



# The Ring Fixator System

## Part C: The Sheffield Ring Fixator - Limb Reconstruction and Complex Trauma

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The Sheffield Ring Fixator was designed to provide maximum support for the bone, with a frame suitable for dealing with simple and complex trauma cases and providing the full range of requirements of a Limb Reconstruction System. Tensioned Kirschner wires provide stable fixation in metaphyseal bone. It is this property that has been responsible for their successful use in metaphyseal and articular fractures. The use of four fully tensioned wires mounted on a single ring provides sufficient stability to support an unstable tibial plateau fracture<sup>1</sup>. In further studies three wires have proved sufficient to support metaphyseal fractures of the distal tibia<sup>2</sup>. Beam-loading is retained by using a further ring for diaphyseal fixation<sup>3,4</sup>, through tapered 6 mm screws which provide good purchase in cortical bone. Application of these screws is simplified by the use of a standard clamp design (Sheffield Clamp) which spreads the load around the ring. For unstable fracture configurations and complex limb reconstruction cases, an additional single screw holder is used with a screw placed at 60-90 degrees to the first two screws. Fixation may be further enhanced with the use of Hydroxyapatite coated screws (OsteoTite). The avoidance of screws in the metaphyseal ring allows the device to retain the important elastic, self-stiffening properties, similar to the Ilizarov fixator<sup>5,6</sup>. However, for a pure diaphyseal deformity or shaft fracture an all screw system may be used. In this case dynamisation may be achieved by exchanging the threaded bar supports for telescoping Reduction Units. The rings are normally attached to each other with threaded bars, but Reduction Units may be used to fine tune the reduction. A series of modular attachments has been designed to facilitate cross joint fixation and deformity correction.

## I. INDICATIONS

### A. Acute trauma

- Tibial articular fractures: plateau and pilon
- Tibial articular fractures with diaphyseal extension
- High energy diaphyseal fractures of the tibia
- Femoral fractures, particularly distal
- Humeral fractures

### B. Limb reconstruction

- Correction of post-traumatic, acquired and congenital deformities: simple, juxta-articular, oblique plane, multiplanar. The Sheffield Ring Fixator is usually used in the lower limb for tibial and foot deformities, but is also useful for femoral and knee deformities. It may also be used in the upper limb, particularly the humerus.
- Arthrodesis: knee, ankle and subtalar joints
- Limb Lengthening: monofocal and bifocal
- Non-union and bone loss:
  - Monofocal - compression, neutralisation, distraction
  - Bifocal - bone transport, acute shortening, combined multifocal
- Joint contracture in adults and children: knee, ankle and foot
- Articulated distraction: ankle, foot and knee

*Current systems are appropriate for children of 8 years and over.*

## 2. LIMB RECONSTRUCTION SYSTEM (LRS) OR THE SHEFFIELD RING FIXATOR (SRF)?

### LRS

The LRS is indicated for lengthening and deformity correction in long bones. It is commonly used in the femur, where circular devices are relatively cumbersome and tolerated less well than monolateral devices. In the tibia it is primarily used for lengthening and bone transport, although the OF-Garches T-Clamp, a component of the LRS, would permit simple uniplanar corrections of small angular deformities (e.g. high tibial osteotomy). The LRS may be used in conjunction with the SRF to bridge the knee, or the ankle to support the foot.

### SRF

The SRF is mainly indicated for the tibia or the foot. It is a strong fixator, permitting immediate full weightbearing and progressive correction of a deformity. It is particularly useful in heavy patients or where the bone quality is poor, and for more complex deformity corrections, arthrodesis, correction of contractures and articulated distraction. It may be used in the femur but is less comfortable for the patient than the LRS.

## 3. DEFINITIONS

### CORA

Centre Of Rotational Angulation; the axis of the deformity in any one plane.

### Hinge

Normally used as one of a pair, these provide an axis about which the deformity is corrected. This axis should have a carefully defined relationship with the CORA.

### Motor

A construction which permits controlled alteration of length and is used to drive the correction of a deformity. It usually consists of a combination of threaded bars and hinges, or extension plates and compression-distraction modules.

### Coronal plane (frontal plane)

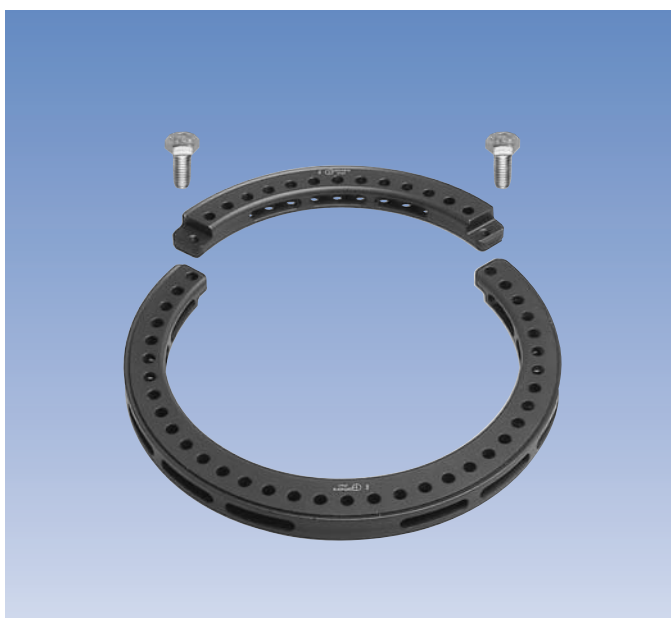
The axis of deformity as seen on an Antero-Posterior X-ray.

### Sagittal plane

The axis of deformity as seen on an Lateral X-ray.

## I. OVERVIEW

The Sheffield Ring Fixator consists of reinforced 2/3 and 1/3 rings capable of supporting up to four 2 mm wires, tensioned to 1400 Newtons. A full ring may be constructed by joining 1/3 and 2/3 components. These rings are used to support both metaphyseal and diaphyseal segments. In the metaphyseal segment, wires are attached to the ring using wire securing pins and wire slider units. The metaphyseal ring may be connected to a diaphyseal ring using three threaded bars or reduction units. Diaphyseal fixation is achieved with bone screws attached to a ring by the Sheffield Clamp. Additional fixation may be achieved with a single screw holder attached to the ring. In this configuration the fixator may be used for the treatment of metaphyseal and articular fractures of the proximal and distal tibia. With the addition of hinge clamps and threaded bars, the device may be taken on to the foot or across the knee. A third ring, fixed with wires or screws according to location, may be used for more complex fracture patterns and limb reconstruction, e.g. for bone transport or segmental fractures. The system components are shown in the following figures.



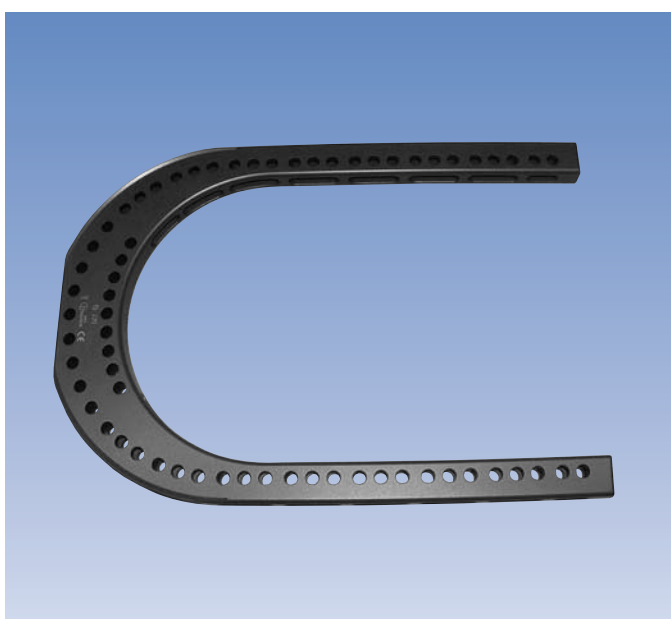
### 2/3 - 1/3 Rings

The rings are available in 2/3 and 1/3 configurations, and can be assembled together to create a full ring. 2/3 rings are commonly used near the joints to allow joint flexion through the opening in the ring. The rings are available in the following sizes:

Ring Size: Inner Diameter	2/3 Ring	2/3 Radio Lucent Ring	1/3 Ring	1/3 Radio Lucent Ring
125 mm	81050A	81125	81051	81125P
150 mm	81000A	81150	81001	81150P
175 mm	81002A	81175	81003	81175P
190 mm	81004A	81190	81005	81190P
220 mm	81006A	81220	81007	81220P

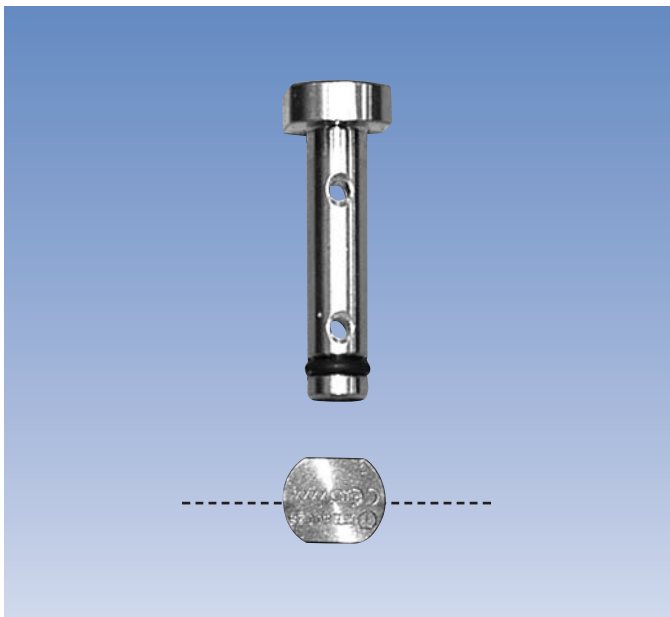
The rings are assembled with two:

#### 81008 Ring Locking Screw (length 16 mm)



#### 81500 Foot Ring - Inner Ø 150 mm

Foot fixation is indicated where ankle stabilisation is required during limb lengthening, and where a second level of fixation is required for a low tibial non-union. It is also indicated for severe pilon fractures and articulated distraction of the ankle. It can be applied to fuse the ankle and subtalar joints, for triple fusion and foot contracture. In most instances a foot ring is selected; however where correction of the midfoot is required with respect to the hindfoot, two 2/3 rings are used.

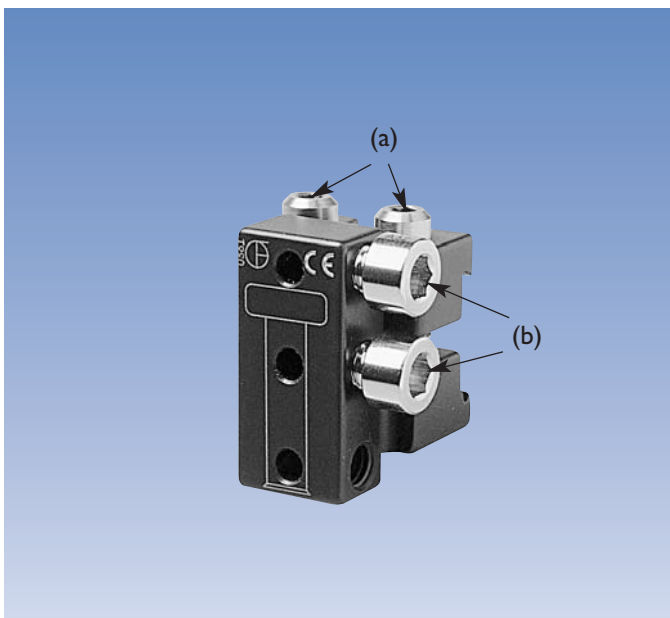


## 80025 Two-Hole Kirschner Wire

### Securing Pin

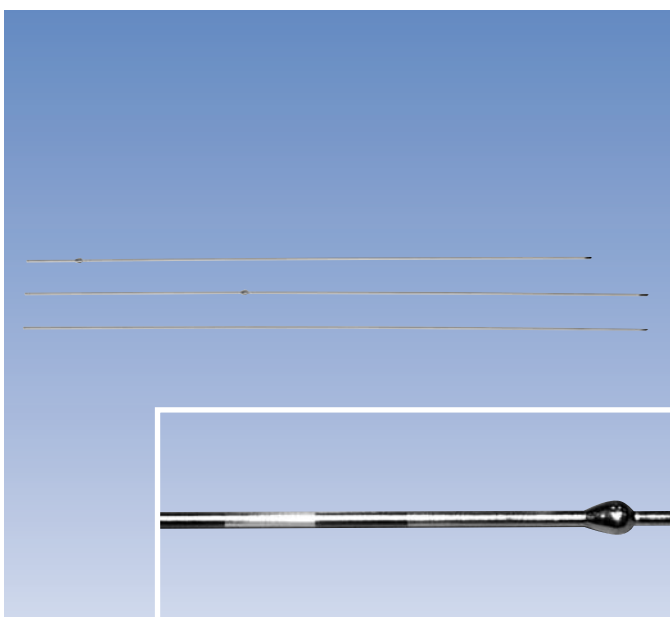
A 6 mm rod with two 2 mm diameter holes for the Kirschner wires. The hole in the securing pin closer to its head is offset from the center of the ring slot. This avoids contact between the crossing wires in the bone. It may only be used with Kirschner wires with lateral olives. Wires without olives may be used, but require a wire clamp slider unit at each end to secure the wire to the ring.

Note: the squared edges on the head of the pin line up with the holes for the wires, making it easier to insert the first wire.



## 80031 Three-Hole Wire Clamp Slider Unit

This component is used to secure wires to a ring. It has four screws: two (a) attach the slider unit to the ring, while the remaining two (b) grip the Kirschner wires in the slider unit, in any two of the three holes. The central wire hole is offset to avoid contact between the crossing wires in the bone. It may be used with all types of wire, allowing them to be placed above, below or through the ring. Three-hole wire clamp slider units should be used with 1 or 2 wires only.



## Kirschner Wires

Kirschner Wire (2 mm diameter) with Lateral Olive

Lengths: 400 mm (80112), 350 mm (80111), 310 mm (80101)

Kirschner Wire (2 mm diameter) with Central Olive

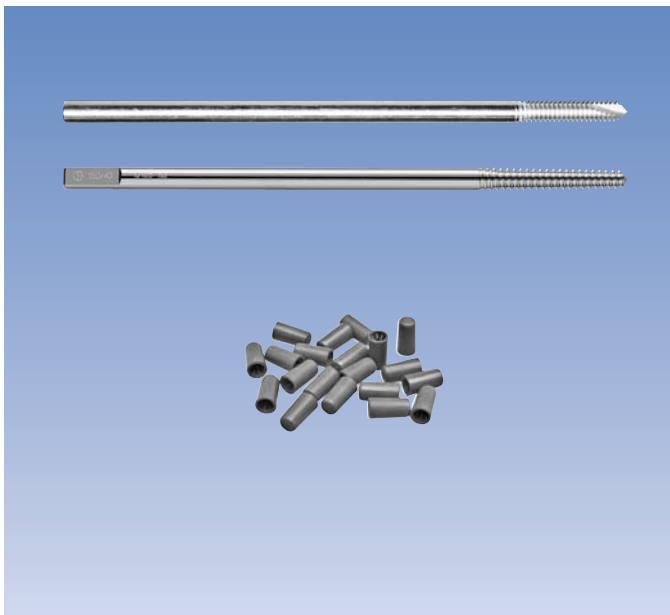
Lengths: 450 mm (80123), 400 mm (80121)

Kirschner Wire (2 mm diameter) without Olive

Lengths: 450 mm (80124), 400 mm (80122)

Note: all of the wires have markings at the end away from the tip. For the olive wires, this means that the markings are always on the same side of the bone as the olive. For removal, the central olive wires should always be pulled out by grasping the end with the markings.

## EQUIPMENT REQUIRED



### Screws

Either standard tapered cortical screws or XCaliber screws are used, but they should not be mixed. Suggested sizes:

Tibia:

**10110** Standard Cortical Screw 110/30 mm or  
**911530** XCaliber screw 150/30 mm

**10114** Standard Cortical Screw 130/40 mm or  
**911540** XCaliber screw 150/40 mm

Femur:

**10165** Standard Cortical Screw 150/40 mm or  
**911540** XCaliber screw 150/40 mm

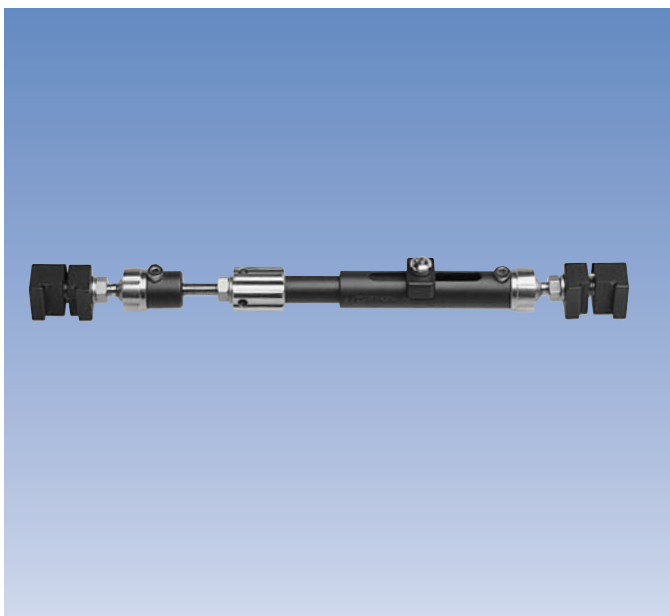
**10103** Standard Cortical Screw 180/50 mm or  
**911550** XCaliber screw 150/50 mm

**912640** XCaliber screw 260/40 mm

**912650** XCaliber screw 260/50 mm

XCaliber screws are designed to be cut to length after insertion and fixator application.

