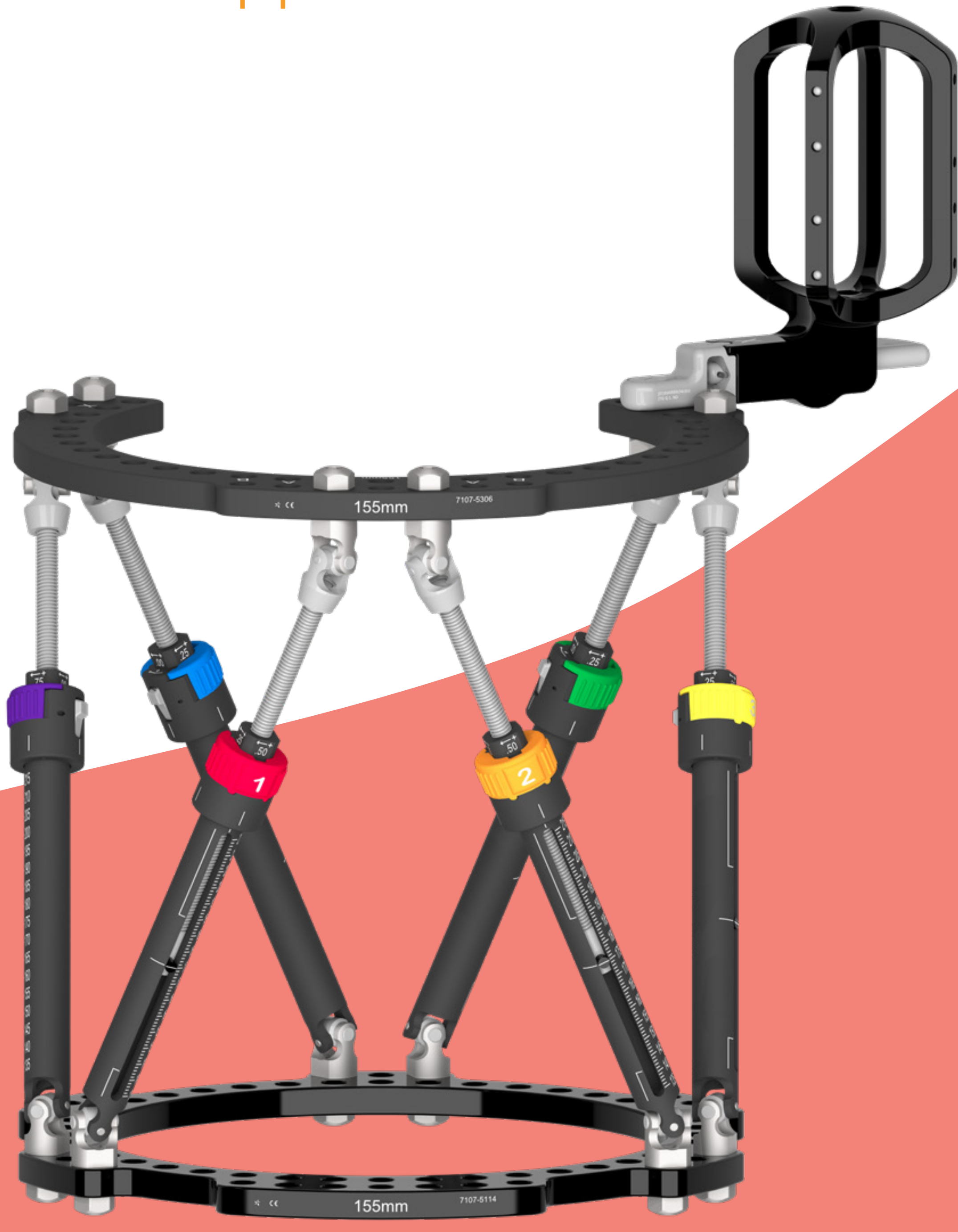
SMART TSF◊
Circular Fixator

Compendium of TSF Applications



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Compendium of TSF◊ Applications

System Overview

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Techniques in Trauma

Techniques in Deformity Correction

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Smith & Nephew's External Fixation Systems may be used for patients fitting the indications and that do not present any of the contraindications. The subject system is intended to be used for children and adults of all ages. The general principles of good patient selection and sound surgical judgement apply to external fixation procedures. Preoperative planning and meticulous surgical technique are essential to achieve optimum results. Considerations of anatomical loading, soft-tissue condition, and component placement are critical to minimize a variety of complications. An individualized configuration should be designed for each case to suit the specific application.

For more information on the products in this surgical technique, including indications for use, contraindications, effects, precautions and warnings, please consult the products' Instructions for Use (IFU).

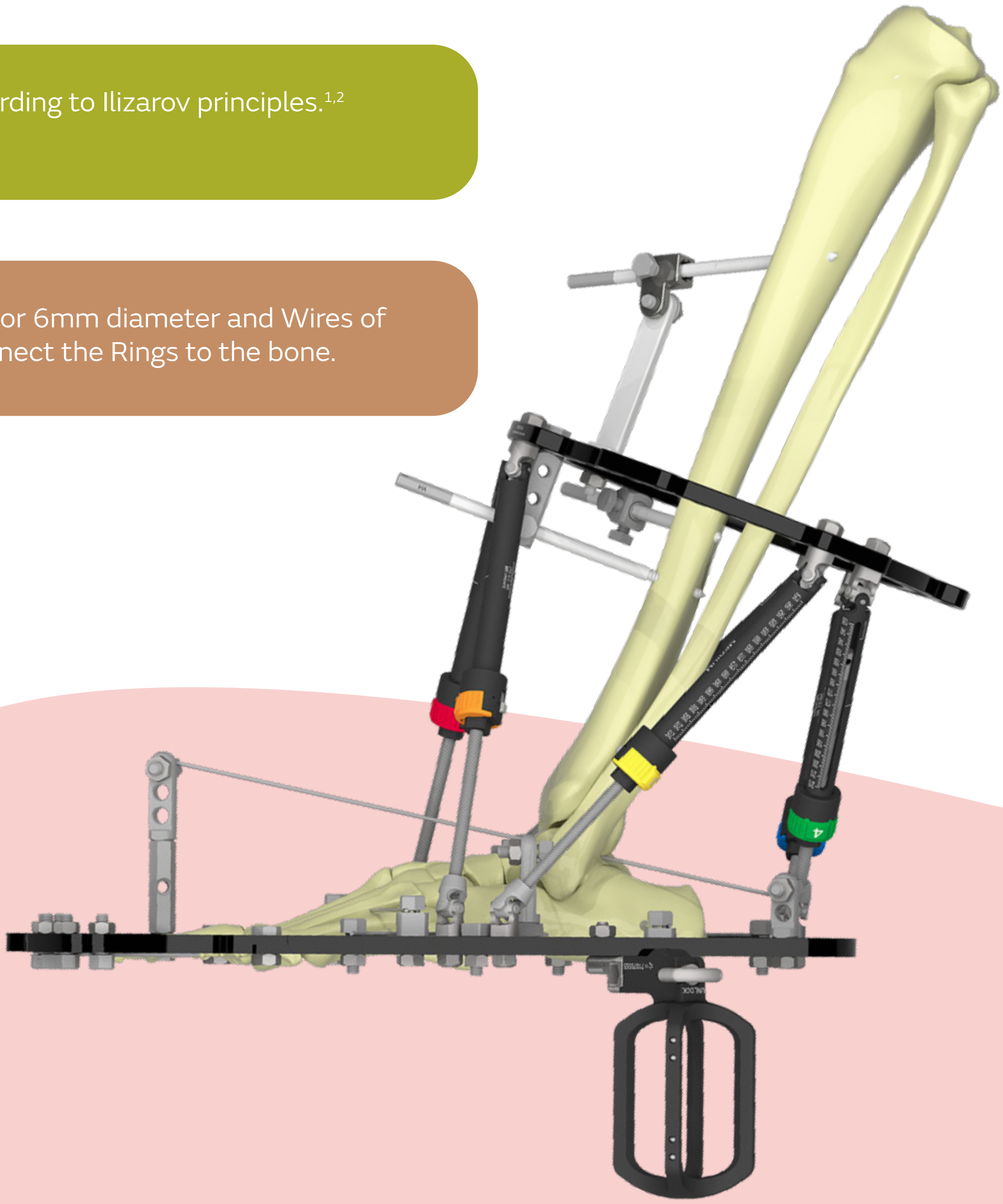
System overview

SMART TSF◊ is a Ring-based External Fixator used in the management of fractures and correction of long bone deformities.

The TSF construct consists of two Rings and six telescoping Struts in the specific configuration described in “TSF Assembly.”

The TSF is applied to bone according to Ilizarov principles.[1,2]

HA-Coated Half Pins of 4.5mm or 6mm diameter and Wires of 1.5mm or 1.8mm diameter connect the Rings to the bone.



Once TSF◊ has been surgically applied, the parameters of the deformity and the details of the hardware can be entered in the web-based application SMART-TSF.com. The program will generate a prescription of Strut adjustments that reduce the angulations, rotations and translations to zero. The patient performs the Strut adjustments at a rate and rhythm determined by the surgeon. The Strut adjustments cause movement of one Ring relative to the other. The Strut adjustment schedule may last a number of weeks, thereafter, the patient enters the consolidation phase of bone healing.

The TSF system offers the following –

- Early and progressive weight-bearing when appropriate[3,4]
- Fixation in good bone with soft tissue coverage, staying away from the compromised zone of injury
- Anatomic reduction and alignment can be refined post-operatively[2]
- No hardware left behind after treatment
- Restoration of the mechanical axis of the limb[5]

SMART TSF components are compatible with all existing TAYLOR SPATIAL FRAME◊ Hardware. SMART TSF Software supports constructs assembled using classic TAYLOR SPATIAL FRAME Hardware. A complete list of components is detailed in the ILIZAROV™ and TAYLOR SPATIAL FRAME Pocket Guide (Literature no 29781).

Constructing a Stable Frame

Fundamental principles of Stable Frame construction

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The views and opinions expressed in this section are those of the surgeon.

Introduction

One of the biggest advantages of using a TSF◊ for circular ring fixation is the ability to modulate the biomechanics of the construct based on the pathology you are treating. Fracture healing requires a degree of flexibility to induce fracture micromotion and thus proceed with secondary callus formation. Gradual "downgrading" of construct stability, or "dynamization" is also desired toward the end of treatment to allow for controlled fracture remodeling. This is in distinction to treating a hypertrophic nonunion with deformity where a relatively rigid frame is required to provide an adequate distraction force required to correct a stiff nonunion **(Figure 1)**.

However, the construct must allow for the combined stability of the frame augmented with the additional stability afforded by distraction forces of the soft tissues. The use of distraction osteogenesis also requires a distinct mechanical environment to provide stability to the corticotomy site to protect and promote the initial neovascularization and further the progression of the regenerate. Yet as the healing of the regenerate progresses, more dynamic axial micromotion is required to promote regenerate maturation and reverse dynamization (more stable) is also necessary for remodeling to allow for frame removal. These constructs all have in common the need for a basic frame that is stable throughout the range of application indications.

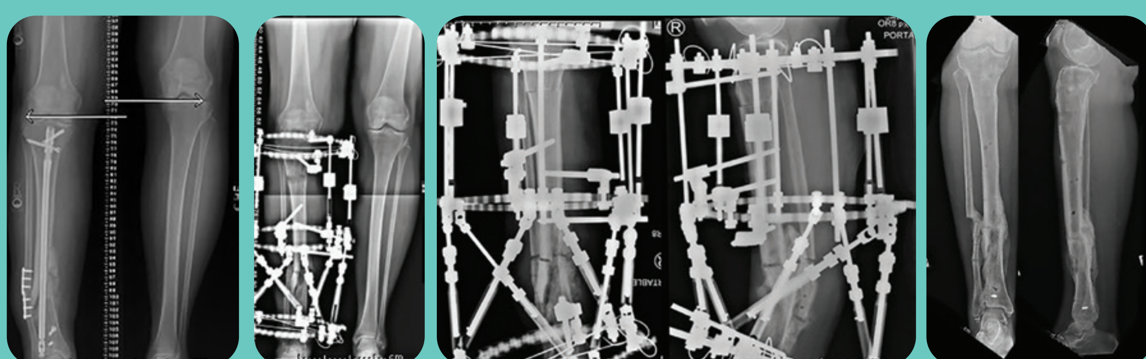

Figure 1
Hypertrophic nonunion with leg length discrepancy, treatment initially requires a rigid frame to bridge the three limb segments.

1. The proximal limb segment above the corticotomy for distraction and resolution of the leg length discrepancy.
2. The intercalary limb segment between the proximal corticotomy and the hypertrophic nonunion site. Distraction across the nonunion to correct the deformity and heal the nonunion.
3. Distal limb segment below the nonunion which requires stability to allow for this bifocal transport to progress.

Terminology

Limb segment

The segment of bone above a fracture site is a limb segment. Likewise, the bone below the fracture site is also another “limb segment.” The area of bone above a corticotomy is a limb segment, as is the bone below the corticotomy, or the regenerate.

The regions of bone above and below a nonunion site are both limb segments. Similarly the bone above a joint contracture is a limb segment as is the bone below the joint contracture.

A tibial transport that involves segmental defect, and a nonunion as well as a proximal corticotomy, has three limb segments. Similarly, a proximal tibial deformity with a proximal corticotomy in association with a distal tibial nonunion also has three limb segments **(Figure 2a)**.

The fixation for each limb segment should span the entire limb segment for maximal stability. Fixation as close to the pathology and as far away from the pathology at the ends of the segment is much more stable than all the fixation localized in the middle of the segment.

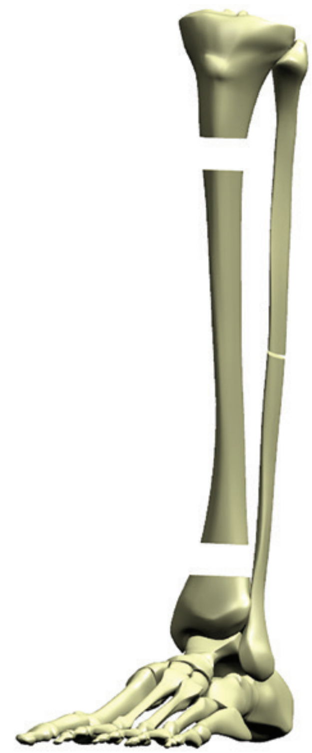

Figure 2a

Levels of fixation

Every limb segment is usually defined by a Ring attached to that limb segment **(Figure 2b)**. Wires or pins placed in a single axial plane is one level of fixation. This fixation is usually attached directly onto the Ring. Wires or pins that are attached above or below the Ring are designated as an additional level of fixation.

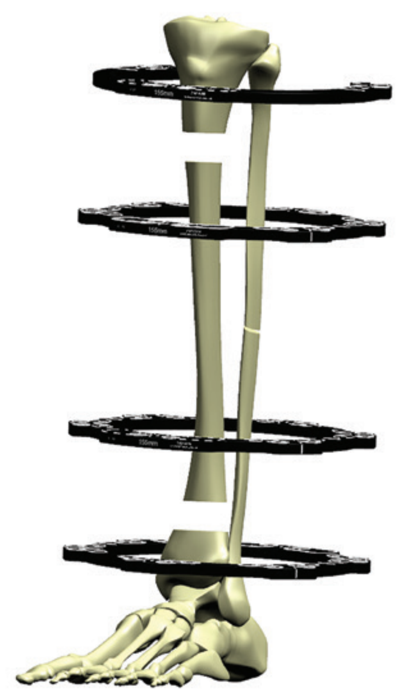

Figure 2b

What constitutes a “Stable” Frame?

Tensioned wire placement

Every limb segment requires at least one level of fixation, usually a Ring positioned on each limb segment. Thus a minimum of one Ring per limb segment is required.

For each limb segment (Ring) the most stable construct is two tensioned wires crossing at 90° to each other **(Figure 3a)**. This means that the wires are perpendicular to each other and would require a medial to lateral wire, as well as a wire with front to back placement. This prevents translation along the wires as well as rotational torque (bending) to the limb segment. Anatomy, however, normally precludes the ideal wire placement.

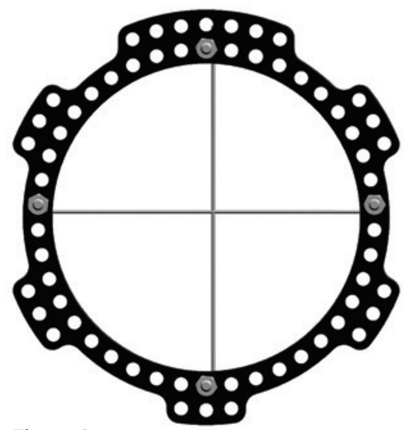

Figure 3a

In order to avoid neurovascular structures, the wires are always placed at less than 90° but not less than a 30° crossing angle **(Figure 3b)**.

As the wire angles converge, the potential translation along the relative combined wire axis of the limb segment becomes greater, as does the rotational torque (bending moments).

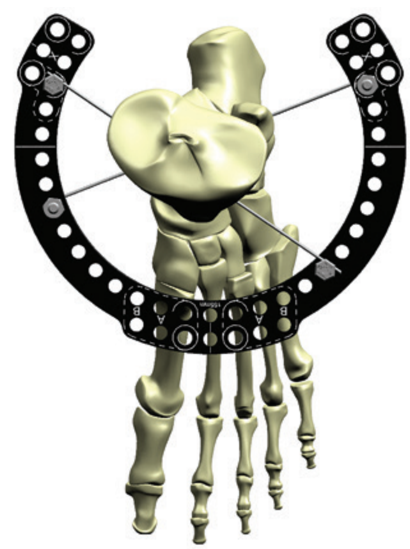

Figure 3b

To compensate for this inability to achieve a 90° wire spread on a Ring, a third wire can be placed on the Ring. Usually you can achieve 45°- 60° of divergence between each wire and this wire orientation per limb segment is helpful but still does not achieve the optimum stability that 90°-90° achieves **(Figure 3c)**.

Placing wires both above and below the Ring drives stability.

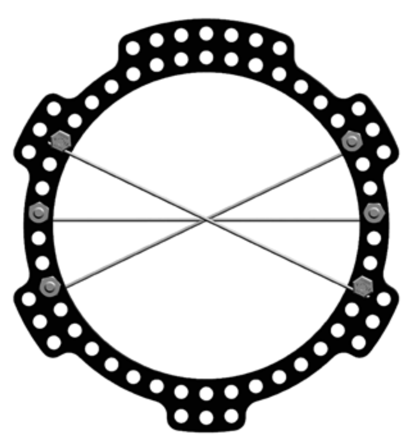

Figure 3c

The addition of an Olive Wire as the third divergent wire will significantly increase the stability of the Ring segment by preventing any additional translational motion **(Figure 4a)**.

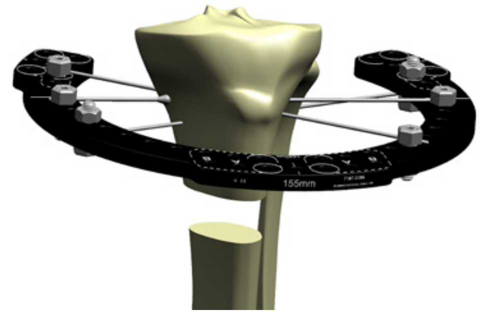

Figure 4a

The placement of two opposing Olive Wires locks the bone into position and is a standard way to increase frame stability for that limb segment **(Figure 4b)**.

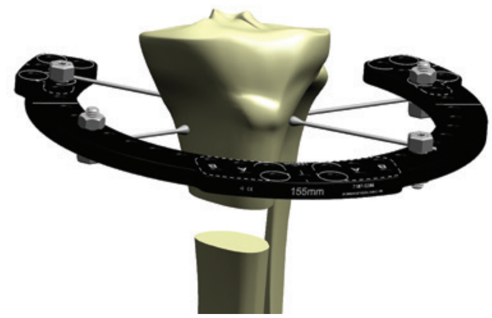

Figure 4b

An additional level of fixation on this limb segment is still necessary. This can be achieved by adding additional tensioned wires elevated above or dropped below the Ring using posts **(Figure 4c)**. Alternatively, placing coronal plane wires above and below the Ring, in addition to the wires placed directly on the Ring, is also a way to achieve maximal segment stability.

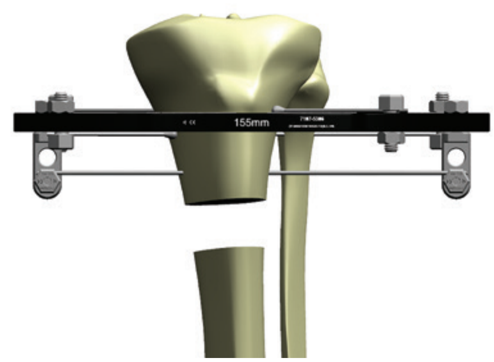

Figure 4c

For an all-wire construct, the most stable construct is:

- two Rings per limb segment and
- two to three wires per Ring

This frame is very stable with two levels of fixation per limb segment. Divergent wires are attached to the proximal and distal Rings. A second level of fixation on each segment is accomplished by the addition of a Ring to each segment attached with two additional divergent wires. Note that none of the wires at each Ring cross at 90°; however, if the limb segment is taken as a unit looking at both Rings in that segment, the wires at different levels do achieve that 90°-90° orientation **(Figure 4d)**. This will not always be the case because of the variable anatomy at the location of the segment and thus the need for half pin augmentation.

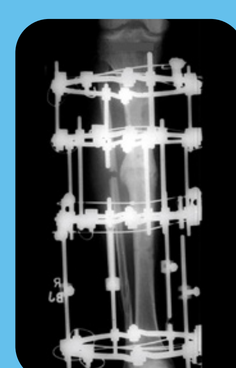

Figure 4d

Half Pins

The use of an additional Ring is often not feasible due to available room needed for an additional Ring. Thus the ability to add another level of fixation above or below the Ring is achieved by using a half pin (often called Schanz Pin) **(Figure 5a)**.

While two wires placed in 90°-90° configuration is the target for optimal stability, most frames utilize half pins as a strategy to increase stability without the constraint of available wire corridors.

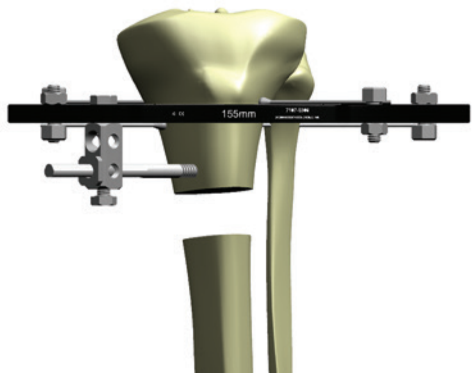

Figure 5a

In terms of comparable stability, two half pins placed on the same level with 30°-45° of pin divergence is equivalent to one tensioned wire **(Figure 5b)**. A stable limb segment then can consist of two tensioned wires mounted on the Ring with two additional half pins mounted above and/or below the Ring. Each pin is placed through divergent (non-orthogonal) orientation. This formula achieves two levels of fixation per limb segment and the pin/wire trajectories achieve the desired equivalency of a 90°-90° tensioned wire frame.

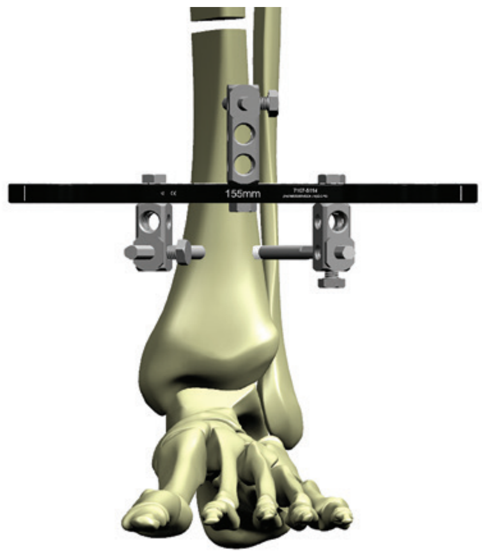

Figure 5b

Figure 6 shows a hypertrophic nonunion which is very stiff and requires a very stable frame to affect a slow correction. It has two limb segments with two levels of fixation per limb segment. The distal limb segment below the nonunion is stabilized with two opposing Olive Wires mounted directly onto the distal Ring with two additional half pins elevated off the Ring and placed in 80° divergence (two Olive Wires and two half pins equals one additional wire) **(Figure 6)**.

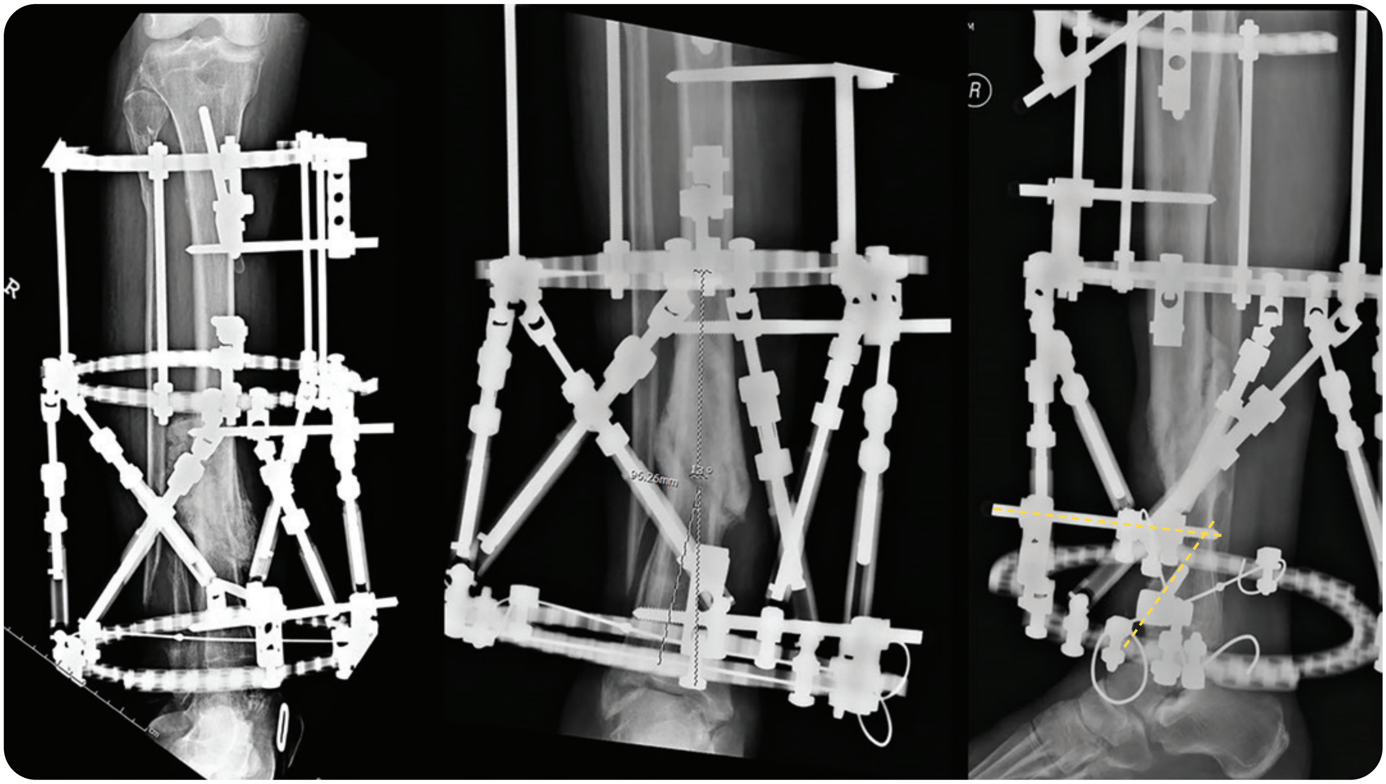

Figure 6

The proximal limb segment has two levels of fixation with the fixation spanning the entire limb segment using two Rings. Each Ring has two widely divergent half pins achieving the equivalent stability of two 90°-90° tensioned wires. This is a very stable frame and achieves excellent correction and complete healing of this hypertrophic nonunion with exuberant callus.

Full half pin frames can also be used successfully and with equivalent mechanical stability by placing three 60° divergent 6mm half pins above and below a Ring spanning the entire length of the limb segment **(Figure 7a)**.

A similar second Ring with divergent pins above and below the Ring is also placed. This six-pin frame with divergent 6mm half pins is equivalent to a four-Ring tensioned wire frame in terms of axial stability and bending resistance while allowing axial micromotion **(Figure 7b)**.

The addition of out-of-plane half pins to any limb segment produces a significant increase in stability to that particular limb segment and should be utilized when a very rigid frame is indicated, such as for deformity, lengthening or nonunion treatment.

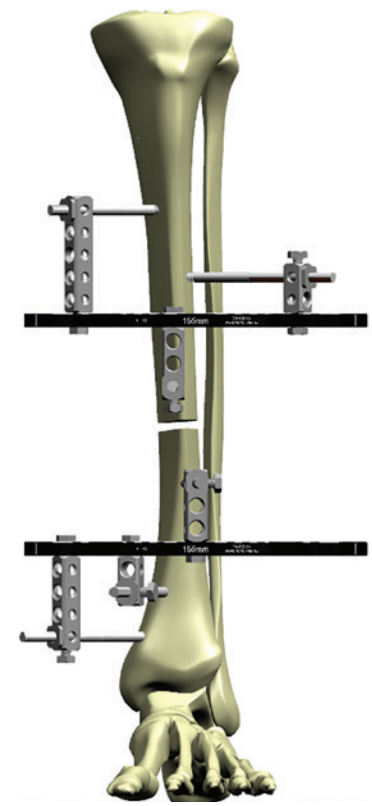

Figure 7a

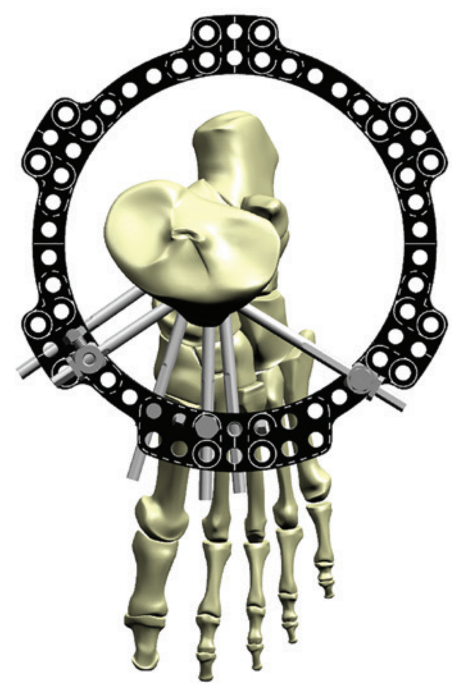

Figure 7b

Steerage Pins

The addition of half pins can increase the compressive forces across a fracture line and increase the overall stability of a fracture frame. The pins should be placed parallel to their respective fracture line orientation **(Figure 8a)**. With fracture loading, the resultant motion vectors of both limb segments serve to force them together in a compression mode. The pins have to be located on each separate limb segment in order for this compression vector to work.

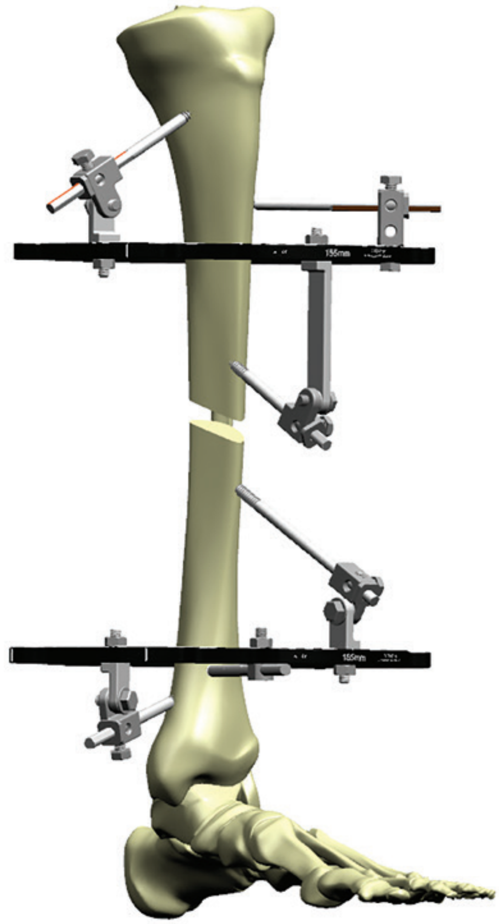

Figure 8a

Note that two half pins are each located in a separate limb segment, each on separate Rings. One above the oblique fracture line and the second below the fracture line, both positioned parallel to the orientation of that oblique fracture line. This pin placement will convert the normal cantilever shear forces that want to distract the fracture to a resultant compressive force. The result is an increase in frame stability and fracture fragment contact **(Figure 8b)**.

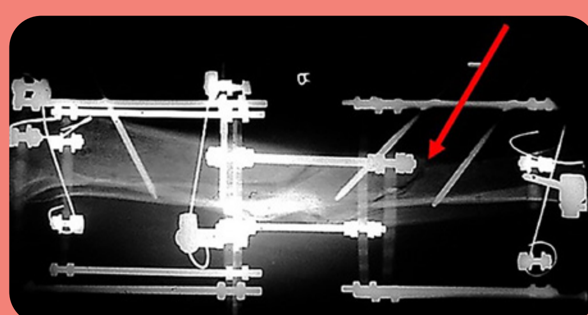

Figure 8b

Hypertrophic nonunion with two limb segments and one Ring per each limb segment.

The widely divergent 6mm half pins are placed above and below the Ring in at least 60° of divergence in all three planes, achieving two levels of fixation per segment.

This stable frame demonstrates a wide divergent pin spread covering the entirety of each limb segment, while providing at least two levels of fixation per limb segment **(Figure 9)**.

