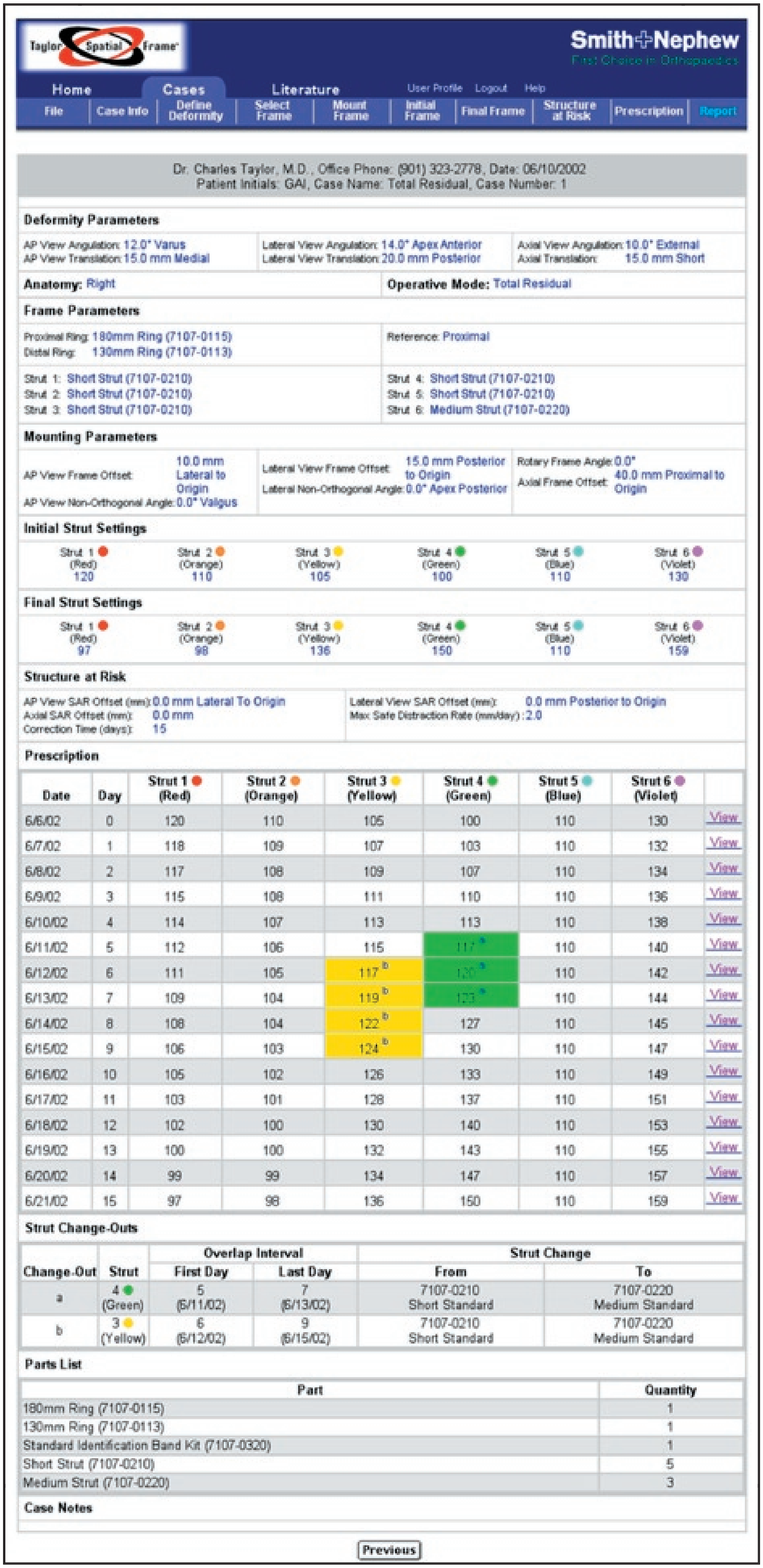


Fig. 53

Fig. 54



Dr. Charles Taylor, M.D., Office Phone: (901) 323-2778, Date: 06/10/2002
Patient Initials: GAI, Case Name: Total Residual, Case Number: 1

Deformity Parameters

AP View Angulation: 12.0° Varus
AP View Translation: 15.0 mm Medial
Lateral View Angulation: 14.0° Apex Anterior
Lateral View Translation: 20.0 mm Posterior
Axial View Angulation: 10.0° External
Axial Translation: 15.0 mm Short

Anatomy: Right
Operative Mode: Total Residual

Frame Parameters

Proximal Ring: 180mm Ring (7107-0115)
Distal Ring: 130mm Ring (7107-0113)
Reference: Proximal

Strut 1: Short Strut (7107-0210)
Strut 2: Short Strut (7107-0210)
Strut 3: Short Strut (7107-0210)
Strut 4: Short Strut (7107-0210)
Strut 5: Short Strut (7107-0210)
Strut 6: Medium Strut (7107-0220)