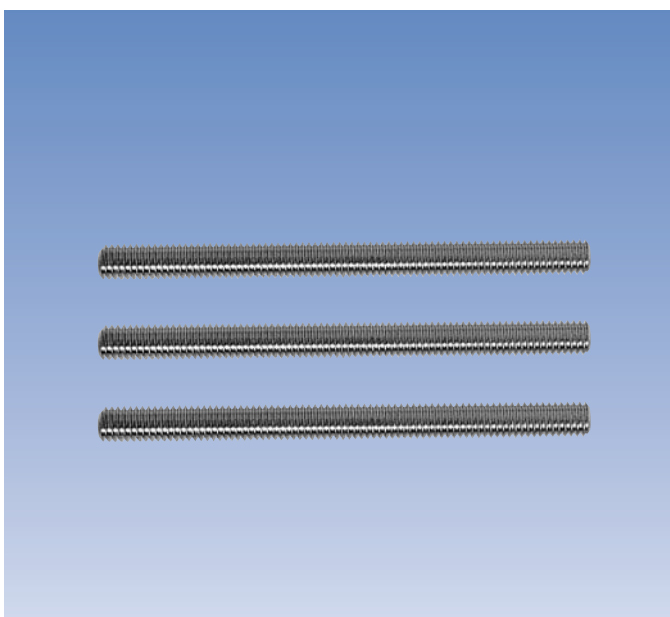
### **10200 Sterilizable Screw Covers (set of 20)**



### **80047 Reduction Unit**

Telescopic, ball-jointed bars, connected to the rings via integral slider units. Three are required for adequate stability.

They may be used for dynamisation by releasing the central body locking nuts. They may also be used to provide temporary stability while a frame is being revised by, for instance, the insertion of hinges.



### **Threaded Bars without Nuts and Washers (set of 3)**

**81036** Length 80 mm

**81037** Length 120 mm

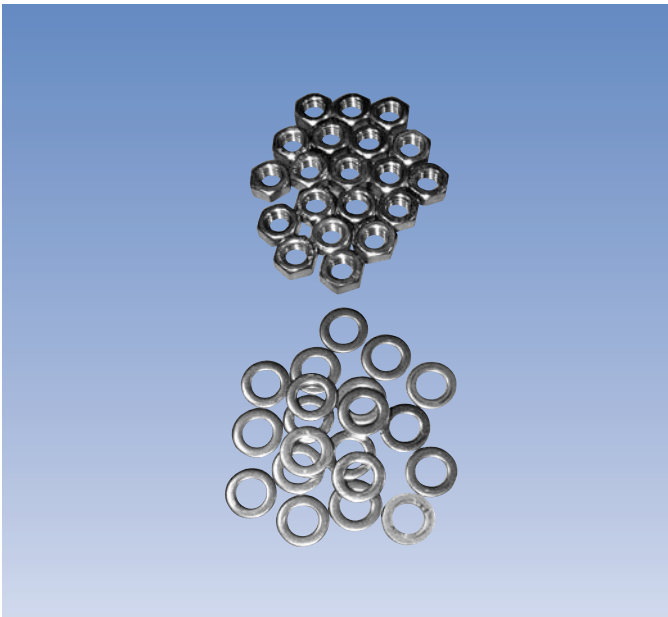
**81038** Length 160 mm

**81039** Length 200 mm

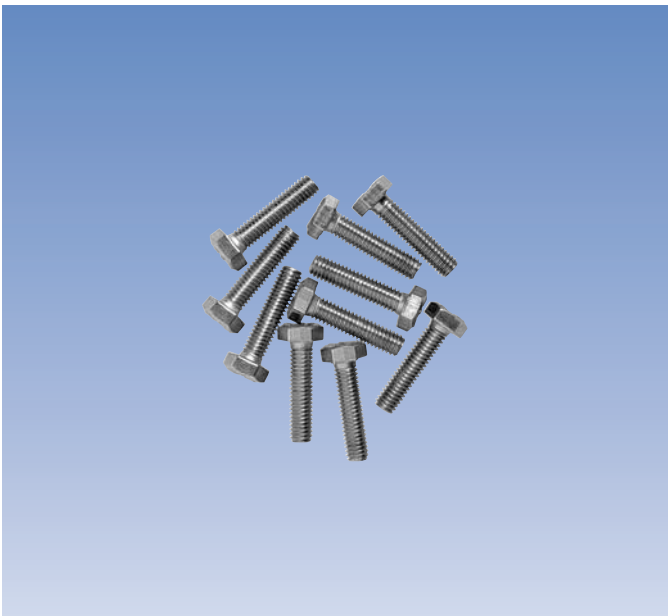
**81048** Length 300 mm

**81049** Length 400 mm

## EQUIPMENT REQUIRED



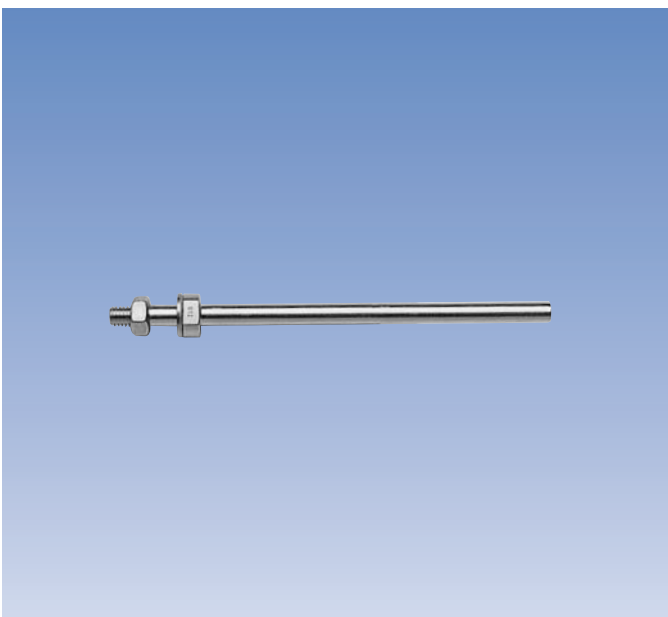
**81022 Nuts and Washers**  
**(pack of 20 of each)**



**Bolts without Nuts and Washers**  
**(pack of 10)**

81024 Length 25 mm

81021 Length 35 mm



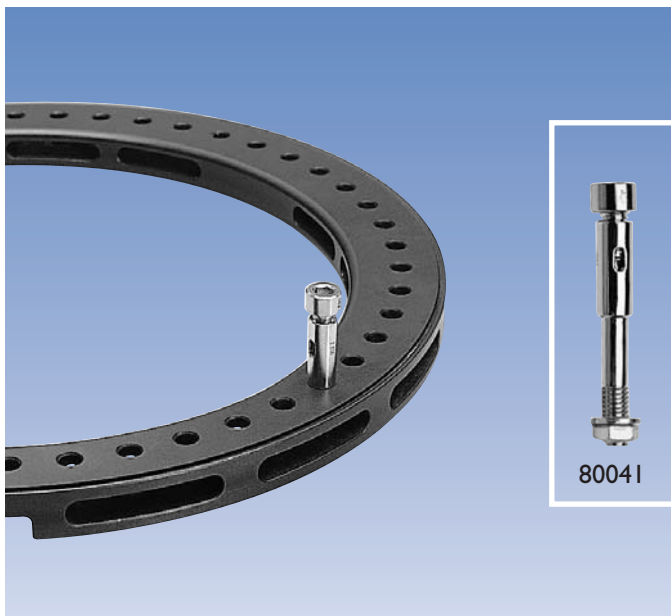
**Post**

80042 Length 50 mm

80044 Length 100 mm

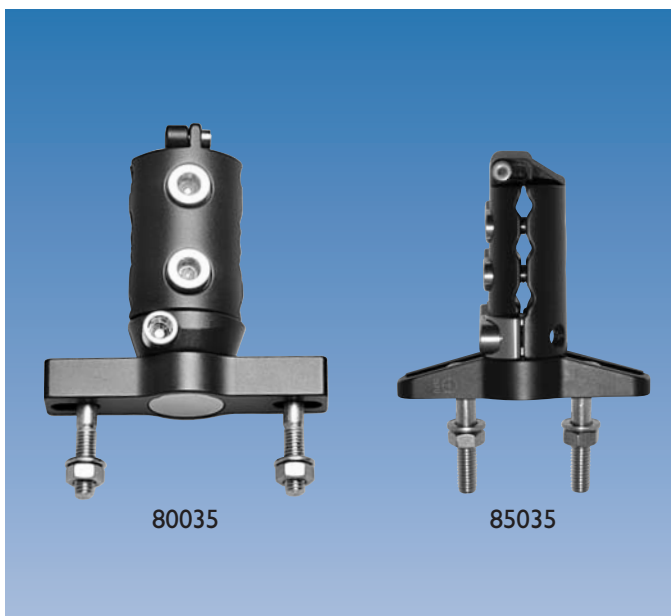
Posts can provide support for supplementary fixation, and are useful for referencing.





### 8004I Independent Wire Clamp

Used with a 2 mm Kirschner wire with central olive, to secure an unstable fragment. A Washer (W2200, set of 4) may be used over the wire to reinforce cortical contact. The Independent Wire Clamp is applied directly to the ring.

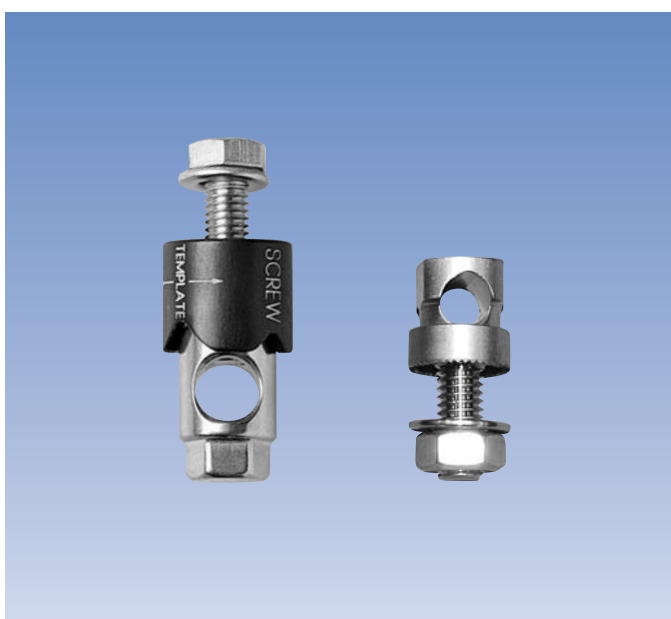


### 80035 Sheffield Clamp

This is similar to a ProCallus Straight Clamp but has a broad flange connecting it to the ring, and a rotational element to ensure optimal screw placement. It is used for diaphyseal fixation, and normally carries two or three 6 mm bone screws. It acts as its own template.

### 85035 Paediatric Clamp

Not to be used in adult patients, but in patients weighing less than 44 Kg (100 pounds). To be used with 125 or 150 mm rings, and 4.5-3.5 mm or 6.0-5.0 mm screws depending upon the bone diameter.



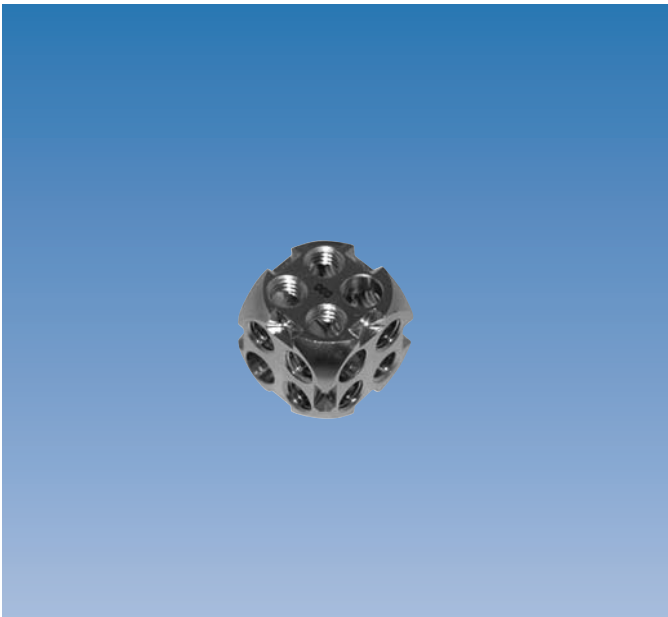
### 80074 Single Screw Clamp

This is used to insert a single diaphyseal bone screw, usually at about 90 degrees to screws in the Sheffield clamp, for additional stability.

It may also be used to anchor Compression-Distraction Clicker Units for lengthening; six are required.

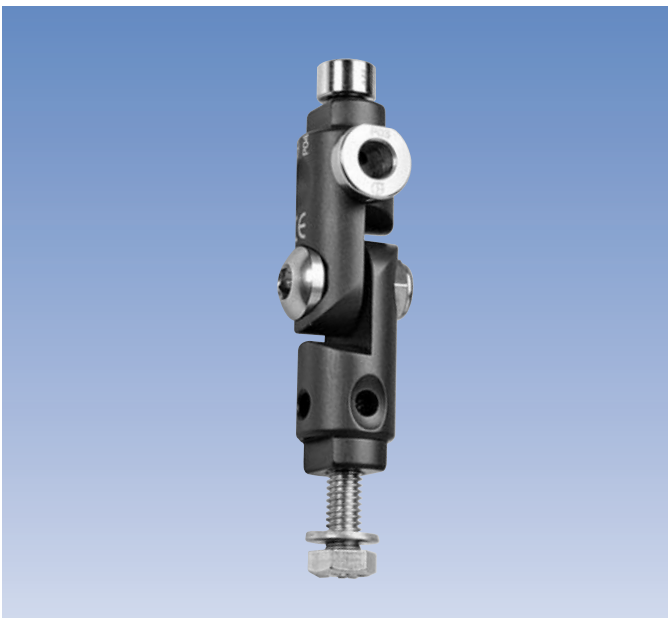
### 80076 Half Pin fixation bolt

This is used to attach a bone screw to a ring.



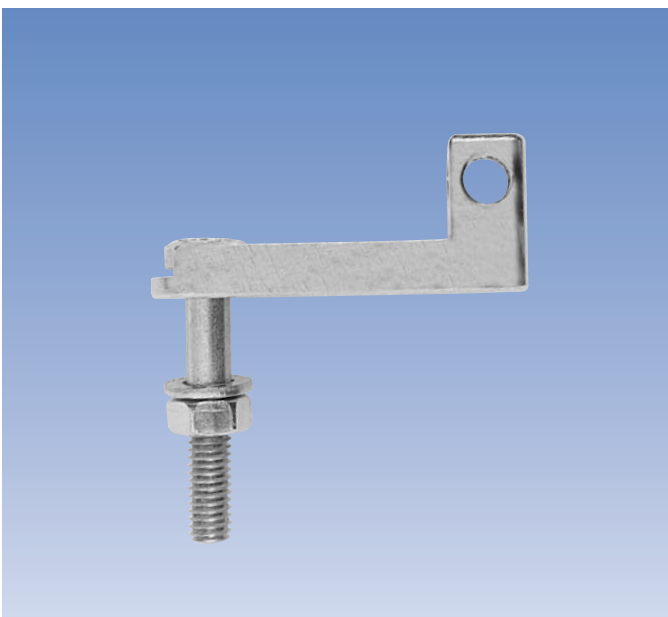
### 81018 Magic Cube

The Magic Cube provides a range of options for screw or wire fixation. It can be attached directly to a ring, mounted on an extension plate or post, or suspended between rings on a threaded bar.



### 81015 Hinge Clamp

The hinge clamp is multifunctional and can be used as a hinge or motor, or a clamp to secure a screw or wire. These techniques are described in the following sections.