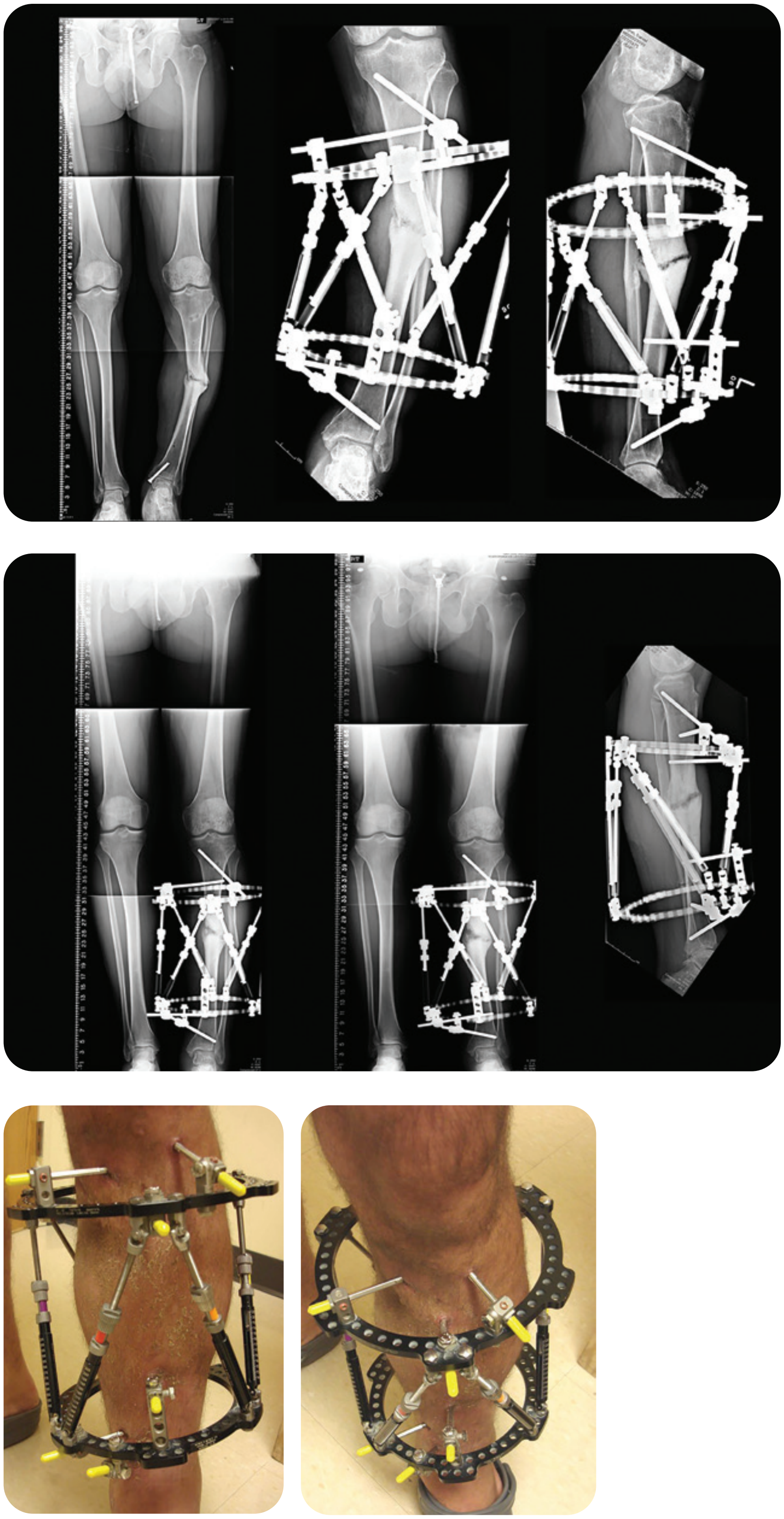

Figure 9

Example - Malunion with varus deformity with a corticotomy

Two limb segments with one Ring per segment. Distal Ring fixation using two divergent wires and an Olive Wire on the Ring and an additional half pin placed above the Ring, achieving two levels of fixation in that limb segment. The proximal limb segment is stabilized by a single Ring with four divergent half pins placed above and below the Ring to achieve a wide area of proximal segment fixation **(Figure 10a)**.

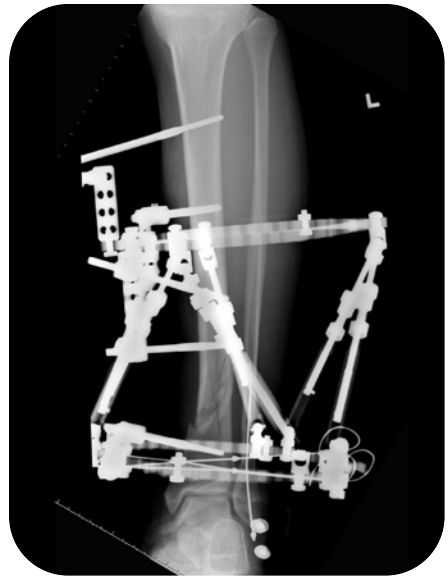

Figure 10a

Example - Two limb segment pilon fracture

The distal segment is stabilized with three tensioned wires including two Olive Wires and an additional half pin placed above the Ring for two levels of fixation. Proximal limb segment with single Ring and four divergent half pins placed above and below the Ring again achieve two levels of fixation for this limb segment **(Figure 10b)**.

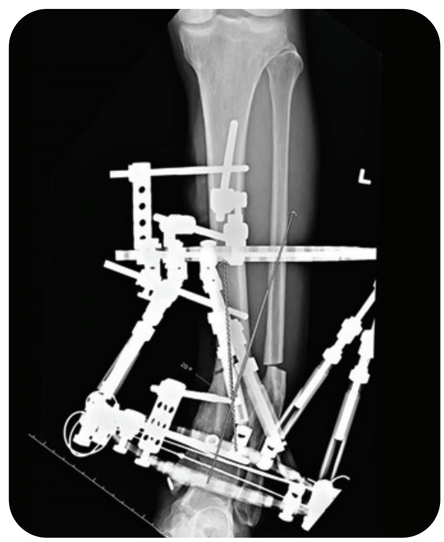

Figure 10b

Example – Short periarticular segment

Additional stability of a short distal limb segment can be achieved with out-of-plane tensioned wires. Note the wires in the coronal plane that course above the Ring on one side and below the Ring on the opposite side **(Figure 10c)**. This configuration again confers two levels of fixation for this small limb segment.

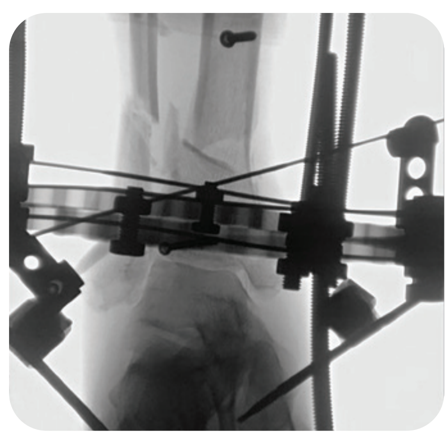

Figure 10c

Bone transport constructs require the ability to vary the biomechanics as treatment progresses **(Figure 11)**. The top limb segment should be constrained and attached to the distal limb segment. In this fashion the unstable transport segment can depart to eventually dock with a stable limb segment.

Less constrained frames risk the development of inadequate regenerate and nonunion at the docking site because of the inherent instability. Note the long Threaded Rods connecting the proximal limb segment to the distal limb segment and thus avoiding construct instability. The proximal Ring fixation demonstrates two levels of fixation with three divergent half pins and smooth wires. Distal limb segment fixation of the small segment is accomplished with five tensioned wires and two coronal plane wires attached above and below the distal Ring for two levels of fixation.

The intercalary transport Ring is mobile along the long Threaded Rods and thus the docking site will be in perfect alignment as docking occurs. The transport Ring segment is stabilized with a Ring and half pins above and below the Ring. Note that the majority of fixation is located distally on the transport segment. This fixation "pulls" the segment distally and is much more stable, controllable and facilitates docking by being able to compress symmetrically at the docking site. When fixation is more proximal above the transport Ring, this is very unstable and the transport segment will drift with distraction. It is much easier to "pull" a string of spaghetti rather than push it!

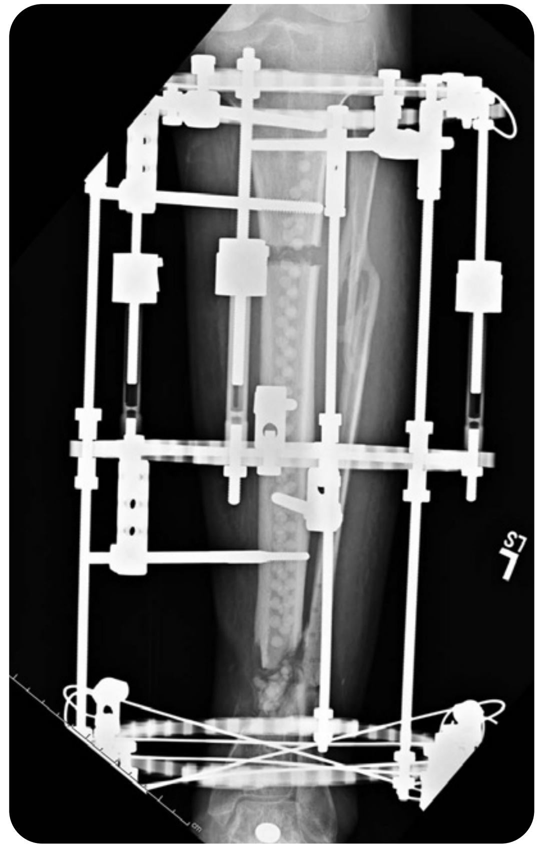

Figure 11

Factors that increase frame stability size of Rings

It is important to use Rings that are not excessively large. Rings with large diameters place the fixation points far away from the point of contact to bone and the fixation is prone to excessive cantilever, bending and potential shearing of the pin or wire. Decreasing Ring size also helps to increase axial stability. Increasing the number of Ring-to-Ring connections between limb segments also improves frame stability, especially in large patients that require large Rings **(Figure 12a)**.

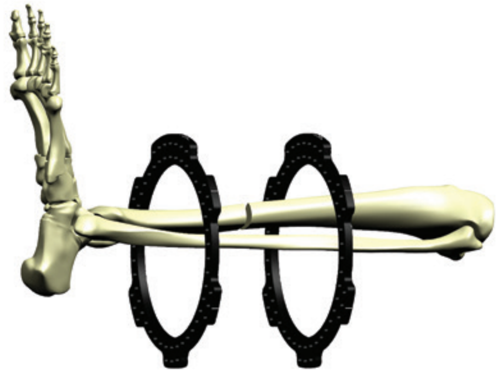

Figure 12a

Pin and wire diameter

Increasing pin and wire diameter improves the resistance to bending and torsion as well as improving axial stability **(Figure 12b)**. Wires tensioned appropriately and tensioned to the correct level increases the axial stability of the frame. Use of Olive Wires as previously noted adds resistance to translation and bending.

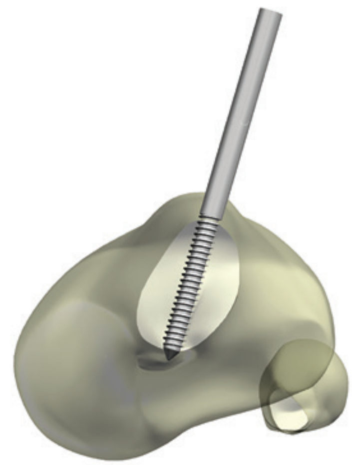

Figure 12b
Pin diameter does not exceed 1/3 diameter of bone

Counter Ring compression

Tightening or compressing the Rings toward each other where two Rings are used in a limb segment or on either side of a fracture serves to increase the wire deflection on each Ring and subsequently increases the wire stiffness **(Figure 12c)**. This self-stiffening effect has the same impact as re-tensioning the wires and improves frame stability and decreases the pain that an unstable frame will cause.

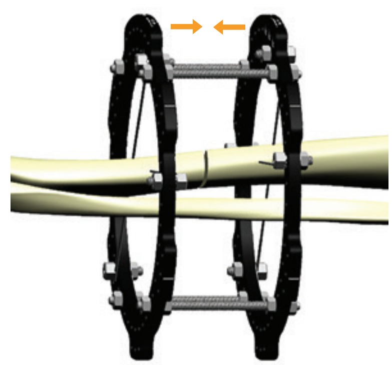

Figure 12c

Techniques in Trauma

TSF◊ in the management of open tibial fractures

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The views and opinions expressed in this section are those of the surgeon.

Introduction

The spatial frame remains the gold standard for management of open tibial fractures (Gustillo Grade II+). In a review of 111 tibial fractures treated with TSF (55 open, 56 closed) at a Level One Trauma Centre between 2009 and 2020, union was shown to be 93.5% and average time in frame was 27.9 weeks.[1] This compares to 74% success in a fix and flap approach,[2] and 92% in nail-plate techniques.[3] Patients with complex soft tissue injuries that are not open should also be considered for Ring fixation **(Figure 1a)**.

Like all external fixation constructs the Ring fixator should be constructed to allow for the fracture pattern and likely future treatment requirements:

1. Is "dialed in deformity" needed for soft tissue management **(Figure 1b)**
2. Will soft tissue reconstruction be needed and therefore access for microvascular flaps **(Figure 1c)**
3. Will secondary bone transport be required needing a suitable Ring construct (ie Ring blocks).

In addition, when faced with a complex open fracture, there are considerations for fixation:

1. Long working lengths do not control angular deformity well and Ring blocks may be required.
2. All fixation should be outside of the zone of injury and the zone of subsequent surgery.
3. Patients will typically be wearing their Rings for upwards of 6 months and as such non-bridging weight-bearing constructs are to be preferred.

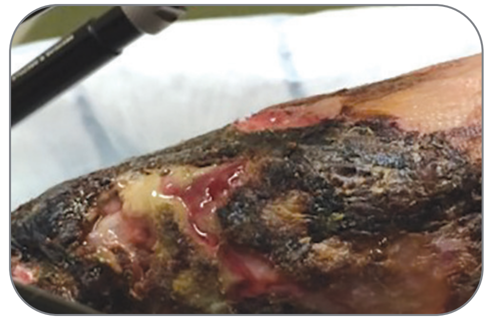


Figure 1a
Challenging soft tissue

Figure 1b
Bony deformity to close soft tissue

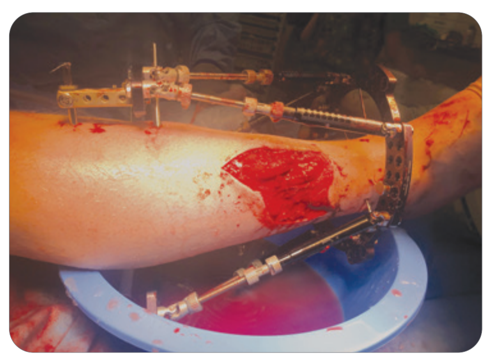


Figure 1c
Rotary frame offset used to leave a window over the wound

Spatial corrections in trauma

When planning fixation it is also important to consider the correction power of the Rings and planning for any likely corrections. The angle of the Struts and the working length of the hexapod are intimately related:

- Lower-angled Struts provide better length corrections.
- Lower angles provide stronger translations.
- 45 degree-angled Struts provide optimal rotational corrections.

The working length can be adjusted using Ring blocks **(Figure 2a)** or angled pin connectors and drop wires **(Figure 2b)**, and the same fracture can be effectively treated with constructs that provide optimal corrective power.

A further consideration when undertaking spatial corrections in trauma is the fibula. In all but the most unusual circumstances, the fibula will also be fractured. Undertaking corrections without holding the fibula at the ankle at the syndesmosis risks altering the ankle geometry. It is therefore recommended to transfix the fibula and tibia with at least one Olive Wire.

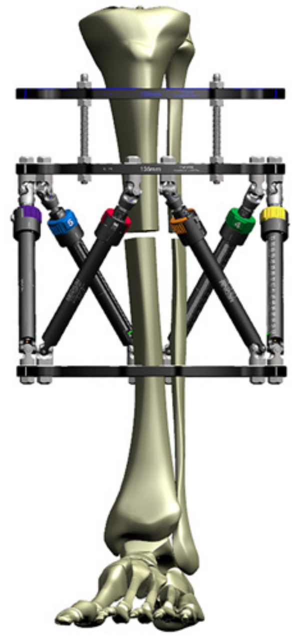


Figure 2a
Construct optimized for rotational correction

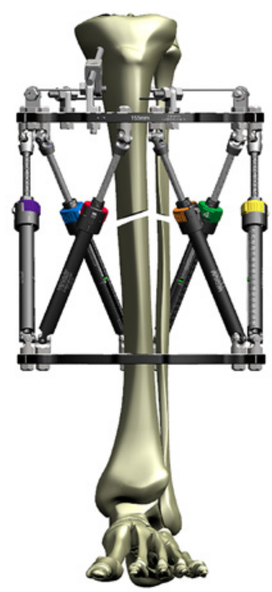


Figure 2b
Construct optimized for AXIAL correction

Segmental fractures

While stacked Rings work well for segmental fractures, the intermediate Ring must have two points of fixation to the intermediate segment or correction will not occur correctly **(Figure 3a)**.

In the case where the soft tissues do not allow for two points of fixation then a single half pin may be used so long as the apex of the half pin is at 90º to the correction plane. Single points of fixation do not withstand rotational forces and ideally should not be used.

Stacked frames should also not be considered for bone transport. The construct is not biomechanically sound and does not provide 1mm of axial translation reliably. The variation in Strut angles as the floating Ring traverses, results in poor regenerate formation at best or failure of transport at worst.

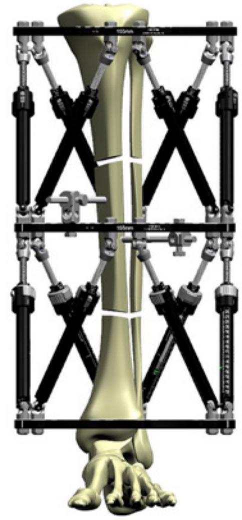


Figure 3a
Segmental fractures fixed with a stacked frame

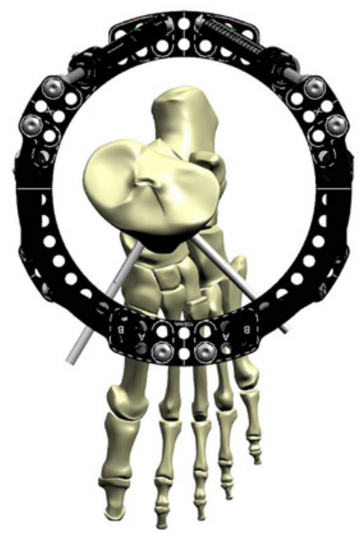
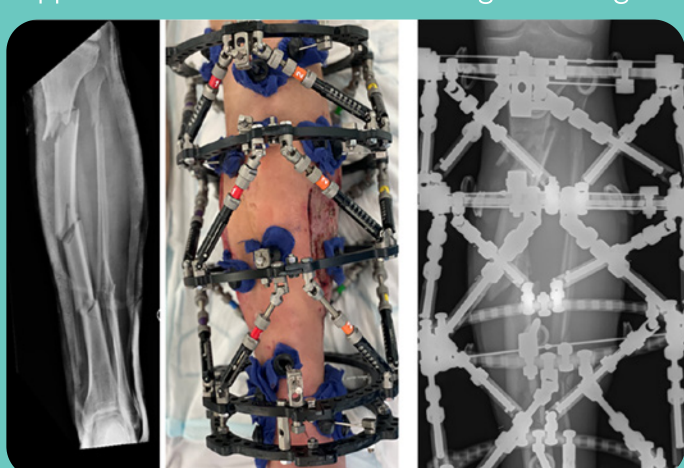


Figure 3b
Note two points of fixation at ideally 90º to each other, on the intermediate Ring

Case Example

This segmental fracture was complicated by an acute compartment syndrome, and the fasciotomy complicated by slow healing. A circular frame was chosen for definitive treatment, and applied about 4 weeks post-injury.

The image shows a stacked TSF◊, fixed using the principles illustrated in "Fundamental Principles of Stable Frame Construction." Software allowed fine-tuning of correction over five weeks to achieve contact and alignment. The stable construct supported the stimulation of full weight-bearing.



Courtesy of Mr. Badri Narayan, FRCS Liverpool University Hospitals

Hardware options – Step-off plates

A standard two Ring TSF◊ construct is sufficient for the majority of fracture applications. When close to the knee, a 2/3 Ring can be utilised to allow for knee flexion.

Consideration should be given to the Ring sizes spacing and points of fixation to ensure optimal stability of the frame.

The proximal and distal Rings are then connected with TSF Struts with a resultant frame that is able to undertake a trauma correction as needed and does not suffer from instability. The SMART TSF◊ software provides the flexibility to utilise Step-Off Plates for patients who have soft tissue impingement issues (Neutral Step-Off, **Figure 4a**), to avoid Strut change outs (30mm Step-Off) or to undertake custom strut mounts **(Figure 4b)**.

While these options provide flexibility, and the software will not allow a deformity correction on an "unstable" construct, it is important to remember that the "standard" hexapod configuration provides optimal stability.

Figure 4a
Neutral Step-off Plates allows a "window" over soft tissue

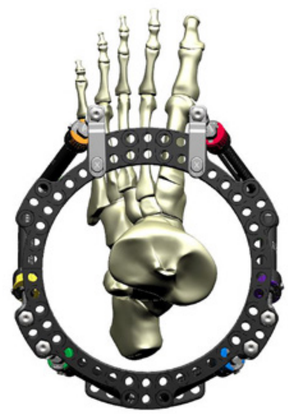


Figure 4b
Top down view showing clearance of Struts from soft tissue

Figure 4c
30mm Step-Off Plate used to create space over wound

Figure 4d
30mm Step-Off Plates on Struts 4 and 5 can be removed during correction

Hardware options – Dynamization

If Dynamization is likely to be employed at a later stage, it is helpful to incorporate the Dynamization Kit hardware at the time of primary surgery. Placing the Dynamization Washers on the back face of the most orthogonal Ring **(Figure 5a)** will leave the frame in a static position and allows it to be easily converted later without the need for additional hardware in clinic **(Figure 5b)**.

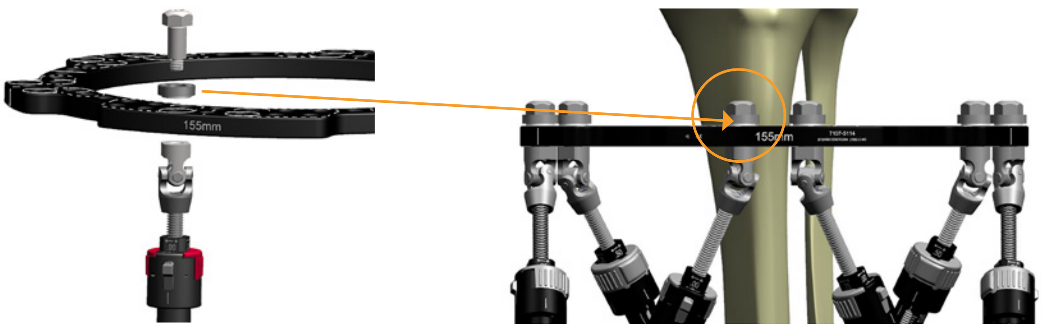


Figure 5a
Dynamization Washer above the Ring – not driving any axial micromotion

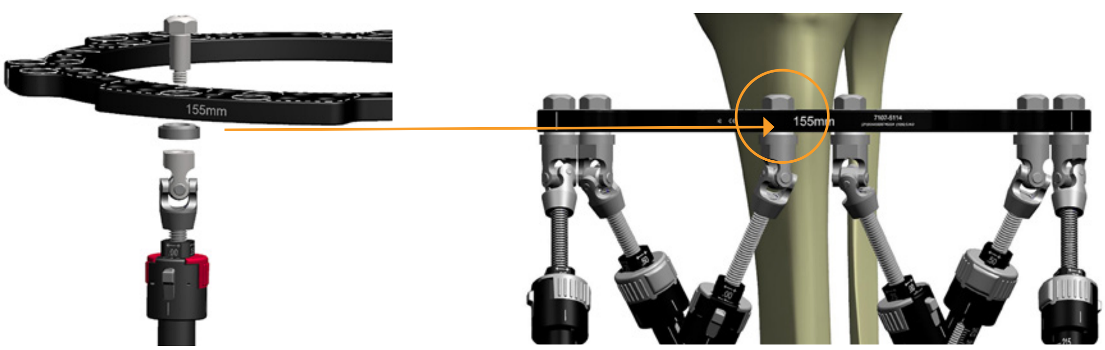


Figure 5b
Dynamization Washer below the Ring – driving axial micromotion

Hardware options – Pin placement

Particularly in the case of open fractures, it is essential to optimise soft tissues and reduce the risk of soft tissue complications. Any strategy to reduce pin site complications starts in theatre and particularly when a known correction is taking place, a hybrid construct with half pins and fine wires is optimal to providing correction. The longevity of any external fixator is dependent on bone-pin interface surviving the duration of treatment and use of pins, in addition to traditional tensioned wires, will help ensure rigid Ring-to-bone segment fixation so that every frame movement is translated to bone segment movement.

Placement of half pins should provide a fixation angle of as close to 90º as possible, and the use of a steerage pin on the apex of the tension side of the deformity helps reduce soft tissue complications and maximise deformity correction power **(Figure 6a)**.

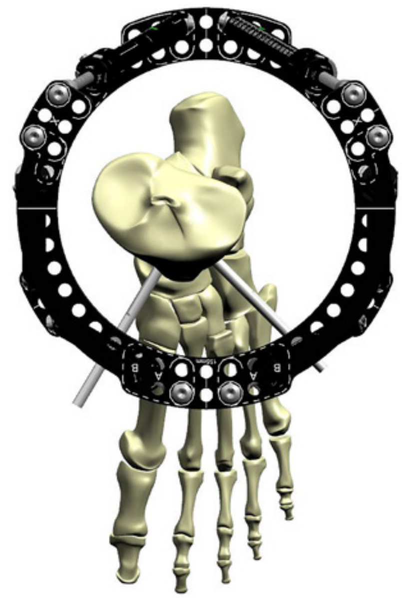


Figure 6a

Particularly in the peri-articular fixation segments the use of the short Angled Pin Connector helps to reduces the modulus mismatch, helps to reduce the risk of periprosthetic frame fracture and ultimately increases stability of the Ring, particularly against bending and torsional moments where fine wires do not provide optimal stability **(Figures 6b and 6c).**

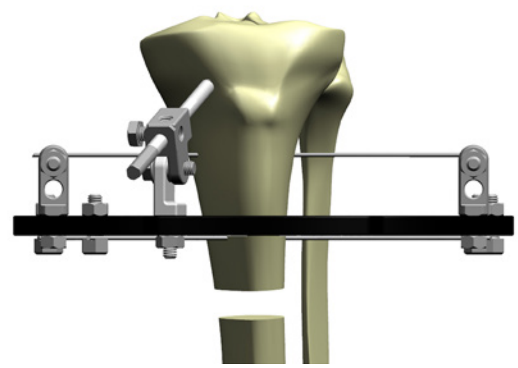


Figure 6b
Proximal fixation optimized with angled pin connector to increase frame stability

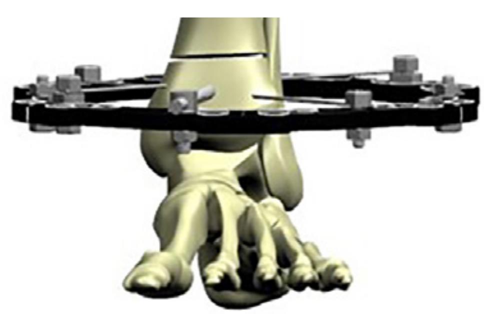


Figure 6c
Use of a half pin in small distal segment fixation can avoid the need to bridge the ankle.

Hardware options – Custom Strut Mount

The frame construct can be used to optimise soft tissue reconstruction. At the most basic level the use of 2/3 Rings with two rotated 2/3 Rings can provide ample space for both free flap anastomosis and insertion **(Figure 7a)**.

Figure 7a
Proximal 2/3 Ring with 180º Rotary Offset combined with Custom Strut Mount on the Distal Ring to maximize the window over a wound

In some circumstances Custom Strut Mount can be used to allow for soft tissue swelling or to accommodate a free flap **(Figure 7b and 7c)**.

In practice there can be difficulties with achieving stability as the subspherical Rings suffer reduced torsional rigidity. Strategies to reduce this risk include the use of rotated 2/3 Ring blocks **(Figures 7d and 7e)**.

At the time of primary surgery the surgeon should account for likely swelling, and walking to the end of the bed for an axial view of the leg is recommended to reduce the incidence of soft tissue impingement with hardware **(Figures 7d and 7e)**.

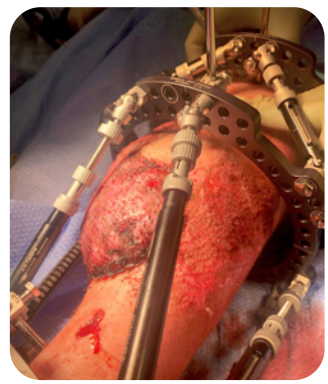


Figure 7b
Custom Strut Mount utilized to avoid impingement on tissue flap

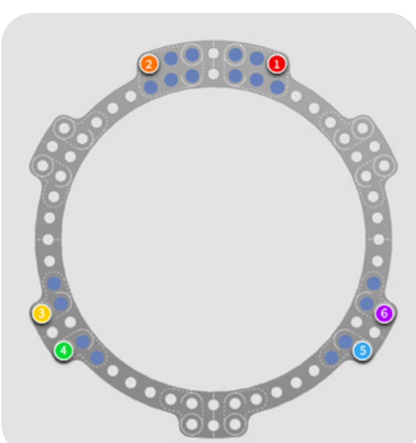
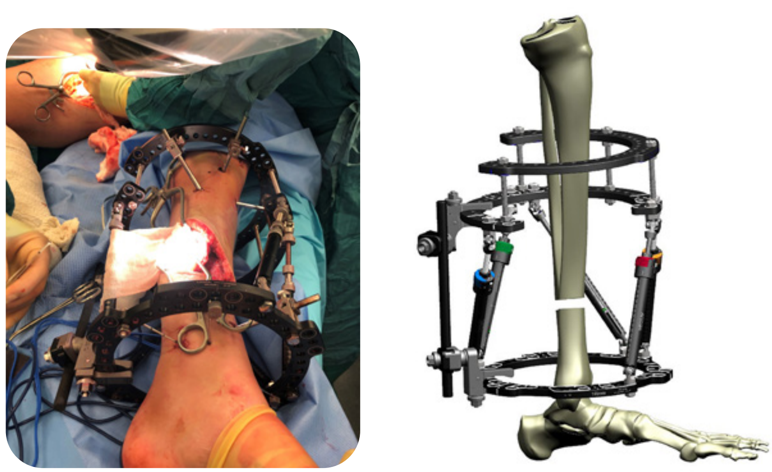


Figure 7c
Custom Strut Mount options are shown in blue in the software



Figures 7d and 7e
Proximal Ring Block using two offset 2/3 Rings allows soft tissue reconstruction. Note Frame Stabilization tool allowing Strut 3 to be removed temporarily

Early correction vs late correction

In the majority of cases a sensible strategy is to either place a temporary ex-fix, or the author's preferred strategy is to place the primary frame on admission at the time of initial debridement. Using a primary spatial frame has some significant added benefits as it allows for the use of "dialled in deformity" and distraction histogenesis for soft tissues. This can allow for the primary closure of soft tissues that would otherwise be unreconstructable **(Figure 8a)**. There is evidence to support this approach[4] and, although not ideal for all patients it offers flexibility in terms of reconstruction.

Figure 8a
Intentional deformity of the bone to close soft tissue
Image courtesy of Om Lahoti, FRCS

Planning for bone transport

While the two-Ring TSF is an adequate construct for the majority of cases where a bone transport is likely to be required, it is ideal to utilise a proximal and distal Ring block with a stable construct including half pins and fine wires at the time of primary surgery. Ideally the blocks would be parallel, allowing for a simple bone transport **(Figure 8b)**; however, sometimes this is not possible and it is more than acceptable to use non-parallel rings in association with a balanced cable or utilise the Hexapod in a "Rings first" mode to correct to parallel rings. The primary consideration is getting the rotation correct as this is impossible to correct once bone transport is underway.

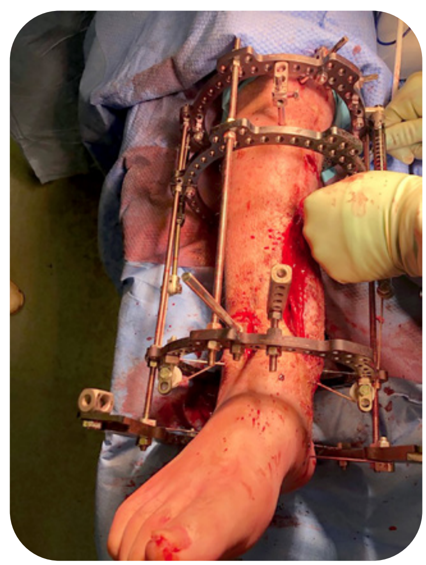


Figure 8b

Watch Dr. Stephen Quinnan perform Balanced Cable Transport

Special consideration - The open pilon fracture

The open pilon provides a special case, with poor soft tissues, and often complex intra-articulate fragments. Whatever strategy is chosen with regards to a delayed or acute TSF application, we would recommend the use of fragment-specific fixation with either lag screws or adjunctive mini plates to reduce and hold the articular block prior to TSF application.

In many cases the ankle will not need to be bridged. In situations where bridging is necessary, this can be achieved with a Foot Ring **(Figure 9a)**. An alternative strategy is a Ring block using a Half Ring connected to the distal 2/3 Ring **(Figure 9b)**. This approach achieves bridging across the joint and still allows access to soft tissues for reconstruction.