Mounting Parameters

AP View Frame Offset: 10.0 mm Lateral to Origin
AP View Non-Orthogonal Angle: 0.0° Valgus
Lateral View Frame Offset: 15.0 mm Posterior to Origin
Lateral Non-Orthogonal Angle: 0.0° Apex Posterior
Rotary Frame Angle: 0.0°
Axial Frame Offset: 40.0 mm Proximal to Origin

Initial Strut Settings

Strut 1 (Red)	Strut 2 (Orange)	Strut 3 (Yellow)	Strut 4 (Green)	Strut 5 (Blue)	Strut 6 (Violet)
120	110	105	100	110	130

Final Strut Settings

Strut 1 (Red)	Strut 2 (Orange)	Strut 3 (Yellow)	Strut 4 (Green)	Strut 5 (Blue)	Strut 6 (Violet)
97	98	136	150	110	159

Structure at Risk

AP View SAR Offset (mm): 0.0 mm Lateral To Origin
Axial SAR Offset (mm): 0.0 mm
Correction Time (days): 15
Lateral View SAR Offset (mm): 0.0 mm Posterior to Origin
Max Safe Distraction Rate (mm/day): 2.0

Prescription

Date	Day	Strut 1 (Red)	Strut 2 (Orange)	Strut 3 (Yellow)	Strut 4 (Green)	Strut 5 (Blue)	Strut 6 (Violet)	
6/6/02	0	120	110	105	100	110	130	View
6/7/02	1	118	109	107	103	110	132	View
6/8/02	2	117	108	109	107	110	134	View
6/9/02	3	115	108	111	110	110	136	View
6/10/02	4	114	107	113	113	110	138	View
6/11/02	5	112	106	115	117 a	110	140	View
6/12/02	6	111	105	117 b	120 a	110	142	View
6/13/02	7	109	104	119 b	123 a	110	144	View
6/14/02	8	108	104	122 b	127	110	145	View
6/15/02	9	106	103	124 b	130	110	147	View
6/16/02	10	105	102	126	133	110	149	View
6/17/02	11	103	101	128	137	110	151	View
6/18/02	12	102	100	130	140	110	153	View
6/19/02	13	100	100	132	143	110	155	View
6/20/02	14	99	99	134	147	110	157	View
6/21/02	15	97	98	136	150	110	159	View

Strut Change-Outs

Change-Out	Strut	Overlap Interval		Strut Change	
		First Day	Last Day	From	To
a	4 (Green)	5 (6/11/02)	7 (6/13/02)	7107-0210 Short Standard	7107-0220 Medium Standard
b	3 (Yellow)	6 (6/12/02)	9 (6/15/02)	7107-0210 Short Standard	7107-0220 Medium Standard

Parts List

Part	Quantity
180mm Ring (7107-0115)	1
130mm Ring (7107-0113)	1
Standard Identification Band Kit (7107-0320)	1
Short Strut (7107-0210)	5
Medium Strut (7107-0220)	3

Case Notes

Previous

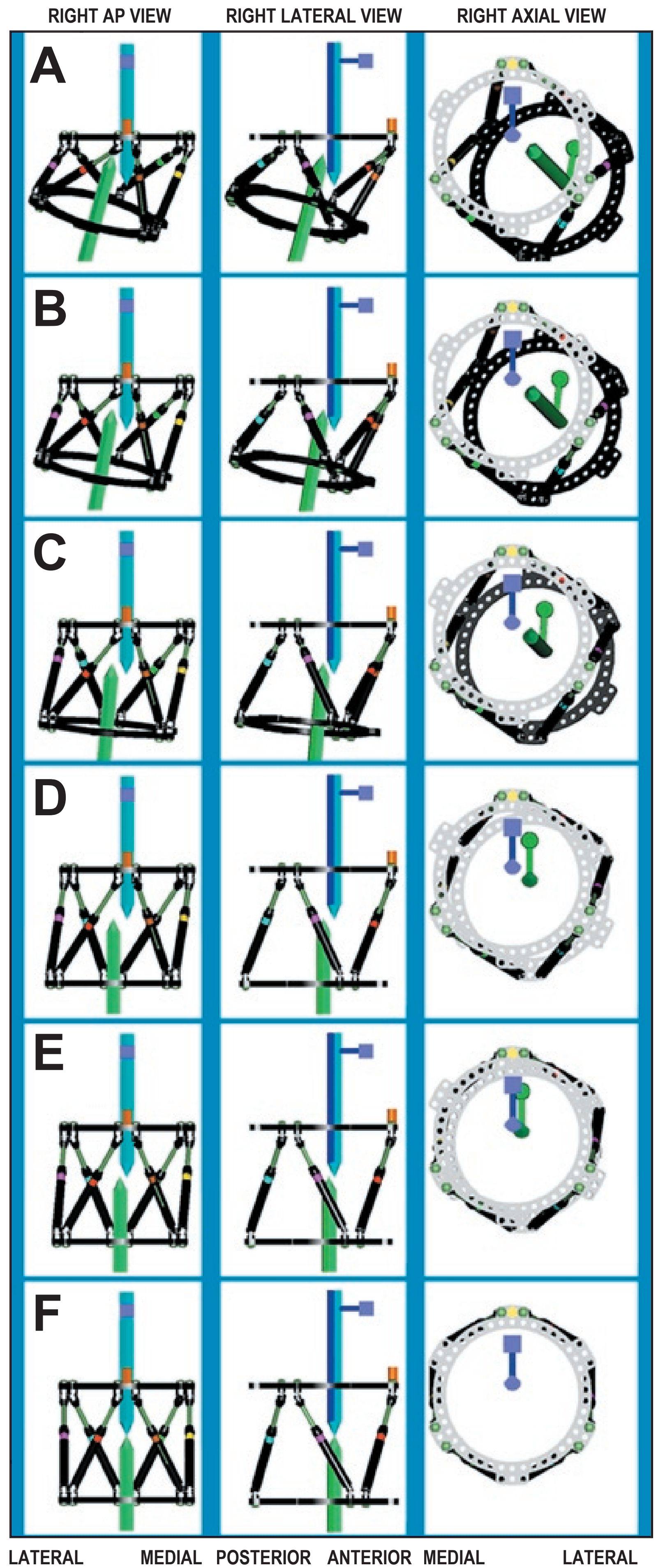
In the report window (**Fig. 54**), physician and patient information is reiterated.