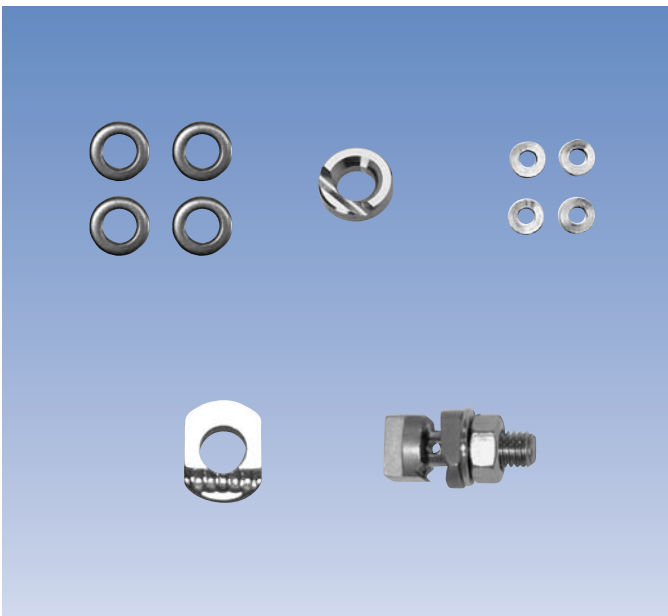
### 81020 Extension Plate

This is used for juxta-articular hinge placement, or with a slotted washer and bolt to angle wires off the ring. A Compression-Distraction Clicker Unit with extension plates attached to each ring may be used as a motor. It may also be useful to connect rings of different sizes.



**81010 Translation Rotation Hinge**

These units may be used as simple hinges but are primarily indicated for correction of translation (see multiplanar deformity) and rotation. They may also be used to connect rings of differing diameters.



**81023 Slotted Washers (pack of 10)**

Slotted washers may be mounted on to the ring to provide a single level of wire fixation parallel to the ring. Where angled wires are required, a bolt and slotted washer combination may be used with a hinge clamp or extension plate. The most efficient configurations are in combination with the wire clamp component of the hinge clamp, using the hinge bolt to mount the washer, or attached to the side of an extension plate if it is fitted at 90 degrees to the ring. The wire is sandwiched between a slotted and plain washer.

**80077 Wire fixation bolt**

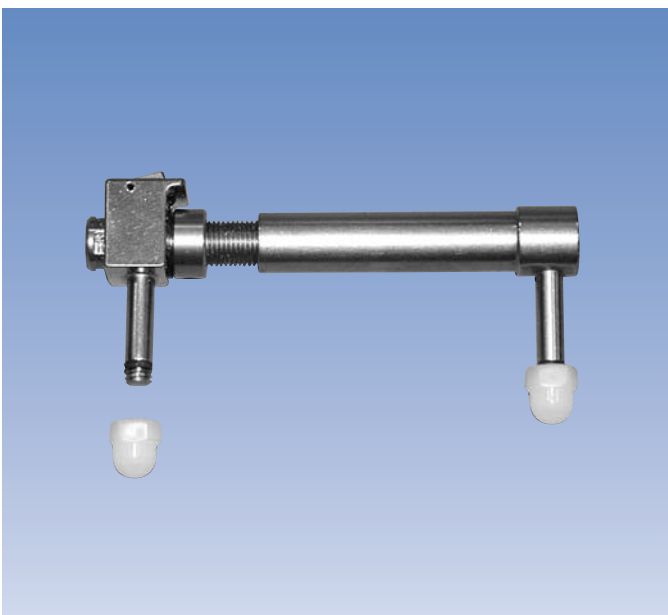
Used to fix a wire close to a ring or extension plate. The serrations in the washer help to grip the wire.

**W2200 2 mm Washers (pack of 4)**

For use to supplement cortical fixation of wires with a central olive.

**74405 Revision Locking Screw Washers (pack of 4)**

For use with the slotted washer.



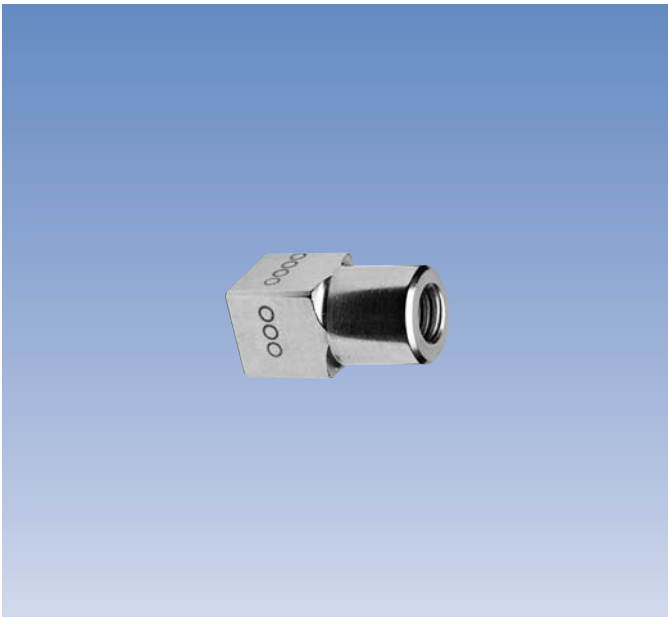
**Compression-Distraction Clicker Units**

**50008 Standard**

**50009 Long**

With the blue button depressed and held they act as normal compression-distraction units. When the blue button is depressed transiently, they permit lengthening or shortening of one quarter turn (0.25 mm) only.

The white plastic nuts are used to retain the distractors in place.



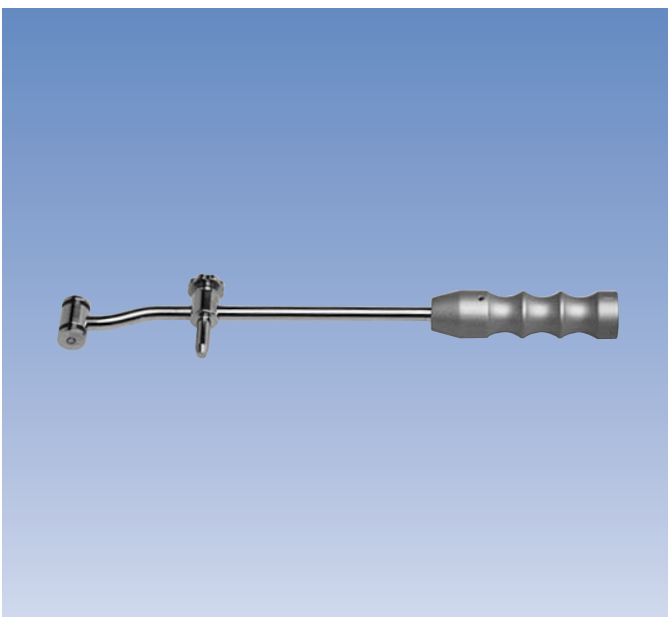
## 81025 Counter Nut

They are used for more accurate lengthening or angular correction. The usual rate for lengthening is one millimetre per day (one full rotation of the nut), normally divided into 4 steps. Therefore, the patient usually begins each day with the same number of markers facing a particular direction. They may also be used as nuts where a fixing is required in a captive device such as the Sheffield Clamp or an extension plate.



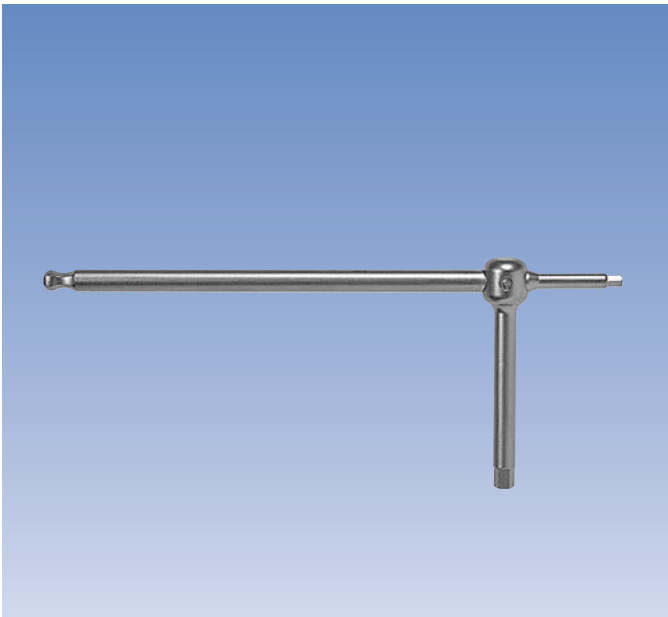
## 18001 Wire Tensioner

Calibrated from 600-1400N.



## 18002 Wire Guide

Used as an aid to accurate placement of a second wire when parallel wires are used.

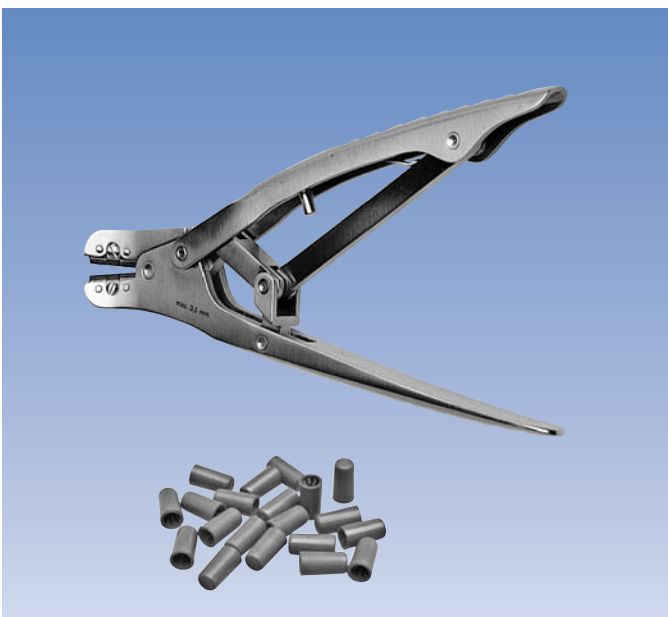


**91017 Universal Allen Wrench 3 mm/5 mm, and Wire Bender**

The hole in the polyhedral end of the wrench can be fitted over the end of the wire. The instrument can then be used as a Wire Bender.



**81031 Open End Wrench  
81030 Speed Wrench  
10017 Allen Wrench 6 mm**



**W1003 Wire Cutter**

**80200 Kirschner Wire Covers  
(pack of 20)**

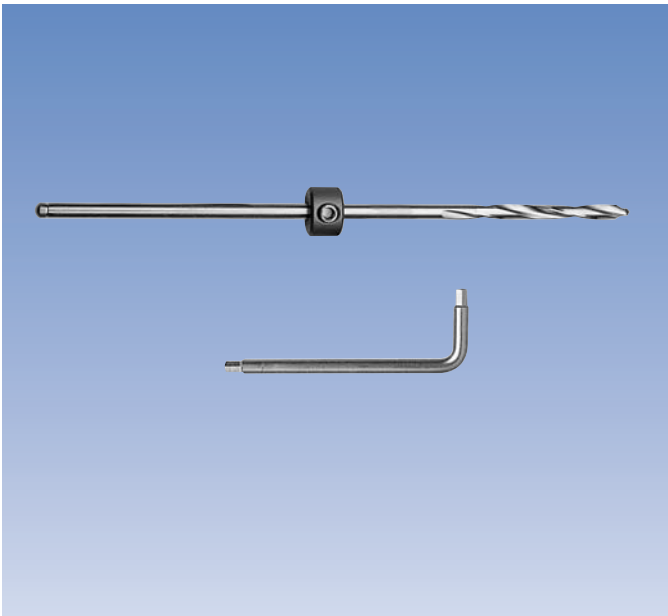


### Screw Guide

- 11102 Length 60 mm
- 11137 Length 80 mm
- 11103 Length 100 mm

### Drill Guide

- 11138 Length 60 mm
- 11105 Length 80 mm



### Drill Bit Kit Ø 4.8 mm

- 11001 Length 180 mm
- 11002 Length 240 mm

## I. GENERAL PRINCIPLES

### A. Wire placement

#### Standard Wire Configurations

The advantage of this system is its ability to support 4 fully tensioned wires on one ring. The most economical way to do this is with two parallel sets of wires systems using two wire slider units and two wire securing pins. If the wires are crossed at 70° the system is very stable; the majority of frames are constructed in this way, as described in the Operative Technique Manual 12, part B. If the securing pin for the second group of wires is placed in the 9th or 10th hole away from the first one in any size of ring, a crossing angle of 70° will normally be obtained.

#### Reference Wire Configurations

Where there is difficulty with joint orientation and wire placement, despite angling the Image Intensifier to make the ring image a straight edge, use of the reference system described below should be considered.

#### Proximal Tibia

- 1) The anatomical axis and joint line are visualised using fluoroscopy and marked on the skin with a skin marker.
- 2) A coronal plane reference wire is inserted, freehand under X-ray control and at least 15 mm below the joint line, so that it is perpendicular to the anatomical axis of the proximal tibia; it will then be 3 degrees varus to the joint line.
- 3) Assuming a normal tibio-fibular relationship, the transfibular wire will be inserted through the centre of the ring and through the middle of the fibula head. Therefore the coronal plane reference wire, which will be attached above the ring, should be inserted just above the head of the fibula and 15 mm below the joint line.
- 4) The reference wire is attached to the proximal ring with two wire slider units.
- 5) A temporary threaded bar or a 100 mm post is inserted through the central anterior hole of the proximal ring, which is then positioned so that the bar or post is parallel to the proximal anatomical axis and aligned with the tibial tuberosity and the anterior tibial margin.
- 6) The reference wire may be utilised in the metaphyseal fixation or used simply as a temporary wire.
- 7) For the proximal tibia four wires are usually required. A second parallel wire may be placed in the reference clamps, with a single wire in both the medial face and transfibular positions. Alternatively, two wires may be inserted in the medial face clamp with a single wire in both the reference position and fibula head.

#### Distal Tibia

- 1) Three or four wires are required; in a distal tibial mounting the reference wire will be in the coronal plane, parallel to the ankle joint and at right angles to the anatomical axis, at least 5 mm proximal to the joint line.
- 2) Depending on the indication, it may be necessary either to transfix the fibula (lengthening or deformity) or avoid the fibula to encourage ankle movement (some pilon fractures). Biomechanically at least three wires are required, so fixation may be completed with one transfibular wire and one medial face wire.  
Parallel wire placement if desired should be in the coronal plane or transfibular positions, not in the medial face, where it is more likely to cause irritation.

### B. Screw placement

Screws are normally inserted with the Sheffield Clamp antero-medial, but may on occasion (open fracture or deformity with medial hinge placement) be placed anteriorly. The Sheffield Clamp is normally positioned inside the ring construction but may be placed outside if for example there is a long fracture extension.

Screw length should be chosen so that the screw shanks just pass through the Sheffield Clamp.

The usual configuration is for two screws in a Sheffield Clamp in the 1 and 5 positions, and a single screw at 60 - 90 degrees to this, the exact angle being governed by local factors. Insertion too close to the anterior compartment muscles should be avoided, because this may lead to discomfort and premature loosening. The screw is normally positioned inside the ring construction, closer to the ring than the nearest of the Sheffield Clamp screws, but may be placed on the far side of the ring if required.

### C. Independent screw placement

This can be achieved with one of the Single Screw Clamps, for screw insertion at a fixed angle and distance to the ring, or with the Hinge Clamp, which allows screw insertion at a variable distance or angle. A Magic Cube can also be used, with wide options for distance from the ring and screw direction.

**D. Hinges and motors**

Hinge clamps are used as hinges and motors for correction of deformities.

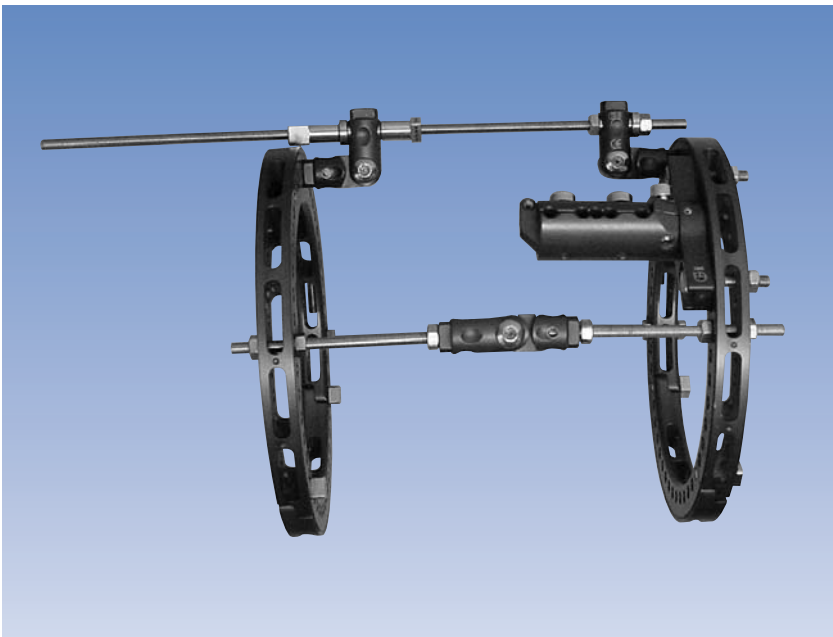
**Assembly**

Two rings are connected by three threaded bar systems. Two of the bars contain hinges in symmetrical positions to define the axis of correction. When used as a hinge, threaded rods are inserted into each end of the clamp and secured with nuts and washers. The opposite ends of each rod are secured to the rings with nuts and washers. The level of the hinge in relation to the rings should be planned pre-operatively to coincide with the axis of deformity correction (CORA); this can be adjusted by using threaded rods of different lengths. If required, one end of the clamp can be mounted directly to a ring and the other end attached to a threaded rod. To function properly, both hinges should be coaxial and at the same level on the frame. The central axis bolt of each hinge is cannulated to allow passage of a 2 mm wire to ensure that the axis of both is the same and that it passes through the estimated position of the CORA.