Special consideration – Using the Compass Hinge across a joint

It is worth considering the use of hinges which can be required in the ankle, knee or sometimes in the elbow. The approach to bridging the knee is simple:

1. Undertake thorough wash-out and debridement, bridging the knee or ankle with a spanning external fixation.
2. Once soft tissues are amenable, undertake a joint reduction and fixation.
3. Apply the Compass Hinge pair first at the isometric point using a fine wire for guidance **(Figure 9c)**. The femur can be controlled with a 2/3 205mm or larger Ring, and the tibia should also be controlled with a 2/3 Ring far enough distal to allow flexion. Position of the matching tibial Ring should be undertaken first as this will likely also need fine wires to neutralise the joint fragments.
4. The Hexapod can then be built below to provide a complete construct **(Figure 9d)**.

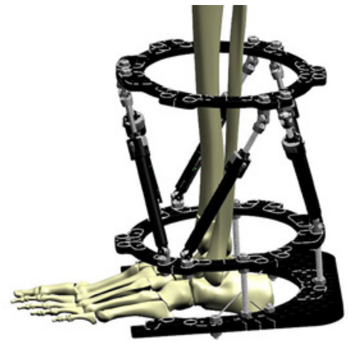


Figure 9a

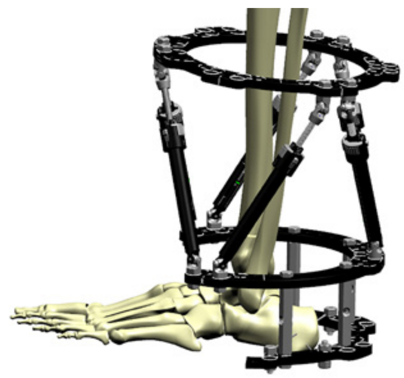


Figure 9b

Figure 9c

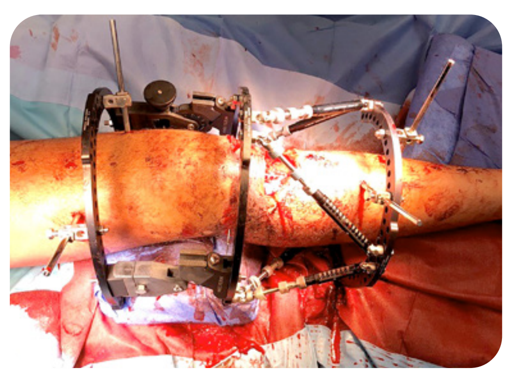


Figure 9d

Software

Trauma Dots is a deformity analysis technique designed to digitally reduce displaced fracture fragments. It has the advantage of simple application and the ability to reduce a bone based on four reduction keys and their matching reduction points **(Figure 10a)**.

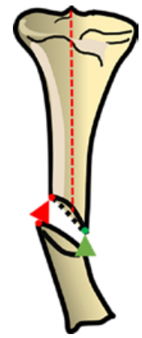


Figure 10a

When undertaking deformity correction for open fractures trauma dots is the preferred method. Clear near orthogonal plain film radiographs are required in order to achieve the reduction and ideally would be centered on the fracture site not the proximal Ring **(Figure 10b)**.

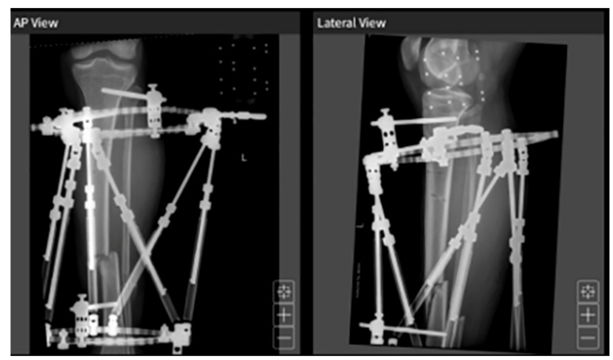


Figure 10b

Identification of the reduction keys and matching reduction points **(Figure 10c)** does not need to cover the whole width of the bone, but will be more accurate if points on either side of the projection are chosen.

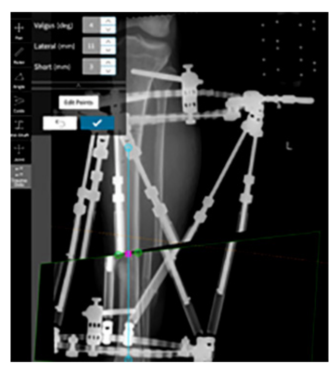


Figure 10c

Provisional reduction can then be adjusted as necessary with “nudge” tools and the reduction parameters checked.

In my experience, this method reliably leads to accurate corrections and reduction of the fracture with a single step **(Figure 10d)**.

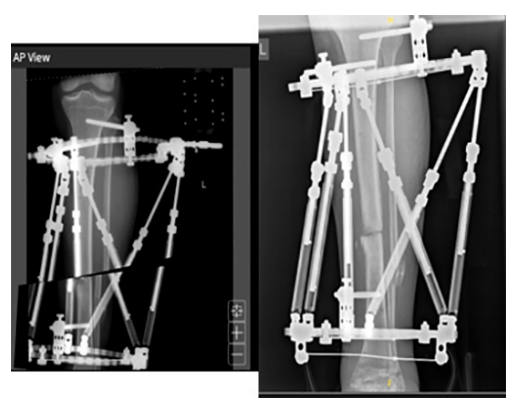


Figure 10d

TSF◊ for proximal tibial fractures

Richard Gellman, MD; San Joaquin General Hospital, CA

The views and opinions expressed in this section are those of the surgeon.

Introduction

The TAYLOR SPATIAL FRAME◊ (TSF) is an excellent device to treat complex challenges in the proximal tibia. Due to the abundance of excellent periarticular plating systems available to surgeons in North America and Europe, the use of ring fixation is generally reserved for more select cases.

- Infected nonunions and/or malunions of the tibial plateau or proximal tibia, with or without bone loss
- Extra articular AO type A tibial plateau fractures with soft tissue challenges, the decision to select a method that allows immediate full weight bearing
- Segmental tibia fracture patterns
- Type B1 or C1 tibial plateau fractures can be reduced and stabilized with small fragment screw fixation followed by frame application or with the use of wire fixation alone.
- Fractures below a total knee replacement where there is sufficient "real estate" for pin and wire fixation around the tibial stem
- Certain pediatric fractures where flexible nailing techniques would not provide sufficient stability
- Patients with a complex soft tissue injury where the use of a TSF will allow bony union to be achieved without the need for free flap reconstruction

Technique

Success in using TSF◊ Ring fixation in the proximal tibia requires careful preoperative planning of wire and half pin placement. Surgeons accustomed to using the TSF with a standard transverse smooth wire to establish coronal plane alignment and then adding three multiplanar half pins in a “one method fits all” approach to fixation in the proximal tibia will need to expand their horizons. Bone “tunnels,” or defects from previous screws used for internal fixation, or fractures that extend into the plateau may prohibit insertion of commonly used transverse wires.

It is critical to carefully align the single proximal Ring parallel to the knee joint in the coronal plane and within 5 degrees in the sagittal plane to ensure accurate visualization of radiographs for deformity correction **(Figure 1)**.

Wire fixation must be carefully planned. The goal is to stabilize any simple fracture, often with opposing Olive Wires. Wire fixation is placed proximal, distal or at an angle to avoid poor fixation in areas of internal fixation screw tracks. Five points of fixation for the single proximal Ring is ideal. This can be an all-wire construct or any combination of wires and half pins depending on fracture or deformity configuration.

Wire and half pin fixation should be placed no closer than 1cm from the internal fixation or knee replacement components to lessen risk of infection.

There is controversy regarding the placement of wire fixation within the anatomic recesses of the knee joint capsule. Whenever possible, it is advisable to keep fixation about 1-1.5 cm distal to the joint. However, in cases of very proximal fractures or bone loss near the joint, it may be necessary to place wire fixation just below the articular plateau. In these patients, vigilant pin care and removal of infected wires will be necessary to prevent septic arthritis **(Figure 2)**.

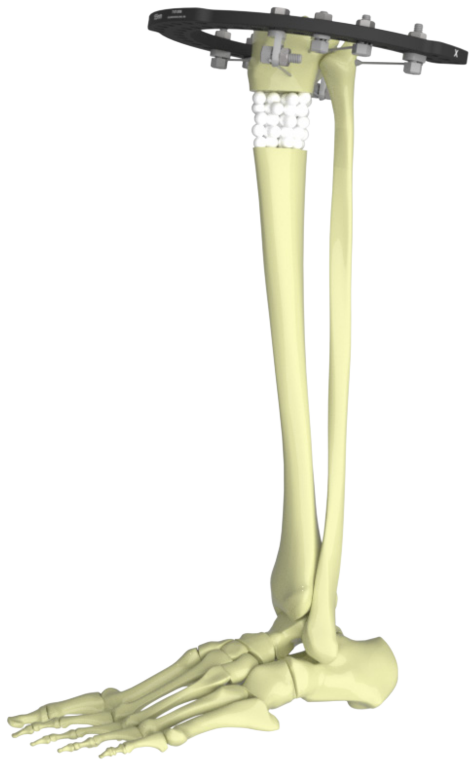


Figure 1

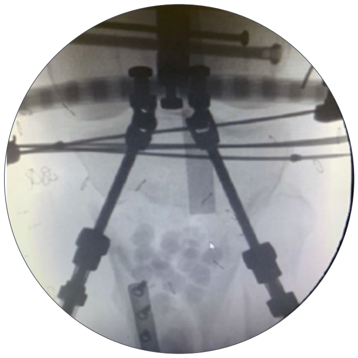


Figure 2

In general, Ring fixation in the mid-tibia is achieved with a Ring block assembled with 150mm Threaded Rods and secured initially with a transverse Smooth Wire above the proximal Ring to establish the coronal plane alignment followed by a sagittal plane half pin on the distal Ring to set the sagittal plane alignment.

Three more half pins are added to create a strong construct that will allow for removal of the transverse wire in the clinic if it becomes infected or symptomatic during treatment.

Alternatively, some frame mechanic studies have shown that one Ring with multiplanar angled half pin configurations can provide similar stability as the two-Ring construct described above **(Figure 3)**.

I typically use a single distal Ring only in lighter patients or pediatric patients that have rapid healing times.

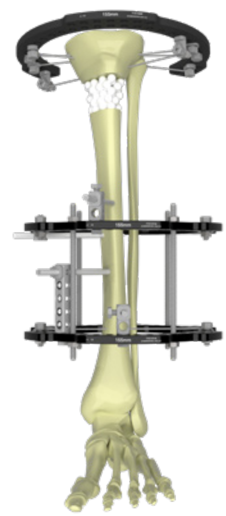


Figure 3

Strut selection is dependent on the clinical problem. In general, I use FAST FX◊ or SMART FX struts for acute fractures or lax nonunions where I can apply axial traction following frame application to obtain an initial closed reduction with ease **(Figure 4)**. For malunions or stiff nonunions, I prefer Standard Struts.

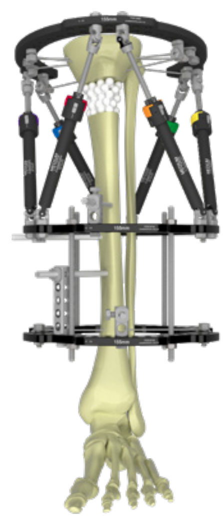
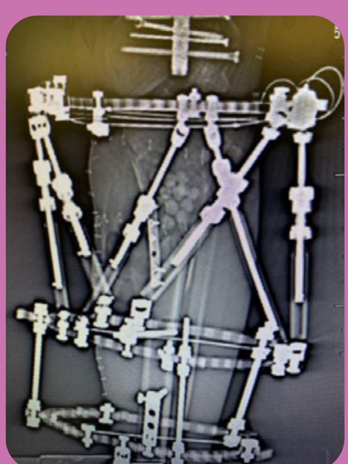


Figure 4

Case Example

A straight EVOS◊ MINI plate provides structural support to the defect filled with graft.



Software strategies

Which deformity analysis strategy chosen in SMART TSF◊ software is at the discretion of the surgeon and their level of comfort with each method. In theory, any method will work for any fracture or deformity. TraumaDots lends itself to a fracture configuration where two bone fragments need to be re-aligned. In a fracture with bone loss, SuperDot provides an easier means to define the hinge point for correction.

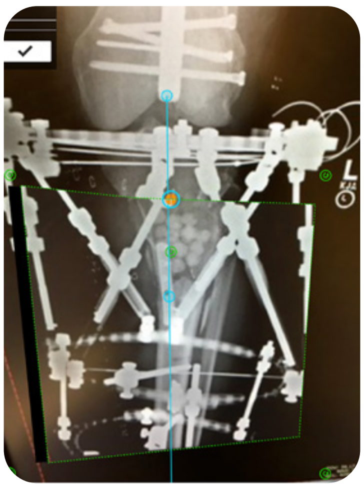


Figure 6a

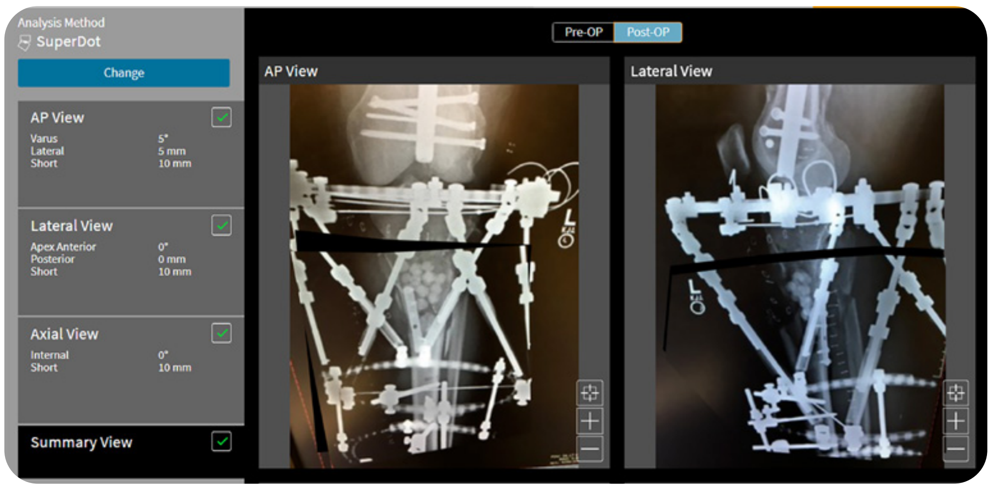


Figure 6b

In the above example the distal fragment is traced out to include the area of bone loss **(Figure 6a)**. The SuperDot is placed on the fracture line. The software generates a prescription to drive regeneration from the fracture site **(Figure 6b)**.

Fracture healing

Depending on the indication for a TSF◊, one of the greatest challenges is how to best assess fracture union or maturation of regenerate bone following distraction osteogenesis. Formation of 3 of 4 cortices on plain radiographs is the standard for defects of the tibial shaft, whereas assessment of bone density and filling in of fracture defects is necessary in metaphyseal bone **(Figure 7)**.

Figure 7

Once there are radiographic signs of healing, Struts can be replaced with Threaded Rods, adding conical washers or Conversion Clamps to maintain the exact Ring position. This allows better visualization around the fracture and distraction sites **(Figure 8)**.

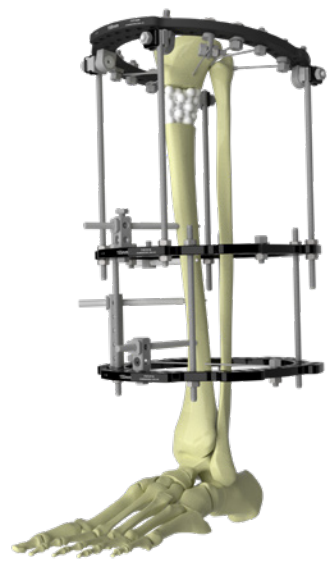


Figure 8

CT scans are commonly used to provide the most accurate assessment of fracture healing prior to frame removal **(Figure 9)**.

Figure 9

TSF◊ for distal tibial fractures

Badri Narayan, FRCS; Liverpool University Hospitals, UK

The views and opinions expressed in this section are those of the surgeon.

Treatment with TSF can be a suitable strategy for:

- AO/OTA 43A and 43C fractures complicated by severe soft tissue injury, including acute compartment syndrome **(Figure 1)**
- AO/OTA 43A and 43C fractures with tenuous skin
- Patient preference for ring fixation

Procedure

The limb is prepared and draped above the level of the knee, ensuring that the patella is visible.

A tourniquet is used only for the reduction of the articular surface in fractures where anatomical reduction and screw fixation of displaced articular fragments is indicated. Such screw fixation, if indicated, is first performed, and the skin incision(s) closed **(Figure 2)**. The tourniquet is now deflated and can be removed.

External fixation

A distal reference configuration is chosen. Rings of appropriate size are slid over the leg (one or two for the proximal fragment, and one for the distal fragment).

The leg is placed either on an elevated radiolucent block, or on plastic supports, so as to facilitate intraoperative screening.

Figure 1

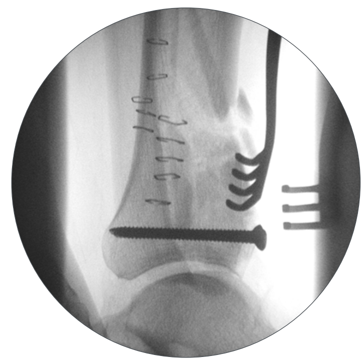


Figure 2

Distal Ring

A transverse Olive Wire is inserted from lateral to medial in the distal fragment, ensuring that this wire is superior to the synovial reflection of the ankle. As a rule of thumb, a transverse wire placed at the level of the epiphyseal scar of the tibia is safe.

While rotation of the Ring can be adjusted in the program, it is simpler to achieve this intra-operatively.

Two short Threaded Rods can be run superiorly off the centre of the Master Tab, and the Ring rotated until these are nearly superimposed on the AP view. Bolts holding Half Rings can also
be used similarly.

The Ring is now fixed superior to this wire using Wire Fixation Bolts, making sure that wire fixation holes (for Struts 1, 2, 3 and 6) are avoided. The Wire Fixation Bolt on the near side of the olive is tightened to avoid the Ring sliding on the wire, thus achieving referencing in the AP plane **(Figure 3a)**.

The image intensifier is now switched to the lateral view, and the Ring is visualised. It is tilted so as to be perpendicular to the posterior cortex of the distal tibial fragment. If visualising this is difficult, the articular surface of the lower tibia is chosen, and the Ring is tilted forward relative to this (anterior distal, posterior proximal) by about 10 degrees.

A temporary positioning wire can be placed to set the tilt of the Ring in the sagittal plane. The Wire Guide (102930) or Wire Fixation Bolt is placed on the Ring directly over the anterior cortex. A Smooth Wire is drilled through this in an anteroposterior direction, reaching but not exiting the posterior cortex. This holds the Ring perpendicular to the tibia in the sagittal plane, thus making sure the Ring is orthogonal to the distal fragment **(Figure 3b)**.

A medial face wire is now driven in the distal fragment proximal to the Ring. The Wire Guide can be used to ensure that this wire remains flush with the Ring. The position of the Ring is confirmed on the Lateral view, and both wires are tensioned. The AP positioning wire can now be removed **(Figure 3c)**.

A third retrofibular wire can be passed above the Ring; this crosses the medial face wire at a very good crossing angle.

The distal tibia provides two safe zones for half pins – anterior to posterior (AP) lateral to the Tibialis Anterior, or medial to lateral (ML) from the bare area of the tibia. Fracture configuration and soft tissue injury will dictate whether the use of such half pins is possible.

An AP half pin can be safely inserted at this stage if indicated **(Figure 3d)**. If an ML half pin is used, one must ensure it does not come in the way of Struts 1 and 6 (left tibia) or Struts 2 and 3 (right tibia), and, if in doubt, this pin can be inserted after the struts are attached to the two Rings.

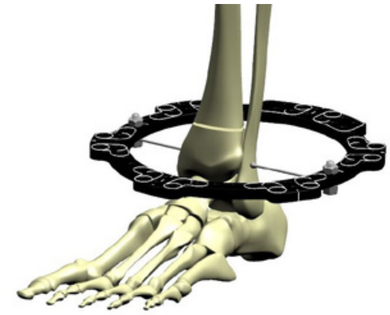


Figure 3a

Figure 3b

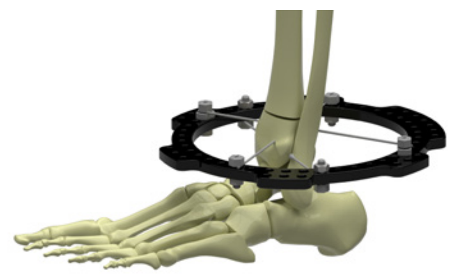


Figure 3c

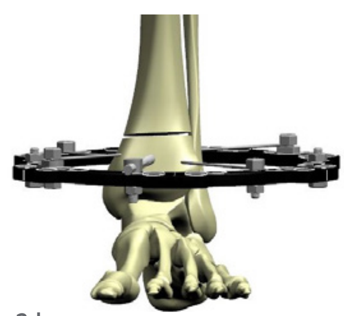


Figure 3d

Proximal Ring block

The proximal Ring block is constructed and attached using standard technique **(Figure 4a)**.

Typically, a distance of about 7 to 8 finger-breadths between the Rings on either side of the fracture allows the use of the FAST FX◊ or SMART FX Short and Medium Struts, permitting a stable frame and, at the same time, minimising Strut changes **(Figure 4b)**.

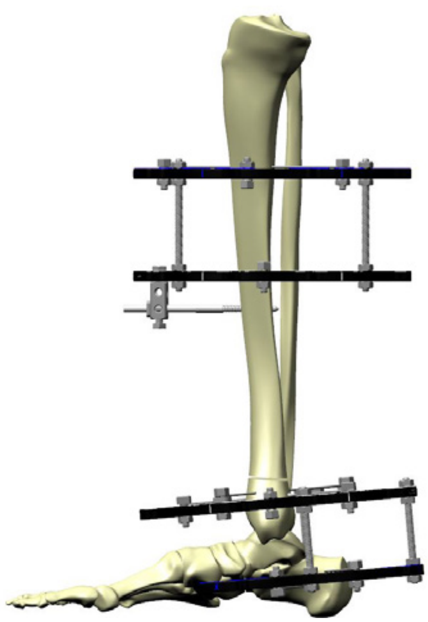


Figure 4a

Figure 4b

Additional stability

A single Ring with three wires, or three wires and a half pin may not provide enough stability for weight bearing, particularly in large individuals. Fracture configuration may also not permit this number of fixation points. In such cases, an extension to the foot allows greater security of distal fixation **(Figure 5)**. If used, this part of the construct can be removed at about six to eight weeks.

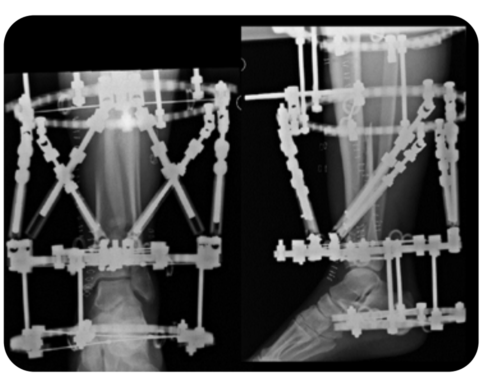


Figure 5

Reduction and correction

The use of SMART FX or FAST FX◊ Struts allow a provisional reduction in the operating Theatre. SMART FX Struts are locked by removing the Acute Adjustment Bands.

AP and lateral radiographs can be captured in Theatre or on the following day post-op. X-ray images should focus on the fracture and include the Beacon where used. At least one of the AP or Lateral images should be a true orthogonal image of the anatomy. The Ring does not need to be visualized orthogonally **(Figure 6)**.

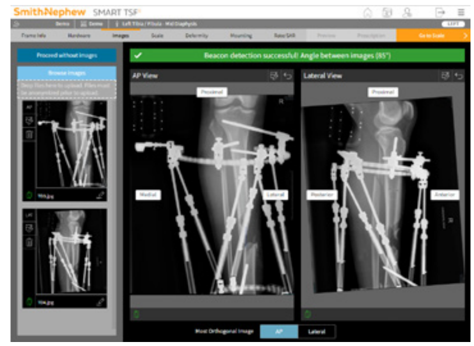


Figure 6

Progression of healing

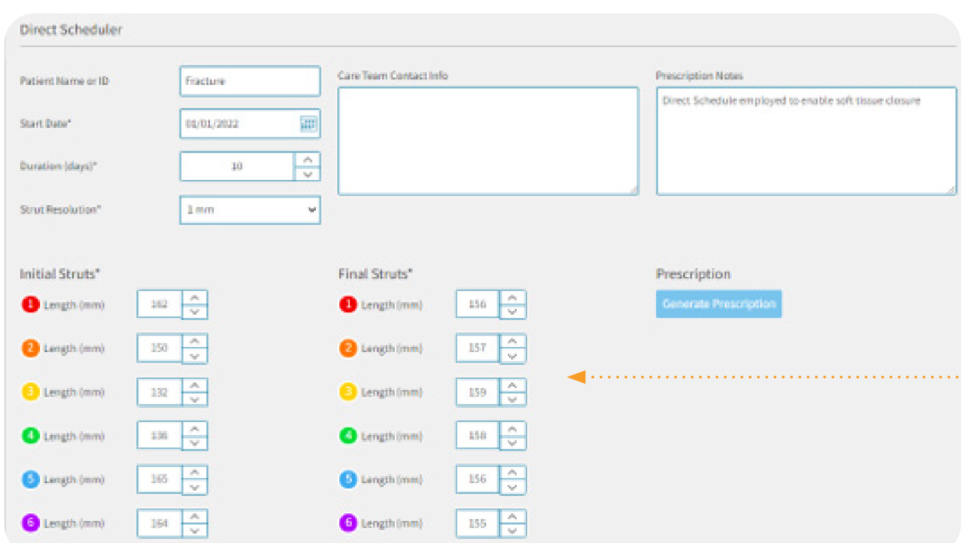
Fractures of the distal tibia typically heal in about 16-20 weeks. Refer to commentary about CT scans, page 33. Dynamization or reverse-dynamization may enhance fracture healing, and can be employed at the surgeon's discretion.

Soft tissue strategies

The gold standard for soft tissue loss over the medial tibia is a local plastic surgical flap. In situations where a flap cannot be performed, a TSF◊ can be used with "intentional deformation" of the fracture while approximating the skin. For example, a case with anteromedial soft tissue loss with a distal tibial fracture is held with a TSF applied with fracture "mal-reduced" in varus and recurvatum. The skin ends can now be brought together, and the skin sutured. The fracture is gradually brought into alignment after a latency period of four to six weeks.

The DIRECT SCHEDULER tool in SMART TSF◊ software facilitates input of initial and final Strut settings, with no need for deformity analysis or Mounting Parameters. It will generate a schedule to get from initial to final settings, at a pace defined by soft tissue healing **(Figure 7)**.

Initial Strut Settings are the Strut settings when the limb is deformed.



Final Strut Settings are the Strut settings when the limb is straight.

Figure 6
Direct Scheduler can be found in the Resources section of SMART-TSF.com

Digital deformity reduction method

B. J Ollivere, MBBS, FRCS, MD; University of Nottingham, UK

The views and opinions expressed in this section are those of the surgeon.

The traditional analyses of deformity and deformity correction are still as current today as they were when developed in parallel to circular Ilizarov fixators and later the TAYLOR SPATIAL FRAME◊ hexapod system. These original techniques all depend on initial deformity analysis and then often the use of carefully placed hinges to correct the deformity with a suitably placed osteotomy. The most common (and still used) technique is that of the center of rotation and angulation (CORA). Later with the development of the hexapod system "rules free corrections" were enabled as the frame can move in six degrees of freedom allowing for more complex corrections. This has evolved in a number of different directions including the origin and corresponding point method and more recently the SuperDot technique. While powerful tools, these again are designed to straighten a deformed bone although all have been used in fracture reduction.

The TraumaDots method is a rules-free deformity correction method that is designed to straighten a fractured or deformed bone. The system is a simple technique to allow complex deformity corrections. It is ideal for the reduction of fractures, removal of residual deformity in an applied frame or for correction of progressive deformities such as a Charcot foot. As it does not rely on a "cut out," TraumaDots is particularly helpful when correcting complex deformities such as Charcot or shortened fractures as all the reduction points can be visualized prior to the correction of the fracture.

Concept of TraumaDots

When undertaking a fracture reduction in open surgery, surgeons will use “reduction keys” to align fracture fragments. The surgeon does not have the advantage of long leg alignment views, however, can achieve a reduction both at the fracture site and along the axis of the limb through accurate direct fracture reduction. When undertaking nailing the converse is true. Indirect reduction is undertaken with care to attend to the longitudinal axis of the bone in order to achieve an overall satisfactory alignment of the limb. In some complex cases the nail can be used to achieve an indirect reduction purely through use of the long axis of the limb.

TraumaDots is a method for achieving direct reduction and overall limb alignment through the use of two matching reduction keys **(Figure 1)**.

Consider a displaced fracture **(Figure 2a)**, reduction of a single point (origin and corresponding point method), **(Figure 2b)** cannot accurately reduce the fracture; however, the use of two points **(Figure 2c)** can.

In clinical practice the identification of two points per fragment can also be used to both reduce the fracture and calculate the axis line of the reference fragment allowing deformity measurements to be calculated **(Figure 3)**. If the Beacon is used then AP and Lateral images are tied together in 3D space allowing for digital deformity correction.

TraumaDots can be used when there is comminution, shortening or for complex deformities with shortening where it can be easier to utilize than other methods. However in these circumstances the “nudge” buttons **(Figure 4)** are likely to be needed to fine tune the correction.

X-ray images for TraumaDots

TraumaDots can be used in either distal or proximal referencing. The ideal X-rays are orthogonal to each other and focused on the fracture site. Use of the Beacon is not essential; however, it is designed to increase the accuracy of deformity correction and mounting parameter measurements and is recommended.

In order to achieve accurate deformity correction it is essential to rotate the radiographs once they have been imported **(Figure 4)**.

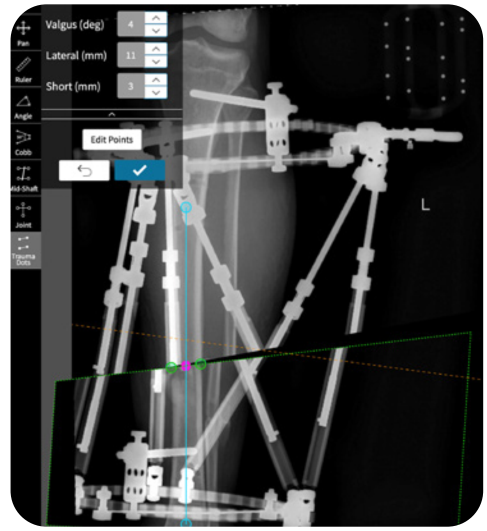


Figure 1
Use of the “nudge” buttons to fine tune TraumaDots correction

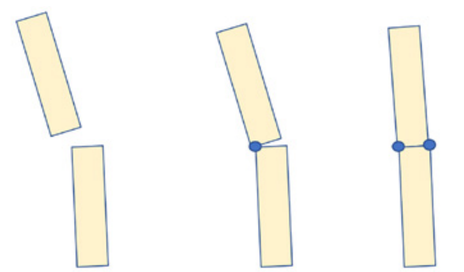


Figure 2a **Figure 2b** **Figure 2c**

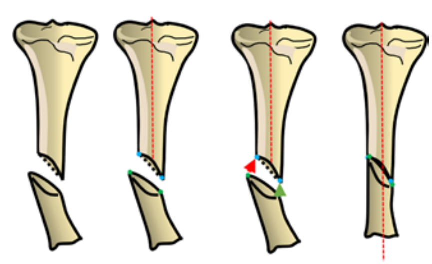


Figure 3

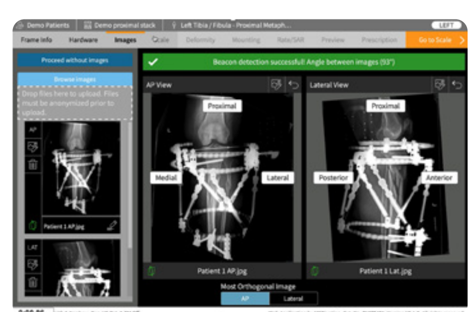


Figure 4
Correctly rotated images

Undertaking deformity correction

Once the X-rays are successfully imported, rotated, and the Beacon has been recognized the provisional reduction is undertaken. To achieve this first zoom in on the X-ray **(Figure 5a)**. Start with the reference fragment first and identify the two reduction keys and mark them on the X-ray. They may be moved, or restarted until the "tick" box is clicked **(Figure 5b)**. At this point the software will add the long axis of the bone in its presumed position. This can be adjusted if necessary. Next mark the moving fragment reduction keys **(Figure 5c)**. The software calculates an origin (orange) and corresponding point (pink). Clicking "save points" will apply the reduction **(Figure 5d)** and allow for fine tuning with the "nudge" arrows.

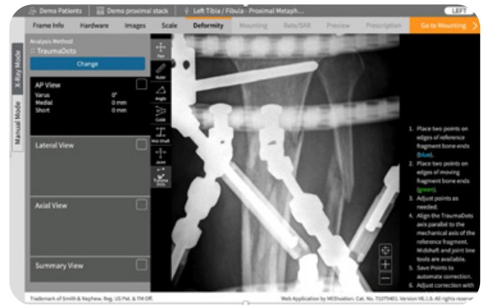


Figure 5a

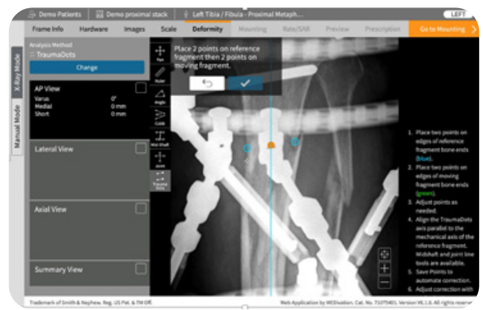


Figure 5b

Figure 5c

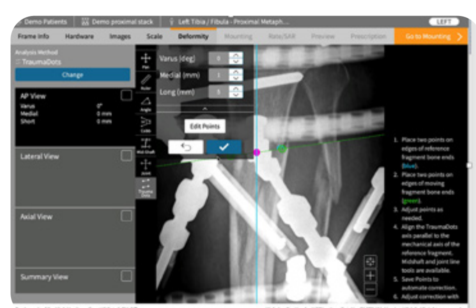


Figure 5d

Techniques in deformity correction

Managing hypertrophic nonunions with TSF◊

Nando Ferreira, PhD; Stellenbosch University, Cape Town, SA

The views and opinions expressed in this section are those of the surgeon.