The mounting parameters, initial and final strut settings, the coordinates of the structure at risk, as well as the safe velocity are shown in table form.

The daily adjustment schedule is also provided. Critical days when struts need to be swapped out are highlighted and color coded and identified with a letter.

The strut exchanges are listed and explained in chronological order, and a list of necessary Spatial Frame parts is also given.

Fig. 55



The Total Residual correction program can be used to prepare a daily schedule to correct a deformity via ***way points***. In this case **(Fig. 55)** correcting angulation, rotation and length in the first step **(rows A-B-C-D)**, and correcting translation in a second step **(rows E-F)**.

Way Point Correction with Web Based Software

1. Build a chronic case using the actual deformity and mounting parameters. Generate the strut lengths for the initial frame. Write these down, S1-6.

2. Create a total residual case with the following.

A. Use the deformity parameters that characterize the intended way point under define deformity. (Usually all deformity parameters set to zero with the AP view translation and Lateral view translation kept at their original values.)

B. Set the button for total residual.

C. Insert the strut lengths determined above S1-6 under initial frame. Complete the total residual program for the schedule and report. The preceeding will take the moving fragment to the way point. The strut lengths for the way point are S1-6.

To go from the way point to anatomic reduction -

3. Create a total residual case with the following.

A. Enter the remaining AP view translation and Lateral view translation under define deformity.

B. Set the button for total residual.

C. Insert the strut lengths determined above s1-6 under initial frame. Complete the total residual program for the schedule and report. The preceding will take the moving fragment from the way point to anatomic reduction.

Discussion: In step 2 above the graphical representation of the deformity will not match the complete 6 axis deformity, only the components of which you want to correct first. In step 3 above the graphical representation of the remaining deformity will match the actual remaining deformity.

Proximal Tibial Deformities - Varus Deformity

The deformity will be analyzed using the proximal fragment as the reference fragment. The distal fragment is deformed with respect to a normal proximal fragment. If additional fibular length is needed, then the fibula is generally fixed at each end and osteotomized. If no additional fibular length is needed, most tibial deformities can be corrected without fixing or osteotomizing the fibula. In those cases where the fibula is too long either actually or functionally (by virtue of a slack lateral collateral ligament), the tibia can be lengthened relative to the fibula.

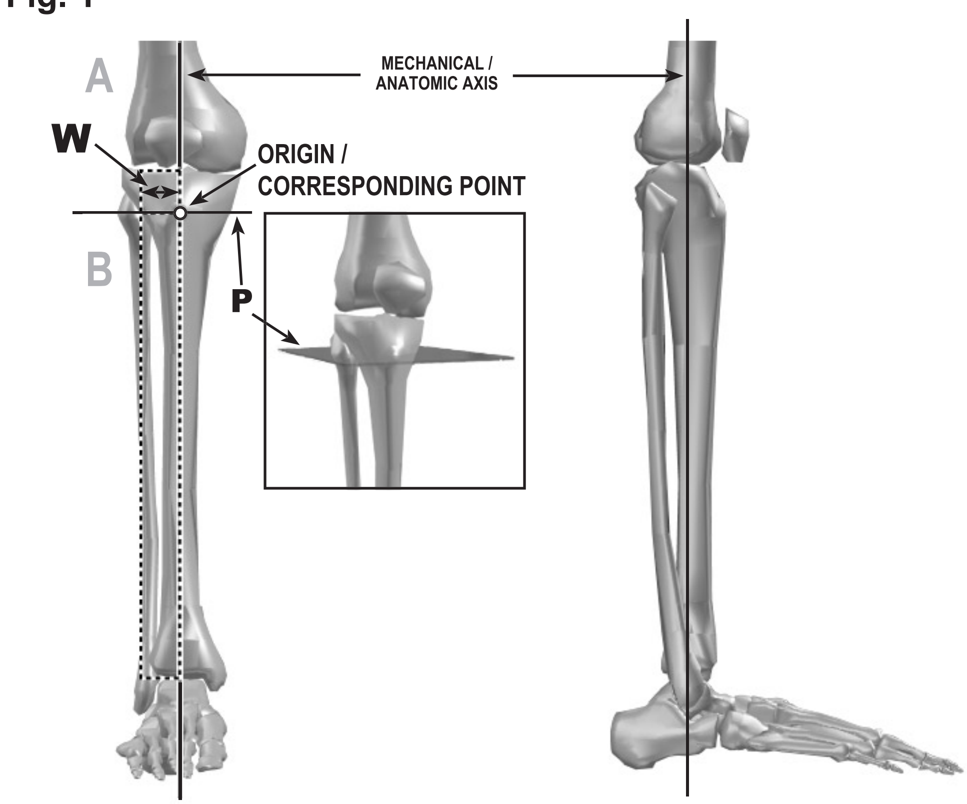
In degenerative arthritis with only varus, an HTO can be performed which fully corrects alignment and translation without cutting the fibula. In Blount's deformities with varus and rotation, the tibial malalignment, malrotation, and malposition may be corrected without fibular osteotomy.