The third bar is known as the motor, and controls the rate and magnitude of correction. It should be fixed midway between the two hinges. The motor consists of a distraction mechanism, and can be assembled in different ways:

- a) Two hinges, each attached to a ring, are angled to allow a connecting threaded bar to pass through the screw centraliser of each hinge. A counter nut system moves the rings in relation to each other. The hinges should be placed inside the rings for a distracting motor and outside for a compressing motor.
- b) An Extension Plate is mounted on each ring and a Compression/Distractor Unit inserted into the holes in the extension plate which are parallel to the axes of the hinges. This ensures that the Compression/Distractor unit can articulate in the extension plates as the rings change their respective angles. The Compression/Distractor Clicker Units are provided with directional arrow labels, which can be used to indicate the direction that the patient should turn the device to achieve correction. Counter-clockwise turns will lengthen the distractor, and clockwise turns will compress it.
- c) A Compression/Distractor Clicker Unit can also be mounted on single screw clamps.
- d) A threaded bar is located in two supplementary screw holders, each of which is mounted on a ring.

Once the frame is built, it should be tested to ensure that it will articulate to the desired correction angle.



a) Frame for angular correction with hinge clamps and threaded rods as a distracting motor



b) Frame for angular correction with CD Unit as motor

**Frame Mounting**

A pre-assembled frame with hinges is placed around the deformed limb and the hinges positioned over the CORA. If there are no neurovascular structures at risk, a temporary wire can be inserted through the hinges across the limb as a reference point for the CORA. The angles of the rings are adjusted so that each ring is perpendicular to the long axis of their respective bone segments, in both the coronal and sagittal planes. The rings can then be secured in the correct position by attaching them to metaphyseal reference wires or diaphyseal reference screws. When a satisfactory frame position is achieved, additional wires or bone screws are then inserted to achieve final frame stability.



## Single Screw Clamp

The outer sleeve is positioned in the 'template' position, a screw guide inserted down to the bone, and the ring bolt gently tightened. The screw hole is drilled, and the screw inserted. The screw guide is withdrawn, the sleeve rotated to the 'screw' position, and the screw locked in place by tightening the ring bolt.

## Hinge Clamp Screw Fixation

The wire bearing end of a hinge clamp is attached to the ring, either directly with a 25 mm bolt, or with a threaded bar, and a screw introduced at a chosen position or angle to the bone. It is indicated where a second level of fixation is required, for example in a low diaphyseal fracture non-union where the wire bearing ring is too far from the fracture focus. It is also indicated for stabilising segmental fractures.

The centering sleeve should be removed and a screw guide inserted through the clamp. The bone is then pre-drilled through a drill guide, and the screw inserted, after which the screw guide is replaced with the centering sleeve. This should be oriented with the flat edge of the flange pointing towards the open end of the clamp, so that a locking bolt can pass through the slot and lock the bone screw.

## E. Independent wire placement

This can be at a fixed distance from the ring, parallel to it, or at a variable distance and angle.

### Independent Wire Clamp

Two of these used on opposite sides enable wire positioning at any angle 10 mm above the surface of the ring, parallel to it. They can also be used mounted on a post to vary the distance from the ring, but in this situation the amount of wire tension possible is decreased.

### Hinge Clamp Wire Fixation

In some situations wires need to be placed at some distance from the ring. These wires may be inserted parallel or angled in relation to the ring and bone axis. Angled olive wires are used for oblique fractures, articular fracture fragments and forefoot fixation.

Two holes are provided, one in the plane of the hinge to allow angled wire placement at low tension, and one at right angles to the hinge permitting parallel wire placement at higher tensions. They are indicated for the stabilisation of third fragments and fractures of increasing obliquity (see fracture section), where central olive wires may be placed in counter-opposed parallel configurations, or angled across the fracture.

To position an oblique wire using the Hinge Clamp, the hinge can be locked into an angled position with a 5 mm Allen Key. A wire is inserted through the clamp and soft tissue and drilled through the bone. If the exit point of the wire is not conveniently close to a clamp on the opposite side, the clamp position can be adjusted with stacked washers, or by mounting it onto a threaded rod. It is important to note that the further away the clamp is from the ring, the less wire tension can be applied. Excessive tension may cause the locked hinge to slip. Tensioning should cease if bending of the clamps is noted. In this situation, more tension will be obtained using a slotted washer in combination with a half hinge.

### Slotted Washer

This can also be used to achieve independent wire insertion. It can be mounted directly to a ring or extension plate with a 25 mm bolt, in which case the wire is parallel to the ring. For an angled wire, the slotted washer is fitted over a 35 mm bolt located in the centering sleeve of the screw hole of a hinge clamp, which may be mounted with either end attached to the ring, to vary the distance from it. Alternatively a hinge may be separated, and one half screwed to a ring with a 25 mm bolt or threaded bar. The hinge bolt can then be used to mount the slotted washer, and provides more stability than when a complete hinge clamp is used.

### Magic Cube

The Magic Cube can be used to secure fixation of a wire with or without olive. In the latter case, the wire is locked into position with a locking bolt (81019, pack of 2). The cube can be mounted directly to a ring, on an extension plate or post, or suspended between 2 rings on a threaded bar. Two cubes can be used to provide oblique wire fixation, which can be particularly useful with the foot ring.



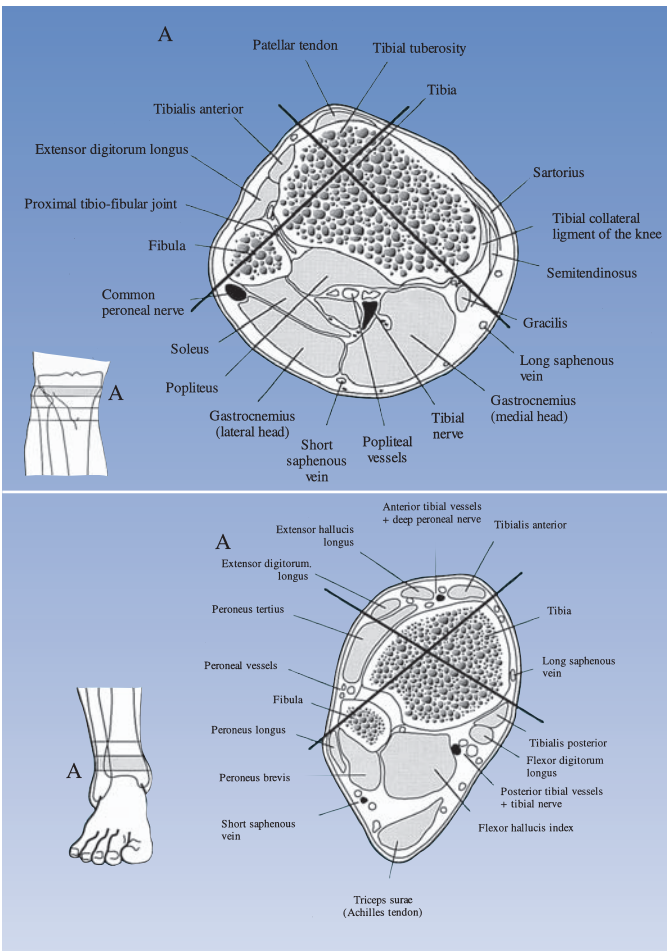
## 2. TRAUMA APPLICATIONS

### A. General points

A two ring fixator is constructed with three 6 mm threaded bars placed antero-laterally, postero-medially and postero-laterally.

#### Basic Principles of Sheffield Ring Fixator

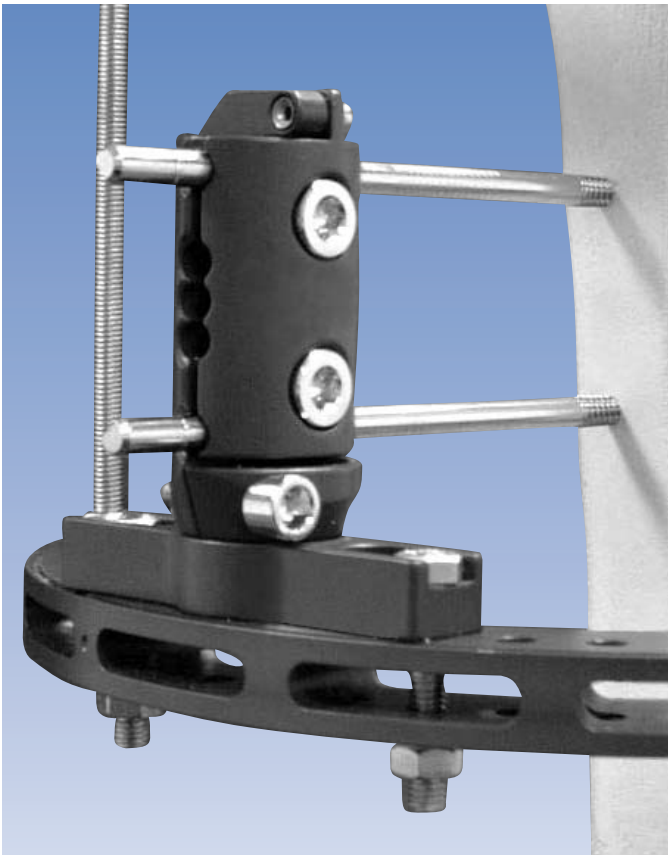
- Ring connecting reduction units or bars should be spaced as evenly as possible around the rings. Normally 3 are sufficient. If 4 are used, care should be taken that excessive vertical loads are not transmitted to the ring by uneven alteration of the lengths of the connecting bars.
- Rings should be assembled so that the 1/3 components, or the gaps where a 2/3 ring is used alone, are above each other.
- The space in a 2/3 ring, or the 1/3 component of a complete ring, should always be positioned posteriorly.
- A Sheffield Clamp should always be positioned on the 2/3 component of a ring.



#### Metaphyseal Wire Insertion

Wires are used in the metaphysis only, and should be inserted parallel to the joint surfaces, although 3 degrees of varus at the tibial plateau is more anatomical and therefore ideal. Accurate positioning of these wires is critical, and peripheral olive wires are normally used. These must be placed through a ring using a wire securing pin, and the Image Intensifier adjusted so that the ring appears as a single straight edge parallel to and below the articular surface.

Where the anatomy is difficult a plain wire should be selected and inserted free-hand before the fixator is applied. Plain wires are secured with two wire slider units. The wires should have a crossing angle of at least 70 degrees, and the crossing should be in the central area of the bone. Standard positions for the proximal and distal tibia are shown in the drawings on this page.



## Diaphyseal Screw Insertion

With metaphyseal referencing complete the relationship of the ring to the joint surface is fixed. Using longitudinal traction the fracture is then reduced, taking particular care to check the rotation of the leg and avoid any translational deformity at the fracture site. Two screw guides are inserted in the Sheffield Clamp and under X-ray control two cortical screws are inserted at right angles to and in the centre of the diaphysis, in the widest positions in the clamp. The screw guides are removed and the clamp locked. The diaphyseal ring will then be fixed at right angles to the axis of the shaft, and diaphyseal referencing is complete. Using this referencing technique the fracture will be accurately reduced. Any residual shortening may be corrected by distracting the threaded bars, and lateral translation by releasing the Sheffield Clamp locking screws and adjusting the position of the screws in the clamp.

## B. TIBIAL FRACTURES INCLUDING SEGMENTAL AND OBLIQUE FRACTURES IN THE DIAPHYSIS AND METAPHYSEO-DIAPHYSEAL JUNCTION

### Indications

1. Open fractures, fractures with severe soft tissue disruption or infected fractures.
2. Metaphyseal fractures, proximal or distal.
3. Unstable fractures in any part of the bone.

### Frame Design

2 ring 'standard' frame:

- 4 wires in the metaphyseal ring.
- 2 screws in the Sheffield clamp and a third screw placed more anteriorly on the diaphyseal ring.
- 3 threaded rods or reduction units; one postero-lateral, one postero-medial and one antero-lateral are sufficient for most patients and most fractures. Rarely four may be required for very heavy patients or very severe comminution.

### Components

- 2 x 2/3 rings
- 3 x threaded rods or reduction units
- 4 x 2.0 mm peripheral olive wires
- 3 x wire slider units and 3 x wire securing pins (or 6 wire slider units if smooth or central olives wires are used)
- Sheffield Clamp
- Single screw clamp
- 3 x 6 mm screws. OsteoTite Bone Screws should be used for poor bone stock or where prolonged treatment may be anticipated (e.g. Gustilo III B or C fractures).
- Where three rings are used for a segmental fracture or where an additional ring is used for an unstable fracture, 3 x 300 or 400 mm threaded bars or 6 shorter threaded bars are used.
- Other devices and implants for supplementary fixation; for example hinge clamps, screws and wires.

### Pre-Operative Planning

Ring Size:

Rings should be chosen to allow two finger-breadths between the ring and the leg at any point. Rings that are too large provide less rigid fixation, and so a reasonable balance should be sought, allowing enough space for post-operative swelling at all points around the frame. Both rings should be the same size and this should be dictated by the largest size required.

**Fracture Morphology**

**Oblique Fractures**

Fractures with an obliquity of more than 30° are unstable and may require supplementary fixation, usually with olive wires. These are most effective when they pass through the fracture site and transfix both fragments. One olive wire placed perpendicular to the fracture line is sufficient for 45° obliquities but two opposing olive wires perpendicular to the long axis of the bone are recommended for obliquities >60°. Olive wires away from the fracture are recommended for 30° short oblique fractures. They can be attached to the frame via a third ring, or by attaching hinge clamps to one of the rings, directly or with a threaded bar. When using hinge clamps with horizontal wires, the hole in line with the hinge axis should be used for optimal tensioning. Angled wires are inserted with the aid of slotted washers attached to hinge clamps as described previously, or to the side of an extension plate when they are close to the ring. Sagittal plane fractures of high obliquity cannot be fixed in this way. Independently mounted screws or a pair of coronal plane arched wires may be used.

**Comminuted Fractures**

Large fracture fragments can often be held using olive wires placed through the fracture site, sometimes mounted on a third ring.  
(See X-ray on page 21).

**Segmental Fractures**

These should be stabilised with a three ring system. Long segmental fractures can be stabilised using wire fixation in both metaphyses and screws in the central fragment, or for shorter segments two levels of screws and one of wires. The intended position of all wires and screws should be decided before building the frame. The central fragment is fixed with screws. The proximal and distal fragments are fixed with wires or screws depending on the amount of diaphyseal bone available. The rings may be fixed by 3 long threaded bars or 2 sets of shorter bars. Using the latter method, the mechanical environment for each of the fractures may be treated independently.

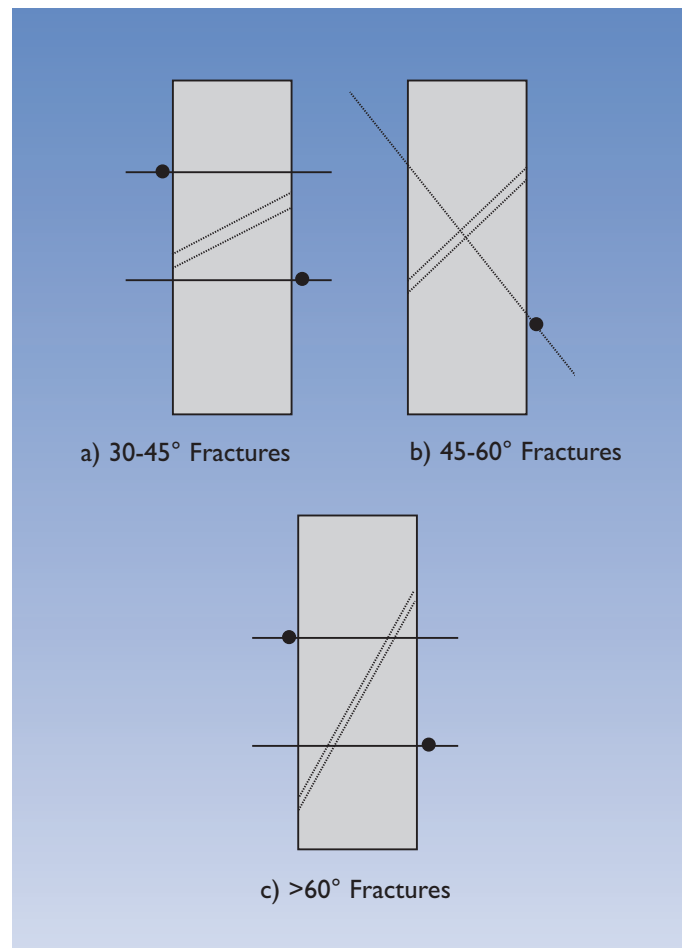
**Fibula**

The condition of the fibula should also be examined but it is usually left without any specific surgical procedure, unless the ankle joint is involved. The fibula gains some stability from the wire fixation of the tibial metaphysis. Rarely is open reduction and internal fixation of the fibula indicated.

**Wire and Screw Fixation**

Safe corridors for diaphyseal wires and screws should be checked with particular reference to the intended position of any soft tissue procedures. In an open fracture this part of the fixation may be delayed until immediately after a flap has been applied. In this situation the vascular pedicle or axial vessels must be identified and avoided.