Introduction

Hypertrophic tibial nonunions are ideally suitable for management with TSF circular fixation because of the fixator's ability to affect closed distraction and accurate deformity correction while simultaneously providing stable fixation to allow early functional rehabilitation.

When one appreciates that excessive strain is the root cause of hypertrophic nonunions, reducing the strain across the nonunion site would conceivably allow for bone formation and union. The mechanobiological explanation for how closed distraction promotes healing in stiff nonunions is two-fold; firstly, the use of a mechanically competent external fixator, like the TSF, reduces excessive parasitic interfragmentary motion while a small amount of distraction increases the interfragmentary distance. The end result of this approach is decreased strain to within tolerable limits for bone formation.[1]

TSF construct

A standard two-Ring TSF construct is applied with each Ring firmly affixed to the respective bone segment in the classic Rings First method. The proximal and distal Rings are then connected with TSF Struts with a resultant frame that mimics the fracture deformity. Depending on the deformity severity, Ring sizes and spacing should be considered to prevent acute Struts-to-Ring connection angles and resultant conformational instability.[2]

Proximal fixation consists of one tensioned wire and two hydroxyapatite (HA) coated half pins. The medial pin is placed on an Angled Pin Connector which allows a long pin to be placed and ensures rigid fixation of the proximal Ring to the proximal bone segment. A Ring block with two tensioned wires and two HA Coated Half Pins ensures fixation over a large area for distal fixation. A fibula osteotomy is performed, most commonly in the distal third of the fibula.

Case example

A 34-year-old-female who sustained an open fracture of her right proximal tibia was treated by open reduction and internal fixation with proximal tibial locking plate. She complicated with fracture related infection and fixation failure for which she underwent debridement, removal of the locking plate and systemic antibiotic therapy. At presentation to the reconstruction unit the patient had a stiff, varus collapsed hypertrophic nonunion of the right proximal tibia and was clear of infection **(Figure 1a)**. Application of a TSF was performed **(Figure 1b)** and union achieved **(Figure 1c)**.

Figure 1a

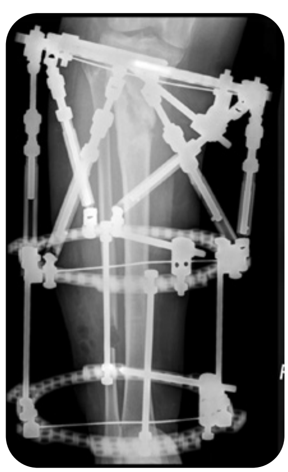


Figure 1b

Figure 1c

Safe zones and pin insertion

It is important to note that any strategy to reduce pin site complications starts in theatre. The longevity of any external fixator is dependent on bone-pin interface surviving the duration of treatment. Pins are routinely added to traditional tensioned wires to ensure rigid Ring-to-bone segment fixation so that every frame movement is accurately translated to bone segment movement. The use of Angled Pin Connectors allows pin placement that is oblique relative to the Ring which allows better purchase in short peri-articular bone segments.

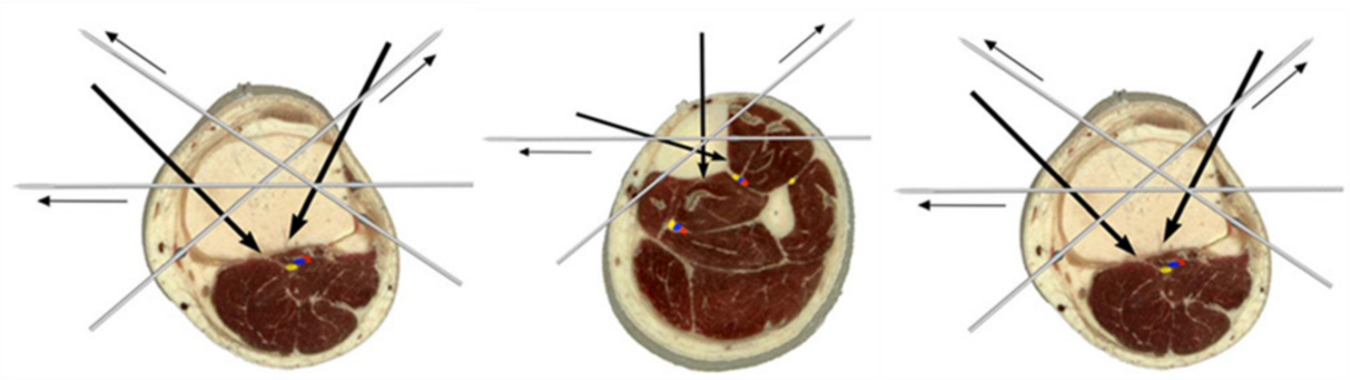


Figure 2
Unaltered figures from Nayagam et al. Safe corridors in external fixation: the lower leg (tibia, fibula, hindfoot and forefoot). Strateg Trauma Limb Reconstr. 2007;2(2-3):105-110.

A thorough anatomical knowledge is paramount for safe pin and wire placement to avoid iatrogenic damage to vital structures like nerves, vessels and tendons. It is advisable to consult wire placement atlases or published articles that describe safe zones/corridors when applying these devices.[4] It is generally accepted that transverse wires, antero-lateral to postero-medial "face" wires and antero-medial half-pins can safely be placed along the entire length of the tibia **(Figure 2)**.

Osteotomy options

Osteotomy through the nonunion site is generally not advisable. Even deformities that appear very stiff on examination are generally easily correctable with gradual TSF correction. A fibula osteotomy might be required and is performed where most convenient, unless an associated fibula deformity is present; in this case a fibula osteotomy at the level of the fibula deformity is advised.

Software planning

At the conclusion of the surgical procedure, all clinical parameters required to plan the correction are documented on the TSF◊ Worksheet. Alternatively, they can be entered directly into the software using the Intra-Op feature on any mobile device. These inputs include the sizes of the Rings used, Struts used and their settings, rotatory frame offset and the axial rotational deformity measurement. These measurements, along with the radiographic analysis findings will be needed to plan the deformity correction schedule.

Imaging and diagnostics

Accurate post-operative X-rays are vital to accurate planning and subsequent correction. The X-ray images can then be uploaded onto the SMART TSF platform in-suite deformity analysis and correction planning **(Figure 3)**.

The most important considerations when taking post-operative X-rays are:

1. The two views should be perpendicular to each other.
2. Either the AP or Lateral X-ray image should be orthogonal to the bone and the most orthogonal view selected in the software.
3. The Origin and Corresponding Point, including segmental axes and the the SMART TSF Beacon if used, should be visible on the X-rays.
4. Although not absolutely necessary, it is advisable to be able to see the entire reference Ring on both views.
5. You should add a size marker to calculate image magnification. The Beacon will accomplish this, as well as calibrate the image for subsequent measurements.

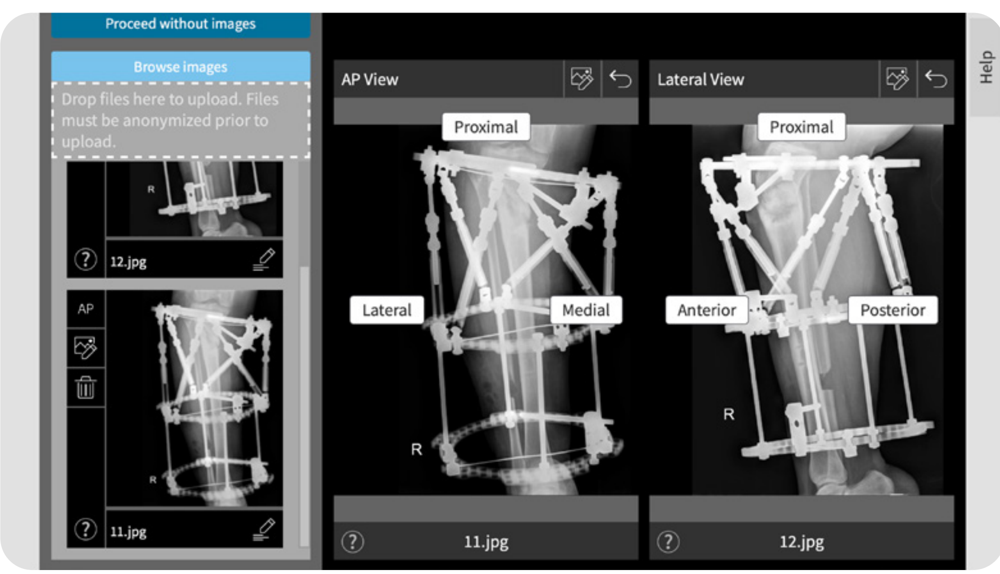


Figure 3

Software planning strategies

The reference Ring is generally chosen as the Ring closest to the area of interest – the nonunion site in this case. This allows mounting and deformity parameter measurements with the least amount of parallax error.

Following the Rings First method of frame application, the Total Residual mode (crooked frame on crooked bone) is usually preferred for analysis and correction planning. In this software mode, correction could potentially end with a slightly crooked frame but anatomically aligned bone.

Following analysis, the true three-dimensional deformity should be accurately represented in the software. Use these images to compare with your post-operative X-rays prior to commencing any correction. Pay specific attention to the relationship between the Rings and their respective bone segments. If the in-suite graphic representations are not similar, go and look for mistakes during data entry **(Figure 4a and 4b)**.

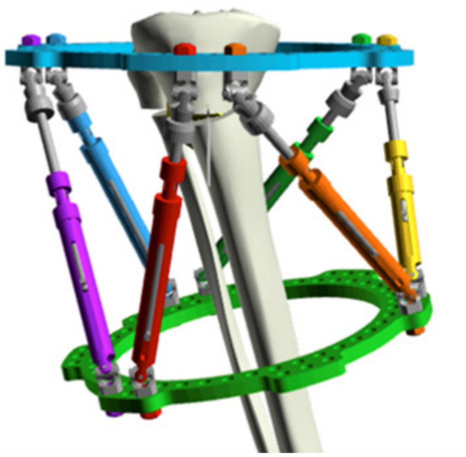


Figure 4a

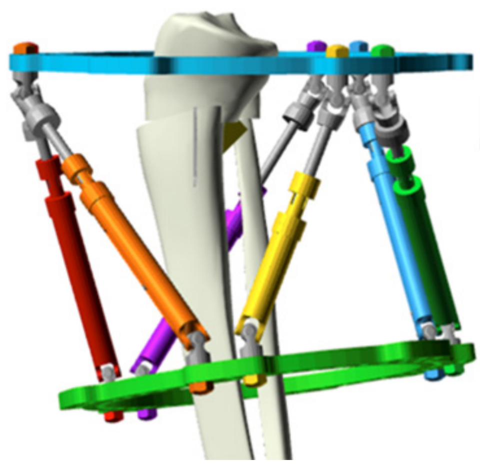


Figure 4b

Common places where mistakes are made include:

- Selecting the incorrect-sided (left versus right) limb
- Inadvertently clicking varus instead of valgus, anterior versus posterior, etc.
- Images loaded on the SMART TSF◊ software being incorrectly orientated – anterior/posterior error of the lateral radiograph is most frequent
- Incorrect strut measurements captured or entered

Software methods

Closed distraction of hypertrophic tibial nonunions are ideally suited for the Apex = Corresponding Point method of deformity planning (Origin and Corresponding point analysis method on the SMART TSF◊ software) **(Figure 5)**. This planning method allows the physician to predetermine the amount of length to be added to the correction and uses the apex of deformity as the hinge point, which eliminates the need to measure or enter any translational parameters. One does then only have to calculate angular deformities, mount the reference Ring relative to the apex of the deformity and decide on the amount of additional length required. This can simplify radiological analysis considerably.

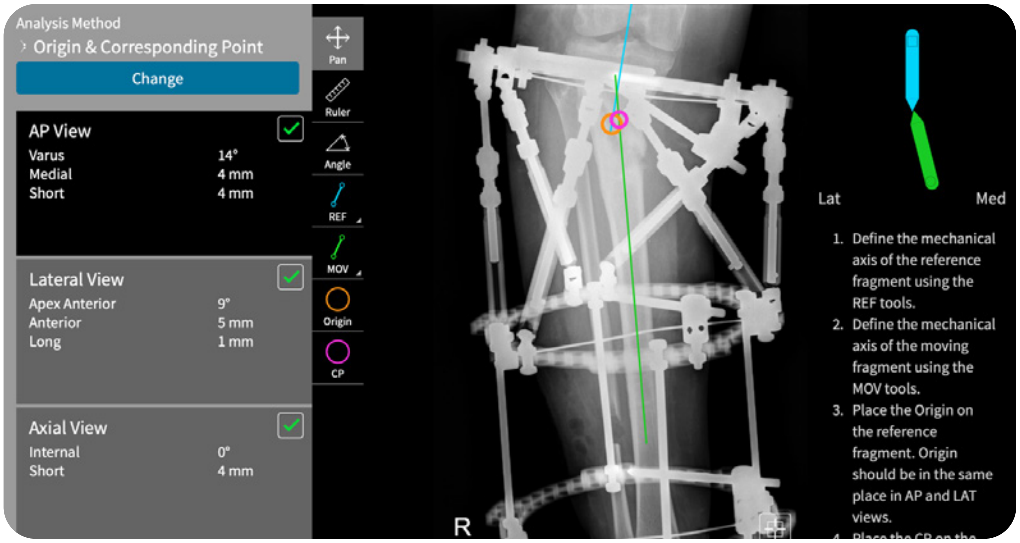


Figure 5

Structure at risk

Nonunions frequently complicate high-energy trauma fractures. As such, soft tissue flaps or scarred tissue might be present around the nonunion site. What happens with these soft tissues during distraction and deformity correction should be considered when programming the rate of correction. Here the Structure at Risk (SAR) function in the SMART TSF◊ software allows the physician to control the rate of distraction of any area of concern **(Figure 6)**. It is prudent to limit the rate of lengthening at this zone – 2mm per day in this case example.

Figure 6

Post-correction considerations

As no osteotomy is performed through the nonunion site, no mandatory latency period is required, and correction can commence as soon as a correction schedule is calculated.

Any frame stable enough to effect correction and distraction will undoubtedly be stable enough to allow early weight bearing and functional rehabilitation. Early active range of motion of adjacent joints and weight bearing as tolerated is advised. Emphasis on proprioceptive retraining and normalization of gait pattern is key during the initial post-operative period.

Managing paediatric deformity with TSF◊

Patrick Foster, FRCS; Leeds Teaching Hospitals, UK

The views and opinions expressed in this section are those of the surgeon.

Principles

Deformity correction in children is "orthopaedics" in its purest form when considering the origin of the word from the Greek meaning "straight child." TSF is an extremely versatile and powerful tool for this type of work and if used correctly after appropriate training is safe and tolerated very well by children. Circular frames (including TSF) are also extremely safe and effective for treating complex tibial fractures in children but this chapter will focus on deformity correction.

Pre-operative planning and preparation is paramount, even more so when compared to adults. As well as standard deformity analysis and planning (don't forget rotation), the added dimension of timing is crucial, as the bones are still growing – the surgeon must be aware of the natural history of the condition he or she is treating. Sometimes it is easier to wait until the child has stopped growing and treat the residual and permanent deformity rather than a "moving target." However often it is not required or appropriate to wait that long, and at the other age spectrum, although TSFs can be applied on very young children (when absolutely necessary), it is generally easier for the child and family to understand and cope after reaching the age of six. Other timing issues may be important such as school examinations in older children.

As well as bone length discrepancy and deformity, the surgeon must take into account joint stability and soft tissue tension before taking on a lengthening with TSF, particularly with Congenital Femoral Deficiency and Fibula Hemimelia. Additional surgical procedures may be required before the lengthening, either separately or at the same sitting as TSF application. This may be a simple procedure such as gastrocnemius or ilio-tibial band release, or more major such as pelvic osteotomy (such as Dega) to improve hip coverage. It is much easier to prevent hip and knee dislocation or contracture rather than attempting to salvage the situation during or after lengthening. The frame construct can protect against joint subluxation and contracture by appropriate spanning, such as across the knee into tibia when lengthening the femur, potentially with hinge, and across the ankle into the heel and foot when lengthening the tibia. Post-operative physiotherapy is vital to further protect the joint stability and movement, as well as to promote general mobility, and should be put in place in advance.

In terms of TSF construct and planning, chronic mode is ideal for treating childhood deformity, and gives the child and family a clear picture of what the TSF is going to achieve when the Rings are adjusted from crooked to parallel. The frame should be made stable enough to allow full weight bearing from the outset, and stable enough to be discharged from hospital within a few days and attend school within a week. This means there should be enough Rings on the tibia to make it stable, and enough fixation elements on each Ring to make it stable, just like a frame on an adult. It is a mistake to think that all TSFs should only have two Rings, and a mistake to think that a child's frame only needs a minimal amount of fixation to the bone.

In terms of wire and pin placement, great care must be made to avoid the growth plates, in particular the tibial tuberosity which is vulnerable to a stray pin – a bone tether in that area soon leads to apex posterior angulation (recurvatum) and shortening. Some surgeons prefer smaller diameter wires (1.5mm) and less tension (90-110kgs) for children than in adults, but in my practice this is reserved only for extremely small bones such as children's metatarsals and club hand frames for example. If using half pins the 4.5mm pin should be considered instead of 6mm for bones less than 2cm diameter, or an all-wire construct.

For lengthening rate and rhythm the distractions can start slightly earlier than in adults (days six to eight) and at a faster rate (0.8-1mm). In my experience premature consolidation of the regenerate only occurs when the child and family fall several days behind with the planned TSF program. If at all possible the child should be directly involved in the TSF corrections, and other procedures such as pinsite care. I find that children especially appreciate the use of the myTSF app to run the corrections. Once the chronic mode plan is completed I prefer to swap the TSF to straight rods in the outpatient clinic to avoid the temptation for a child to add in some extra turns as well as other benefits such as better visibility on X-ray views and decreased weight. As expected, quality of childhood regenerate is generally better than in adults, hence shorter frame times, but only if a stable frame with enough Rings and fixation elements was applied at the outset. Distal tibia osteotomy and lengthening is just as successful as proximal in children and should be considered if it suits the individual case.

Children often cope extremely well with a stable frame and so are not in a massive rush to have it removed, rather than risk a premature removal and treatment failure which is dispiriting to say the least, particularly in children. Waiting until the regenerate is fully strong also means that upon frame removal, precautions such as casting and activity modification are not required which is beneficial for the child and family all round.

Case example

A girl aged six with Ollier disease (multiple enchondromatosis). Following deformity analysis the plan was to lengthen the tibia 4cm with a 15 degree correction valgus to varus in the proximal tibia, and a chronic mode TSF◊ program was made with neutral Strut length of 170mm, so with standard Medium Struts no Strut changes were required. There was no rotational or sagittal plane deformity clinically. With the short length of bone, two Rings were required instead of three on this rare occasion **(Figures 1 and 2)**.

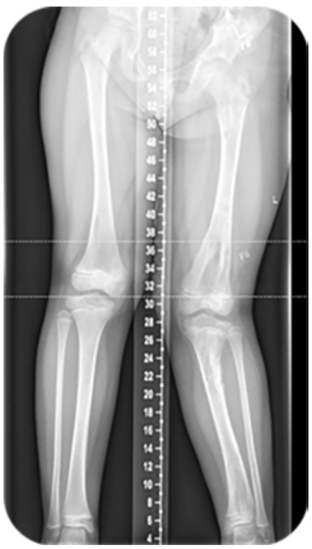


Figure 1

Figure 2

In her case she had a very flexible ankle with over 20 degrees of preoperative dorsiflexion so neither gastrocnemius release nor spanning the ankle was required. After prebuilding the chronic mode construct while the patient was in the anaesthetic room, the fibula osteotomy was performed, and the distal fibula was stabilised to the tibia with a 3.5mm screw **(Figures 3 and 4)**. Some surgeons also fix the proximal fibula to the frame or tibia but in my experience some distal migration of the proximal fibula is of no clinical consequence, and fixation in that area is often irritating to the child.

Figure 3

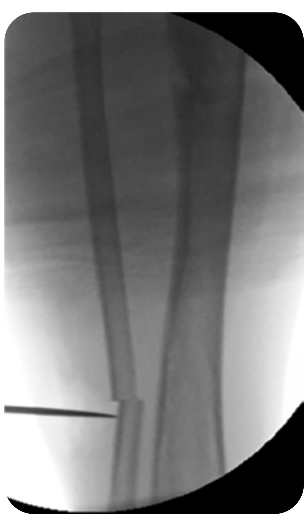


Figure 4

Figures 5 and 6 demonstrate that great care was taken to avoid the growth plates including tibial tuberosity.

Figure 5

Figure 6

Figures 7 and 8 show the stable construct which matches the deformity.

- Proximal 2/3 155mm Ring with two 1.8mm Olive Wires tensioned to 110-130kgs, and two 4.5mm HA pins.
- Distal Ring 155mm full Ring with two 1.8mm Olive Wires, one plain wire and one x 4.5mm HA pin.
- Proximal tibia corticotomy created with three x 3.8mm drill passes and osteotome through a 1cm incision.

With chronic mode since the TSF◊ program is already done it does not matter if the post-operative X-ray is neither calibrated nor centered exactly on the reference Ring.

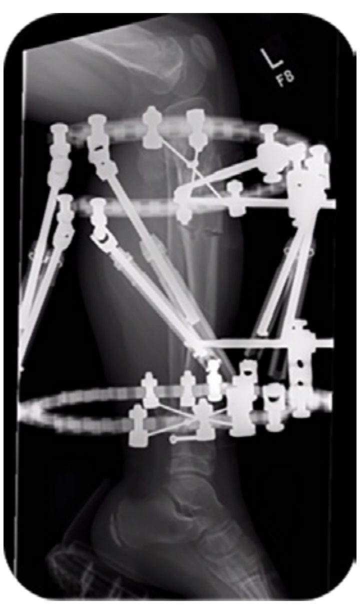


Figure 7

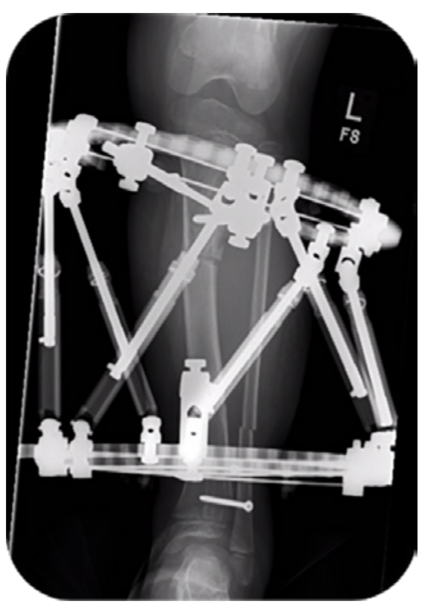


Figure 8

Post-operative treatment

Physical therapy can begin on post-operative day one, including weight bearing. Ollier's is known to lead to swift regenerate formation so turns are started on day six with a rate of 1mm per day. As well as interim clinic appointments the position at the end of the program was checked with X-rays. Upon completion of the correction, Struts can be replaced with Threaded Rods.

Figure 9

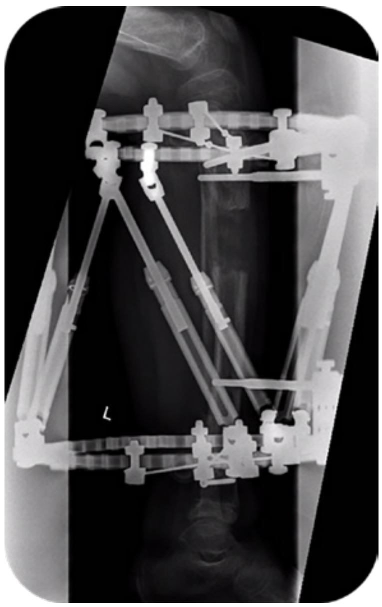


Figure 10

After four months the frame was removed under a short general anaesthetic and no cast or splintage was required. **Figures 9 and 10** show the clinical and radiological result. With her condition she is likely to develop more of a leg length discrepancy by skeletal maturity so will need at least annual follow-up and probably left femoral lengthening or right-sided epiphyseodesis at the appropriate time.

TSF◊ for High Tibial Osteotomy

Janet Conway, MD; Sinai Hospital, Baltimore, MD

The views and opinions expressed in this section are those of the surgeon.

Introduction

There are many options for performing a high tibial osteotomy.[1-4] External fixation and gradual correction has many advantages in these cases. Near immediate full weight bearing is possible and allows for accurate post-op adjustments to achieve the exact mechanical axis for successfully unloading the medial compartment. The medial opening wedge is regenerate bone that is stimulated to heal with full weight bearing. The typical time for external fixation wear is four to five months with activity restrictions limited to impact sports only.

Standing assessment reveals bowing of one or both legs. Medial knee pain is present upon joint line palpation. With chronic meniscal tears, joint swelling is common. Joint line laxity is present secondary to the loss of medial joint space and the lateral collateral ligament laxity that occurs from chronic stretching. Tibial rotational assessment is important. Any excessive external or internal rotation must be corrected. Joint range of motion is documented and it is important to note any lack of full extension of the knee or ankle equinus. These issues when noted can be addressed at the surgical setting with a gastrocnemius recession or planning some extension into the frame correction.

Radiographic evaluation

Standing full limb radiographs are taken. The mechanical axis of the whole limb is assessed with a line drawn from the center of the femoral head to the center of the ankle. With medial-compartment osteoarthritis (MCOA) or varus tibiae this line falls entirely within the medial compartment when compared to normal alignment which is entirely within 1cm of the center of the knee joint. A long lateral radiograph assesses the sagittal plane alignment. The normal posterior proximal tibial angle is 80˚ **(Figures1a and 1b)**. Anything less than this is considered pro-curvatum and can be corrected with the gradual external fixator.

MRI imaging of the knee is essential for pre-operative evaluation. Any asymptomatic lateral joint line pathology is detected as well as any patella-femoral joint pathology. The medial joint line will be narrowed with cartilage loss and associated meniscal tear.

Figure 1a

Figure 1b

Determining the degree of correction

Minimal, moderate and severe MCOA can be addressed using varying degrees of correction. The mechanical axis is shifted laterally according to the degree of arthritis. The maximum correction is to a point just lateral to the lateral tibial spine. Minimal or moderate correction can be to the center of the knee joint or slightly lateral to the lateral tibial spine respectively. The pre-operative standing leg radiograph is used for planning.

A line representing the new mechanical axis is drawn from the center of the femoral head to the desired correction point – for example just lateral to the lateral tibial spine.

A second line is drawn from the center of the ankle up through the mid-shaft tibia and extending proximally.

The angle this line creates is the angle of correction that will be placed into the deformity parameter section of the SMART TSF◊ software **(Figure 2)**.

Figure 2

Knee arthroscopy is performed at time of surgery.

A distal tibio-fibular screw (Figure 3a) is inserted at the level of the distal syndesmosis, angled proximal medial to distal lateral.

Perform the fibular osteotomy (Figure 3b) at the level of the mid-shaft fibula. This is a 3-4cm incision overlying the lateral fibula using the interval between the gastrocsoleus muscle complex and the peroneals. Utilizing this corridor minimizes bleeding. The fibula is exposed and a 1.8mm Wire or small drill is used to mark out the oblique fibular osteotomy. The osteotomy is pre-drilled anterior proximal to distal posterior. This creates an oblique osteotomy that maximizes surface area for healing and allows the bone ends to slide past each other with the varus to valgus correction. Confirm under fluoroscopy that the osteotomy can 100% translate to avoid an incomplete osteotomy. Pack the wound and close at the end to allow for hemostasis and prevention of a hematoma.

Mark the level of the osteotomy (Figure 3c) for the tibia using a wire and a marking pen This should be approximately 4-5cm below the level of the top of the fibula.

Determine Ring size. A 2/3 Ring allows flexion of the knee.

Insert a Reference Wire. Place a 1.8mm Wire just anterior to the fibula only capturing the tibia. The Wire should be placed parallel to the knee joint with the patella facing forward as well as parallel to the floor. Tension the wire to 110kgs.

Mount the Proximal 2/3 Ring (Figure 3d) at the level of the head of the fibula. The entire frame needs to be mounted with the patella facing forward. The Ring should be fixed proximal to the Wire. This allows for maximum pin/wire fixation proximal to the osteotomy.

Add additional fixation. Select a 2 Hole Rancho Cube or Pin Fixation Clamp and place it directly anteriorly on the Master Tab in the center hole. Before placing this pin, ensure that there is adequate room on the medial/lateral side of the Ring for the soft tissue. Adjust accordingly by tapping the Ring over on the Wire. Now make sure that the Two Hole Rancho Cube will still capture the bone. This can be done manually or with fluoroscopy. Use the lateral C-arm shot to correctly place the pin mounting the frame orthogonally in the sagittal plane. Proper sagittal alignment is when the Ring is tilted 10° to the joint line. Once the frame is aligned correctly drill and place the pin. Adjustments can be made to the sagittal alignment with the 4.8mm Drill in place by adjusting your hand before the second cortex is drilled. Self-drilling pins are not recommended and hydroxyapatite-coated pins are preferred to help prevent pin loosening and infection. Place the pin and use the C-arm to check that it has bi-cortical purchase. Once it is placed fix it to the Rancho Cube with two Set Screws or 8mm Bolts. Now the proximal Ring is mounted. Remaining fixation will be placed after the second Ring is mounted.

Figure 3a

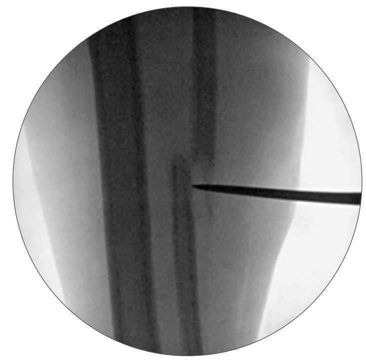


Figure 3b

Figure 3c

Figure 3d

Mount the second Ring (Figure 4a). This can be placed anywhere along the distal portion of the limb. Using a Medium Strut with the length at the mid-point is a good general guide to where the second Full Ring will be mounted. This setting allows for adjustments to be easily made after the frame is mounted without having to do a Strut change early in the correction phase. Mark the AP and LAT center of the second Ring using bolts. Ensure there is proper clearance of the Ring around the soft tissues. Mount the Ring with a transverse Wire placed parallel to the floor and perpendicular to the tibial bone on the AP projection. Be careful to keep the patella forward during mounting of the distal Ring as well if you are not planning rotational correction. If you are planning rotational correction, consider mounting the distal Ring orthogonal to the foot with the foot forward instead of the patella. Fix the Ring to the leg in a similar fashion as the proximal Ring to ensure that the frontal and coronal plane alignment are correct. Tension the Wire to 130kgs. Center the Ring on the leg with respect to the soft tissues. Once the Ring is accommodating medially and laterally, use a Three Hole Cube to fix the Ring in the sagittal plane. Place this Cube distal to the Ring and check the lateral X-ray to ensure that the Pin is placed perpendicular to the tibial shaft. Place the Pin and secure in the Cube.

Figure 4a

Place six Medium Struts (Figure 4b) in their positions. The author's preference is for Standard Struts. Note the initial Strut settings and size for the frame planning schedule. After the osteotomy you will verify that these numbers are the same.

Figure 4b

Add additional fixation (Figure 4c). This includes two more Half Pins proximally and two more Half Pins distally. The proximal ring can accommodate a One Hole Cube with a washer and a Pin Fixation Bolt. The distal Ring can accommodate two more Pins inside the Ring.

Figure 4c

Perform the osteotomy (Figure 4d) 4cm distal to the proximal Ring using multiple drill holes and an osteotome. Ensure the osteotomy is complete by detaching the Struts from one of the Rings and counter-rotating the Rings. If the Rings do not rotate freely, the osteotomy is not complete. Once complete, re-attach the Struts back up and check to make sure the osteotomy is not displaced on the fluoroscopy and the Strut numbers are the same as noted previously.

All wounds are closed. Antiseptic-soaked ILIZAROV™ Sponges are placed around the Pins and 4x4s are stuffed into the frame to help control swelling with a stockinette around the frame to hold them in place.

Figure 4d

Software

HTO serves to re-align the axis of the limb, rather than correcting a bony deformity. Essentially a deformity is created in order to shift the axis. The Osteotomy Sandbox in SMART TSF◊ serves as a useful tool to perform the virtual osteotomy and measure the extent of angular correction needed **(Figure 5)**.