In proximal tibial deformities with varus, rotation, and significant procurvatum (procurvatum is greater than varus) it will generally be necessary to osteotomize the fibula as well.

Imagine the anatomic tibia being composed of two fragments, A and B, meeting at the level of the proximal tibial fibular joint. The mechanical axis passes through the center of the knee joint and ankle joint on AP view and passes through the proximal 1/5 of the knee joint and center of the ankle on lateral view. Construct a box representing each of the fragments as a rectangle of width **W** from the proximal tibial fibular joint to the mechanical axis line. Again, in the anatomic situation these boxes are perfectly apposed at the level of the proximal tibial fibular joint. Choose the *Origin* as the intersection of the proximal fragment mechanical axis with a plane, **P**, passing through the proximal tibial fibular joint. The *Corresponding Point* is the intersection of the mechanical axis of the distal fragment and the plane, **P**, passing through the proximal tibial fibular joint. Thus, in the anatomically reduced position the *Origin* and the *Corresponding Point* are coincident. **(Fig. 1)**

In dealing with proximal tibial deformity, the fibula will be used to determine the length needed. The mechanical axis drawn in the proximal and distal fragment will be used to assess any angulation or translation. With congenital deformity as well as remodeled post traumatic deformity, it may be difficult to identify the true *Corresponding Point* in the deformed fragment to match the *Origin* in the reference fragment. The surgeon wants to bring the mechanical axis of the deformed fragment to coincide with the mechanical axis of the reference fragment. The difficulty is determining which point along the mechanical axis of the deformed fragment corresponds to a particular point on the mechanical axis of the reference fragment, which has been chosen as *Origin*.

Fig. 1



If the surgeon wishes to keep fibular length as is, then the deformity must be characterized or understood in some manner as to keep the lateral side of the distal fragment box at the same length when the deformity is corrected. In **figure 2** choose the *Origin* as that point (on the reference fragment) of intersection of the mechanical axis with a horizontal plane passing through the proximal tibial fibular joint. Measure the distance from the *Origin* to the proximal tibial joint, length **W**.