As a general rule, metaphyseal bone is fixed with tensioned wires and diaphyseal bone with cortical bone screws.



**Operative Technique**

**Preassembly**

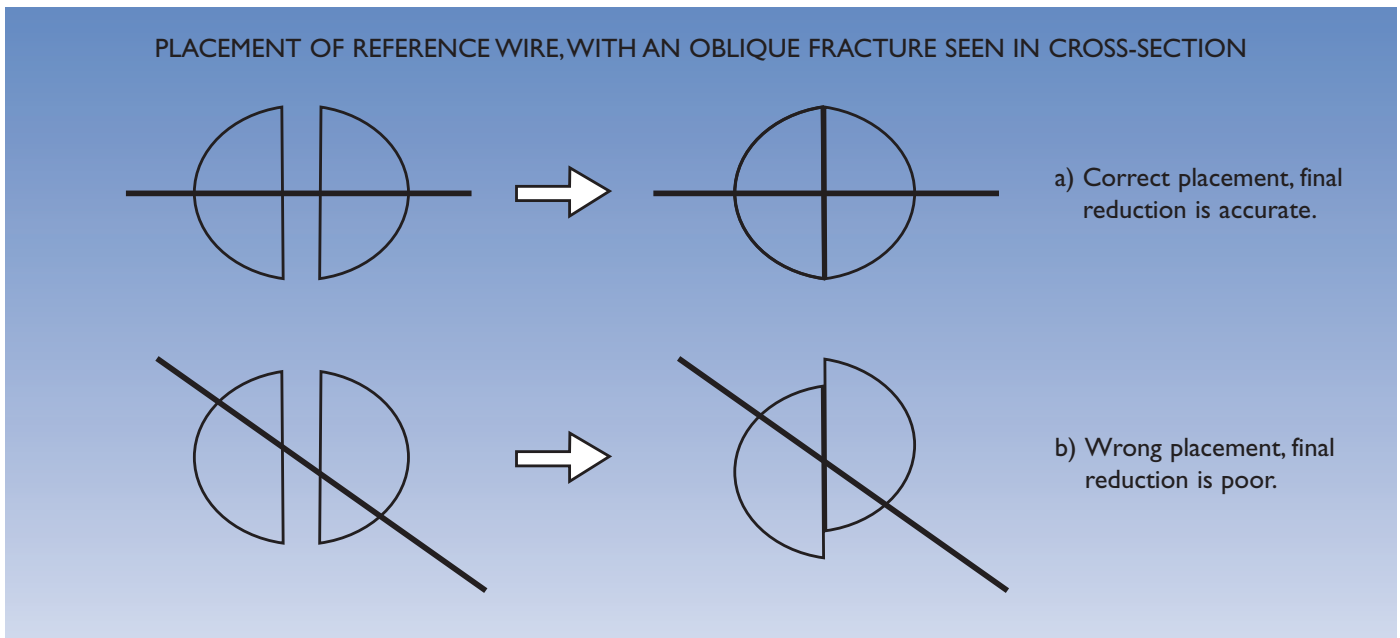
- 1) The frame is pre-built on a sterile theatre trolley according to the pre-operative plan. The Sheffield Clamp is placed antero-medially on the diaphyseal ring, and can always be moved later. The rings should be parallel and rotationally aligned, so that a threaded rod connecting the rings will pass through the same hole in both rings. A complete ring should be used distally where the addition of a foot ring may be required to cross the ankle.
- 2) The patient is positioned in a supine position on the table and manual longitudinal traction used to achieve an approximate reduction, paying particular attention to the rotation of the limb.
- 3) Landmarks are marked out on the skin: joint lines, epiphyses (in the immature skeleton), tibial tuberosity, tibial anatomical axis and postero-medial border, and the positions of the fracture, fibula head and lateral malleolus.
- 4) The frame is offered up to the leg which is positioned with the patella pointing directly upwards. A bolt or threaded bar placed into the central holes of the two rings is lined up with the anterior tibial crest. Towel packs are placed under the knee and heel to align the leg in the sagittal plane, so that the antero-lateral threaded rod is parallel with the crest of the tibia, when viewed from the side.

**Referencing**

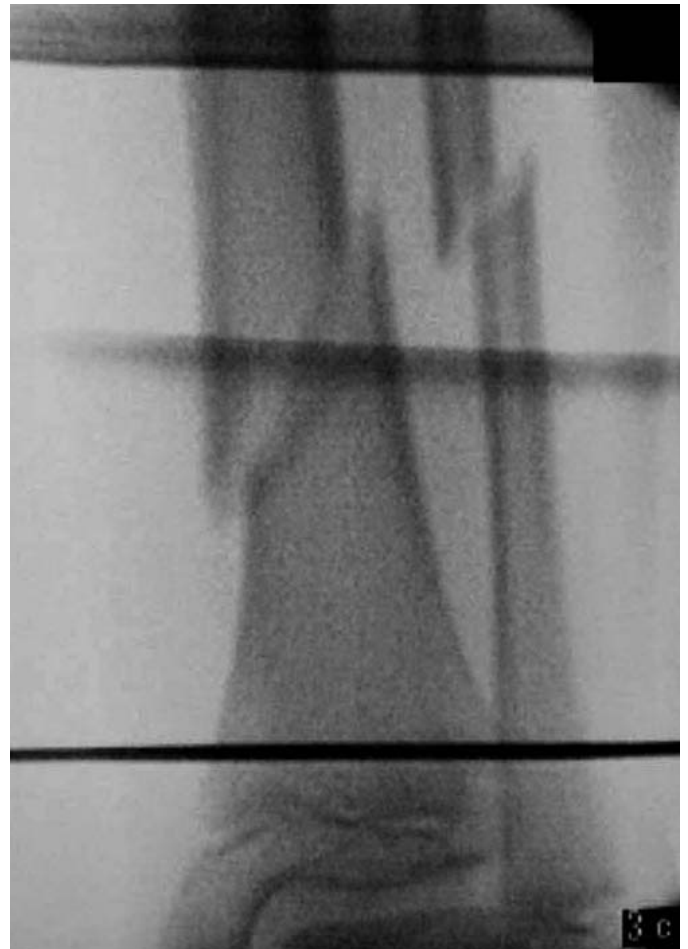
- 5) A coronal plane reference wire is then inserted. This is placed at least 15 mm away from the joint line proximally and at least 5 mm away from the joint line distally, thus avoiding the joint capsule. A peripheral olive wire may be used, inserted through a wire securing pin in the ring, or a plain wire independent of the frame. The reference wire should be perpendicular to the axis of the bone. The best way to do this is by ensuring that the wire is parallel to its neighbouring joint using AP views on image intensification, allowing for a 3° varus slope in the knee. Time spent at this stage is well invested. If a wire is not correct, it should be replaced using a new wire, since blunting of wire tips may lead to local thermal bone necrosis on reinsertion.

*NOTE:*

*Before the wire is inserted, the plane of the fracture should be examined with reference to any planned additional fixation. If the fracture is finally reduced using olive wires, it is achieved by translation over the reference wire.*



For oblique fractures, the choice of reference wire position should therefore be dictated by the plane of the fracture. For a true coronal plane fracture (i.e. a fracture in which the true obliquity can be seen on an AP X-ray, and no obliquity can be seen on a lateral view) a coronal plane wire is ideal, and is also the easiest reference to apply. It is attached to the frame between the ring and the joint line by inserting the wire securing pin towards the joint surface and the Wire Slider Unit in the corresponding position, and tensioned to 1200-1400N. The wire ends are cut and bent out of the way. In order to maximise crossing angles a transfibular wire is used from postero-lateral to antero-medial.



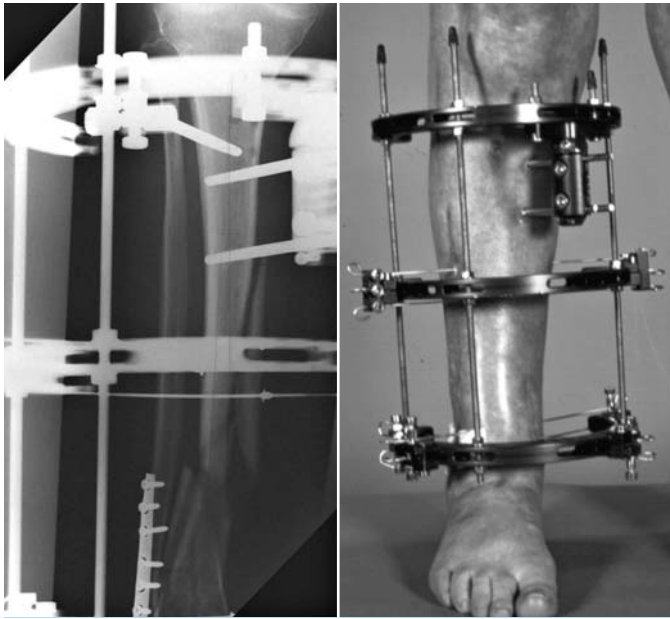
Reference wire parallel to the ankle.

- 6) Reduction is checked and the limb position should be central within the frame. The assistant should at this stage maintain the position of the patella pointing vertically upwards and confirm that foot rotation is correct. The frame is aligned so that the anterior threaded rod is parallel with the anterior tibial crest in the coronal (frontal) plane.
- 7) The position of the Sheffield Clamp is adjusted and the first 6 mm screw inserted in the screw seat furthest from the ring using the standard technique. The screw should be positioned in the centre of the medial face of the bone and traverse the bone across its maximum diameter to the far cortex. A further screw should be inserted in the position on the clamp nearest the ring. The screw guides are removed, the screw sites irrigated and screw shafts washed. The clamp cover is tightened first, followed by the rotation locking screw. The frame is now referenced both proximally and distally.

### Reduction

- 8) In the case of oblique fractures additional stabilisation, usually in the form of olive wires, may be required to facilitate reduction and reduce fracture motion. In poor quality bone washers should be used over the olives to spread the load more evenly. The olive wires should be tensioned to between 600-800N only. The ideal relationship of the wires to the plane of the fracture is determined as described on page 18; insertion techniques are the same for plain and peripheral olive wires, noting the more limited crossing angles in the tibial diaphysis. The wires may be attached to an additional ring using wire slider units or hinge clamps.

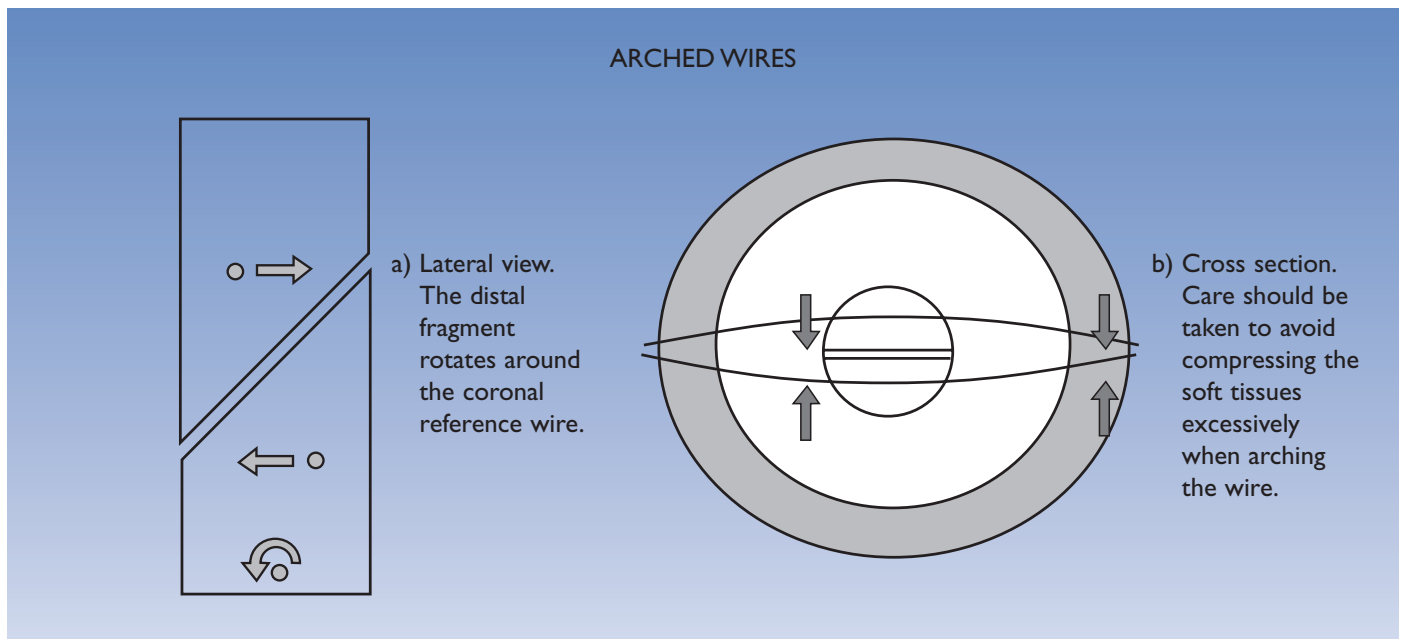
9) Tensioning these additional wires draws the fracture together, provided that the bone is able to slide over the metaphyseal reference wire, and the screws to slide in the Sheffield Clamp. To permit this movement, the clamp cover must be loosened slightly. The tensioning device is now used to pull the olive and the bone across and reduce the fracture accurately under Image Intensifier control. Initially tension is applied with both hinge clamps loose, so that the olive is pulled on to the cortex of the bone. The hinge clamp on the side of the olive is then tightened and tensioning continued. The hinge clamp on the other side is then tightened after a tension of 600-800N has been applied. Finally the clamp cover is tightened. For oblique fractures in the sagittal plane, or large anterior wedges, two plain wires are placed transversely, one in each segment, and arched towards each other by moving the wire slider units 1-3 holes from their resting position towards the fracture. Tensioning to 1200N will pull the fragments together, rotating around the reference wire. Diaphyseal segmental fractures should also be stabilised and reduced at this stage.



Olive wires on a third ring for a severely comminuted fracture. X-ray and clinical appearance.



X-ray of the final result. The retained washers show where the olive wires were positioned.



### Fixation

- 10) Metaphyseal fixation is completed with a further three wires proximally (or two distally). A wire securing pin is inserted into the middle hole of the last group of holes on the lateral side of the 2/3 ring, pointing in the direction of the joint. The transfibular wires are inserted according to the standard technique, checking that the engraving on the slider unit matches the pin. The wire that passes outside the ring may catch on the reference wire and if so, can be omitted. Both wires are tensioned to 1200-1400N, the wire that passes through the middle of the ring first. Once tensioned and locked, the wire ends should be cut and bent.
- 11) A wire securing pin is inserted into the equivalent hole on the medial side, but pointing in the opposite direction, and two parallel medial face wires are inserted, again positioning the wire slider unit so that the image matches the securing pin. Starting with the wire through the middle of the ring, both wires are tensioned to 1200-1400N, and then cut and bent. There should now be at least 4 wires, two through the middle of the ring, one proximal and one distal to the ring.
- 12) A third bone screw is inserted through the single screw holder into the anterior tibial crest using the standard technique described under 'independent screw placement', positioning the teeth of the screw guide on either side of the crest to prevent the drill from slipping. The frame is now complete.
- 13) A final check of the reduction is made on the Image Intensifier in two planes. The reduction units may be useful at this stage for any residual corrections.
- 14) The leg is washed and the screw sites wrapped in paraffin tulle and gauze. A Collar and Cuff strap connected to one of the rings should be used to maintain the foot in a plantigrade position. A bandage applied to the other leg will save the patient from injury to this leg during recovery from the anaesthetic.

Long segmental fractures should be approached by referencing each metaphysis, and completing the metaphyseal fixation with tensioned wires. Accurate reduction and fixation of the middle segment can then be performed using screws. Careful alignment of the anterior threaded bar with the anatomic axis will avoid translational deformity.

### Post-Operative Care

The pin-site dressings are removed on day 2 and the patient should be carefully instructed on pin-site care. Physiotherapy is commenced, and full weightbearing and active joint mobilisation are encouraged from day one. Patients are typically seen at two weeks and six weeks and then as appropriate. Olive or arched wires are usually removed to begin dynamisation at 6 weeks and further dynamisation can be achieved by removal of the orthogonal screw, and/or unlocking the reduction units or releasing the threaded rods. Hinges and motors can be added for any necessary deformity corrections in outpatients. Frame removal is usually performed as an outpatient procedure although an anaesthetic may be required, especially if hydroxyapatite screws have been used.





## Case Example

### History

This is a 9 year old girl who was injured in a road traffic accident. She sustained a closed short oblique/spiral fracture of her distal tibia.

### Indications

A Sheffield Ring Fixator was chosen because:

- 1) The fracture was too unstable for closed treatment.
- 2) The fixator would not cause any damage to the growth plate.
- 3) The distal fragment is small.
- 4) Minimal soft tissue damage and advantageous biomechanics would allow early mobility and healing to progress quickly.