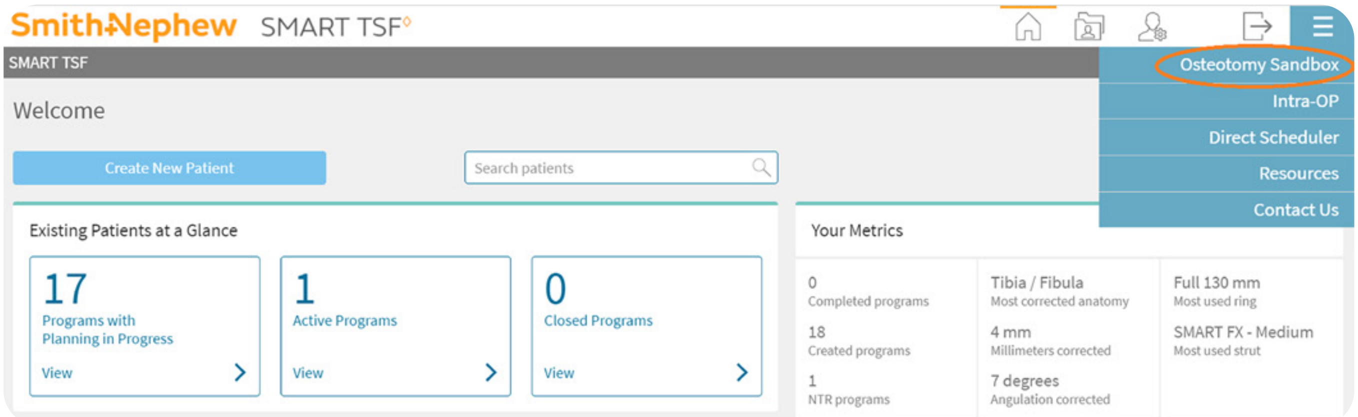


Figure 5
Osteotomy Sandbox can be found in the Resources section of smart-TSF.com

- Full limb standing X-rays are uploaded to Osteotomy Sandbox. The images must have a means of calibrating them.
- Joint Lines and a mechanical axis can be drawn.
- The SuperDot method can be used to perform a virtual cut.
- The moving fragment is picked up and re-positioned on the desired axis.
- The measured deformity is entered post-operatively on the Deformity tab in the Software.
- AP Angulation is typically 10-16˚ of varus.
- AP Translation is typically 5mm-10mm medial.
- Rotation is based upon pre-operative clinical assessment.
- Lateral Angulation is entered as 10˚ Apex Anterior, as frames always go into pro-curvatum. Planning the pro-curvatum ahead in the initial frame schedule prevents multiple residual corrections.
- Lateral Translation is usually zero.
- Axial Translation of 5-10mm Short allows clearance of the moving fragment relative to the reference, and can be applied before or in conjunction with any angular movement.

Using Osteotomy Sandbox for pre-operative planning

Import a full leg X-ray into the Osteotomy Sandbox. The Cobb Angle Tool is used to measure the deformity. The first line is drawn from the center of the femoral head through the knee, or more correctly the lateral tibial spine.

The second line is drawn from the center of the ankle through the knee. The Joint Line Tool can be used to define the correct axis.

Figure 6 shows these lines intersect in the mid-femur, representing the CORA. Using Osteotomy Rule 2, the planned osteotomy will be 4-5cm distal to the top of the fibula.

Figure 6

Use the SuperDot tool to simulate the osteotomy. Divide AP image at osteotomy, capturing the moving fragment, in this case the distal fragment.

Place the Super Dot axis over the axis of the moving fragment. Using the handles, move the fragment into position until the Super Dot axis aligns with the axis of the reference fragment **(Figure 7)**.

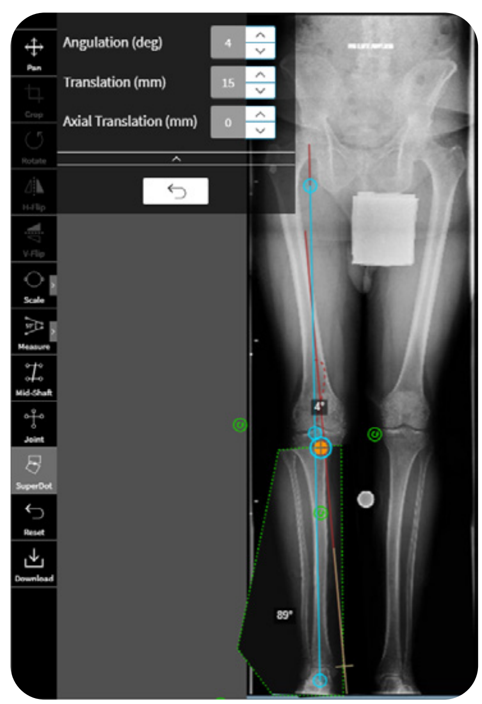


Figure 7

The same analysis can be performed on the Lateral view if there is deformity in the coronal plane. As frames almost always go into pro-curvatum, it is a good idea to assume 10° of Apex Anterior in deformity planning and resist the drift into pro-curvatum. Additionally 5-10mm Short is typically programmed.

Rotation is a clinical assessment.

Once the TSF◊ is applied the known deformity parameters measured pre-operatively are programmed using the classic Origin and Corresponding Point method **(Figure 8)**.

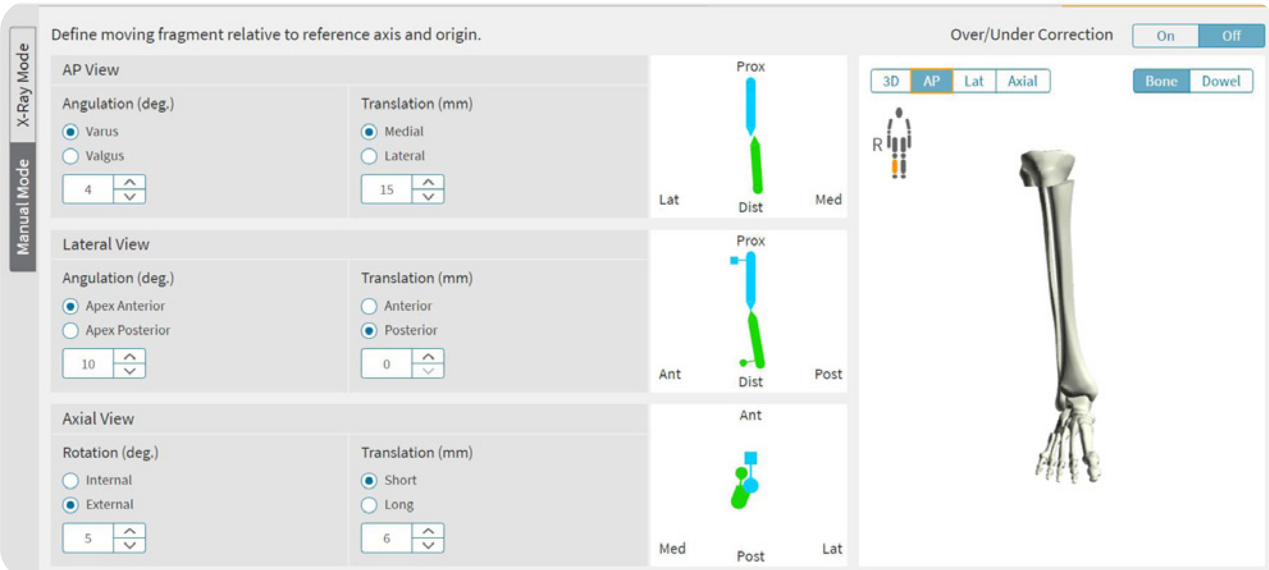


Figure 8

Note

Placing the SuperDot at the center of the osteotomy is the most reproducible landmark to find on the Lateral image. As this is Osteotomy Rule 2, translation occurs, and the SMART TSF software measures this.

The SuperDot can alternatively be placed at the CORA, as shown in **Figure 9**. The drawback with this strategy is potential difficulty in placing the SuperDot at the same location on the Lateral image.

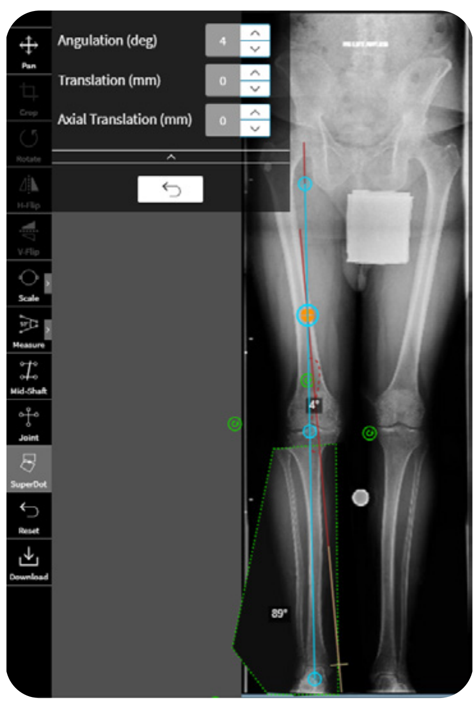


Figure 9

Post-op considerations

The patient can perform range of motion of the knee and ankle and weight bear as tolerated on the limb. Pin care is with Hexagonal sponges and saline. Showers with antibacterial soap are allowed after the stitches or staples are removed and the pin care is performed following showers. Physical therapy is three times per week and is for range of motion of the knee and gait training. DVT prophylaxis is recommended for four to six weeks. Post-operative visits are scheduled two weeks post-operatively and then weekly until the correction is perfect on the standing erect leg and long lateral radiograph. Radiographs are performed monthly following the achievement of the correction until the bone is consolidated. Prior to frame removal, the frame can be dynamized to reduce the tension in the device and allow the bone to experience more load for one month prior to removal. The average frame time is four to five months. Once the bone has healed the frame is removed under anesthesia as an outpatient. Weight bearing following frame removal is 50% for two weeks followed by 100% for two weeks. This is allowed with the use of crutches for one month. This is to prevent any fractures through the pin sites while they remodel. After one month, physical therapy is continued until the patient is strong enough to resume all of their desired activities.

See Dr. Conway perform her HTO Technique at:

www.vumedi.com/video/high-tibial-osteotomy-4/

Ankle arthrodesis with TSF◊

LTC Justin Orr, MD; William Beaumont Army Med Center, El Paso, TX

The views and opinions expressed in this section are those of the surgeon.

Introduction

Current recommendations for primary and revision tibiotalar joint arthrodesis favor internal compression techniques using screw and/or plate internal fixation, with satisfactory outcomes being reported for most patients. Similarly, when there is concomitant subtalar joint arthritis, current recommendations for primary and revision tibiotalocalcaneal (TTC) arthrodesis favor screw and/or plate internal fixation or retrograde TTC intramedullary nailing. Favorable union rates and outcomes for primary and revision tibiotalar arthrodeses have been reported using circular fixation techniques.[1,2] In select patients, ankle and TTC arthrodesis with internal fixation may be limited or even contraindicated given insufficient bone stock to adequately support implants, an abundance of avascular bone, a history of deep infection or osteomyelitis, in cases of prior failed total ankle replacement with significant osseous defects, or in cases when previous ankle or TTC arthrodesis has failed. Ring fixation may facilitate clinically acceptable limb salvage in these complex cases.

Circular Fixation for Ankle Arthrodesis

The most common indication for ankle arthrodesis is severe, destructive arthritis that fails non-operative management, most commonly post-traumatic in origin. Regardless of the method of fixation, ankle arthrodesis is contraindicated in patients with peripheral vascular disease until adequate circulation for healing can be re-established. Absolute indications for arthrodesis include ankle arthritis associated with neuropathy, extensive avascular necrosis of the talus and/or distal tibia, severe coronal or sagittal plane deformity and non-reconstructable ankle ligament insufficiency. Joint-sparing procedures may be favored when ankle arthritis is associated with ipsilateral hindfoot arthritis or a contralateral ankle or TTC arthrodesis.

External fixation may confer advantages over internal fixation in several situations, specifically:

1. History of septic arthrosis or osteomyelitis
2. Compromised soft tissue envelope about the ankle
3. Inadequate bone stock at the arthrodesis site to support internal fixation limited to the tibia and talus
4. Leg length discrepancy that is inadequately treated with a shoe modification, requiring potential distraction osteogenesis for limb lengthening
5. Failed prior ankle arthrodesis using internal fixation
6. Neuropathic joint arthropathy

While contraindications to ankle arthrodesis are few, considerations relative to external fixation for ankle arthrodesis are patients with in-dwelling total joint arthroplasties, as potential pin tract infections may lead to periprosthetic infection, and sensory neuropathy of the contralateral leg, as the external fixator may cause wounds to the contralateral lower extremity unbeknownst to the patient.

Preoperative planning

Patient history, clinical evaluation, and routine ankle radiographs establish the diagnosis of symptomatic ankle arthritis. On examination, particular attention is paid to associated malalignment deformities and/or presence of ankle equinus contracture, as adjunctive deformity corrective procedures or Achilles tendon lengthening may be necessary. Weight bearing radiographs of the ankle usually confirm the diagnosis. The soft tissue envelope about the ankle and the vascular status must be evaluated. Poor soft tissues about the ankle, often secondary to trauma and/or prior surgery, typically necessitate a less invasive exposure for joint preparation. Compromised perfusion of the extremity should prompt vascular consultation to optimize the chance for union and proper soft tissue healing.

Routine weight bearing AP, mortise and lateral ankle radiographs generally suffice, but if there is any suspicion on clinical evaluation for limb malalignment or foot pathology, then mechanical axis, hip and knee, and foot radiographs should also be evaluated. CT and MRI are not routinely required.

Simply placing a tibiotalar arthrodesis in neutral plantarflexion/dorsiflexion (0°), subtle hindfoot valgus (0-5°) and avoidance of internal rotation will generally result in a functional, plantigrade foot. However, disregard for whole limb and foot alignment may lead to a poor functional outcome, despite successful ankle fusion. Limb malalignment may need to be addressed before or simultaneous to ankle arthrodesis. A powerful advantage of arthrodesis with circular fixation in the setting of proximal or distal malalignment or limb length discrepancy is that simultaneous combined procedures can be performed, such as proximal tibial corticotomy with lengthening/realignment and ankle arthrodesis or concomitant ankle and foot procedures.

Planning should include the potential for a staged procedure. Irrigation and debridement, hardware removal and infection management strategies should be planned as the first stage. If the ankle is determined to be unstable at that time, the frame may be placed for support. In a second stage, the ankle is again debrided, and compression may be applied through the ankle if there is no evidence of persistent infection. Alternatively, the plan can be for a single-stage procedure if the surgeon is satisfied that all of the infected tissue has been removed.

Operative technique

A proximal regional anesthetic typically suffices for both ankle and TTC arthrodeses using external fixation. Tourniquet (thigh) use is generally limited to the approaches for joint preparation. Circular fixation alone cannot produce fusion; proper joint preparation is essential. Therefore, if there is any concern for the perfusion of any of the joint surfaces, then the tourniquet must be released before wound closure to confirm bleeding at the arthrodesis site. Tourniquet use is not recommended during application of the frame.

The patient is positioned supine, often with a support under the hip of the operative leg. The goal is to orient the lower leg parallel to the operating table and floor to facilitate proper placement of the external fixator. A sterile proximal calf support (bump) should be created to suspend the lower leg during frame placement. The lower leg is prepared and draped in usual sterile fashion, and the leg is exsanguinated using a tension bandage unless persistent infection is suspected.

Once the joint(s) are fully exposed, attention is now turned to meticulous joint preparation. I routinely use joint distraction with either lamina spreaders or an invasive joint distractor placed over anterior smooth pins in the distal tibia and talar head-neck junction. Remaining articular cartilage is removed with a sharp elevator, osteotome or chisel. I prefer to maintain the architecture of the subchondral bone of the tibial plafond and talar dome, which facilitates easy adjustment of coronal and sagittal plane alignment without compromising limb length or bony apposition. On the contrary, flat cuts sacrifice limb length and make alignment adjustments more challenging. In the setting of malalignment, some deformity correction may need to be made through the joints with limited sacrifice of the subchondral osseous anatomy. The subchondral bone is penetrated with a drill bit and/or narrow chisel. This promotes fusion by increasing surface area, delivering autogenous bone graft to the arthrodesis site, and encouraging bridging trabeculae for fusion.

The malleoli are preserved when possible, and the medial and lateral gutters are prepared as described above to further increase the arthrodesis surface area. Autogenous or allograft bone grafting is at the discretion of the individual surgeon, but excessive use of bone graft might prevent bony apposition and should be avoided when possible.

Once the joint is prepared, attention is then turned to ankle joint reduction and provisional alignment prior to application of the frame. I find that provisional fixation with one or two smooth, large-diameter Steinmann pins is often necessary to maintain ideal position prior to application of the frame **(Figure 1)**. This pin is placed similar to the guide pin used for retrograde IM TTC nail procedures. Provisional fixation should maintain adequate reduction of the prepared talus within the prepared ankle mortise.

Optimal function and potential for fusion is established with maximum contact between the arthrodesis surfaces, avoiding anterior translation of the talus within the ankle mortise. Valgus is generally established in the hindfoot; varus malalignment at the ankle joint must be avoided. Furthermore, calcaneus or equinus positioning must be corrected to a neutral sagittal plane alignment. Finally, the second metatarsal should be in line with the tibial crest to ensure proper rotational positioning, avoiding internal rotation.

The wound is then gently irrigated and meticulously closed in a layered fashion, making sure to re-approximate the extensor retinaculum and subcutaneous skin. The skin is closed in a tension-free manner, using non-braided suture.

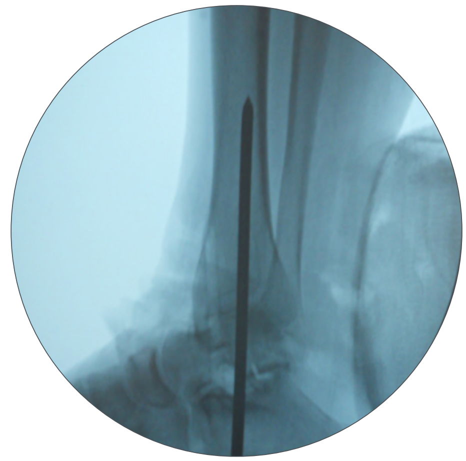


Figure 1

Frame application

For ankle and TTC arthrodesis, a thorough understanding of cross-sectional anatomy of distal lower extremity is paramount for safe use of transosseous fixation. In general, I recommend the use of 1.8mm thin wires and 5mm or 6mm HA-coated pins for ankle and TTC external fixator arthrodesis.

Fixation in the foot

I generally prefer to place the Foot Ring first, with the tibia Ring or Ring block slid up the leg and placed second. An orthogonally placed long Foot Ring that matches the size of the patient's anatomy is placed first.

With a two-finger breadth distance between the back of the heel skin and the inner surface of the Foot Ring, I place two oblique transosseous Olive Wires through the calcaneus **(Figure 2a)**. The first is placed posteromedial to anterolateral, and the second is placed posterolateral to anteromedial. The olives should be on opposite sides of the calcaneus to maximize stability. Also, in order to maximize stability, one calcaneal Olive Wire should be placed above the foot plate, and the second wire placed below the foot plate.

I recommend one transosseous smooth or Olive Wire traversing the first and second metatarsals and one wire traversing the fifth through third (or second) metatarsals. It is not advisable to attempt to capture all five metatarsals with a single wire, as this can lead to unwanted flattening of the normal cascade of the forefoot **(Figure 2b)**.

I also place a third midfoot wire through the cuneiforms and possibly capturing the cuboid **(Figure 2c)**. Be sure during wire placement to avoid placing wires in locations where connection to the Foot Ring will interfere with Strut placement. Dashed lines indicate options for Strut Mount other than default.

Once attached, the orthogonal Foot Ring should bisect the medial and lateral columns of the foot as you look at it clinically, and the center of the Ring should line up with the lateral border of the second metatarsal **(Figure 2d)**. Once the wires are placed, close the foot plate with a size-matched Half-Ring, and tension the wires to 50-90kg tension. It is critical to tension wires only after closure of the ring.

Figure 2a

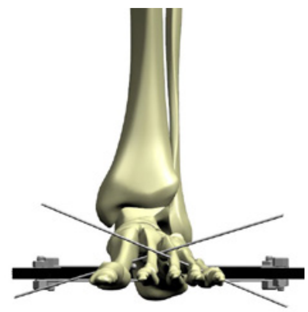


Figure 2b

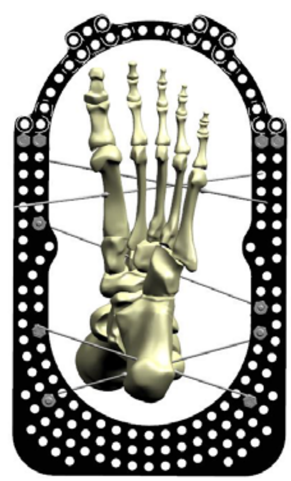


Figure 2c

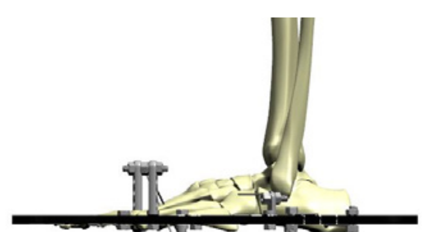


Figure 2d

Isolated tibiotalar arthodesis

If I am performing a TTC arthrodesis, no dedicated fixation in the talus is required at this point, as we will be axially compressing across the entire subtalar and tibiotalar joint axis. If, however, I am performing an isolated tibiotalar arthrodesis, the talus will require fixation in order to isolate the tibiotalar joint from the rest of the foot.

There are two techniques to perform this: a "drop" wire or an isolated talar intermediate Ring **(Figure 3a)**. I prefer the intermediate Ring technique because it allows me to attach the foot wires to the Foot Ring without any concern for where Struts will be placed.

In this technique, I first line up a 2/3 Ring, open anteriorly, centered on the talus at or just above the level of the lateral process. A medial to lateral Olive Wire is then placed under direct AP fluoroscopy. This wire should be parallel to the previously placed orthogonal Foot Ring and tibiotalar joint, and is generally perpendicular to the anatomic axis of the tibia above unless there is a malalignment deformity. The wire is attached to the anterior open 2/3 Ring. The center of the ring is ideally correspondent to the center of the tibiotalar joint on AP and lateral radiographs **(Figure 3b)**. After tensioning the wire, this open 2/3 ring is attached to the orthogonal Foot Ring below with four Threaded Rods. If there is a parallelism mismatch between the Foot Ring and talar intermediate Ring, Conical Washers can be used to offset any subtle mismatch.

Struts will be connected from the tibial Ring to the intermediate 2/3 Ring around the talus **(Figures 3c and 3d)**.

With the "drop" wire technique, the same talus Olive Wire is placed; however, it is attached directly to the Foot Ring using appropriate length Posts and Wire Fixation Bolts. I find this technique to be more cumbersome in terms of fixation crowding and later Strut placement, hence prefer the talar intermediate Ring strategy.

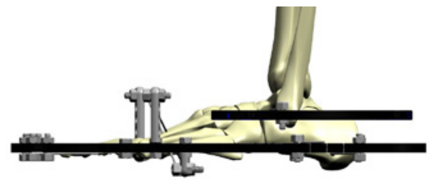


Figure 3a

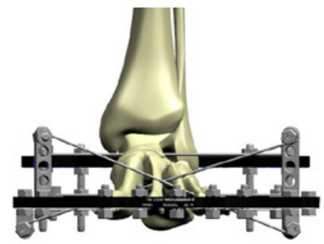


Figure 3b

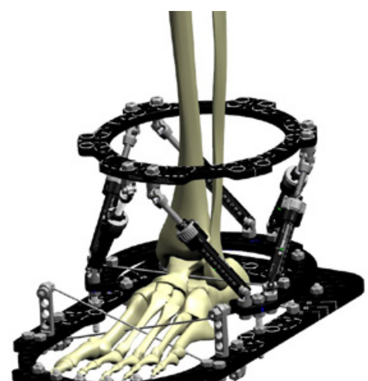


Figure 3c

Figure 3d

Fixation in the tibia

For the purposes of ankle and TTC arthrodesis, I generally recommend a one- or two-Ring proximal tibial block. For a two-Ring block, the block is pre-built, with the Rings connected by Threaded Rods or Sockets, evenly spaced over the circumference of the Rings

The most proximal Ring in the tibial block is generally placed just distal to the midshaft of the tibia **(Figure 4a)**. The distal Ring in the tibial block is generally placed in the distal third of the tibia, well proximal to the metaphyseal flare. The advantage of a two-Ring block is that typically only three HA-Coated Pins can be placed from a single ring. Using two Rings, separated by short Threaded Rods or Sockets, allows for comfortable placement of up to five HA-Coated Pins in multiple orientations with excellent pin spread. Not only does this provide more stability, but should one of the half pins develop loosening or infection, it can be safely removed without losing stability of the frame.

The pins are pre-drilled with continuous irrigation to limit thermal necrosis of the bone.

One pin is placed anteromedially in the flat medial face of the tibia, built off the top Ring with an 85mm Angled Pin Connector directed 30-45° toward the proximal tibia. A second pin is placed medial to lateral in the tibia using a 35mm Angled Pin Connector. Finally, a third pin is placed anteriorly, below the Ring using a 1H Rancho **(Figure 4b)**.

I typically do not place a reference wire to establish orthogonal Ring placement. Angled Pin Connectors obviate the need to use a reference wire. However, if the reference wire technique is used to establish an orthogonal tibia Ring or Ring block, I generally remove it at the end of the case.

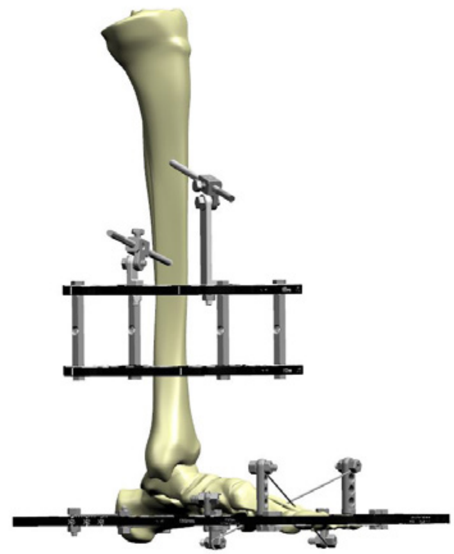


Figure 4a

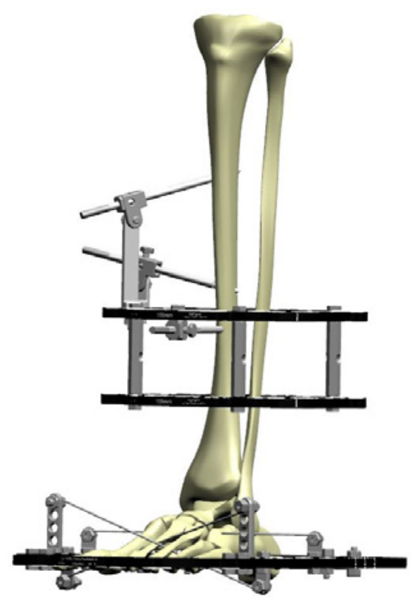


Figure 4b

On the bottom Ring, from which the six Struts will be attached, I place

- One HA Pin anteromedially through a 6mm Pin Fixation Bolt on top of the Ring
- A second anterior pin off a 3H or 4H Rancho Cube or 35mm Angled Pin Connector below the Ring on the inner tab, between the anticipated Struts #1 and #2 **(Figure 5a)**.

Care must be taken to identify the tibialis anterior tendon and protect it during placement of this distal-most anterior pin.

At this point, the tibial block has been established and can be attached to the foot and ankle construct with six Struts.

Ideally, the spacing between the tibia block and the foot block is such that six Medium or Short Struts can be placed with initial Strut settings in the middle of the Struts' ranges **(Figure 5b)**. This will minimize need for Strut changes in clinic.

I will generally at this point remove the previously placed Steinman pin and manually compress the ankle joint (and subtalar joint if performing TTC fusion) acutely in the operating room before locking all the Struts. Alternatively, if the Steinmann pin placed longitudinally for provisional fixation is directly perpendicular to the arthrodesis site, then it can be used as a "rail" during compression.

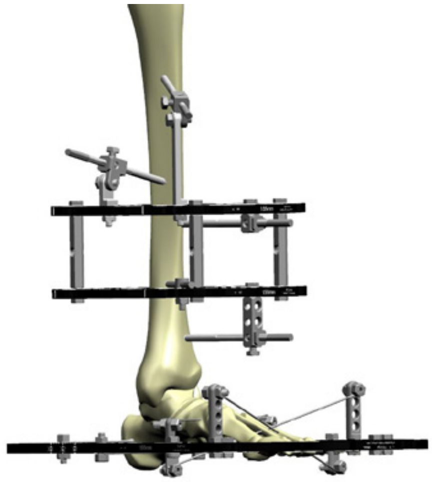


Figure 5a

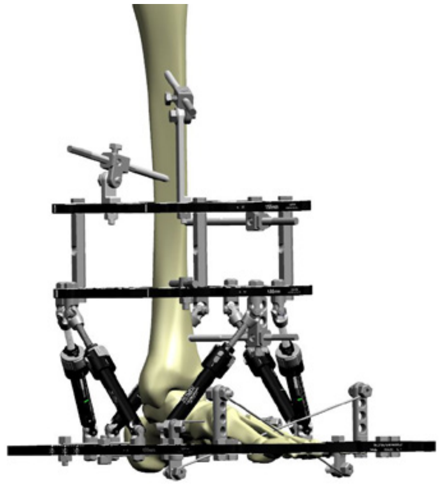


Figure 5b

Tips and tricks

1. Allow adequate space for the calf so that the proximal Ring does not impinge on the soft tissues. One common mistake is to attach the proximal Ring with the bump behind the calf to suspend the leg with no regard for where the calf will be once the bump is removed. If not assessed proactively, the Ring will impinge on the calf, necessitating removal of the Ring and potential repositioning of fixation.

2. Allow adequate room between the posterior heel and the Foot Ring. This space does not need to be more than 2cm, as virtually no swelling occurs posteriorly at the calcaneus, irrespective of how extensive the surgery is. However, with direct contact of the Foot Ring to the calcaneus, the frame potentially may need to be disassembled and remounted in its entirety.

3. Be sure the actual foot is slightly plantar to the Foot Ring. The plantar foot pad is thicker than it appears, and if the Foot Ring is positioned too distally, it will not be possible to pass the wires through the bones of the foot, only the plantar soft tissues.

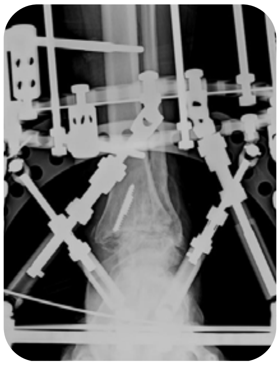
Post-operative

There is no consensus on proper pin management. I allow simple showers with soap after all surgical incisions are healed. In rare cases, I will recommend anti-microbial soap and cotton-tipped applicators for additional pin care. If a pin tract should become infected and fails to respond to proper pin care and oral antibiotic management, the involved pin will need to be removed and replaced with a different pin in a minor operative procedure.

Ankle arthrodesis, regardless of technique, may go on to delayed union, nonunion, and malunion. Generally, delayed union is effectively managed with further compression applied to the arthrodesis site in the office setting, with or without a software program. The risk of malunion (equinus, varus, and excessive valgus), as for arthrodesis using internal fixation, is typically avoided by proper intraoperative positioning of the ankle joint. The advantage of circular fixation is that subtle adjustments are still possible post-operatively. After frame removal, the patient should be protected in a walking cast, boot or brace until the tibial pin sites have healed. With the stiffness at the ankle arthrodesis site, immediate full weight bearing after frame removal may lead to stress fracture through a tibial pin site.

Case example

Post-traumatic OA with 20-30° varus



TSF° applied, compression started post-op day 5

Patient at 2 years post-fusion

Treating Equinus with TSF◊

Nima Heidari, FRCS; Royal London Hospital, UK

The views and opinions expressed in this section are those of the surgeon.

Introduction

Equinus deformity may present as a congenital deformity or occur as a result of lower limb trauma **(Figure 1)**. Correction using the TSF◊ mitigates the need for broad soft tissue dissection and its associated potential complication.

Figure 1

A regional block is preferred to control immediate post-op pain. The limb is draped above the knee, with sandbag under the buttock and patella facing the ceiling. Ideally, the limb can be suspended or held ina locally fashioned suspensory device.

If Tendo Achilles is tight, a gastro-soleus release at the musculo-tendinous junction might be necessary in more severe deformities. However, avoid a triple cut through the tendinous part which can result in loss of power.

A flat surface, such as the lid of an instrument tray, is used to simulate a load-bearing surface intra-operatively **(Figure 2a)**.

Figure 2a

Figure 2b

Figure 2c

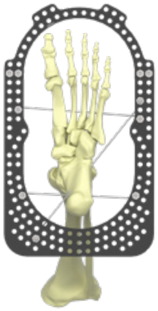


Figure 2d

Frame construction

A Full Ring of appropriate size for the tibia is chosen and slid over the foot to rest at the knee until later. A construct of Foot Ring closed with Half Ring and three 2H Ranchos on the plantar aspect is constructed **(Figure 2b)**. When positioned against the simulated load-bearing surface, the Ranchos serve to appropriately proximalize the Ring on the foot **(Figure 2c)**.

An Olive Wire is inserted lateral to medial through the calcaneus. A Smooth Wire is inserted through the metatarsals. Both wires are tensioned to 90kg. Dressings are applied immediately to minimize risk of pinsite haematoma. The wires are bent over the Wire Fixation Bolt and rotated to snap flush with the bolt. A third wire, an Olive Wire, is inserted posteromedial to anterolateral through the calcaneus **(Figure 2d)**.

The Full Ring resting near the knee can now be brought to the distal tibia and connected to the Foot Ring with six Medium and Long Struts. The severity of the deformity may dictate this. Struts 3 and 6 tend to be Long.

With Struts unlocked, the position of the proximal Ring is chosen. A rolled up swab between the anterior cortex and surface of the Ring serves to ensure clearance, and allow two-finger-breadth check around its circumference.

Verify that the Struts have enough excursion to perform the correction **(Figure 3a)**.

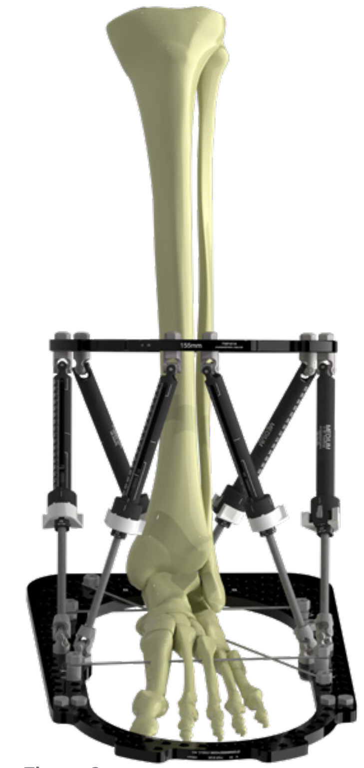


Figure 3a

The Ring is stabilized using an antero-medial Half Pin through an 85mm Angled Pin Connector **(Figure 3b)**.