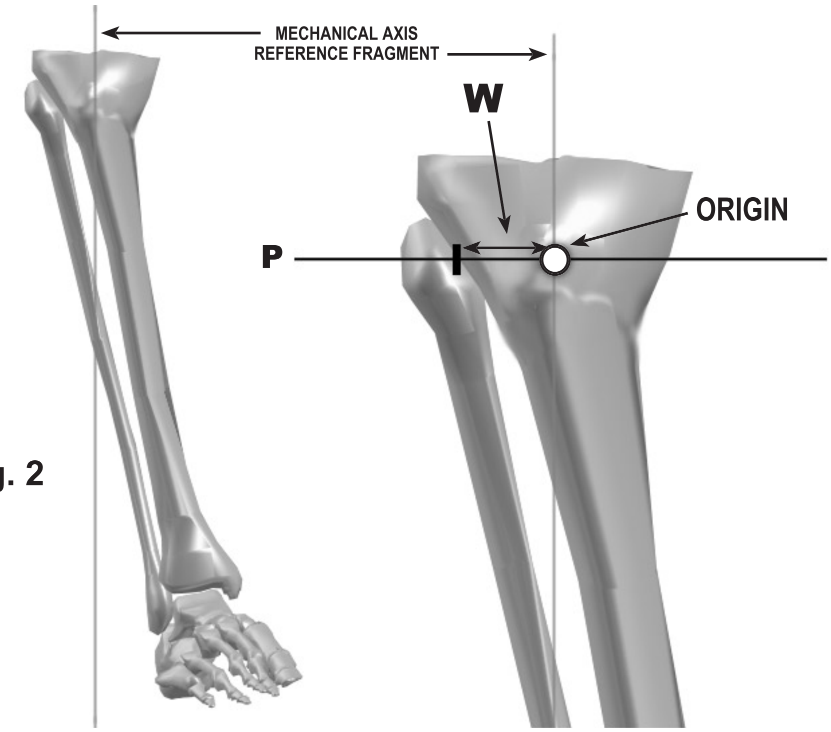
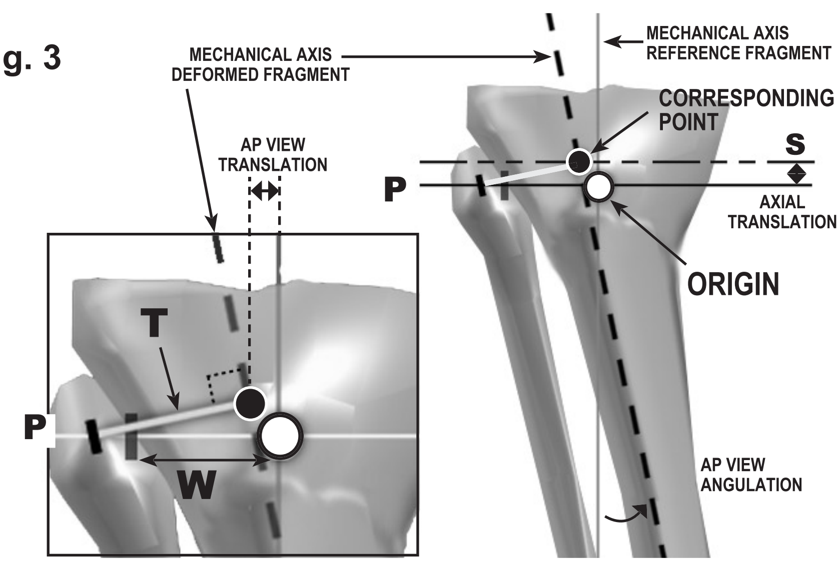


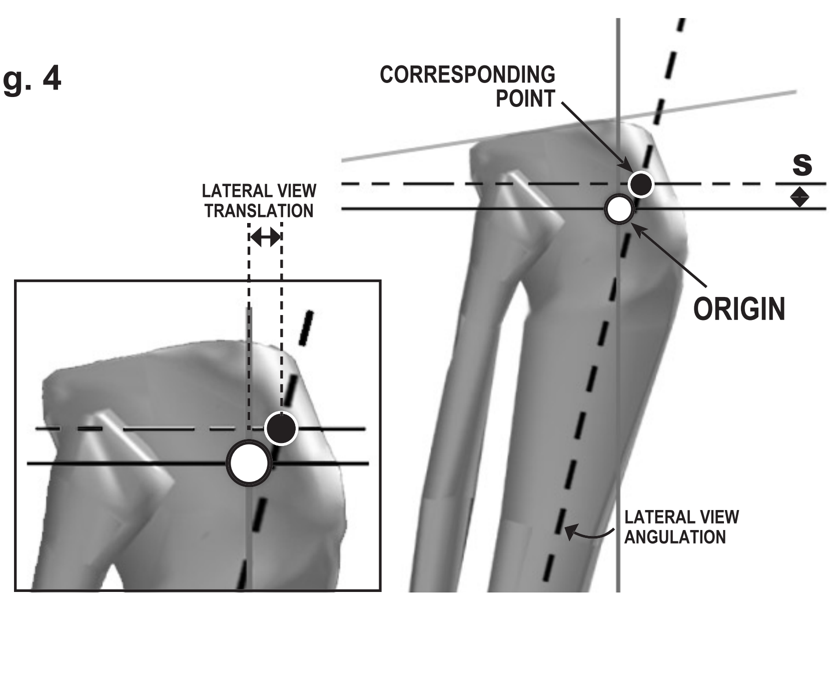
Fig. 2

As shown in **figure 3**, construct a line, **T**, of length **W**, originating from and perpendicular to the mechanical axis of the deformed fragment and terminating on plane **P**.

The perpendicular intersection of **T** with the mechanical axis of the distal fragment represents the true *Corresponding Point* of the *Origin*. Thus the AP view angulation is measured between mechanical axes. The AP view translation and axial translation are measured from the *O*rigin to this constructed *Corresponding Point*.

Fig. 3


Since the amount of shortening, **S**, of the *Corresponding Point* has been determined from the AP view, a second plane parallel to the plane through the proximal tibial fibular joint and located distance **S** proximal is constructed on Lateral view. The intersection of the mechanical axis of the distal fragment with this second plane constitutes the *Corresponding Point* on Lateral view. The Lateral view angulation is measured between mechanical axes on the Lateral view. The Lateral view translation is measured from the *Corresponding Point* to the *Origin* on Lateral view. **(Fig 4)**

Fig. 4


Rotation is measured by comparing the patella and second toe while looking distally. **(Fig. 5)**

Using the Taylor Spatial Frame computer program, input the proper ring sizes, select the chronic deformity mode and choose the neutral frame height, NFH. This is the distance between rings at the end of correction (anatomic restoration). For purely angular deformity use a NFH corresponding to the mid-position of the struts to be used. If the deformity includes a significant shortening, use the more lengthened position of the struts and a correspondingly taller neutral frame height **(Fig. 6)**. Select the correct side right/left. Input the six deformity parameters. Anticipate the position of the proximal ring with respect to the *Origin*. Usually the center of the ring is centered on AP view and 10 – 20 mm posterior to the *Origin* on Lateral view. The proximal ring is usually close to the level of the *Origin*. Enter the mounting parameters in the program. **(Figs. 7-8)** The program will yield the strut lengths to duplicate the deformity.