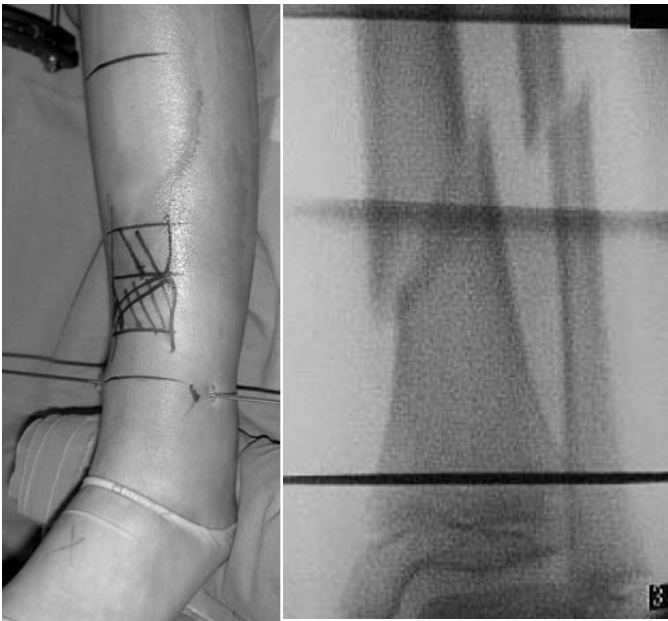
### Pre-operative Planning

A two ring frame was envisaged using hinge clamps to support counter opposed olive wires distant from the fracture. 125 mm rings were chosen and the frame built on a sterile trolley whilst the patient was anaesthetised.

### Metaphyseal Referencing

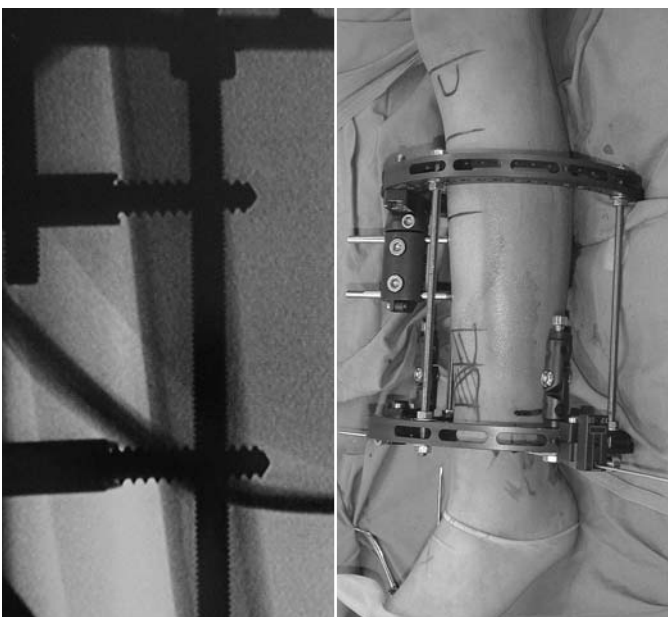
After marking the leg, a smooth coronal plane distal reference wire was inserted.

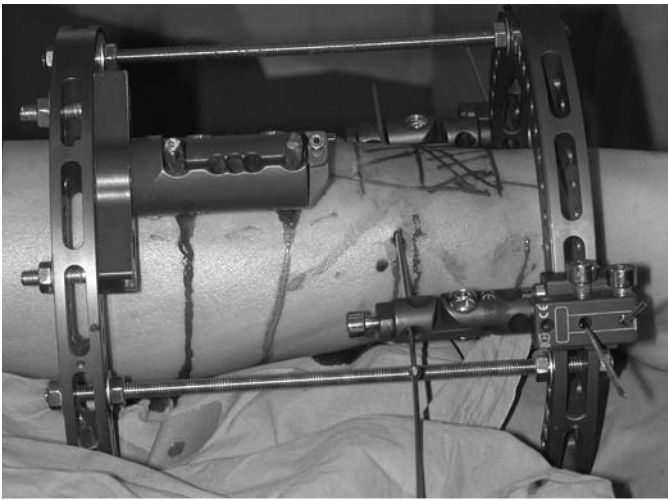
The frame was applied and attached to the reference wire which was tensioned to 1400N.



### Diaphyseal Referencing

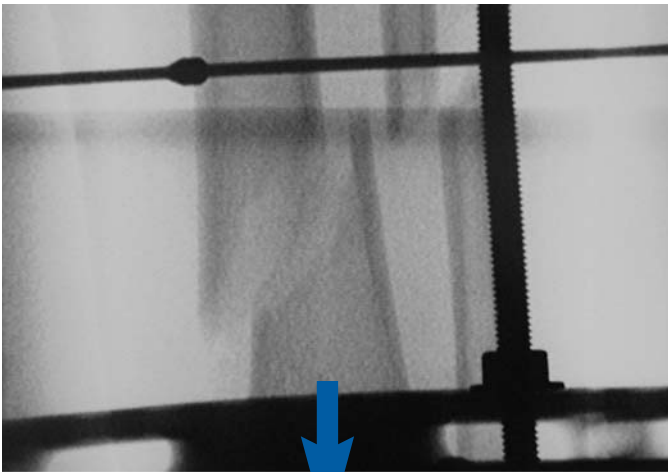
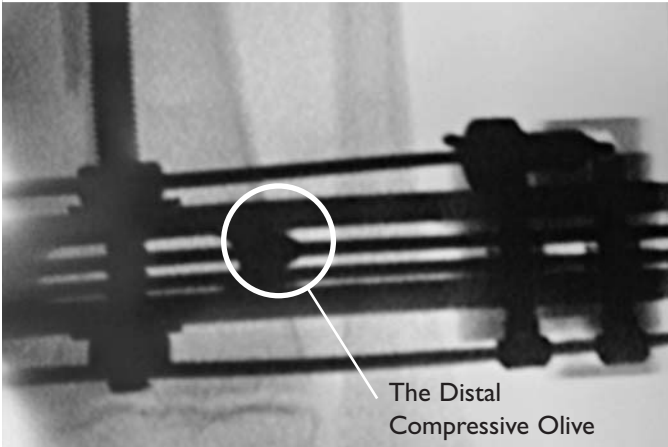
The fracture was reduced using traction and rotation. Two screws were then inserted in the medial face of the bone using the Sheffield Clamp.



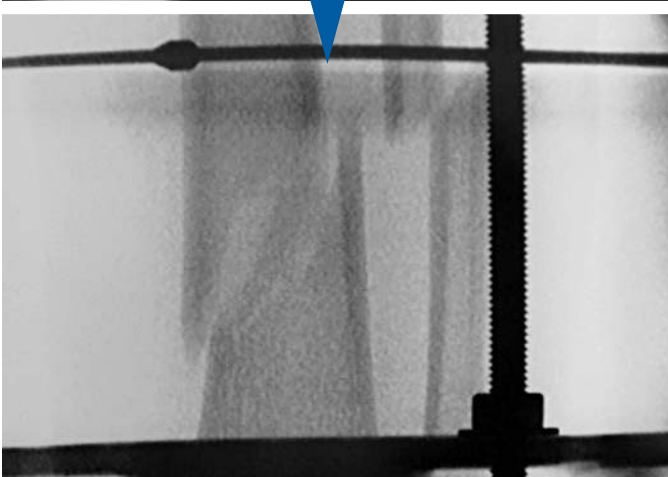


## Additional Fixation and Accurate Reduction

One olive wire was inserted using the hinge clamps, and one using the middle hole on the reference wire clamp.



Using two tensioning tools the olives were then compressed to achieve a final reduction. The wires were locked at the 'olive' end and then tensioned to 600N.



## APPLICATIONS

### Metaphyseal Fixation

To complete the distal fixation, one medial face wire and one transfibular wire were both tensioned to 1400N.

### Diaphyseal Fixation

Due to the light weight of the patient and concern about introducing too many stress risers into such a small bone the orthogonal screw was avoided.



### Post-Operative Course

The child was discharged on day 5 and began weightbearing on day 12.





She soon graduated to walking without crutches. The olive wires were removed in out-patients under local anaesthetic at 7 weeks. The Fixator was removed under general anaesthetic at 10 weeks.

*Follow-up at 7 weeks showing patient weightbearing comfortably.*



*X-rays after fixator removal.*

### C. Tibial plateau fractures

The Sheffield Ring Fixator is particularly indicated for high energy or comminuted Schatzker 4-6 fractures. Simple oblique unstable metaphyseal-diaphyseal segments are well controlled but comminuted fractures which have an angle more than 45 degrees to the shaft may require additional fixation (see p. 18). The fracture configuration is defined pre-operatively using plain and oblique radiographs and CT scans. The patient is placed supine on a radiolucent operating table. The operation is performed under Image Intensifier control and a pre-assembled frame with two 2/3 rings and threaded bars is used, the most common ring size being 175 mm. The fracture is reduced closed by ligamentotaxis, if necessary using distraction applied either with a distractor or an additional femoral ring. Fracture fragments can be manipulated into place with K-wires or tenaculum forceps. Small incisions may be made to assist reduction or to disimpact depressed fragments. Where treatment is delayed beyond two weeks a more formal open reduction may be required. The fracture is usually stabilized with two subchondral interfragmentary screws holding the main fragments; smaller fragments can be fixed with Fragment Fixation Implants. Occasionally a cancellous bone graft is required to support a depressed subchondral bone plate.



The fracture is then neutralized with an external fixator frame with four 2 mm wires to support the plateau.

#### Referencing

- 1) The preconstructed frame is laid over the leg with the proximal ring just below the knee.
- 2) A post is placed in the central hole of the proximal ring and lined up with the tibial tuberosity.
- 3) A proximal metaphyseal reference wire is now inserted. A wire securing pin is placed with the tip facing upwards through the middle hole of the last group of three on the lateral side. The first wire is inserted above the tip of the fibula, exiting anteriorly medial to the patellar tendon, usually above the second slot from the midline of the ring.
- 4) After checking that the fixator is parallel to the limb in the sagittal plane and the anterior reference post is in line with the tibial crest, a second wire is inserted parallel to the first using the wire guide.
- 5) A wire slider unit is slid on to both wires and secured firmly to the ring in the appropriate position.
- 6) Ensuring that the leg is central within the frame, both wires are now tensioned to 1400N.
- 7) The articular block is then reduced provisionally on to the tibia and any metaphyseal-diaphyseal dissociation corrected.
- 8) The base of the Sheffield Clamp is applied directly on to the ring, without intervening washers. The clamp locking screws are loosened and two screw guides inserted in the 1 and 5 seats respectively. The rotation locking screw is released and the clamp rotated so that a trocar in one of the screw guides meets the centre of the diaphysis. If this is not possible, the Sheffield Clamp can be moved by releasing the locking nuts and sliding the clamp, which has slotted holes, or if the distance is too great by moving the whole clamp to an adjacent screw hole on the ring. The screw farthest from the ring is inserted first, after pre-drilling with a 4.8 mm drill bit, and should be placed in the centre of the medial face of the bone, traversing its maximum diameter to the far cortex. A further screw should be inserted in the position on the clamp nearest the ring. The screw guides are removed, screws sites irrigated and screw shafts washed. The clamp cover is tightened first, followed by the rotation locking nut. The frame is now referenced both proximally and distally.

#### Fixation

- 9) One or two medial face wires are inserted from the medial side with the knee flexed, using a wire securing pin with the tip facing distally so that one wire goes through the ring and the other below the ring. With both wires in place they are tensioned to 1400 Newtons.
- 10) Depending on the number and location of wires inserted so far, there should be at least one wire through or adjacent to the fibula tip or head exiting antero-medially to ensure a 60 or 70 degree crossing angle.
- 11) Now a single screw is inserted from the distal ring through a single screw holder, the safest position being in the anterior tibial crest. The single screw holder is attached loosely with the black collar rotated to the template position, with a screw guide and trocar in position, and gently tightened. If the screw guide is pushed down to the bone with the handle perpendicular to the line of the crest, the teeth of the guide will sit firmly on each side, ensuring that the drill bit does not slide off the bone.
- 12) The mechanical axis should now be restored. This is checked under Image Intensifier control using the alignment grid<sup>8,9</sup>.
- 13) Finally all the nuts on the rings are tightened.

The main function of the Sheffield Ring System is to act as a neutralising system, after reduction has been achieved with interfragmentary screws and wires, providing optimal stability.

Where severe comminution is present it is possible to extend the external fixator across the knee, using two bone screws and a Sheffield Clamp attached to a single ring. Two millimetres of distraction may be applied across the knee to protect it and hinge clamps placed at the centre of rotation to permit early protected knee movement. This ring is usually removed after six weeks to avoid knee stiffness and may be disconnected earlier for short periods of physiotherapy.

Post-operative care consists of intravenous antibiotics for 24 hours, passive movement using a continuous passive motion machine and active exercise with the aid of a physiotherapist. The patients are encouraged to mobilise the first day post-operatively and begin weightbearing as early as three weeks.

## Case Example



Schatzker 5 fracture of the left tibial plateau, with CAT scan. Subchondral cannulated screws with a neutralising frame. X-rays after frame removed.

## D. Tibial pilon fractures

The treatment of tibial pilon fractures using the extra-articular approach allows immediate post-operative movement of the joint, and is used routinely for the less comminuted fractures including Rüedi & Allgöwer type II, AO types A & B1.3. More complex fractures, including Rüedi & Allgöwer type III and AO types B3, C2 and C3, may be treated either with the Sheffield Ring System or by a trans-articular approach using the Orthofix Radiolucent Ankle Clamp<sup>10,11</sup>. Pre-operative planning is performed using AP and lateral plain X-rays and CT scans, including axial, coronal and sagittal cuts. The axial cuts are particularly valuable, with the first 2 or 3 slices above the level of the dome of the talus being most important in defining the various articular fragments for reconstruction. The patient is placed on the operating table in the supine position with clear access given to the Image Intensifier. Intra-operative traction may be required and can be provided by an assistant; insertion of a temporary os calcis pin is rarely necessary. Sustained traction intraoperatively can be provided by a distractor or a transarticular fixator, and provides the necessary ligamentotaxis during the procedure. It is often possible to reduce the intra-articular elements of the fracture under Image Intensifier control, using carefully planned small direct incisions and a set of small punches, McDonalds' dissectors and tenaculum forceps. The Fragment Fixation (FFS)<sup>12,13,14,15</sup> Implants can be used both to reduce and fix the bone fragments. The key antero-lateral fragment is usually reduced first; an FFS implant can be used as a joystick to manoeuvre a fragment into place. Tenaculum forceps are useful to control key fragments. It is important to confirm radiologically that any fibular fracture is out to length at this stage. It is not usually necessary to perform open reduction and internal fixation of lateral malleolar fractures, unless the fracture involves the ankle mortise (Refs.<sup>16</sup> and Renzi-Brivio, Personal Communication). Using percutaneous punches, the other fragments are provisionally reduced and stabilized using FFS implants. Through further percutaneous stab incisions one or two cannulated screws or FFS implants are inserted 10-15 mm away from the joint surface, parallel to the joint line, the exact direction of insertion being determined by the results of pre-operative CT axial cuts. When open reduction is required this should also be done through small incisions planned pre-operatively allowing visualisation of the joint through fracture windows.

Skin markings are used to delineate the level of the ankle joint, and outline the lateral malleolus and the postero-medial border of the tibia. The position of the Extensor Hallucis Longus (EHL) tendon is also marked on the skin.

### Referencing

- 1) A two ring frame is pre-built with a Sheffield Clamp attached to the proximal ring on the antero-medial aspect of the tibia. 150 mm 2/3 rings are generally selected, but with large patients or severe swelling, 175 mm rings may be used. The rings are connected by three threaded rods or reduction units. If it is envisaged that the fixation will cross the ankle, the distal ring should be complete.
- 2) The frame is positioned with the distal ring parallel and about 5 mm proximal to the joint surface of the distal tibia.
- 3) A reference post is inserted through the central hole at the front of the proximal ring, and aligned with the anterior tibial crest.
- 4) A wire securing pin is placed on the postero-lateral side of the distal ring and a reference trans-fibular wire with a peripheral olive inserted below the ring, parallel to the joint with Image Intensifier control in the AP plane. It is usually possible to position the wire just proximal to the level of the cannulated screws or FFS wires. The wire should exit antero-medially, medial to the EHL tendon.
- 5) After checking that the fixator is parallel to the limb in the sagittal plane and the anterior reference post is in line with the axis of the distal tibia, a second wire is inserted parallel to the first through the middle of the distal ring using the wire guide.
- 6) A wire slider unit is slid on to both wires and secured firmly to the ring in the appropriate position.
- 7) Ensuring that the leg is central within the frame, both wires are now tensioned to 1400N.
- 8) The articular block is then reduced provisionally on to the tibia and any metaphyseal-diaphyseal dissociation corrected.
- 9) The base of the Sheffield Clamp is applied directly on to the ring anteromedially, without intervening washers. The clamp locking screws are loosened and two screw guides inserted in the 1 and 5 seats respectively. The rotation locking screw is released and the clamp rotated so that a trocar in one of the screw guides meets the centre of the diaphysis. If this is not possible the Sheffield Clamp can be moved by releasing the locking nuts and sliding the clamp on its slotted holes, or if the distance is too great by moving the whole clamp to an adjacent screw hole on the ring. The screw farthest from the ring is inserted first, after pre-drilling with a 4.8 mm drill bit, and should be placed in the centre of the medial face of the bone, traversing its maximum diameter to the far cortex. A further screw should be inserted in the position on the clamp nearest the ring. The screw guides are removed, screws sites irrigated and screw shafts washed. The clamp cover is tightened first, followed by the rotation locking nut. The frame is now referenced both proximally and distally.