Insertion of the second pin on the proximal Ring between Struts 1 and 2 (AP direction) offers the best mechanical advantage for the correction.

A third pin is inserted in the medial face of the anterior cortex, close to the Ring using a 1H Rancho or Pin Fixation Bolt **(Figure 3b)**.

Crossing angle (of 90 degrees) is achieved over the anteromedial border of the tibia without causing soft tissue impingement and the construct has good spread along the tibia.

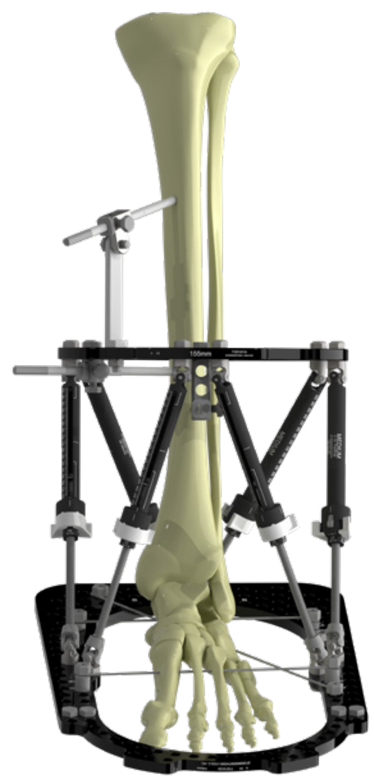


Figure 3b

Additional fixation is added to the foot. Two talar wires are inserted under X-ray control.

One wire is inserted posterolateral to anteromedial. The insertion point is medial to the peroneal tendons, midway to the lateral border of Tendo Achilles. After the wire is inserted through the skin, it is placed on the posterolateral process of the talus. Trajectory is lined up on X-ray prior to intra-osseous insertion **(Figures 4a and 4b)**.

The second wire is inserted lateral to medial under X-ray guidance **(Figure 4c)**.

Figure 4a

Figure 4b

Figure 4c

Fixation is built up from the Foot Ring to meet the wire. See the assembly of Socket and Post in **Figure 5**. Plates and Extended Connectors can also be employed. Additionally, Struts 3 and 6 can be moved 1-2 holes back to prevent collision with a talar wire. Note the hole positions for software entry later.

Both wires are tensioned to 50kg.

Each toe is pinned with 1.8mm wires. Occasionally, 1.5mm wires may be required in the fourth and fifth toe, and even 1.2mm for small anatomy **(Figure 6)**.

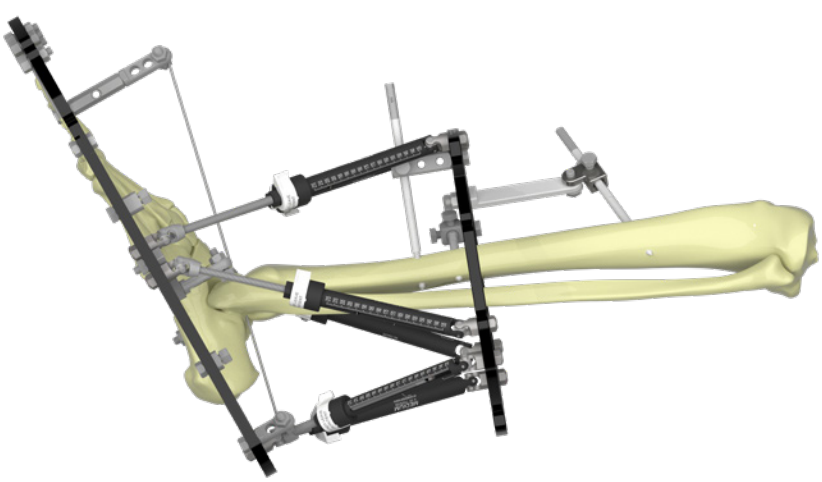


Figure 5

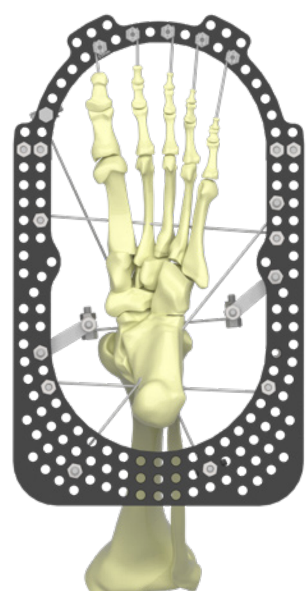


Figure 6

Using SuperDot to digitally correct Equinus

Measure the deformity (Optional)

The Cobb angle tool can be used to measure the Equinus deformity on the Lateral view.

The Angle tool can then be used to draw the optimal angle, 90 degrees to the plantar surface **(Figure 7a)**.

Measuring the deformity is optional, and not a requirement for the SuperDot method.

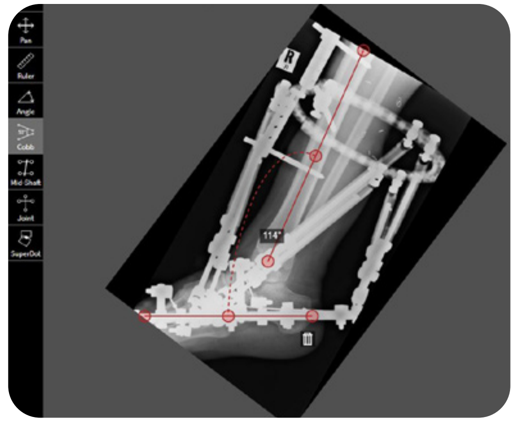


Figure 7a

Plot the SuperDot

Trace out the moving fragment. As Equinus is distally referenced, the tibia will move around the ankle joint.

Draw the mechanical axis of the reference fragment in this case, the foot.

Position the SuperDot on the lateral process of the talus, or center of the ankle joint **(Figure 7b)**.

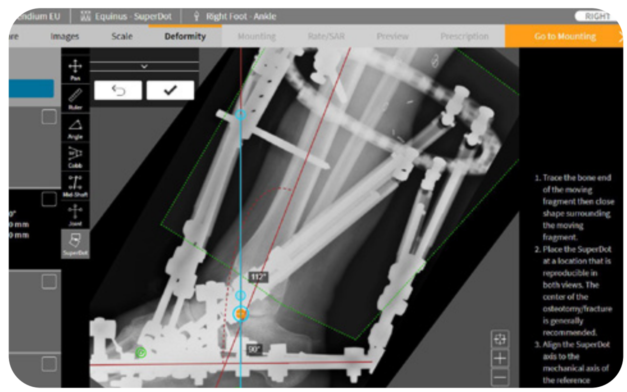


Figure 7b

Correct the bone

Manipulate the moving fragment and move it onto the mechanical axis. Add 5-10mm distraction **(Figure 7c)**.

The deformity is calculated as you move. Fine adjustments can be made using the nudge buttons.

Once anatomical alignment is restored, accept the correction.

There is typically no deformity on the AP. The software requires zero deformity to be confirmed by plotting the SuperDot and leaving the correction at zero. Remember to select "Lateral" for the chosen view that drives axial translation.

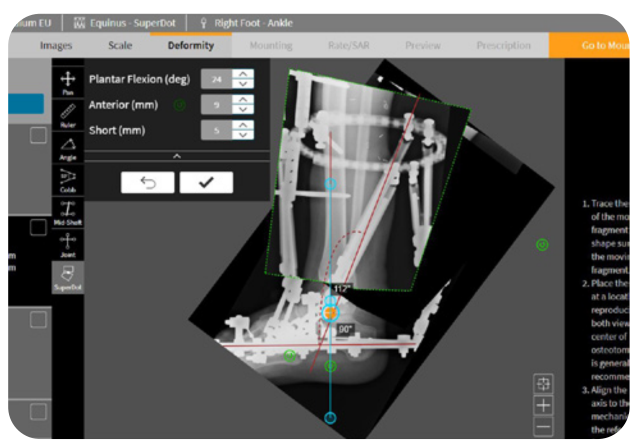


Figure 7c

Post-operative considerations

Post-operative pain relief is important. Correction can begin right away.

The ankle joint is first distracted by 5-10mm.

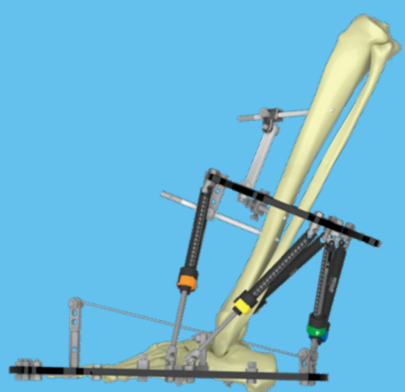
Equinus correction is performed at 1 degree per day.
Over-correction of 10-15 degree dorsiflexion is optimal.

The position is held for six weeks after correction.

Upon frame removal, a night splint is applied for an additional six weeks.
Continued physiotherapy to maintain correction is essential.

Case Example

Immediately post-op



Correction complete

Configuring a TSF◊ Butt Frame

Hemant Sharma, FRCS; Hull Royal Infirmary, UK

The views and opinions expressed in this section are those of the surgeon.

Introduction

Butt joint is a carpentry term which refers to the technique where two pieces of material are joined by simply placing the end or face together. The term was usedby Dr. J Charles Taylor to develop the nomenclature for foot and ankle frames.

Foot deformities are often three-dimensional resulting from a variety of causes. These deformities can be associated with poor soft tissue, infections, leg length discrepancies, etc. Neuromuscular conditions/syndromic feet can cause a particular challenge in correction. Although acute corrections are reasonable, aggressive acute corrections, particularly in presence of scar tissue, can result in neurovascular compromise.

Deformity can result in calluses, pain, stress fractures, ulcerations, infections, difficulty in footwear and compromised function. Differentiation between a progressive condition like Charcot Marie tooth disease and a static condition like cerebral palsy is very helpful in planning.

Soft tissue correction is an integral part of surgical treatment. Secondary compensatory deformities and primary associated deformities must be identified and tackled to provide a plantigrade foot to the patient. Severity of deformity and aetiology directs the treatment strategy.

Detailed history and thorough clinical examination, mobility of different joints and forefoot hindfoot relationship (Coleman block test) should be documented.

Routine pre-operative foot X-rays are not always useful but help in determining the apex of the deformity. Post-operatively, X-rays are hard to interpret, but useful to rule out any subluxations. Foot deformity corrections are best judged clinically. 3D CT scans and recently 3D-printed models of the deformity are very helpful in analysis and surgical planning.

Patient expectations must be aligned with feasible and realistic goals for satisfactory outcome.

Figure 1a

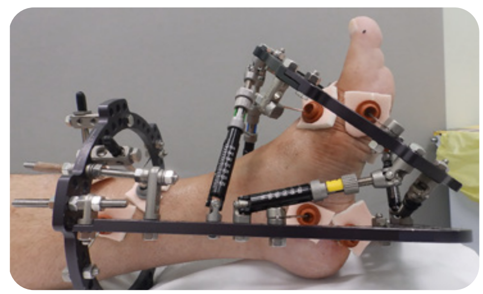


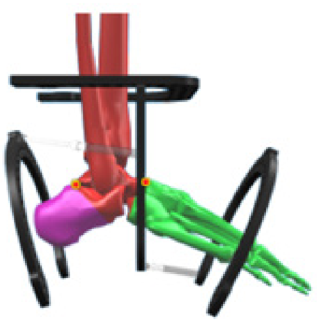
Figure 1b

Applications

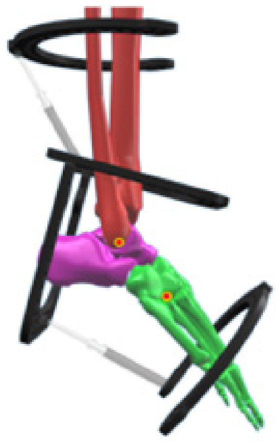
- Mid-foot deformities; rocker bottom/cavus deformity with/without forefoot deformity (adduction, abduction, pronation and supination); secondary to Charcot disease, non-Charcot neuropathic deformity
- Equino-cavo-varus deformity, where other components of the deformity except cavus are acutely corrected and stabilized.
- Midfoot malunion secondary to trauma
- Lisfranc and midfoot fractures

The goal of treatment is a stable plantigrade foot.

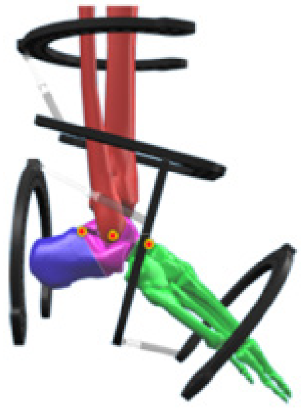
Construct possibilities



1. Correct Hindfoot
2. Correct Forefoot or Midfoot



1. Correct Tibia
2. Correct Forefoot or Midfoot



1. Correct Tibia
2. Correct Hindfoot
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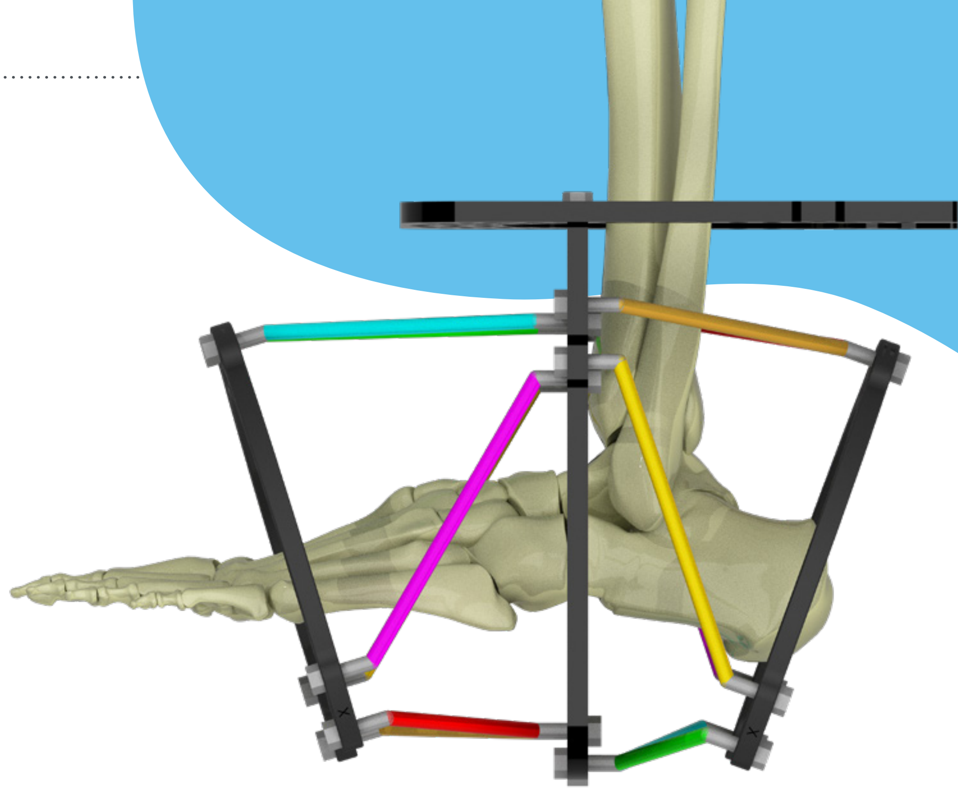
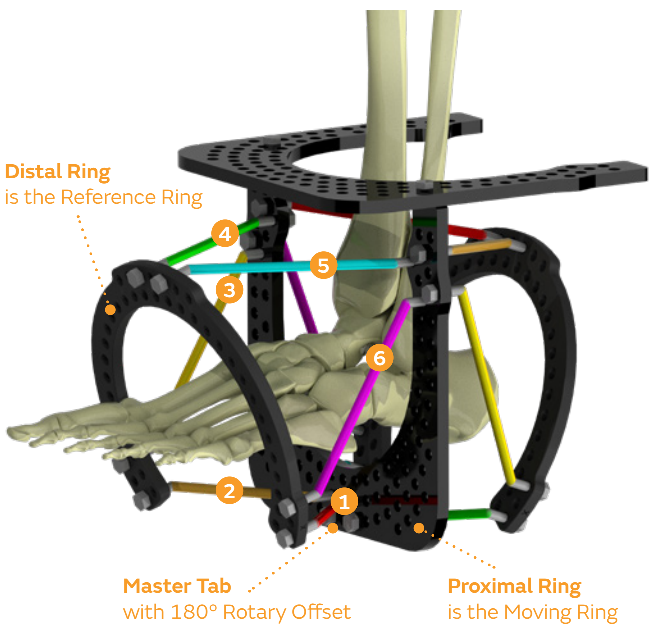
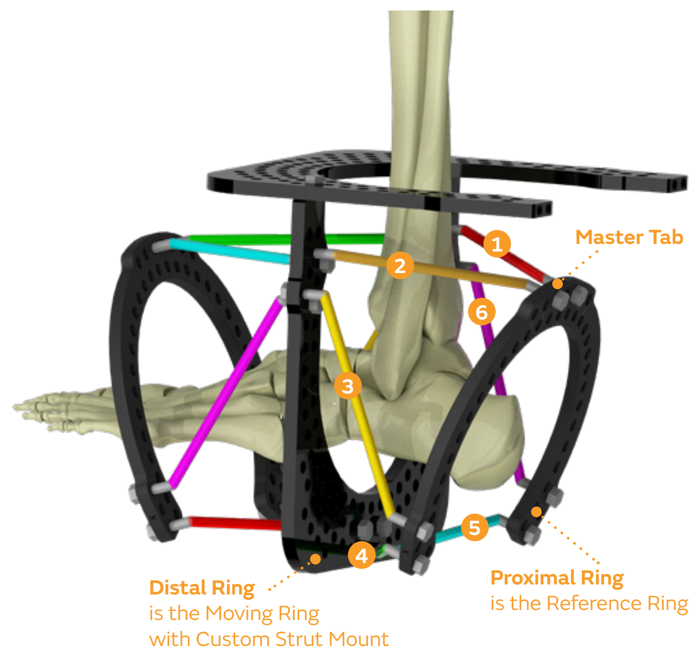


Forefoot Frame - Distally referenced



Hindfoot Frame - Proximally referenced



Surgical technique

- Steindler's procedure to release plantar fascia (if required)
- First metatarsal may be plantar flexed and may need dorsal closing wedge osteotomy
- Cavus is often associated with equinus, which can be corrected acutely either by percutaneous/open Tendo Achilles lengthening.

Proximal Ring Block

Select the appropriate size U-Ring for the tibia and matching U-Ring to configure the "butt" construct **(Figure 2a)**. Sometimes a two-ring block is necessary on the tibia, especially for a neuropathic limb or if a stiffer construct is required.

Insert a transverse wire through the Tibia as a reference wire and tension to 130kg. This wire should be proximal enough on the tibia to leave enough space between the tibial Ring and planned distal foot Ring to prevent impingement. Half pins may be used instead of Wires.

The foot U-Ring is attached posterior to the tibia and should be parallel to the axis of the tibia, allowing two-finger-breadth clearance of the heel pad **(Figure 2b)**.

Place two Olive Wires with as much crossing angle as possible in the calcaneus.

Tension both wires at the same time. Tensioning one wire at a time results in loosening of the first wire when the second wire is tensioned **(Figure 2c)**.

Place two Half Pins each on a 2H or 3H Rancho above and below the tibial Ring, ensuring adequate fixation spread. The first pin is usually placed directly anterior, above the Ring. The second is below the Ring in the anteromedial position.

Tip – These Pins are best placed after Strut application.

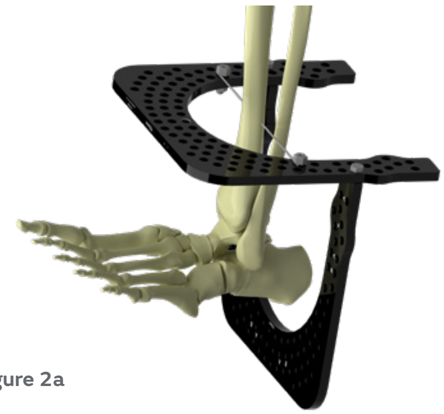


Figure 2a

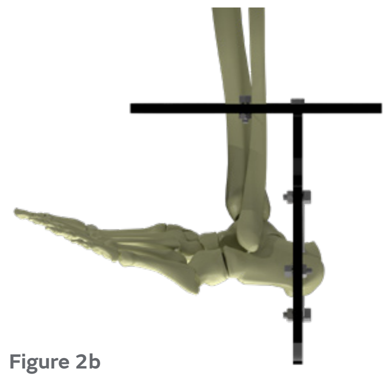


Figure 2b

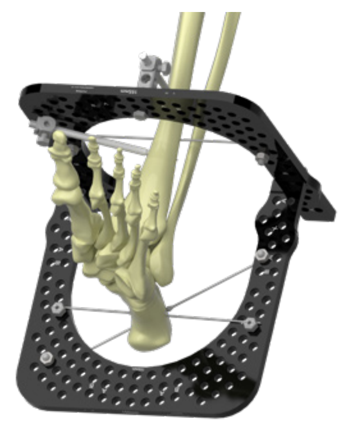


Figure 2c

Fixation of the foot

The second metatarsal is the key to stable foot fixation. Place a dorsal to plantar wire just proximal to second metatarsal neck. This wire should be drilled to the far cortex and tapped through the soft tissue of the plantar surface.

Secure the wire along the equator lines of an appropriate size Full Ring. Orient the Ring to align with the rotation and pronation or supination of the foot. Setting the Ring up in this manner ensures AP offset is "0" **(Figure 3a).**

You can also reference the equator lines on the dorsal and plantar aspect of the Ring. Aligning with the second metatarsal reduces the lateral offset to "0."

Confirm that there is enough space for the Foot Ring and it does not impinge on the tibial U-Ring.

Place a second Olive Wire proximal to Ring **(Figure 3b)**.

Place a third Olive Wire from lateral to medial through metatarsal five, four, three, proximal to the Ring. **(Figure 3c)**.

Strut application

The Master Tab where Struts 1 and 2 meet is on the foot U-Ring resulting in 180° rotary frame offset **(Figure 3d)**. Verify the simulated graphics in smart-TSF.com align with the actual construct.

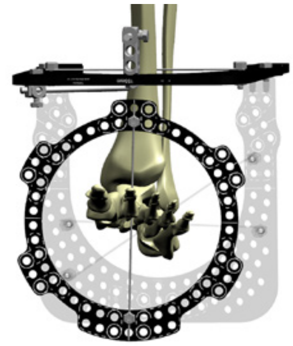


Figure 3a

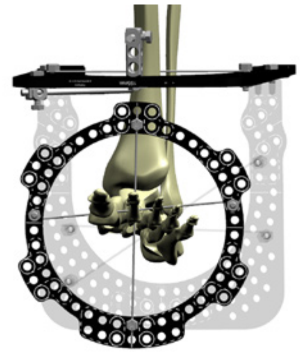


Figure 3b

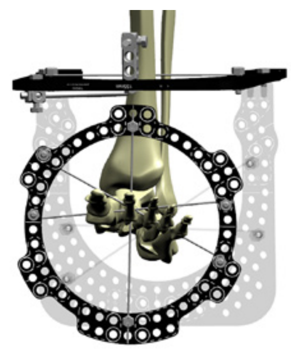


Figure 3c

Figure 3d
Master Tab
Rotary frame offset is 180°

Osteotomy

The author prefers a Gigli saw osteotomy, though drill and osteotome technique is equally acceptable.

Gigli saw

Some Struts may be detached to create space. This is a four-incision technique; usually performed from medial to lateral; dorsomedial, dorsolateral, plantar medial and plantar lateral.

A periosteal elevator is used to create the sub-periosteal passage. Passage on the plantar side due to concavity of the arch can be challenging. Always keep the periosteal elevator on the bone. A long curved artery clip is pushed through the path and #1 braided suture passed. The Gigli saw is then passed.

Pass two Smooth Wires 5-7mm apart at the planned osteotomy level. These wires will ensure that Gigli saw stays in the desired osteotomy site **(Figure 4a)**.

The osteotomy is performed and Gigli saw removed.

Bend the wires to the Ring using the hole on the handle of a Wrench and connect to the Ring with Plates, Posts and Bolts **(Figure 4b)**. These stirrup wires serve to control the distraction at the osteotomy and protect the surrounding small joints from distraction during the correction.

Drill and osteotome

Two to three drill holes are made from medial to lateral side, respecting the concavity of the metatarsal arch **(Figure 4c)**.

Osteotomes do not provide adequate feedback and it can be difficult to judge completeness of osteotomy. Manipulate the osteotomy acutely on table to confirm completeness.

Struts can now be re-connected.

Wiring of the toes

If significant deformity is present or there is history of prior surgery with toe deformities, the toes can be wired and secured to the frame. In most situations the toes can be left free but post-operative regular and aggressive stretching is mandatory, especially in correction phase.

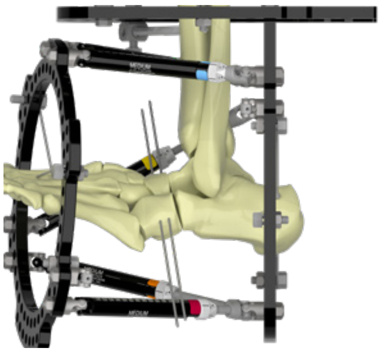


Figure 4a

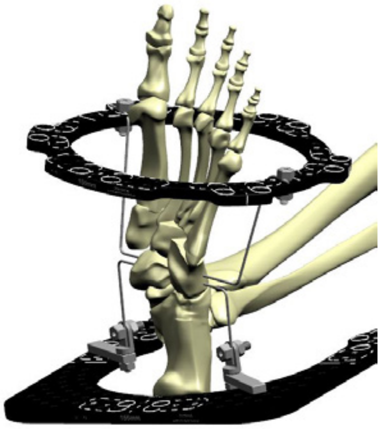


Figure 4b

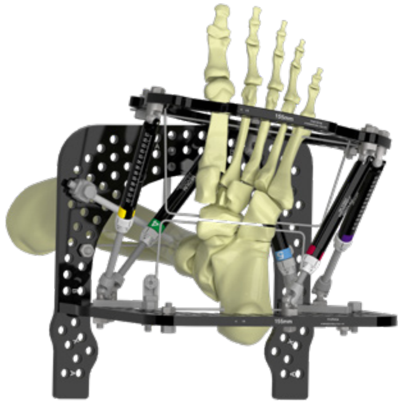


Figure 4c

Classic software planning

Deformity analysis
Draw a line from centre of the ankle.

Draw a line along the second metatarsal shaft. Where these lines meet is the apex of deformity and CORA.

Define origin and corresponding point and calculate deformity

Tip – Always add shortening in the planning to avoid impingement.

Tip – Defining the Corresponding Point at the CORA avoids translation.

Mounting parameters
AP and lateral offset is "zero" if the Reference Ring has been mounted as described.

Rotary frame offset is "180° pronation."

Tip – Verify that Strut orientation in software graphics align with the applied frame

SMART TSF◊ software planning

The Beacon can be attached to either the proximal or distal Ring on the foot, though attaching to the distal Ring on the forefoot reduces the risk of the Beacon hitting the surface the foot rests on during X-ray capture. If not using the Beacon, choosing a Distal Referencing strategy will make manual calculation of Mounting Parameters easier.

Tips for distal referencing

- Angulations and rotations stay the same
- Translations are reversed

Deformity calculations

The traditional Origin & Corresponding Point strategy can be used, whereby the deformity measured on X-ray is input manually on smart-TSF.com. The new SuperDot analysis method, however, simplifies deformity analysis and correction planning in the foot.

SuperDot

On the AP view, segment proximal to the osteotomy is traced out and becomes the Moving Fragment.

The segment distal to the osteotomy is the Reference Fragment. The reference axis is positioned to align with the second metatarsal.

The SuperDot is placed on the osteotomy, typically at the midpoint.

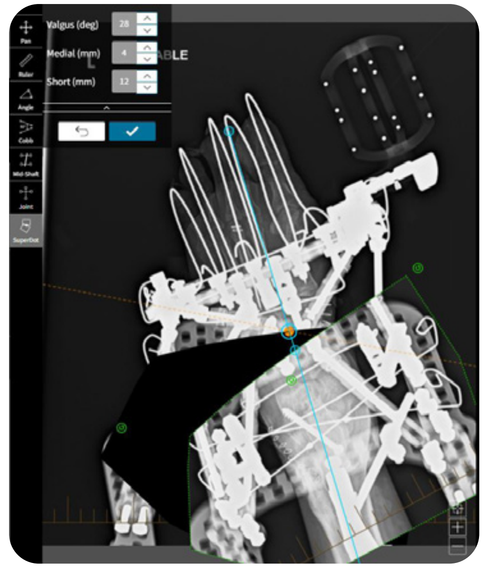
The moving fragment is picked up and positioned as desired, using the reference axis as the indicator of normal alignment.

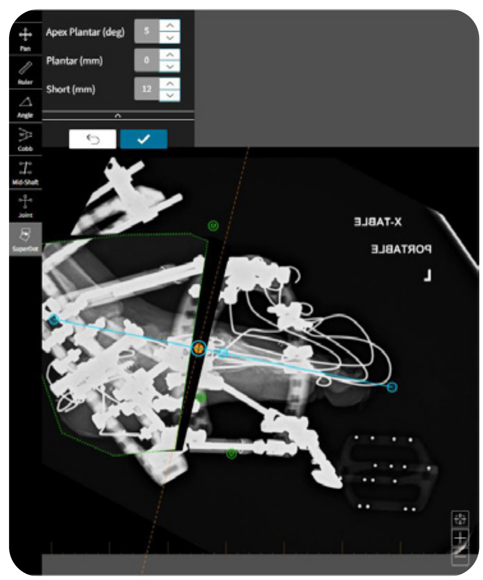
The deformity is thus calculated. Adding millimeters of "Short" helps reduce impingement during the angular correction.

Select the check mark to accept these deformity parameters.

The same is repeated on the Lateral view, once again aligning the reference axis with the second metatarsal.

Rotation is a clinical assessment.





Images courtesy of Mitchell Bernstein, MD

Post-operative

ILIZAROV™ Sponges applied and held with clips or bungs

Nerve catheter block to continue for 48-72 hours, however if nerve catheter is not used, then patient-controlled analgesia (PCA) must continue for 48-72 hrs.

First dressing change in 48hrs should be done prior to stopping the nerve catheter/PCA.

Immediate physiotherapy is started.

Corrections should be started in 48 hours with normal pace defined by soft tissue tension.

Tip - There is a risk of premature consolidation.

Out-patient physiotherapy should be scheduled prior to discharge. Patient must attend twice-weekly physiotherapy. Toe stretching is paramount.

Follow up in one week, and weekly until corrections are completed. Thereafter, six to eight week follow-up is usually adequate until the frame is ready for removal.

Progress of the correction should be monitored using X-rays and, more importantly, clinically-observed shape of the foot.

Post frame removal

Follow-up at two weeks can be with a specialist nurse, with six-week follow-up by the surgeon. Patients should be seen once more at one-year post-op and are usually ready to be discharged at this time. Once the osteotomy has healed, there is no risk of recurrence.

Patients frequently need customised insoles or shoes for pressure distribution, especially if there is neurological compromise. Diabetic patients are more regularly followed up with the specialist team.

Complications

Possible complications include toe contractures, MTP joint subluxation and pre-mature consolidation.

Managing a bifocal deformity with TSF◊

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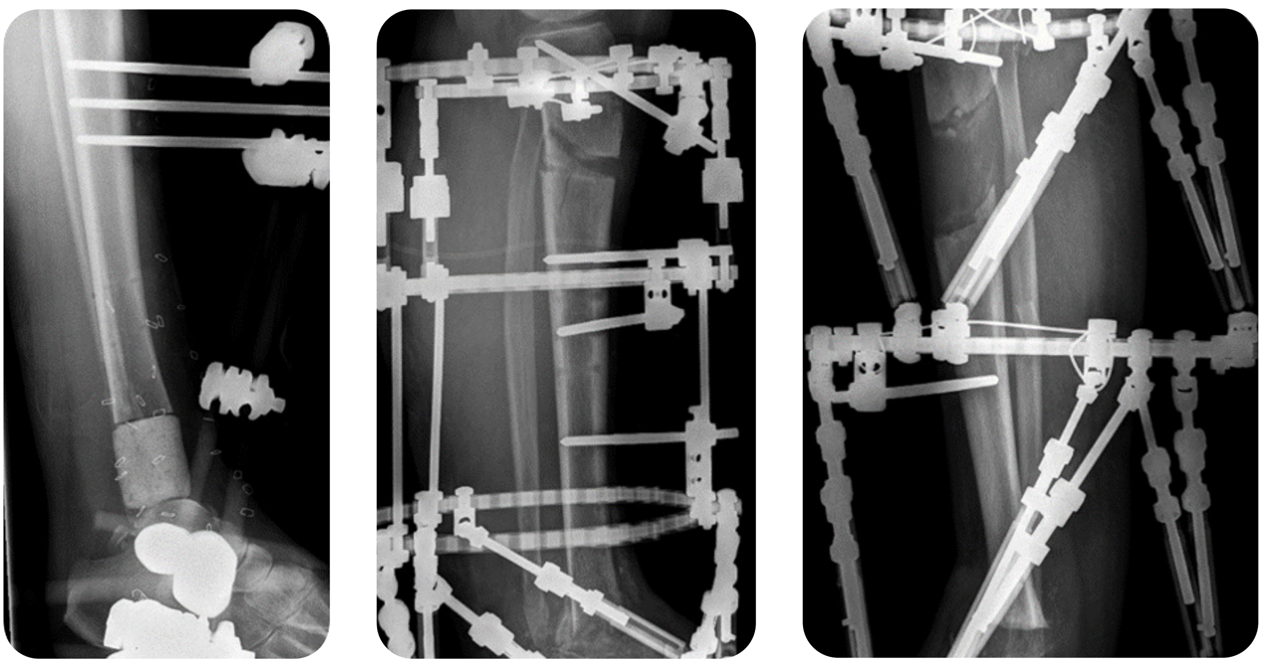
The views and opinions expressed in this section are those of the surgeon.