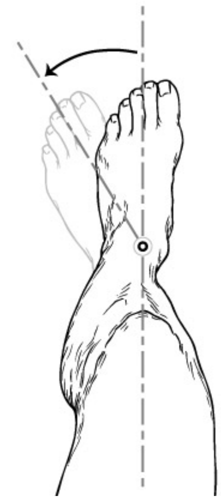


Fig. 5

Clinical examination for rotation.

Fig. 6

Choice of Neutral Frame Height

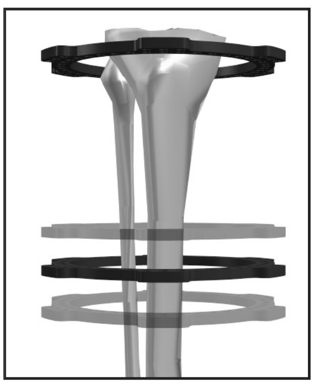


Fig. 7

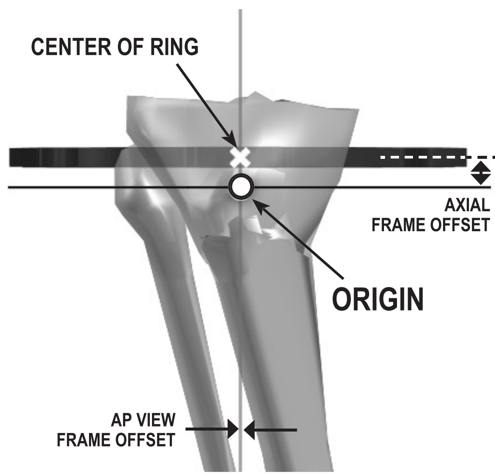
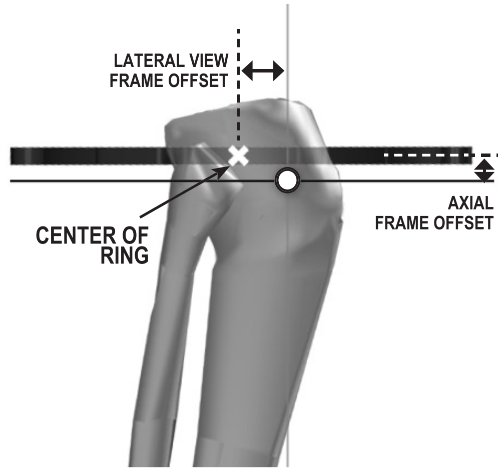
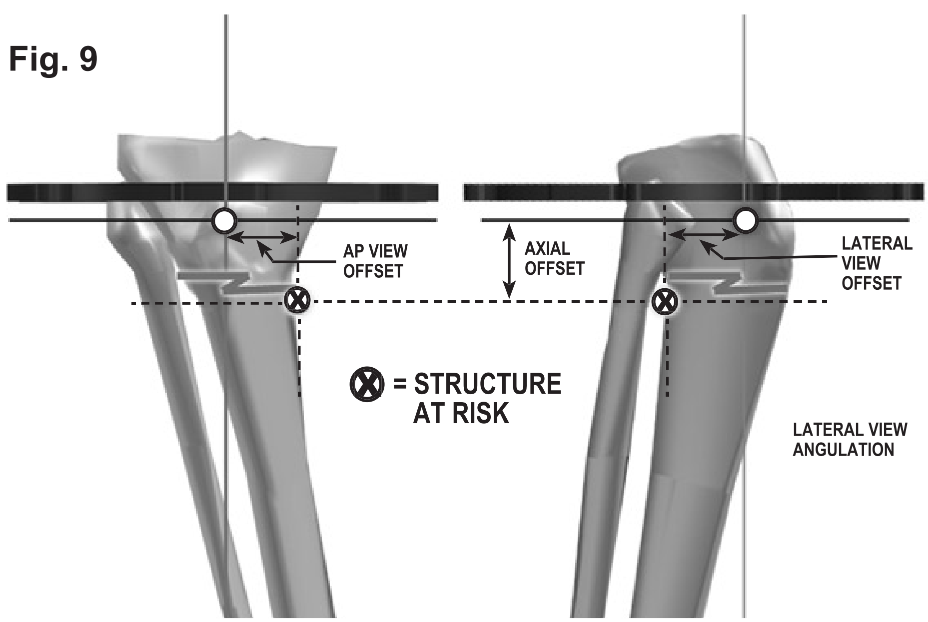


Fig. 8



Determine the structure at risk, usually the posterior medial cortex at the level of intended osteotomy, and input the coordinates with respect to the *Origin* **(Fig. 9)**. Input the safe velocity of the structure at risk. The program will determine the number of days until corrected and prepare a patient schedule with all strut settings given on a daily basis.