### Fixation

10) The second pair of wires is then inserted entering from the postero-medial side, in an antero-lateral direction across the medial tibial face, with the wire securing pin inserted distally, allowing one wire above and one through the ring. This should allow the two wires through the ring to miss one another. This second set of wires exits lateral to or within the peroneus tertius. It is essential to obtain a crossing angle between the two sets of wires of about  $70^\circ$  with the crossing in the centre of the distal tibia. The wires are again located in a wire slider unit and tensioned as above. It is usually possible to guide the wires past any internal fixation in the articular block. In some cases three wires may be sufficient and the fourth wire, normally the one proximal to the distal ring, may not be necessary.

NOTE: Some surgeons prefer to avoid transfixing the fibula since this may limit ankle motion. A satisfactory configuration includes a plain coronal reference wire, a postero-medial to antero-lateral wire and a wire placed behind the fibula exiting antero-medially (personal communication, S. Nayagam).

In severe comminution a further  $2/3$  or foot ring may be used, with hinges at the level of the ankle joint. Post-operatively the patient is given a removable foot support attached to the distal ring to prevent equinus deformity, and active movement of the ankle is encouraged. No more than touch-down weightbearing is allowed for the first three weeks.





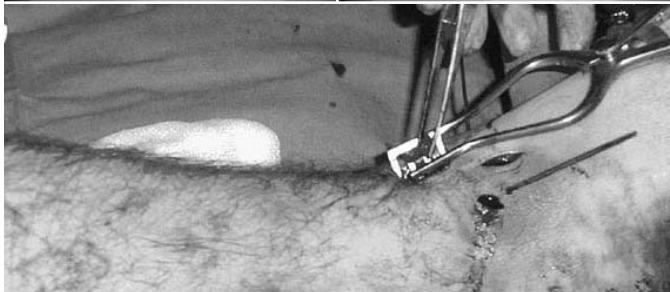
**Case Example**

Comminuted tibial pilon fracture.

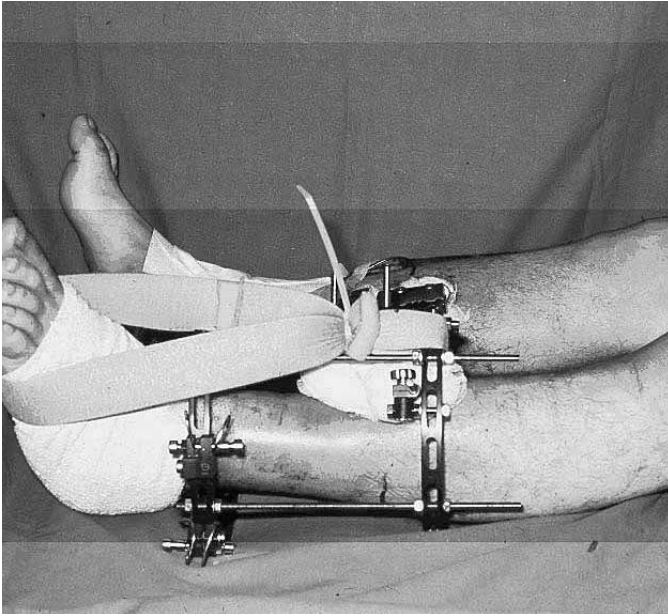


The articular surface is reconstructed with tenaculum forceps and Kirschner wires, prior to the insertion of cannulated screws.

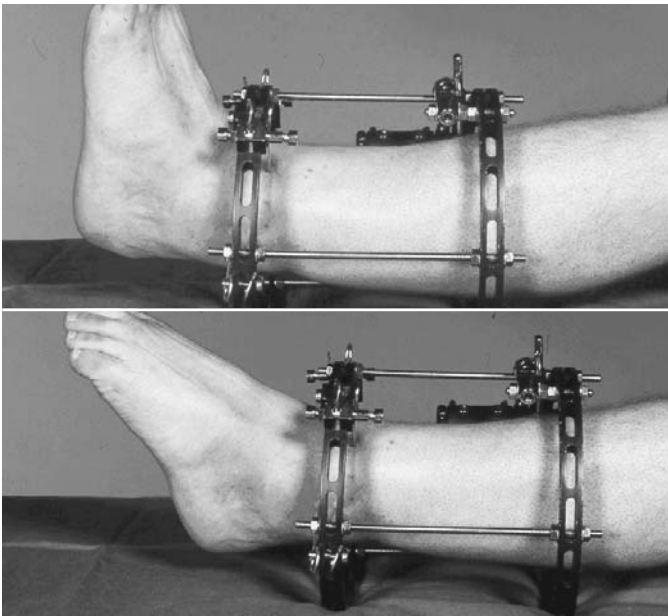
Note the poor condition of the soft tissue in the clinical view.



The articular block of bone is then reattached to the tibia with a three wire frame.



It is usually necessary to support the foot in the initial stages to prevent equinus developing.



Ankle joint movement is encouraged as soon as the soft tissues will allow.  
Full weightbearing is allowed from six weeks.

### 3. LENGTHENING

#### A. Introduction

The Sheffield Ring Fixator (SRF) provides beam loading by fixation with tensioned 2 mm wires, and permits a metaphyseal osteotomy close to the joint, because stable metaphyseal fixation may be achieved in 2.5 cm of bone. Both of these factors lead to broad callus formation. Immediate weightbearing is permitted, and the elastic nature and self-stiffening property of the wires, encourages high patient activity levels and bone maturation. Transfixation of the fibula is performed using transfibular wires in the metaphyseal fixation ring. At the opposite end of the bone, the fibula is temporarily fixed to the tibia with a Kirschner wire or Fragment Fixation System (fibula head) or 3.5 mm unlagged cortical screw (distal fibula). Additional rings may be mounted to cross and protect joints which are unstable or liable to contracture during distraction. Hinge clamps and motors may be applied to correct primary deformity, or residual deformity at the end of lengthening. In the tibia this is usually valgus (approximately 1deg/cm of lengthening) and occasionally posterior angulation. Rings may be used with the LRS for joint protection across knee in femoral lengthening or across the ankle for tibial lengthening. The SRF is indicated in preference to the LRS for longer and complex lengthening<sup>17</sup>.

#### B. Indications

- Limb length discrepancy (LLD) (30% or less) in the tibia
- Short stature
- Shortening with deformity correction (see deformity correction)
- Shortening with unstable joints (see cross joint fixation)

#### C. Frame design

- Proximal metaphyseal (Monofocal) lengthening for LLD - 2 rings
- Bifocal Lengthening for short stature - 3 rings

#### D. Components

##### Monofocal Lengthening

- 2 x 2/3 rings and 2 x 1/3 rings, of the same diameter
- Two wire securing pins; two wire slider units
- 1 Sheffield Clamp
- 1 single screw clamp
- Either: three threaded bars with nuts and washers; three counter nuts
- Or: Six extension plates or six single screw clamps, and three standard or long Compression-Distraction Clicker Units



## Bifocal Lengthening

- 3 x 2/3 rings and 3 x 1/3 rings
- 3 x 400 mm threaded bars, with six sets of nuts and washers
- Six counter nuts
- Four wire securing pins and four wire slider units
- 1 Sheffield Clamp
- 1 Single screw clamp

## E. Proximal tibial lengthening

The fixator is assembled with complete rings and threaded bars in the postero-lateral, postero-medial and antero-lateral positions, leaving the middle holes of the last group of three on the 2/3 ring free. If concomitant deformity correction is required hinges and motors are applied in the appropriate positions (see deformity section).

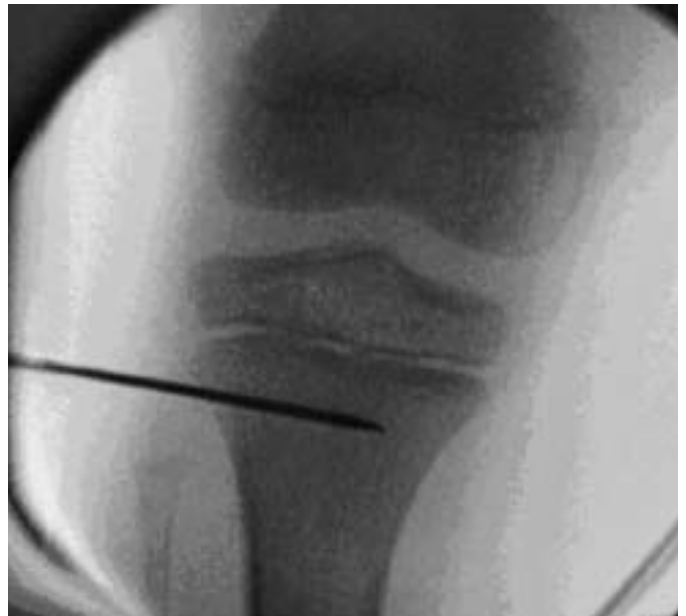
The following landmarks are indicated on the skin: tibial joint line, tibia and fibular epiphyses, tip of the head of the fibula, tibial tuberosity and tibial crest (anatomical axis) and proximal limit of the inferior tibio-fibular joint.

Operative steps are as follows:

- 1) A fibular osteotomy is performed through a 1 cm incision at the junction of the middle and lower thirds, using a 4.8 mm drill bit, carefully positioned drill stop and drill guide and completing it with an osteotome under X-ray control.
- 2) The inferior tibio-fibular joint is fixed with a 3.5 mm unlagged cortical screw.
- 3) A pre-constructed Sheffield Ring Fixator is applied with three 300 mm threaded rods connecting two full rings, allowing sufficient thread outside the diaphyseal ring for the lengthening required. Counter nuts are a valuable aid to the patient. Alternatively 3 Compression-Distraction Clicker Units may be used fixed to the rings with single screw holders or extension plates.

## Referencing

- 4) A reference post or bar is inserted through the central hole at the front of the proximal ring, and aligned with the anterior tibial crest.
- 5) The Image Intensifier is positioned so that the proximal ring is seen as a single bar. It is lined up at right angles (3 degrees varus) to the joint line, so that a wire passing just proximal to the ring is below the epiphysis, or in the mature patient below the joint capsule (15 mm below the joint line). The level of the first wire may also coincide with a point just above the head of the fibula. In the immature skeleton the epiphysis of the fibula is distal to that of the tibia and transfibular wire placement must be between the two epiphyses; if this is not possible, a 2 mm K-wire is inserted into the head of the fibula, to fix it to the tibia.
- 6) A proximal metaphyseal reference wire is now inserted: A wire securing pin is placed with the tip facing upwards through the middle hole of the last group of three on the lateral side. The first wire is inserted above the tip of the fibula, exiting anteriorly medial to the patellar tendon, usually above the second slot from the midline of the ring. After checking that the fixator is parallel to the limb in the sagittal plane and the anterior reference post is in line with the tibial crest, a second wire is inserted parallel to the first using the wire guide.



*Note: Before the epiphyses are fused a coronal plane reference wire may be safer, avoiding both the fibular epiphysis and tibial apophysis. In fibular hemimelia or where an abnormal tibio-fibular relationship exists the wire is inserted with an open technique, to avoid damage to the common peroneal nerve. A 3 cm incision is made with careful dissection down to the bone. The foot is observed for sudden dorsiflexion movement during wire insertion. If the joint is abnormal or hypoplastic, a plain coronal plane reference wire should be inserted first.*

- 7) Ensuring that the leg is central within the frame, the wires are tensioned to 1400N. The flange of the Sheffield Clamp is applied directly on to the ring, without intervening washers. The clamp locking screws are loosened and two screw guides inserted in the 1 and 5 seats respectively. The rotation locking screw is released and the clamp rotated so that a trocar in one of the screw guides meets the centre of the diaphysis. If this is not possible the Sheffield Clamp can be moved by releasing the locking nuts and sliding the clamp on its slotted holes, or if the distance is too great by moving the whole clamp to an adjacent screw hole on the ring. The screw farthest from the ring is inserted first, after pre-drilling with a 4.8 mm drill bit. The screw should be positioned in the centre of the medial face of the bone and traverse its maximum diameter to the far cortex. A further screw should be inserted in the position on the clamp nearest the ring. The screw guides are removed, the screw sites irrigated and screw shafts washed. The clamp cover is tightened first, followed by the rotation locking nut. The frame is now referenced both proximally and distally.

### Fixation

- 8) One or two medial face wires are inserted from the medial side with the knee flexed, using a wire securing pin with the tip facing distally so that one wire goes through the ring and the other below the ring. With both wires in place they are tensioned to 1400 Newtons.
- 9) Depending on the number and location of wires inserted so far, there should be at least one wire through or adjacent to the fibula tip or head exiting antero-medially to ensure a 60 or 70 degree crossing angle.
- 10) Now a single screw is inserted from the distal ring through a single screw clamp, the safest position being in the anterior tibial crest. The single screw clamp is attached loosely with the black collar rotated to the template position, with a screw guide and trocar in position, and gently tightened. If the screw guide is pushed down on to the bone with the handle perpendicular to the line of the crest, the teeth of the guide will sit firmly on each side, ensuring that the drill bit does not slide off the bone.
- 11) After drilling with a 4.8 mm drill bit, using the drill stop and drill guide, a screw is inserted. The clamp bolt is loosened, the drill guide removed and the black collar rotated to the screw position. The screw is irrigated and tightened into position with two spanners.
- 12) The fixator is now firmly secured to the bone, and 2-3 mm of distraction may be applied to all three threaded bars or Compression-Distractor Clicker Units in order to achieve an osteotomy under tension<sup>18</sup>.
- 13) A 3 cm longitudinal antero-medial incision is made, 1 cm distal from the level of the lowermost wire. A self-retaining retractor is applied and the periosteum exposed. Stay sutures are inserted in the anterior and posterior parts of the periosteum and a longitudinal incision made down to the bone. The periosteum is separated with an elevator from the medial and lateral bone surfaces and bone levers inserted to protect the soft tissues during drilling. A 3.2 mm drill bit is inserted into a drill guide and screw guide, and the drill stop adjusted so that just enough of the drill bit is exposed to perform the osteotomy safely. As many holes as possible are drilled in the exposed medial and anterior surfaces, keeping them close together by engaging one of the teeth of the screw guide in the last drilled hole, and proceeding stepwise round the bone. The holes in the medial cortex are connected with a small osteotome. A larger osteotome is used to divide the postero-medial corner; leaving this osteotome in place, another similar osteotome is inserted vertically along the lateral wall of the tibia until the postero-lateral corner is divided. Usually during this manoeuvre the bone gently divides as the posterior wall separates under the effects of the previously applied distraction.
- 14) Complete bone division is confirmed with the triple test, namely ease of distraction, a palpable gap and a radiological gap, which is best seen if the limb is translated during screening.
- 15) The bone gap is closed, and the periosteum and skin sutured.

### F. Bifocal lengthening for short stature

A three-ring frame is built. The steps above are followed except that there is no need to fix the distal tibia with a screw, since it will be fixed by the distal metaphyseal wires. Wires are inserted in the proximal and distal metaphysis followed by a Sheffield Clamp in the middle (diaphyseal) segment. If there is insufficient room for a Sheffield Clamp two single screw clamps may be applied. Proximal and distal osteotomies are performed as described above.

### G. Post-operative care

#### Immediate

The patient is placed on CPM. Knee and ankle exercises are encouraged. The Arterio-Venous Impulse System may be applied for relief of pain and swelling and thrombo-prophylaxis. The foot is supported in the plantigrade position with a support attached to the distal ring.

## Lengthening

Distraction is commenced on the 7-10th day, at a rate of 1/4 mm 4 times per day by turning the counter nut 90° or the clicker unit clockwise by one step. Soft tissue contracture is more frequent with bifocal techniques since lengthening is commenced at 1 mm per day at each site. For bifocal procedures this initial distraction rate is reduced as soon as practical to 3x1/4 mm proximally and 2x1/4 mm distally (the distal site is normally slower to form bone). Even in monofocal cases the lengthening rate is frequently slowed early on according to radiographic appearances, to help avoid joint contractures. Full weightbearing is encouraged as soon as possible and throughout treatment.

If counter nuts are being used for lengthening (see image on page 33), the procedure is as follows. Each counter nut will have a standard nut on the opposite side of the ring. The standard nut is loosened. The counter nut is turned one quarter turn so that the next face of the nut is facing outwards from the ring. This nut is then held in position while the standard nut is tightened again to lock it in place. With the normal amount of lengthening of 1 mm each day, the counter nuts should have the same number of dots on the outwards facing surface when the first lengthening is done each day. To avoid confusion, the three counter nuts should be synchronised at the end of surgery so that the same number of dots is facing outwards on each nut.

## Physiotherapy

For the knee, foot and toes it should be performed daily and pin site care should be carried out according to standard procedure. Follow-up visits with X-rays should be scheduled every 2 weeks until the end of distraction. The fixator connections should be checked every month during distraction or 6 weeks during neutralisation. The rate and rhythm of lengthening is adjusted between 2 and 5 quarters per day according to radiographic appearances and the condition of the soft tissues.