Introduction

Bifocal techniques involve two separate foci of treatment in the same limb segment such as multi-apical bony deformity correction, or correction of a bony deformity with adjacent joint contracture (typically an ankle equinus). In these cases two attached TSF constructs ("stacked frames") can provide simultaneous correction.

Other indications include segmental transport where one focus involves closing a zone of bone loss, and the other focus is the lengthening site, as well as some cases of a tibial mid-shaft deformity with severe associated shortening, where there may be concern about gaining length at a diaphyseal osteotomy site. In this scenario one osteotomy can be used for the deformity, and a metaphyseal osteotomy used to regain length.

These latter cases can be managed with a hybrid construct using TSF at the docking site and classic ILIZAROV™ Threaded Rods proximally, or stacked frames can be used.



Bifocal ankle fusion and lengthening, using a hybrid TSF and classic Ilizarov lengthening rods proximally (left) or "stacked TSF" (right).

Deformity analysis

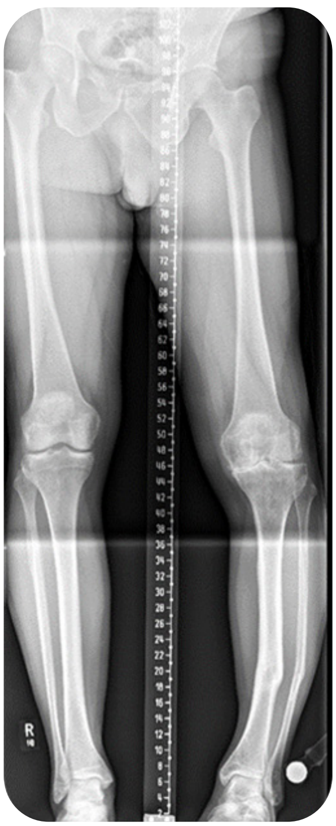
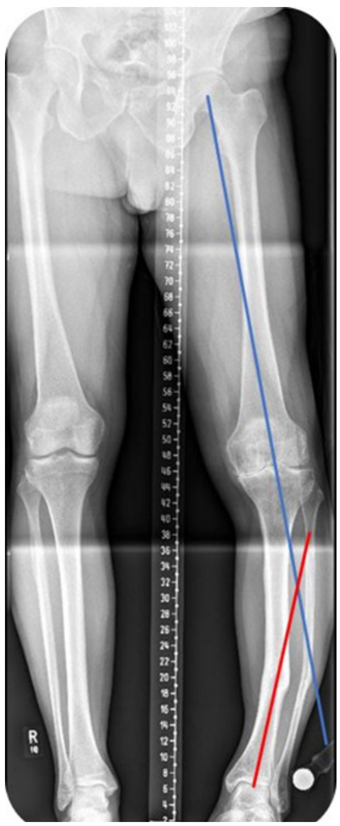
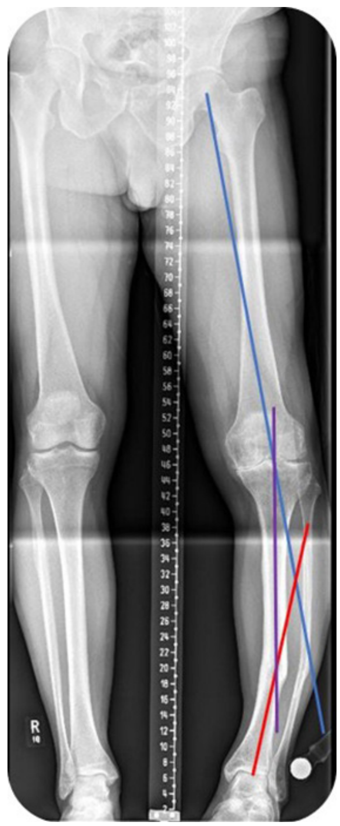
Multiapical deformities need careful systematic analysis to avoid the common pitfall of correcting an "obvious" mid-shaft deformity and leaving an overall malalignment. The method described in Paley's "Principles of Deformity Correction"[1] is used to identify the number of apices of deformity. Rotational abnormalities are difficult to assess radiologically, and almost impossible if associated with angular deformity due to change in the reference axis ("parallactic homologues") so however accurate the planning, a residual correction is often necessary.

Case example

In this example the AP view shows there is overall varus and shortening, and a '"view" at the ankle with an AP knee confirming internal rotation. An extension of the proximal mechanical axis (blue line) and a reconstructed distal mechanical axis (red line) show a CORA outside the bone.

Resolving this with a best fit third line (magenta line) reveals a CORA at the diaphyseal "obvious" deformity and a hidden CORA at the joint level due to varus osteoarthritis. Correcting only at the obvious apex would leave significant residual overall varus. Sagittal planning shows translation, angulation and shortening at the diaphyseal obvious apex.

Two separate osteotomies, each corrected by a separate spatial frame, are necessary. The diaphyseal osteotomy will be through remodelled, cortical bone so regaining length would be best achieved at a proximal osteotomy.

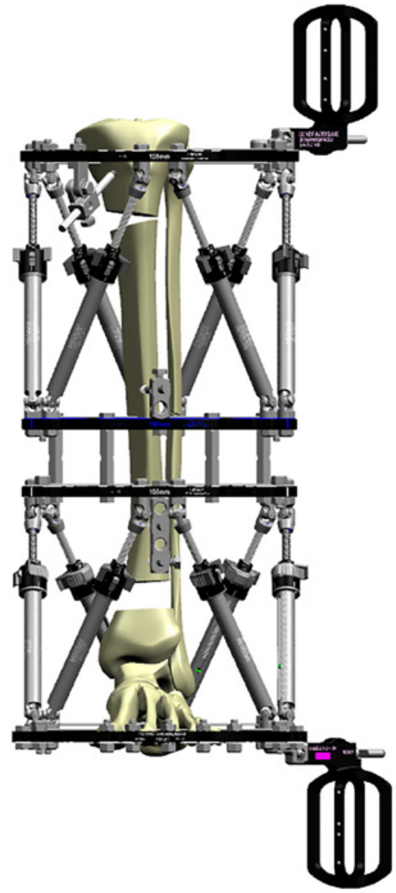




Frame construction

There are two main choices when planning stacked frames; whether to use two completely separate frames and link them with hexagonal sockets or threaded rods, or to create a three-ring construct where the middle Ring is common, and hence the distal Ring of the proximal frame, and the proximal Ring of the distal frame.

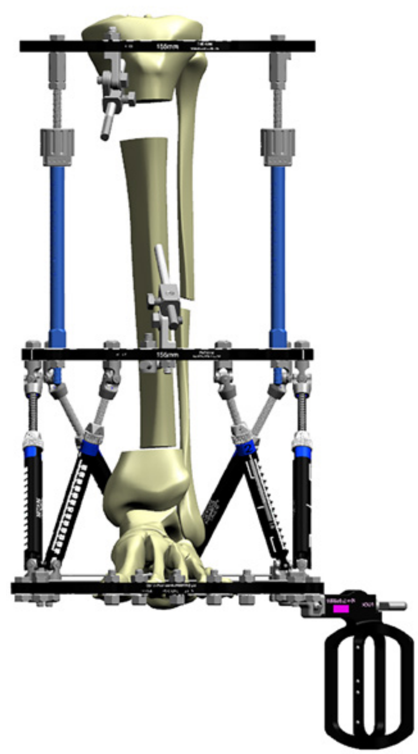
The use of a common Ring reduces the number of holes available for fixation elements; this is particularly problematic if wires are used where all six tabs are occupied by Struts. SMART TSF◊ Rings and Custom Strut Mounting possibilities, however, significantly reduce this problem by the ability to move the Strut positions to adjacent unoccupied holes.

The example shown may be considered for management of a proximal and distal deformity.



This construct shows a proximal frame with ILIZAROV Graduated Telescopic Rods driving axial translation only. Excision of a defect and acute shortening are performed distally. The TSF is used to achieve accurate reduction at the docking site, while the proximal corticotomy is used to restore length.

When planning a frame for segmental transport, there are issues with “working length,” i.e., the mechanical concept of unsupported distance between fixation elements and the bone ends. The excised bone gap starts wide, but the Ring position must allow for docking of the bone ends. With classic TSF the minimum distance must be taken into consideration when planning; with SMART TSF and the use of 30mm Step-Off Plates there is no minimum distance between Rings. Similarly, if there is to be a long regenerate segment at the proximal end of a transport construct, the initial setup can use Step-Off Plates to allow a very short working length at the corticotomy site, then changed out to default Strut positions as the gap widens.

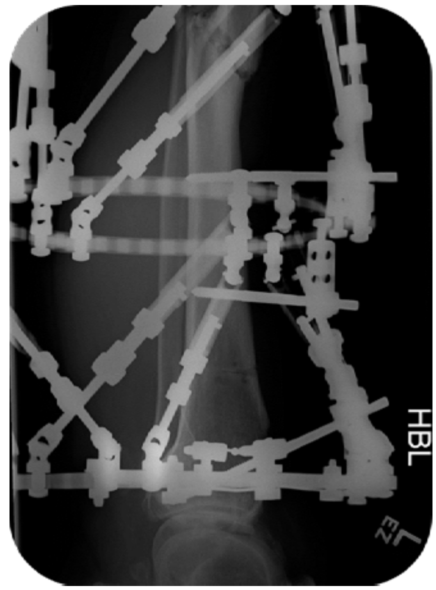


The most proximal Ring should be a 2/3 Ring to allow for knee flexion. In classical Ilizarov fixation "near and far" fixation in a segment can be accomplished using a two-ring block. The stronger TSF◊ rings allow the use of a single Ring, but a greater working length can be achieved by elements mounted off the Ring.

Classically a reference wire parallel with the articular surface above the Ring and below the reflection of the capsule of the knee joint is inserted first, followed by an oblique wire through the fibular head to prevent distal subluxation during lengthening.

An AP half pin can be inserted at the lower end of the tibial tubercle; if this is fixed off a Rancho Cube, then the penetration of the posterior cortex can be close to the corticotomy site and crack into it. For this reason, an oblique half pin is preferred, particularly as it can give a long length of bony fixation. The Angled Pin Connectors will fit between Struts 1 and 2 if the struts are outer mounted and the clamp mounted though the inner central hole. If the fixation hardware impinges against the Strut base, a custom strut mount can be employed.

Diaphyseal fixation is achieved mainly by half pins, again with a good spread of fixation by mounting proximal and distal to the Ring. A distal Ring is fixed by a wire to secure the distal tibio-fibular joint and other wires/half pins as indicated.



Note oblique half pin angling away from the corticotomy

Osteotomies

When planning an osteotomy, bony remodelling should be considered, and the likely quality of regenerate. In the case above, a transverse osteotomy above, below or at the level of deformity will leave a large spur of bone that may cause soft tissue impingement, so an oblique osteotomy can be performed. The fibula must also be divided.

An osteotomy above the deformity causes a posterior bony lump, and likewise below causes an anterior spur. An oblique sliding osteotomy can allow correction of angulation but will prevent rotation at this level.

If the CORA is above the possible osteotomy level (as in the proximal tibia in this example) then Paley Osteotomy Rule 2 applies, i.e., the angulation can be corrected with translation. In this case there will be lateral translation to correct the joint line varus, as well as correction of rotation. Since this osteotomy is through metaphyseal bone, it is better to regain the majority of length here.

Software

For a stacked construct, two separate programs are necessary. A Beacon Mount is attached to the most proximal and most distal Rings. Post-op X-ray images are taken with respect to each segment. SMART TSF◊ software does not require an orthogonal view of the Ring.

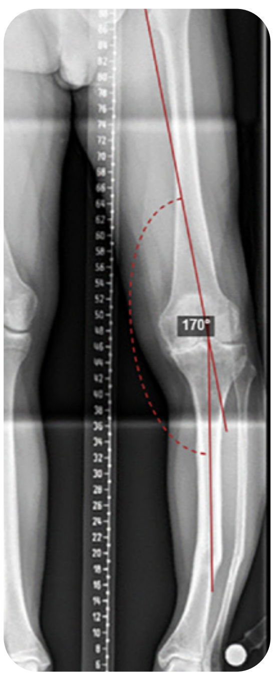
When planning for a translation at the osteotomy site, the planning can actually use the true CORA at the knee level, i.e., the origin and corresponding point can be placed proximal to the ring and without translation. If however there is shortening, then the true origin is virtual and lies along a line projected from the distal axis. This concept of an Extrinsic Origin is handled in SMART TSF by selecting Apex = Corresponding Point.

The parameters are entered into the software program, and a structure at risk identified (usually the fastest moving point on the regenerate) and a prescription generated. The patient is provided with two separate adjustment schedules, and monitored with appropriate radiographs as indicated until correction is complete.

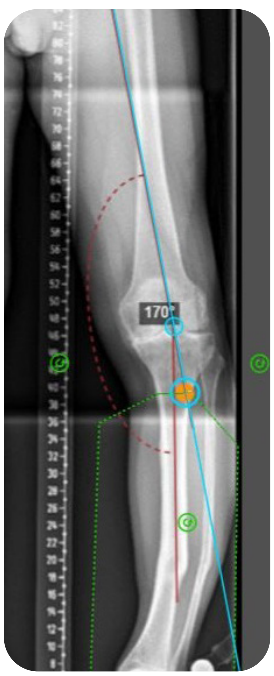
Using Osteotomy Sandbox for pre-operative planning

The Osteotomy Sandbox can be used to plan or play with the Osteotomy location before frame application.

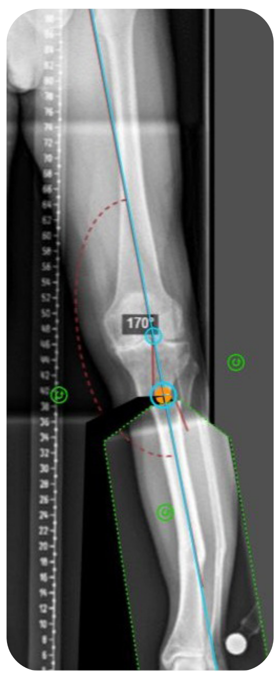
- Bring in a full leg X-ray to the Osteotomy Sandbox
- Use Line tools and Angle Tools to draw the axes
- Use SuperDot tool to trace out the moving fragment and cut the bone
- Place the SuperDot on the cut
- Use the handle to move the bone back onto the axis
- Download and save this image to an external folder
- Upload this image back to the Osteotomy Sandbox
- Repeat the anlaysis for the second deformity



Draw axes for proximal deformity

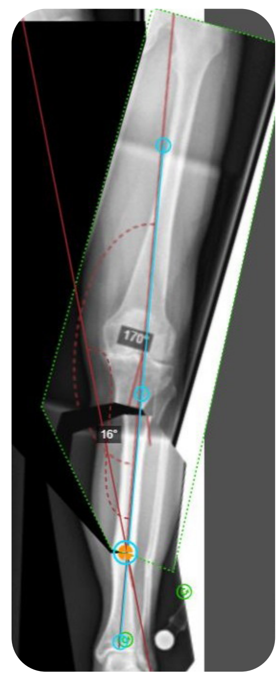


Trace moving fragment, plot the SuperDot



Align the bone to the mechanical axis
Download image and save

Upload new image
Draw axes
Plot the SuperDot
Note distal reference



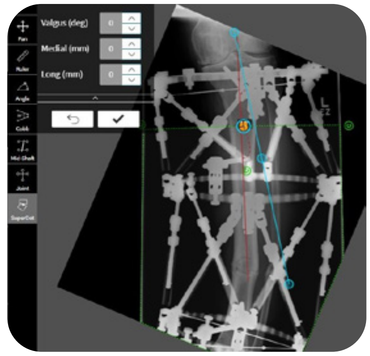
Restore the bone to the mechanical axis

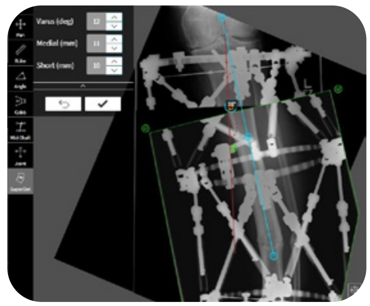
Post-operative software analysis

Proximal deformity

The moving fragment is traced out and the SuperDot placed on the osteotomy. The bone is restored to the mechanical axis.

Analysis is performed on the Lateral, regardless of whether any sagittal plane deformity exists.

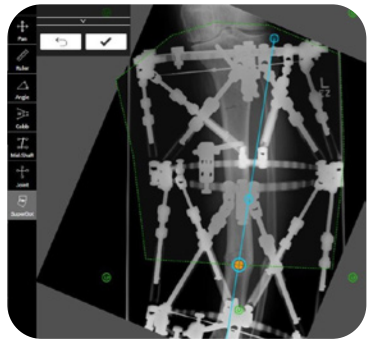


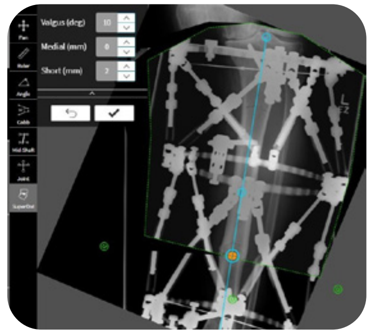


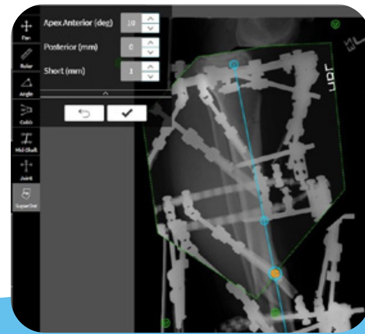
Distal deformity

The moving fragment is traced out and the SuperDot placed on the osteotomy. The bone is restored to the mechanical axis. Analysis also performed on the Lateral.

The patient will have two Prescriptions, one for each TSF.◊







Post correction

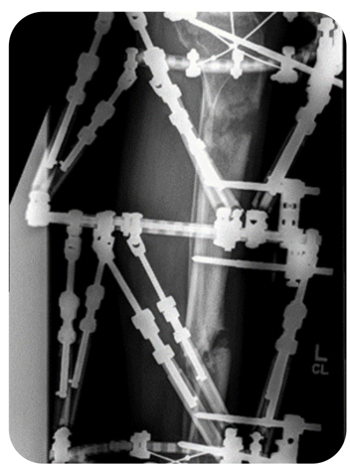
There is apparent residual shortening, but the femoral length confirms this is artefactual foreshortening due to knee flexion. The hip/knee/ankle alignment axis has been slightly over-corrected to offload the medial compartment.

Consolidation is monitored by serial radiographs, and usually occurs at one site before the other allowing partial dismantling of the frame prior to complete union. With modern pin-site care, infection is rare and is usually controllable with a short course of oral antibiotics.

Physiotherapy should ideally start preoperatively to work on muscle length and joint range of movement, and continue throughout and after treatment. Most frame constructs allow weight bearing as tolerated except in the most obese patients.

Night splintage to prevent ankle contractures is usually sufficient, but if an ankle deformity is being corrected distally, it may be necessary to pass K-wires through the toes to prevent contracture.

Frame removal can be either under anaesthesia, sedation, or with gas analgesia in an outpatient setting. It is rare for regenerate to fracture suddenly but it may plastically deform if frame removal is too early. For this reason it is possible to remove or unlock Struts and allow mobilisation for a week or two; if deformity occurs, it is easy to replace the struts and correct the deformity; if not, the frame can be removed with confidence without the need for additional splintage.



How and why I use Chronic Mode in TSF◊ Software

Christopher Iobst, MD, Nationwide Childrens Hospital, OH

The views and opinions expressed in this section are those of the surgeon.

Introduction

This section will explain the use of Chronic Mode for the purposes of pre-building the TSF before surgery. TSF software has two operating modes, **Chronic** and **Total Residual**. Total Residual is the most commonly used mode. It is a Rings-First method, designed for making adjustments to the frame after surgery. It is a useful tool because it does not require Rings to be parallel to one another or even orthogonal to the bone. It allows the surgeon to describe the frame to the software after it has been applied to the patient and to make iterative revisions to the program until the desired result is achieved.

In contrast, Chronic Mode is intended to be planned ahead of surgery. In this mode, the software starts with two non-parallel Rings orthogonal to their respective bone segments **(Figure 1a)**. The adjustment of Struts during the correction results in a final construct with Rings parallel to one another **(Figure 1b)**. It has been described as a "crooked frame on a crooked bone" ending up as a "neutral frame on a straight bone."

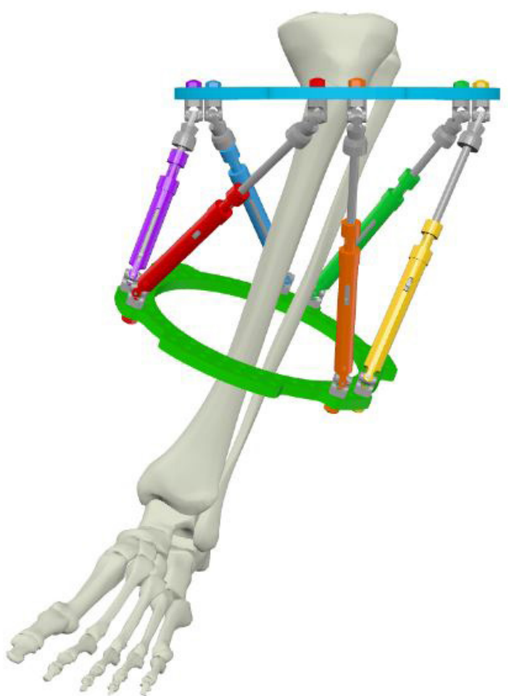


Figure 1a

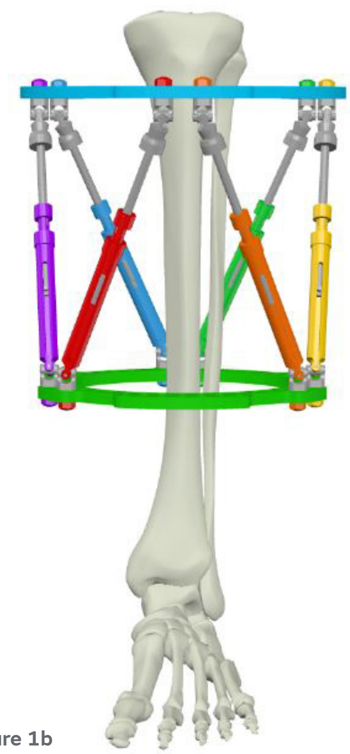


Figure 1b

This technique is helpful both intuitively and visually as the patient and surgeon can watch the Rings gradually become parallel indicating the progression of the correction process. Chronic Mode pre-planning allows the surgeon to optimize the initial Strut settings thereby minimizing Strut change-outs. **Perhaps most importantly, as the final frame is a neutral construct, the patient weight-bears during consolidation on a construct that is orthogonal to the mechanical axis.**[1]

When to use Chronic Mode?

Chronic Mode is best utilized when planning an elective bone deformity correction (eg, malunion, Blount's disease, etc.). With practice, it takes just a few minutes to design a frame that will match the pre-operative deformity. This initial investment in time will pay dividends in the operating room by simplifying and optimizing the frame application.

Chronic Mode requires pre-operative planning and stable alignment, and as such is difficult (but not impossible) to use for acute trauma. Chronic Mode is also not recommended when planning to correct a joint contracture that has a soft tissue release as part of the frame application surgery. Since the degree of joint contracture measured pre-operatively will change after the soft tissue procedure(s), a pre-built frame will no longer match the corrected limb deformity. Equinus contracture correction with concomitant Achilles tendon lengthening, for example, involve partial deformity correction at the time of surgery.

Why Use Chronic Mode?

There are many benefits to pre-building the TSF◊ before surgery. First and foremost, it forces the surgeon to mentally work through the surgery before entering the operating room. By comprehensively analyzing all four dimensions of the deformity, templating the Ring sizes, and determining the desired rate of correction as a pre-operative virtual exercise, the actual surgery will be more efficient and have a better chance for a successful outcome.

Deformity surgeons are encouraged to think through each step of the surgery and write those steps down on paper. This document can be posted in the operating room on the day of surgery to enhance communication among the team as everyone can follow along together. It also helps keep the surgery on track and avoid skipping or missing any steps. Performing the surgery virtually in the pre-operative stage allows the surgeon to anticipate problems before they happen and make appropriate plans.

The second reason to pre-plan in Chronic Mode is the ability to design the cleanest possible Prescription for the patient. The Ring positions can be virtually moved closer together or farther apart in the software until a Prescription is created that has the minimum number of Strut changes possible. In many cases, the distance between the Rings can be manipulated to a sweet spot where no Strut changes are necessary. Since performing Strut changes can be a time-consuming process in clinic that may also cause anxiety for the patient, creating a Prescription that has the fewest possible change-outs is ideal. In addition, by eliminating the need for extra Struts, added cost can be avoided.

The third reason for pre-building with Chronic Mode is the opportunity to have the actual frame in your hands to evaluate. The size and orientation of the construct can be checked on the patient in the clinic or held up to the radiograph for comparison. This visual analysis of the frame also allows the surgeon to double check that there were not any errors in data input into the software which may have produced an unexpected frame design. Having the frame pre-built also saves time in the operating room. Since the frame already matches the limb deformity, once the frame is positioned on the limb in its desired location, the surgeon only needs to fix it in place. This eliminates a lot of time spent thinking through the position of the individual Rings and where fixation elements need to be applied. It allows the ideal position of each fixation element to be chosen since the Struts are already connected to the Rings and, therefore, their path is known and visualized. This prevents any fixation element from being inadvertently placed where Strut traffic will cause a problem.

Setting up a Chronic Mode case

Chronic Mode planning requires the same information as the Total Residual Mode:

- Hardware used
- Deformity parameters
- Mounting parameters

However, there are two additional pieces of information to be gathered before surgery when creating a Chronic Mode plan:

- The patient's appropriate Ring sizes
- Rotational deformity assessment

Chronic Mode summary of workflow

Assessment of the patient and Software inputs often run concurrently as part of the planning. The steps are listed here as a summary, and are not necessarily sequential.

In the clinic	1. Hardware – decide Rings size and Strut family 2. Define Neutral frame height or Neutral Strut length 3. Perform deformity analysis on AP and Lateral radiographs taken orthogonal to the reference segment
Software planning	4. Create a new Chronic Mode case in SMART TSF◊ Software and enter the data points listed in 1- 3 5. Estimate mounting of Reference Ring 6. Adjust Neutral frame parameters to optimize Strut change-outs
Surgery	7. Surgery – apply a pre-built TSF 8. Obtain post-op orthogonal AP and lateral radiographs
Post-op	9. Perform a New Total Residual on Day One of the Chronic Mode Prescription 10. Generate a Prescription for the patient

1. Choose Hardware

Measure the patient in the clinic for Ring size. Commercially made templates or old Rings from previous cases can be used to assess the limb circumference. The ideal Ring size should have one to two fingerbreadths of clearance circumferentially. While it is possible to measure the soft tissue shadow on a radiograph and make an estimate of Ring size, sizing actual Rings on the patient is more precise.

Choose the Strut family, according to surgeon preference.

2. Define the Neutral Frame

The software needs to know the Neutral Frame Height or Neutral Strut Length **(Figure 2)**. This represents the distance between the two Rings when the correction is complete, and the Rings are parallel. The final parallel Ring position can be described by either the actual distance measured between the two Rings (Neutral Frame Height) or by the ending number indicated on each strut (Neutral Strut Length). Because the Rings are parallel, by definition, all six Struts will finish at the exact same number.

Although defining a neutral frame height is an option, it is easier to use the Neutral Strut Length method in Chronic Mode. As a starting point, choose the Neutral Strut Length to be the mid-point of the chosen Strut family. For example, choose 175mm for the Neutral Strut Length when using a medium FAST FX◊ Strut.

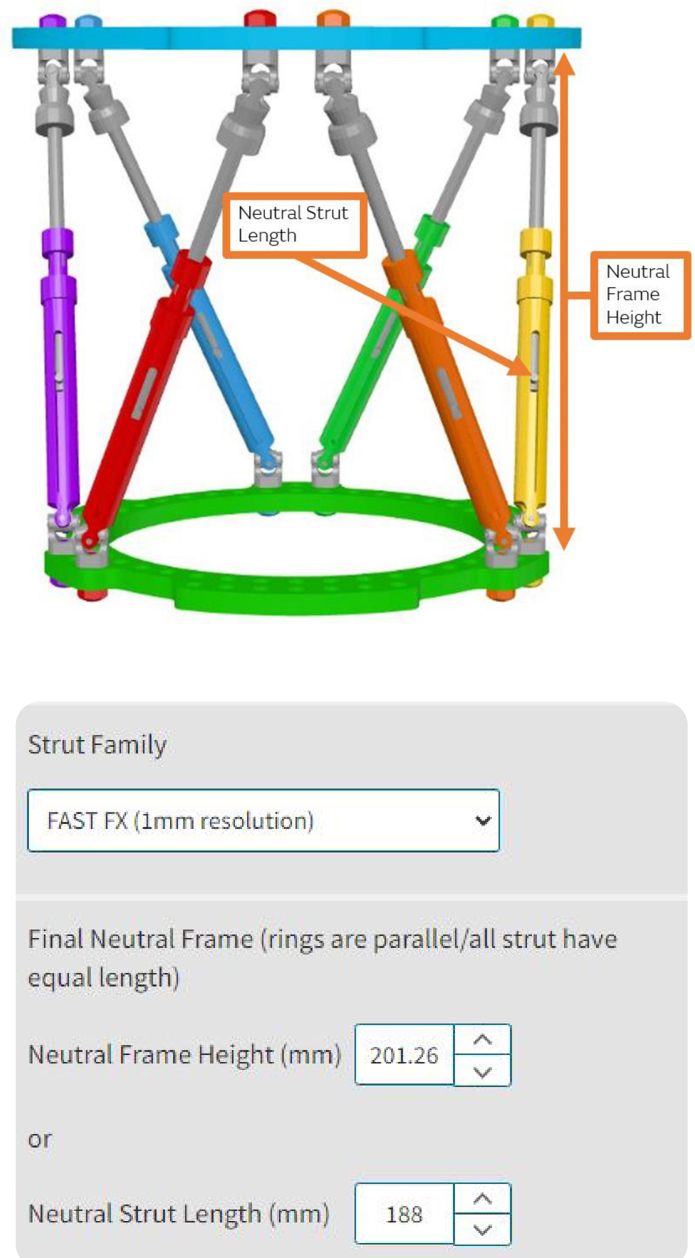


Figure 2

The Chart below **(Figure 3)** helps define reasonable Ring / Strut combinations that result in a final frame with acceptable frame height and angles between Struts **(Figure 4)**.

Ring Combination	SMART STANDARD		
Strut Type	Strut Size	Strut mid-point (mm)	Neutral Frame Height (mm)
80/80	X-Short	83	105.67
105/105	Short	107	126.33
130/130	Medium	147	164.89
155/155	Medium	147	158.48
180/180	Medium	147	150.5
205/205	Long	227	236.07
230/230	Long	227	229.73
80/105	X-Short	83	101.4
105/130	Short	107	122.22
130/155	Medium	147	161.44
155/180	Medium	147	154.25
180/205	Medium	147	145.32
205/230	Long	227	232.74
80/130	Short	107	123.91
105/155	Medium	147	163.2
130/180	Medium	147	156.71
155/205	Medium	147	148.61
180/230	Long	227	234.98

Ring Combination	FAST FX°		
Strut Type	Strut Size	Strut mid-point (mm)	Neutral Frame Height (mm)
80/80	*X-Short	106	130.78
105/105	X-Short	106	125.2
130/130	Short	134	143.16
155/155	Short	134	190.09
180/180	Medium	174	182.62
205/205	Medium	174	174.95
230/230	Long	253	259.06
80/105	X-Short	106	127.63
105/130	X-Short	106	121.04
130/155	Short	134	146.51
155/180	Medium	174	185.59
180/205	Medium	174	178.58
205/230	Medium	174	170.15
80/130	Short	106	122.75
105/155	Short	134	148.49
130/180	Medium	174	187.56
155/205	Medium	174	181.13
180/230	Medium	174	173.39

Ring Combination	SMART FX		
Strut Type	Strut Size	Strut mid-point (mm)	Neutral Frame Height (mm)
80/80	*X-Short	93	116.73
105/105	X-Short	93	110.17
130/130	Short	120	134.34
155/155	Medium	175	190.09
180/180	Medium	175	183.77
205/205	Medium	175	176.16
230/230	Long	251	256.83
80/105	X-Short	93	113.05
105/130	X-Short	93	105.16
130/155	Short	120	129.81
155/180	Medium	175	186.72
180/205	Medium	175	179.76
205/230	Medium	175	171.41
80/130	X-Short	93	107.23
105/155	Short	120	132.13
130/180	Short	120	123.47
155/205	Medium	175	182.3
180/230	Medium	175	174.61

Figure 3
Suggested Ring / Strut assemblies to produce optimum Strut angles on correction
*80/80 Frame is best constructed with SMART Standard Struts

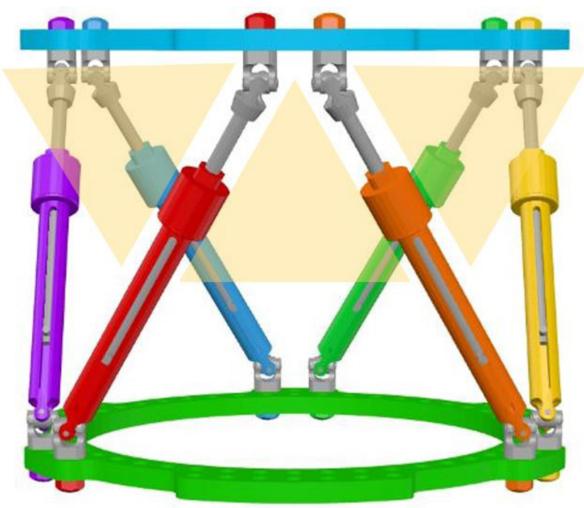


Figure 4
Final frame construct with reasonable Strut angles, Struts at partial excursion and Rings parallel to the mechanical axis. This is the frame the patient will walk on and heal in during the consolidation period.[1]

A Strut angle less than 30° is not recommended[2]

The Neutral Strut Length can be tweaked, then construct viewed in Preview pane to visually assess the angles of Struts

When the neutral Strut length is entered the software will automatically calculate the neutral frame height. This can be used as a point of reference for the surgeon to know how far apart the Rings will be and whether or not this will fit appropriately on the intended limb segment.