Fig. 9



The *Origin* and the *Corresponding Point* will be brought coincident when the deformity is corrected as seen in **figures 10** and **11**.

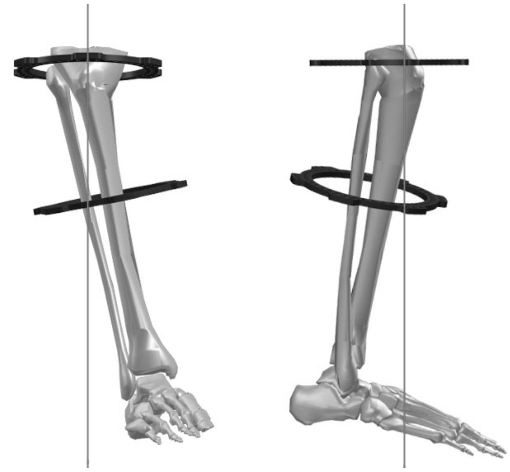


Fig. 10

Varus deformity frame in position. (Struts NOT shown.)

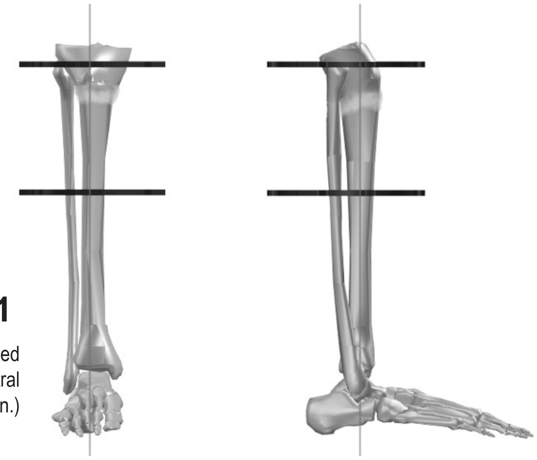


Fig. 11

Varus deformity corrected and frame returned to neutral position. (Struts NOT shown.)

Fibular Head Too Proximal or Slack Lateral Collateral Ligament

Construct the horizontal plane **P** passing through the proximal tibia fibula joint. Choose the *Intrinsic Origin* as that point (on the reference fragment) of intersection of the mechanical axis with a horizontal plane passing through the proximal tibial fibular joint. Measure the distance from the *Origin* to the proximal tibial joint, length **W**.

As shown in **figure 12**, construct a line, **T**, of length **W**, originating from and perpendicular to the mechanical axis of the deformed fragment and terminating on plane **P**. The perpendicular intersection of **T** with the mechanical axis of the distal fragment represents the true *Corresponding Point* of the *Intrinsic Origin*.

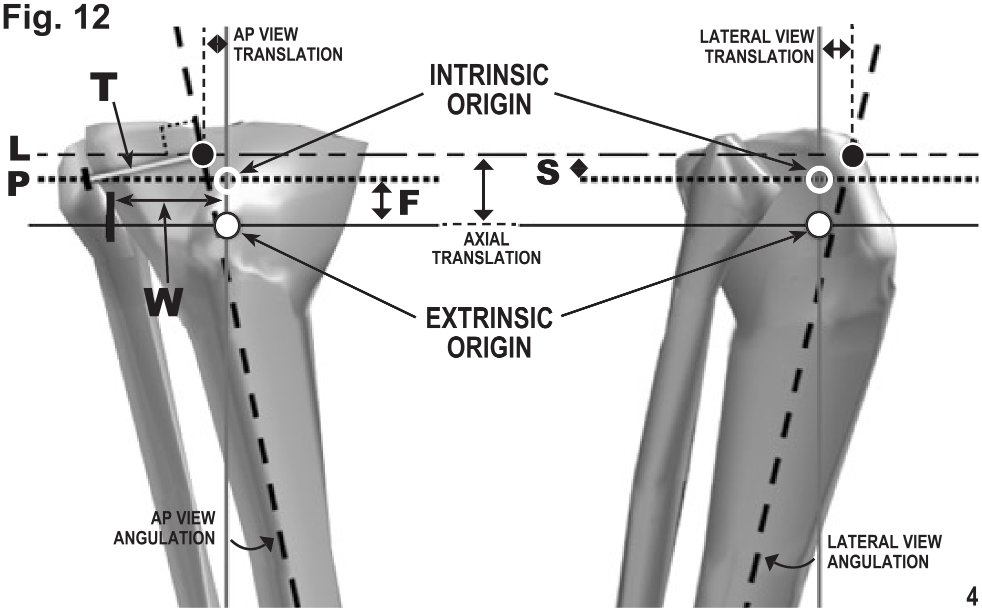
If the fibular head is too proximal by distance **F** or the lateral collateral ligament is slack by distance **F**, locate the *Extrinsic Origin* distance **F** along the mechanical axis of the proximal fragment. Thus the AP view angulation is measured between mechanical axes. The AP view translation and axial translation are measured from the *Extrinsic Origin* to the constructed *Corresponding Point*.