It is important to understand that the initial projected Neutral Strut Length is just a starting point and can be modified after the rest of the Chronic Mode inputs are entered.

3. Deformity analysis

The surgeon will assess the deformity on AP and Lateral radiographs taken orthogonal to the patient's anatomy. Deformity analysis can be performed using the digital tools within SMART TSF◊ **(Figure 5)**, or outside the software and input manually **(Figure 6)**.

A standard assessment of the patient’s limb rotation using the rotational profile prone examination (or with advanced imaging if desired) should be performed. Rotation is the only deformity parameter that cannot be obtained from standard radiographs.

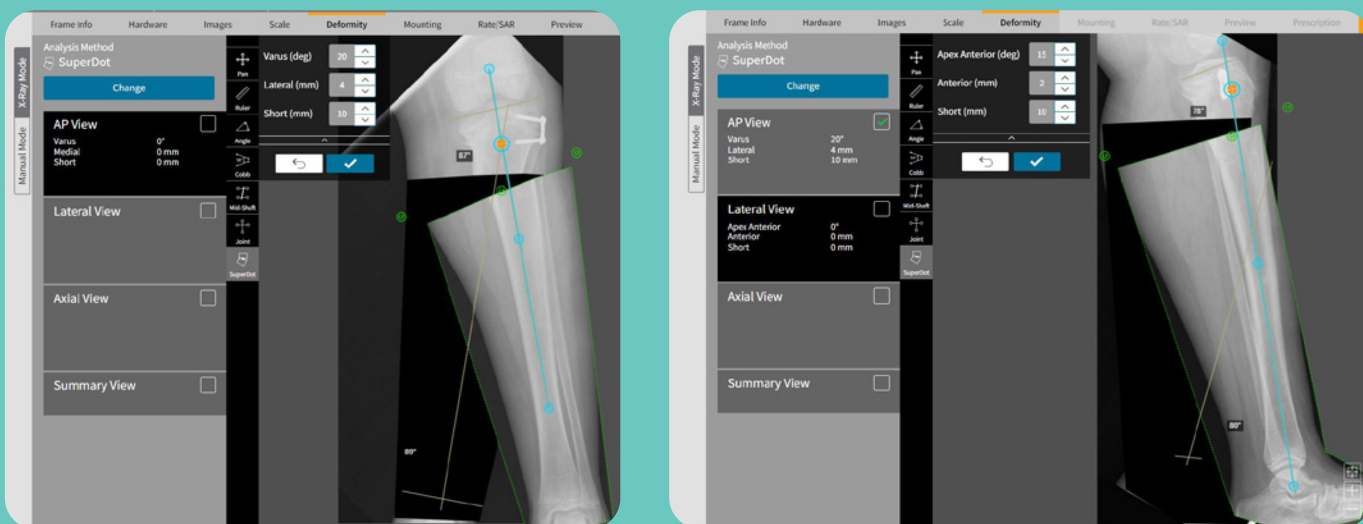
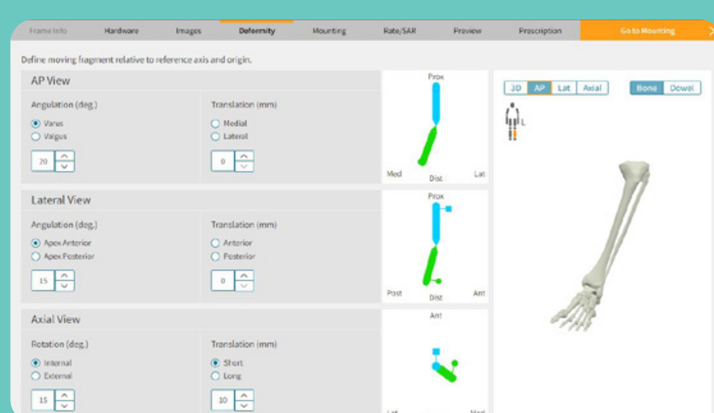


Figure 5
Pre-operative images uploaded for Deformity analysis in SMART TSF Software must have a calibration strategy that can be used to scale the X-rays on the tab “Scale.” Post-operative images can be scaled and calibrated using the SMART TSF Beacon. This example shows how SuperDot can be used to assess the deformity. The advantage of using SuperDot is that it will calculate obligate translation induced by correction in other planes

Figure 6
If deformity analysis is performed outside of SMART-TSF.com, then the magnitude and direction of each deformity parameter is input manually



Regardless of which method is used to define the deformity, the rotation will need to be entered manually based on the physical examination findings **(Figure 7a)**. Therefore, it is imperative for the surgeon to have documented this parameter pre-operatively in the clinic.

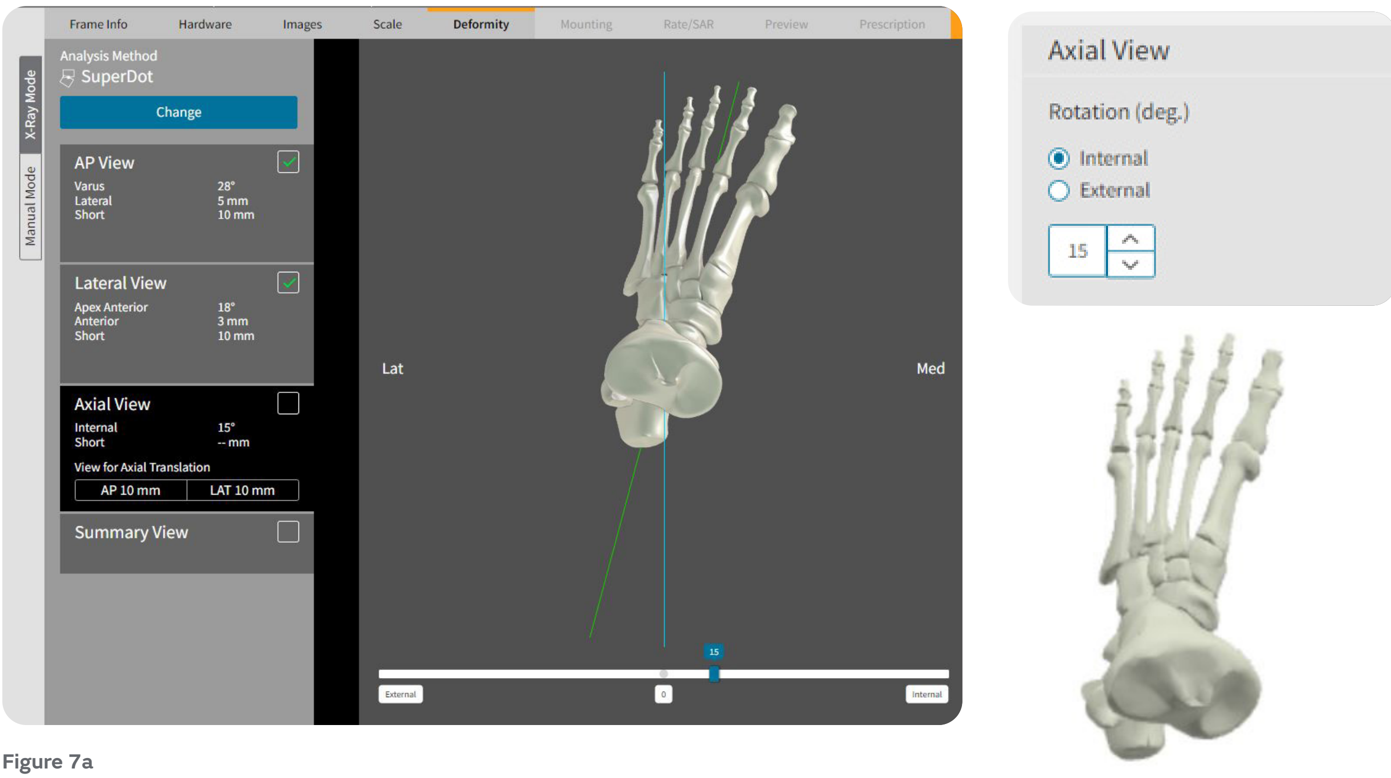


Figure 7a

As the deformity parameters are entered, the three-dimensional image of the bone on the right-hand side of the screen should accurately represent the patient's real deformity **(Figure 7b).** Use this as a double check that the information entered to the deformity parameters is correct (i.e. varus wasn't inadvertently clicked when the patient has valgus).

It is important to note that the over/under correction tab is not active with Chronic Mode. Because the over/under correcting function designs a final frame with Rings that are not parallel, this would violate Chronic Mode's directive to finish the correction program with two parallel Rings.

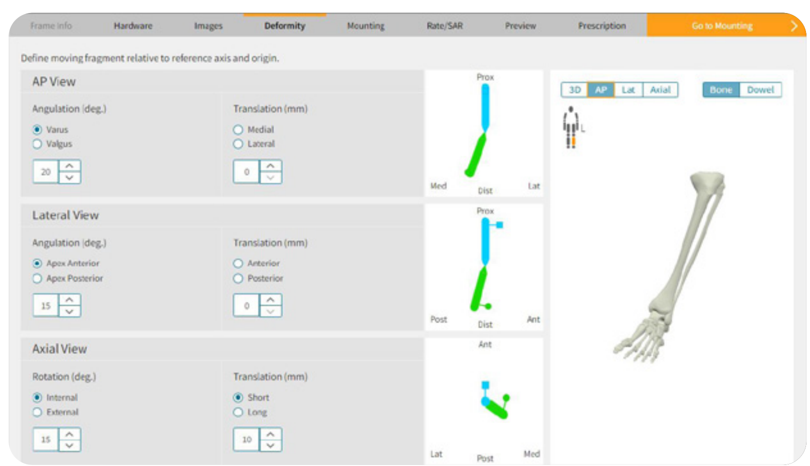


Figure 7b

4. Create a Frame in SMART TSF◊ Software

To begin the Chronic Mode process, the surgeon first logs in to the SMART TSF software to Create a New Patient **(Figure 8a)**

A patient ID must be entered. Any additional information is optional.

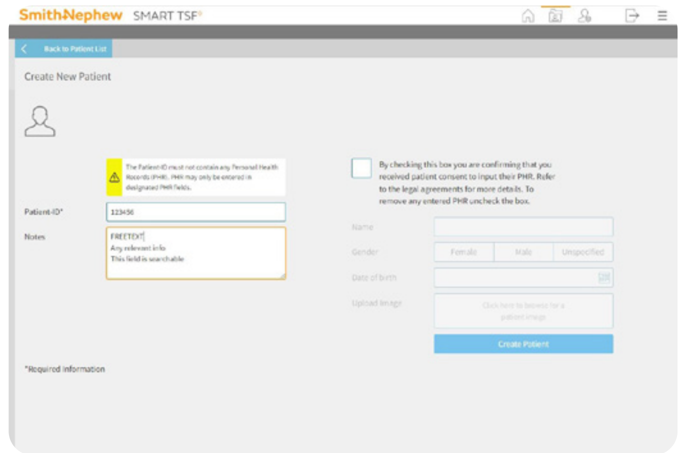


Figure 8a

On the "Patient Sheet" the surgeon selects "Create New Frame." This is where the choice of operating modes is offered. Choose Chronic to indicate that you will be pre-building the frame. Insert the mandatory information on this page (frame name and date) and then select the appropriate anatomy. **(Figure 8b)**

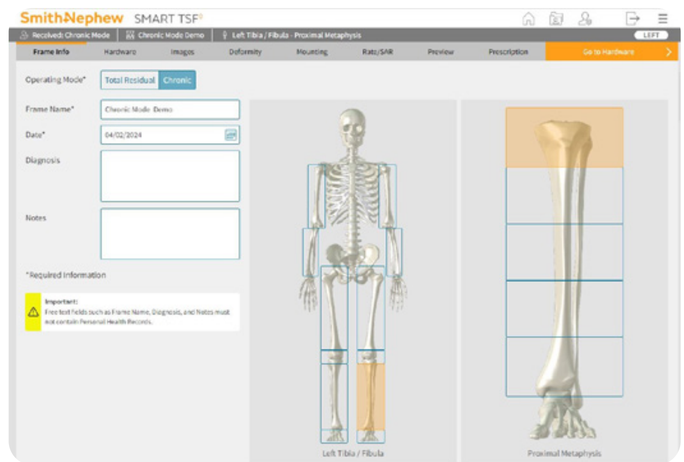


Figure 8b

"Start Program" will direct the surgeon to the Essential Hardware page. **(Figure 8c)**

Enter the Ring size and type as defined in the clinic assessment

Enter either the Neutral Frame Height or Neutral Strut Length, as defined in clinic assessment

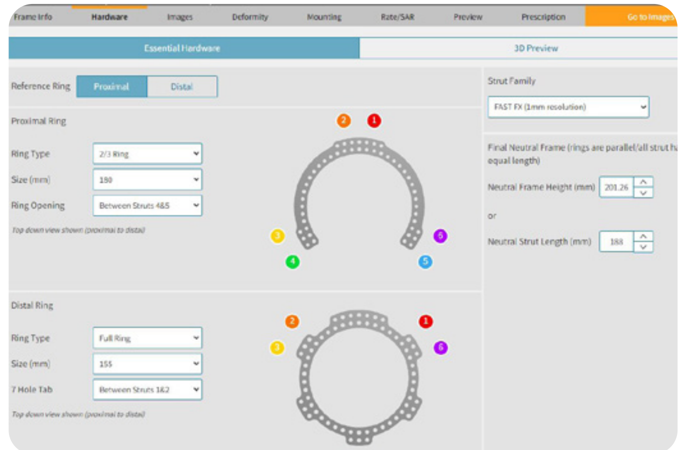


Figure 8c

The 3D preview in SMART TSF◊ shows a neutral frame with the defined Ring sizes and types oriented parallel to one another, six Struts of equal length and Strut angles greater than 30˚. (**Figure 8d)**

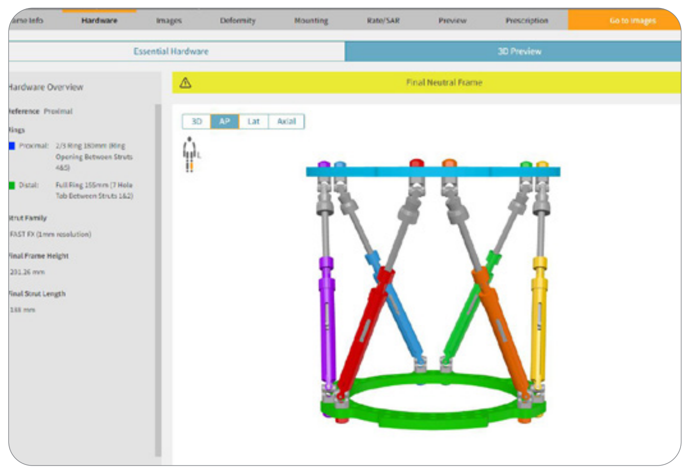


Figure 8d

5. Estimate Mounting of Reference Ring

Until now, every data input in the software has been a measurable, known entity and should be accurate (within the limits of human error).

On the Mounting tab **(Figure 9)**, however, the surgeon must provide an estimation of where the center of the Reference Ring is going to be located relative to the apex of the deformity (origin). In other words, this is the one element of the Chronic Mode that requires an estimation prior to performing the surgery. With practice, the accuracy of the guesses can be improved and often will be nearly perfect.

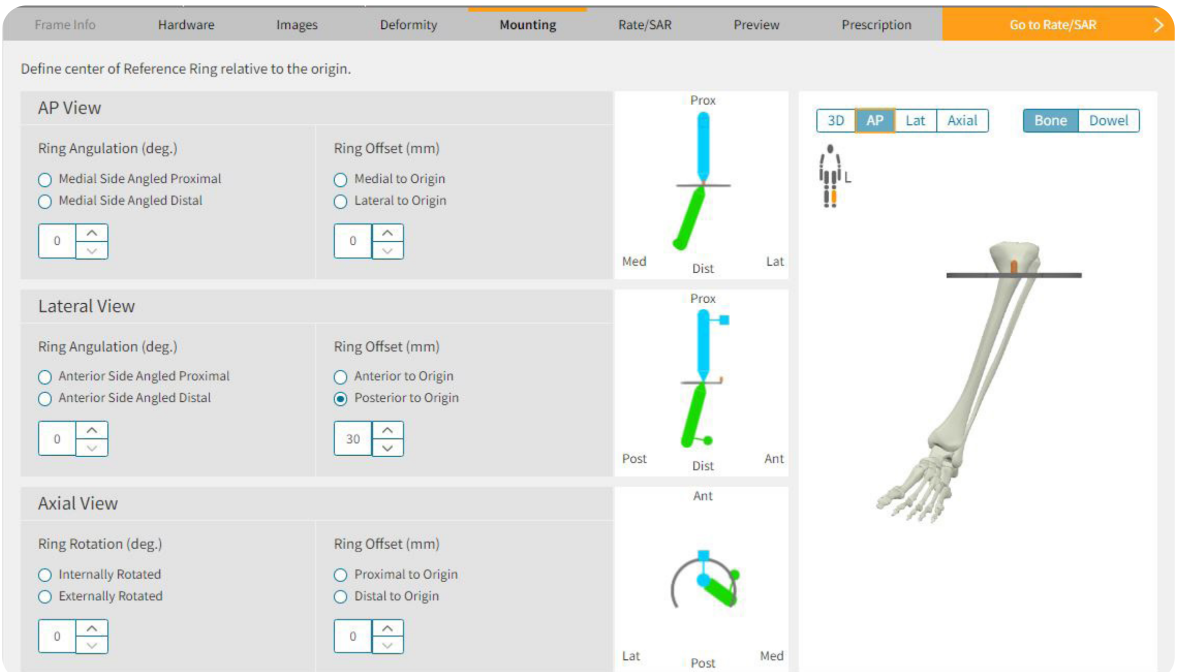


Figure 9 Mounting Parameters in SMART TSF° Software

Of the four required dimensions (axial, rotation, coronal and sagittal planes), the rotation and coronal planes are easily and quickly calculated for most tibial applications. These two measurements can be controlled by the surgeon with meticulous technique in the operating room. By mounting the frame with the Master Tab directly anterior over the crest of the tibia, the rotation plane will measure zero. Similarly, if the Master Tab is centered over the tibia, the medial/lateral component will also measure zero. A short Threaded Rod inserted into the central inner hole of the Master Tab will provide a visual cue of the Ring center position and make it easier for the surgeon to mount the Ring in the desired position with C-arm guidance **(Figure 10)**. The proximal/distal measurement can be determined on the pre-operative radiographs.

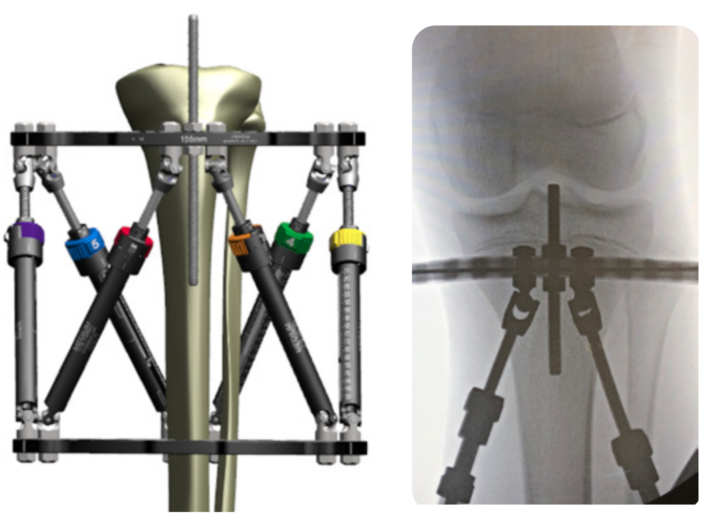


Figure 10 Use a Threaded Rod to assess Ring offset under X-ray visualization

Once the surgeon determines the origin (apex of the deformity), the distance from this point to the anticipated level of attachment for the Reference Ring can be measured. For deformities where the apex is at the level of the physis (i.e. Blount's Disease) the Ring can be mounted on top of a Wire inserted just below the physis. This places the Ring at the level of the apex making the proximal/distal offset zero.

The final component is the location of the center of the Ring relative to the origin in the sagittal plane. For most proximal tibial applications, the center of the Ring is located 25-40mm posterior depending on the size of the patient **(Figure 11).** As the deformity apex moves into the tibial diaphysis or distal tibia, the posterior distance decreases and often becomes close to zero.

Definitive Mounting Parameters will be assessed again later on post-operative radiographs and replace the estimated inputs during planning.

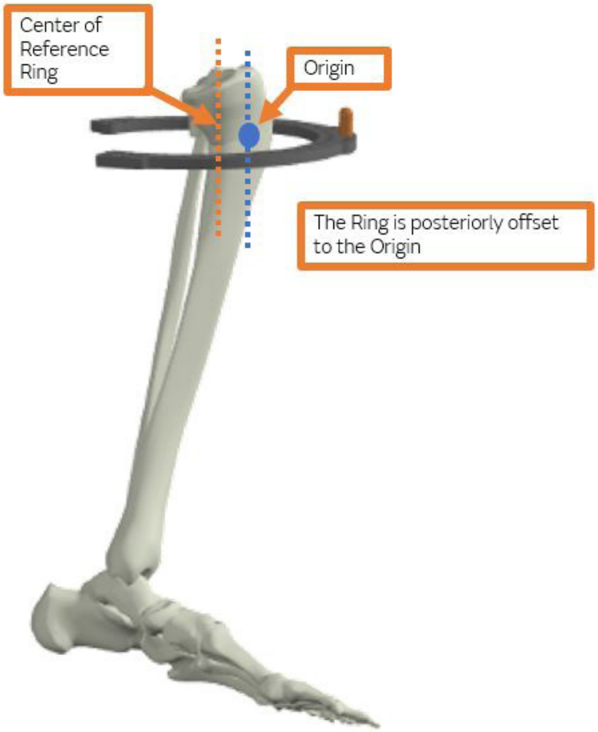


Figure 11

6. Adjust Neutral frame parameters to optimize Strut change-outs

At this point, the surgeon can advance to the next screen (rate/SAR) where the desired rate of correction can be chosen. This screen will reveal the number of Strut change-outs that will be necessary during correction **(Figure 12a)**.

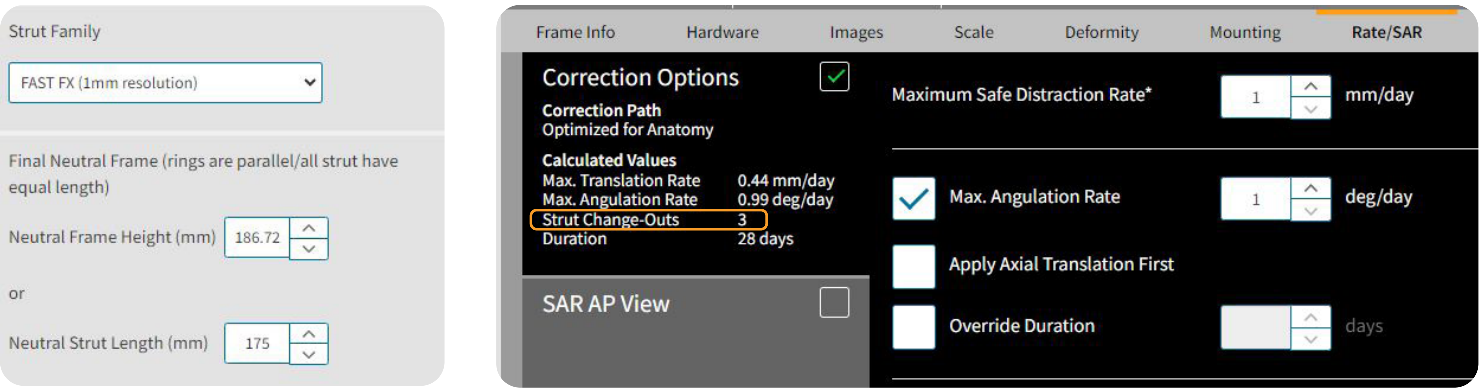


Figure 12a

It is at this point that the surgeon can manipulate the Neutral Strut Length settings on the Hardware tab to create the optimal plan with the least number of Strut changes.

If one or two Struts are predicted to require a change but are only a few increments out of range of the next size, the Neutral Strut Length can be adjusted (up or down) to accommodate the necessary change.

For example, in a right tibia varus limb deformity, the software may determine that Struts 2 and 3 need to start at length 135mm when the Neutral Strut Length was set at 175mm. This mandates two Short Struts changing to Mediums. The shortest excursion on Medium is 143mm, 8mm away from 135mm. By changing the neutral Strut length to 183mm (175+8) the distance between the Rings increases slightly. Struts 2 and 3 will now fit within the excursion of the Medium Struts and two strut change-outs have been eliminated **(Figure 12b)**

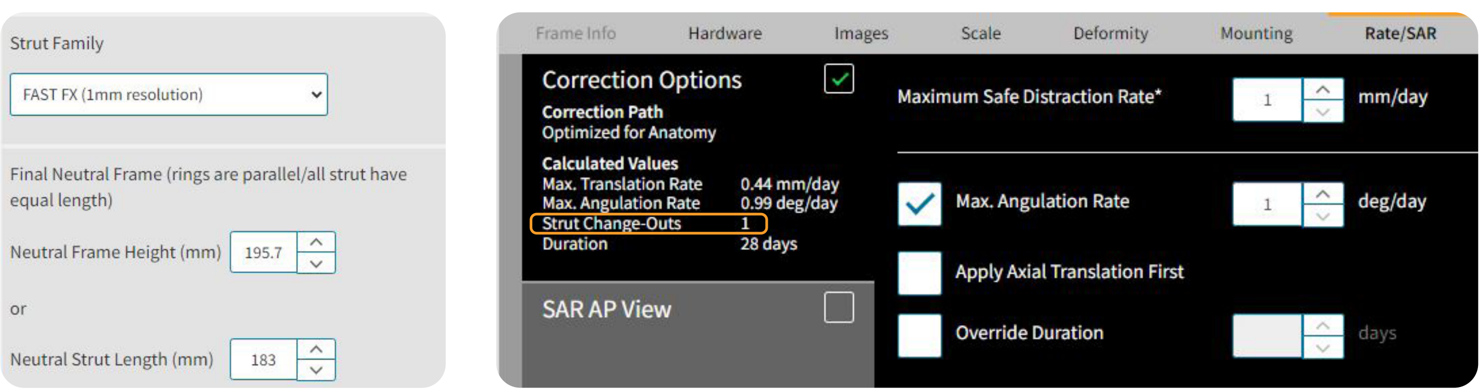


Figure 12b

When the Neutral Strut Length is tweaked, the Preview should be viewed to assess Strut angle.

Adjusting the Neutral Strut Lengths can be done repeatedly until the optimal Strut length is identified that creates a program with the least number of Strut changes. Often, the Neutral Strut Length can be manipulated to eliminate all Strut changes from the Prescription. When adjusting the Neutral Strut length, remember that pulling some Struts into range may also push some Struts out of range. There needs to be a balancing act to find the optimum distance between the Rings for all six Struts.

The other important point is that the surgeon needs to verify that the optimal distance between the Rings will still allow the frame construct to fit appropriately on the patient. In other words, don't increase the distance (or decrease the distance) to the point where the frame no longer anatomically makes sense for your patient, or the Struts assume an unreasonable angle.

On the Preview Tab **(Figure 13a and 13b)** the graphic should illustrate the frame in the desired orientation and location matching the deformity in the bone/limb. This image can be clicked and moved around to evaluate it in all planes. To the right of the screen, the six Struts are listed by type and setting. The initial settings are calculated creating a "crooked" frame that matches the limb deformity. Play the correction to see how the Struts change. If this primary plan indicates that no Strut changes are necessary then you have finished your Chronic Mode pre-build!

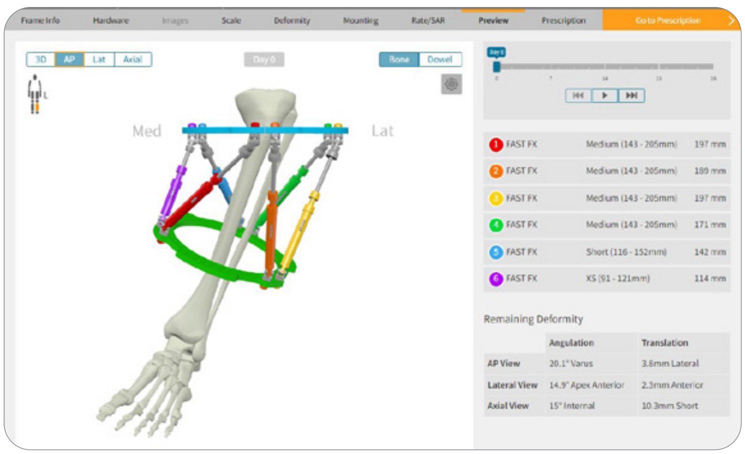


Figure 13a

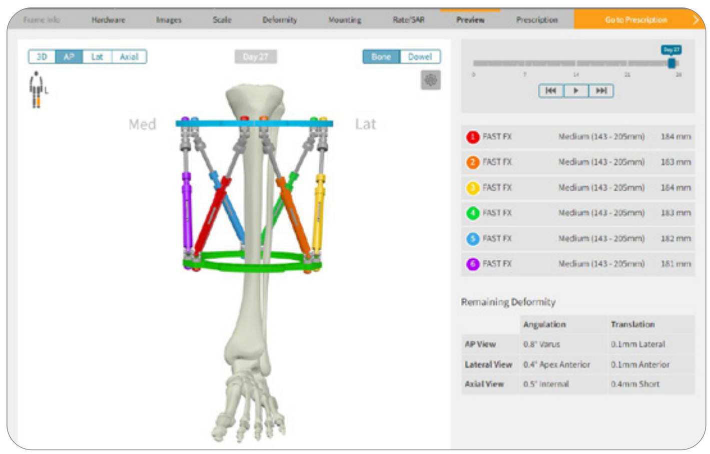


Figure 13b

7. Surgery – apply a pre-built TSF

Referring to the Initial Strut Settings in the Chronic Mode plan, the frame can be assembled and sterilized ahead of surgery. Alternatively, the Rings and Struts can be assembled in the sterile field, at time of surgery. The TSF is attached to the limb using standard protocol described in other chapters. Refer to Section 5 Mounting Parameters to re-visit intra-operative tips for accurate mounting. The osteotomy is performed.

8. Obtain post-op orthogonal AP and Lateral radiographs

Post-operative radiographs should focus on capturing the anatomy – ideally the osteotomy and reference joints. The Beacon will serve to scale and calibrate the X-rays images and automate the Mounting Parameters.

9. Perform a NEW TOTAL RESIDUAL on Day One of the Chronic Mode Prescription

- Converting a Chronic Mode Plan to a Total Residual Program on Day One allows any deviation from the plan to be captured efficiently.
- In the software, navigate to the Chronic Mode plan that has been created and proceed to the Prescription tab. On Day One, select NTR **(Figure 14)**
- Navigate through each tab to check and confirm the inputs.
- Post-op X-ray images can be uploaded to drive accurate digital analysis of the Mounting Parameters.
- The Preview is the final visual check that the Deformity, Hardware and Mounting Parameters align to the clinical presentation.

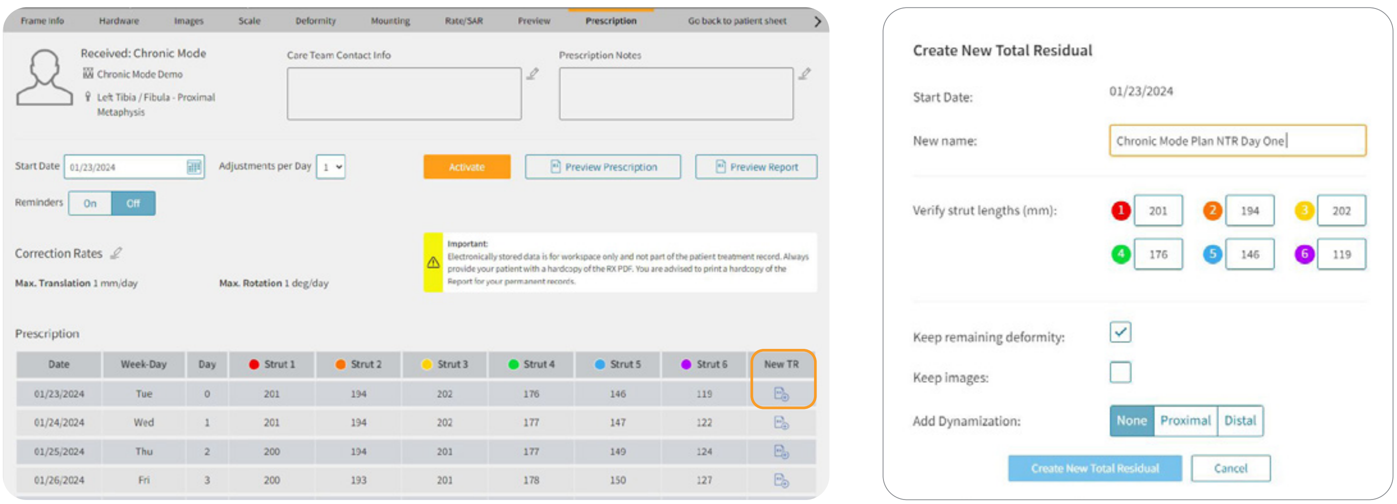


Figure 14

10. Activate the Prescription

Once satisfied that all parameters reflect the patient's deformity, initial hardware settings and correction desired, the program can be activated and Prescription generated for the patient.

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