Since the amount of shortening, **S**, of the *Corresponding Point* has been determined from the AP view, a second plane parallel to the plane through the proximal tibial fibular joint and located distance **S** proximal is constructed on Lateral view. The intersection of the mechanical axis of the distal fragment with this second plane constitutes the *Corresponding Point* on Lateral view. The Lateral view angulation is measured between mechanical axes on the Lateral view. The Lateral view translation is measured from the *Corresponding Point* to the *Extrinsic Origin* on Lateral view **(Fig. 12)**.

Rotation is measured by comparing the patella and second toe while looking distally.

Input the frame, deformity, and mounting parameters. Select the chronic mode and the correct side. Enter the position of the structure at risk and the maximum safe rate of correction. The program will output the adjustment schedule. If the reference ring is mounted in the same location as previous, remember to add **F** to Axial Frame Offset.

Fig. 12



Spatial Definitions

Deformity Parameters

The deformity parameters consist of three angulations and three translations which describe the fragment-to-fragment orientation. Translations are measured from the origin to its corresponding point along the coordinate axes of the reference ring.

If the reference ring is orthogonal to the reference fragment, then translations may also be measured along the reference fragment coordinate axes. If the reference fragment is not orthogonal to the reference ring, as in femoral mountings or residual deformities after fracture fixation, measure translations along the reference ring coordinate axes. The six deformity parameters are:

AP View Translation
Medial/Lateral translation from the origin to the corresponding point, measured on AP radiograph.

Lateral View Translation
Anterior/Posterior translation from the origin to the corresponding point, measured on Lateral radiograph.

Axial Translation
Proximal/Distal translation from the origin to the corresponding point. Can be measured on AP or Lateral radiographs.

AP View Angulation
Angle between fragment centerlines (or perpendicular bisector of joint line) measured on AP radiograph.

Lateral View Angulation
Angle between fragment centerlines (or perpendicular bisector of joint line) measured on Lateral radiograph.

Axial View Angulation
Clinical measurement of the angle between the sagittal plane of the reference fragment and the moving fragment.

Frame Parameters

Characterize the diameters of the rings and the resting length of the struts.

Proximal Ring Diameter

Distal Ring Diameter

Neutral Strut Length
Strut length at neutral position.

Neutral Frame Height
Height of the frame from center of ring to center of ring with all struts at the neutral strut length. Neutral frame height may be used as a frame parameter in lieu of neutral strut length. Neutral frame height must be entered into the appropriate input box of the software.

Mounting Parameters

Four anticipated or measured parameters which define how the reference ring is positioned with respect to the origin. These parameters are measured along the reference ring coordinate axes. The four mounting parameters are:

AP View Frame Offset
Medial/Lateral translation of the center of the reference ring with respect to the origin.

Lateral View Frame Offset
Anterior/Posterior translation of the center of the reference ring with respect to the origin.

Axial Frame Offset
Proximal/Distal translation of the center of the reference ring with respect to the origin.

Rotary Frame Offset
Rotation of the sagittal plane of reference ring from the sagittal plane of the reference fragment.

Moving Fragment

Assumed to be the deformed fragment. Attached to the moving ring.

Origin

Center of rotation of the frame going from neutral to deformed. Usually the interior end of the reference fragment for fractures and chronic post-traumatic deformities. The center of the reference fragment at the level of osteotomy or the physiologic center of angulation is often used for congenital deformities. The origin is chosen by the surgeon.

Preferred Orientation

The computer program assumes the universal joints connecting strut 1 and strut 2 to the proximal ring are aligned directly anterior on the reference fragment. Different rotational alignments, especially for more proximal femoral and humeral applications, can be accommodated by changing rotary frame offset. The frame can be rotated from the preferred orientation to place a 2/3 ring with the void facing the opposite thigh or trunk.

Reference Fragment

Fragment assumed to hold still during deformity correction. Can be either fragment. Generally the short periarticular fragment is the best choice. Its anatomic planes should match AP and Lateral radiographs, and these radiographs must include the intended or actual level of attachment of the reference ring to the reference fragment.

Structure at Risk

Important biologic stucture which will undergo greatest/most critical elongation during deformity correction. This structure may be nerve, vessel, bone, muscle, or skin. To determine total elongation of the structure during deformity correction, input the rectangular coordinates of the structure at risk with respect to the origin into the computer program.

Way Points

Intermediate stages of correction. Used if there is significant bayonnet apposition in a nonunion/malunion or fracture. Allows the fragments to be brought out to length (and angulation eliminated) before interior ends are reapposed. If the deformity parameters of the full deformity are [θ, ϕ, δ, X, Y, Z] the deformity parameters of the way point which fully restores length and angulation would be [0, 0, 0, X, Y, 0].