## Neutralisation

When the desired amount of lengthening has been achieved, checked clinically (confirming patient satisfaction), and radiographically<sup>19</sup> (ideally with a Parallel Beam Scanogram), the nuts on the threaded bars are locked securely and the neutralisation period commenced. Weightbearing is encouraged and radiographic follow-up continued until thick cortical outlines are seen on 3 out of 4 cortices on orthogonal radiographs. Normally full consolidation will occur soon after this.

## Dynamisation

In some cases dynamisation may be helpful and is performed:

- either by exchanging the threaded bars for reduction units, and unlocking the body locking nuts
- or by releasing the nuts on the threaded bars on one side of the ring to allow 3-5 mm of axial movement.

## Fixator Removal

The decision to remove the fixator is based on the quality of the regenerate on X-ray and the mobility of adjacent joints. Consolidation may be accelerated by over-lengthening by 5 mm, and then compressing in the neutralisation phase. The fixator is removed either in the out-patient department or under anaesthetic in the operating theatre according to the patient's age and pain tolerance. Usually no form of additional support is required. In cases where part of the callus column is deficient an above knee plaster (proximal tibial lengthening) or cast brace may be applied for 6 weeks.

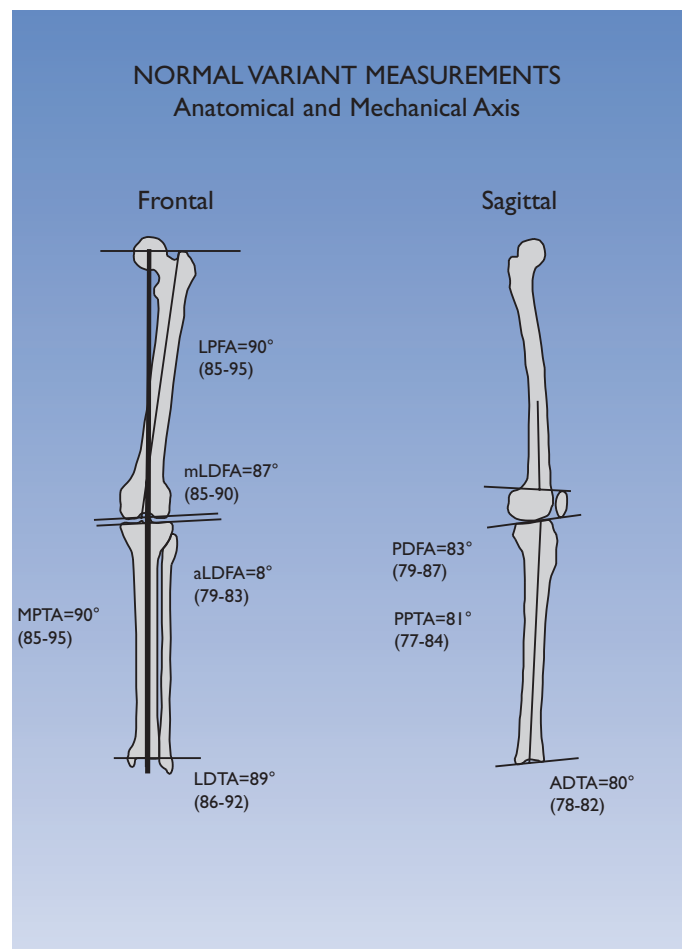
**4. DEFORMITY CORRECTION IN THE LOWER LIMBS (M. OLEKSAK)**

Deformity correction may be required for a bony deformity sufficient to produce a functional deficit, which includes angulation, rotation, translation and shortening; it may also be required for correction of joint malfunction or contracture. Angular deformities may occur in the coronal plane, causing valgus or varus of the affected limb, or in the sagittal plane with a posterior or anterior angulation. A combination of a coronal and sagittal angular deformity at the same level has its maximum angulation in a single oblique plane. Translation of a segment may produce a deformity without angulation, and can occur in both the coronal and sagittal planes. Rotation of a segment around its axis causes a rotational deformity, while shortening presents as a limb length discrepancy clinically. These deformities when they occur singly are termed uniplanar deformities. If one or more other deformities coexist in the same segment, they are termed multiplanar deformities. The site of the deformity may be at the diaphysis, metaphysis or at the level of the joint, and may be either unifocal, or multifocal if there is a deformity at more than one level in the same segment of bone.

Radiographic evaluation of the limb includes views of the segment in two planes at right angles to each other (AP and Lateral) and a mechanical axis view of both lower limbs, the latter being achieved with a weight bearing parallel beam scanogram<sup>19</sup>. These radiographs allow accurate preoperative planning to be performed using both anatomical and mechanical axes. Attention to detail is essential when taking the weightbearing long leg views to ensure that both knees are extended maximally and the patellae are pointing forwards. Blocks are placed under the shorter leg to maintain a level pelvis. Rotational deformities are assessed clinically using Staheli's rotational profile or by using computerised tomography. The preoperative plan is transferred to the deformed segment of bone with relevant skin markings on the leg to achieve optimal surgical correction in all planes of the deformity.

**A. Pre-operative planning**

The anatomical and mechanical axes are assessed using a bilateral long leg view and lateral radiographs of the affected limb. The malalignment and malorientation tests are performed as described by Paley and Tetsworth<sup>20,21</sup>. The femoral mechanical axis is the line between the centre of the femoral head to the centre of the knee joint and differs from the anatomical axis in the femur which is the mid-diaphyseal line. The tibial mechanical axis is a line drawn from the centre of the tibial plafond to the centre of the knee joint, which usually corresponds to the mid-diaphyseal anatomical axis in the tibia. The angle at the intersection of the tibial and femoral mechanical axes at the knee joint gives the magnitude of any deformity present at the femur or tibia. The angle between the femoral and tibial mechanical axis lines and their respective joint orientation lines (Lateral Distal Femoral Angle-LDFA and Medial Proximal Tibial Angle-MPTA) identify the segment responsible for the deformity. The normal LDFA and MPTA are 85 to 90 degrees, so a value outside the mean identifies the segment responsible for the deformity. A normal LDFA and an abnormal MPTA is present in a tibial deformity, whereas a femoral deformity should have a normal MPTA and an abnormal LDFA. If both values are abnormal, deformities exist in both segments in the coronal plane.



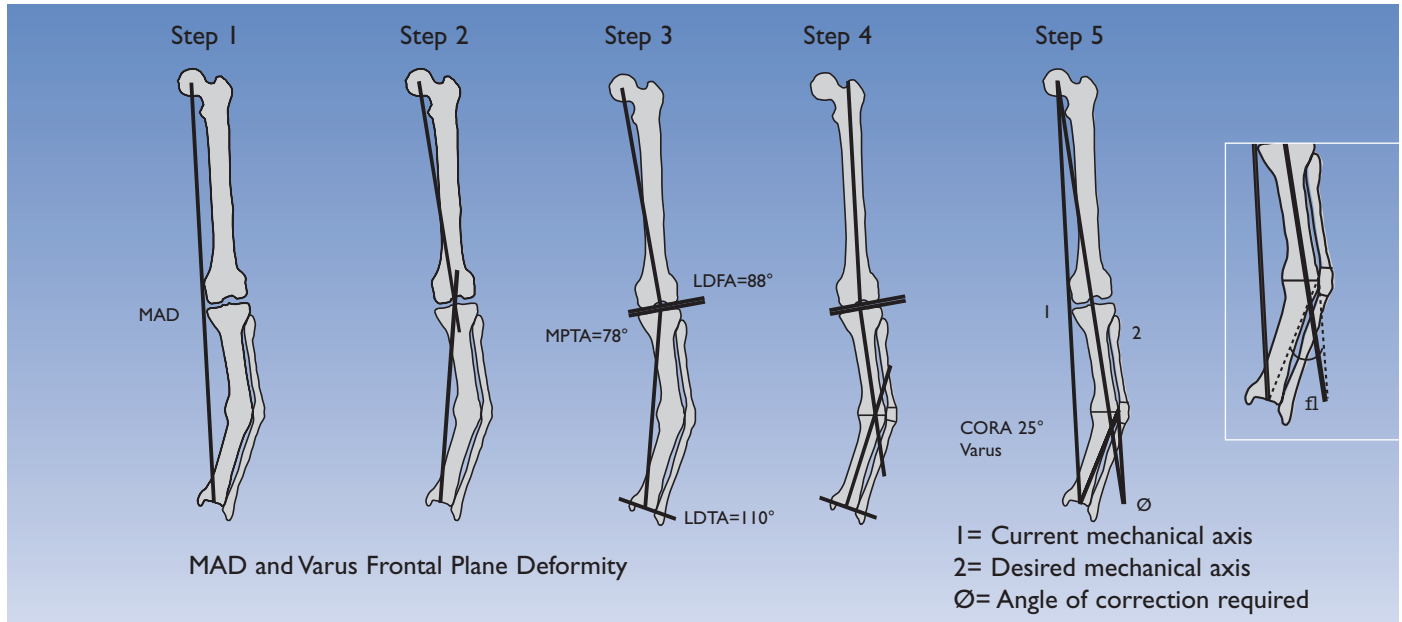
Paley and Tetsworth<sup>20,21</sup>

A line drawn from the centre of the femoral head to the centre of the tibial plafond should pass through the centre of the knee joint on a long leg view.

If it does not, there is a Mechanical Axis Deviation (MAD).

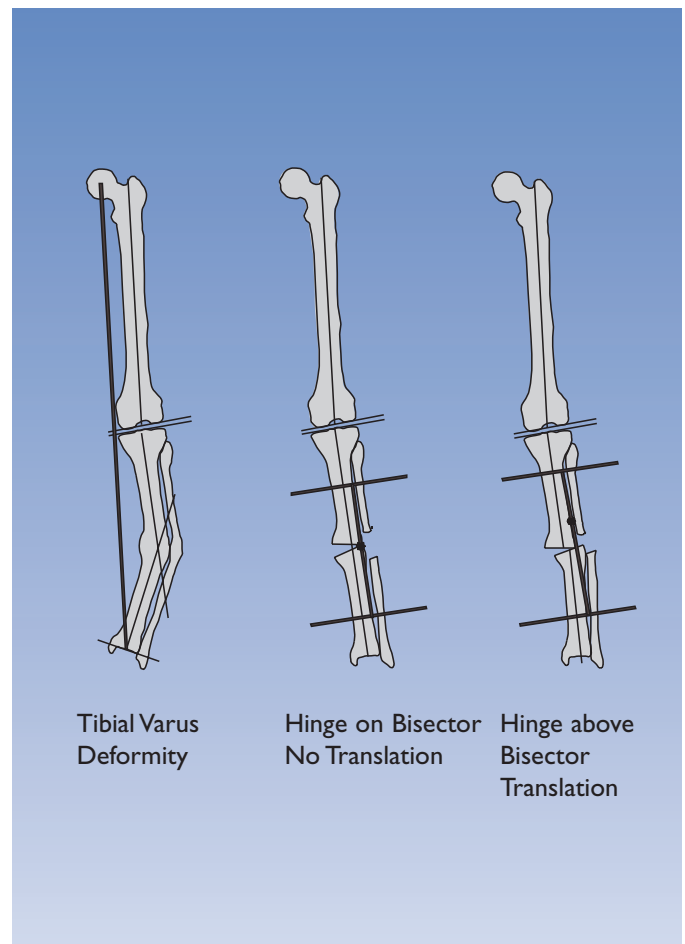
The anatomical axes of both the femur and tibia are their mid-diaphyseal lines. A bony deformity would thus have a proximal and a distal anatomical axis intersecting at the centre of rotation of angulation (CORA). Deformities at diaphyseal level are identified by the anatomical axis intersections, but at metaphyseal or joint level it becomes necessary to make use of the relevant joint orientation angles at the knee joint (LDFA and MPTA), ankle joint (Lateral Distal Tibial Angle-LDTA) or proximal femur to the mechanical and anatomical axes. These values can be obtained from a normal equivalent contralateral side, or if the contralateral joint shaft relationship is abnormal, an average is used to draw the relevant juxta articular mechanical axis.

Equally, a deformity can be identified by intersecting the anatomical axes in the sagittal plane and establishing a joint orientation angle at the proximal and distal tibia using anatomical axes i.e. Proximal Posterior Tibial Angle (PPTA) and the Anterior Distal Tibial Angle (ADTA). In juxta-articular deformities of the sagittal plane, these angles can be used to draw the distal or proximal anatomical axis.



**Hinge and Osteotomy Placement**

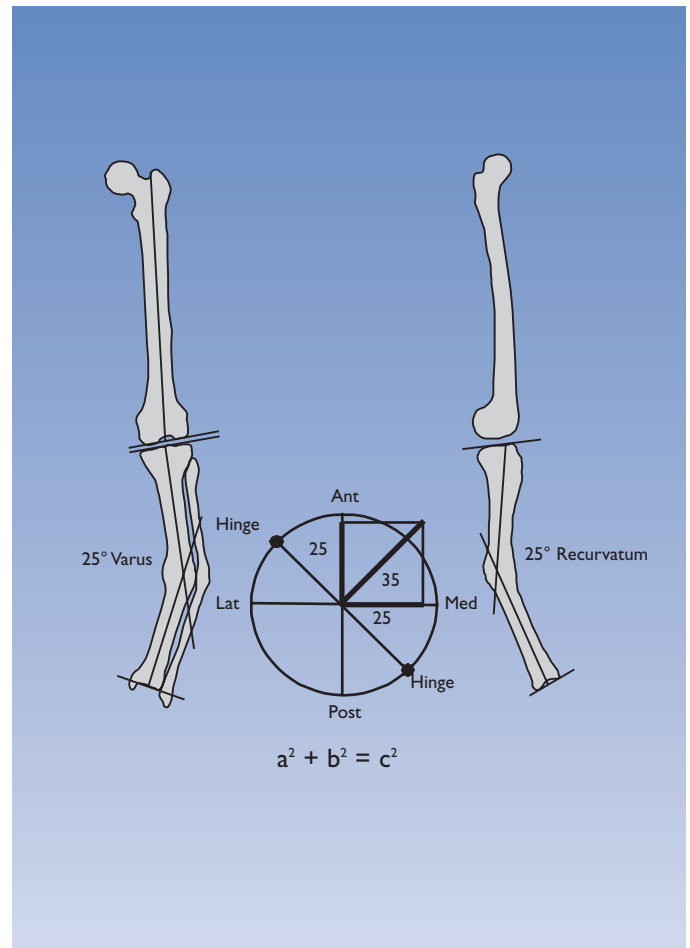
Once the deformities and the relevant CORA's have been defined, planning of osteotomies follows. A bisector line at the CORA identifies the level of ideal hinge placement options. The axis of angulation and ideal hinge placement is perpendicular to the plane of the deformity. Moving the hinge along the bisector lines produces different effects. Thus a hinge at the convex cortex of the osteotomy leads to an opening wedge, whereas the hinge at the concave cortex creates a closing wedge. A hinge placed between the cortices at the centre of the deformity on the bisector line leads to a part closing and part opening wedge or a central wedge, whereas a hinge placed outside the convex cortex of the deformity on the bisector line leads to an opening wedge plus lengthening at both cortices. If hinge placements remain on the bisector line, correction will occur without any translation. If the hinges are placed above or below the bisector line correction occurs with a translation effect and the further away the hinge is situated from the osteotomy site the more translation will occur.





**Oblique Plane Deformities**

Deformities with coronal and sagittal components have the maximum angulation in the oblique plane; with circular frame designs, hinges are positioned precisely with their axis perpendicular to the oblique plane of the deformity. The values of the coronal and sagittal deformities are plotted on a graph overlying the ring; by using Pythagorean vectors, the resultant of the two values determines the magnitude of the deformity in the oblique plane. The hinges are placed on the ring at right angles to the plane of the deformity, and the motor correcting the deformity is placed at a position on the ring crossed by the resultant.



The 25° varus deformity combined with a 25° recurvatum deformity resolved into a 35° deformity in the oblique plane.

**B. Progressive correction of tibial deformities**

Uniplanar deformities of the tibia in the coronal, sagittal and oblique planes are corrected with progressive distraction techniques by placing the hinge axis strategically at the apex of the deformity as defined by the CORA using the Sheffield Ring Fixator. Ideally the osteotomy, CORA and hinges should be at the same level, but occasionally some translational deformities are amenable to correction by siting the hinge above or below the CORA. Translation and rotational deformities can also be corrected with translation/rotation hinges attached to the rings, which progressively realign the deformity. At the end of correction, if length is required, length gain by callotasis is obtained with gradual lengthening. If any soft tissue or joint contractures are impeding the rehabilitation process, gradual correction occasionally aided with soft tissue release is performed by including the joint segments in the frame design.

## Model Example of Progressive Correction of Angulation

### Frame Design

- 2x full Rings
- 2x Threaded Bars with Hinges
- 1x Threaded Bar Motor or Compression-Distractor Clicker Unit Motor

### Components

- 2x 2/3 Rings
- 2x 1/3 Rings
- 5x Threaded Bars
- 4x Hinge Clamps
- 15x Nuts
- 2x Counter Nuts
- 16x Washers
- 2x Extension Plates
- 1x Compression-Distractor Clicker Unit

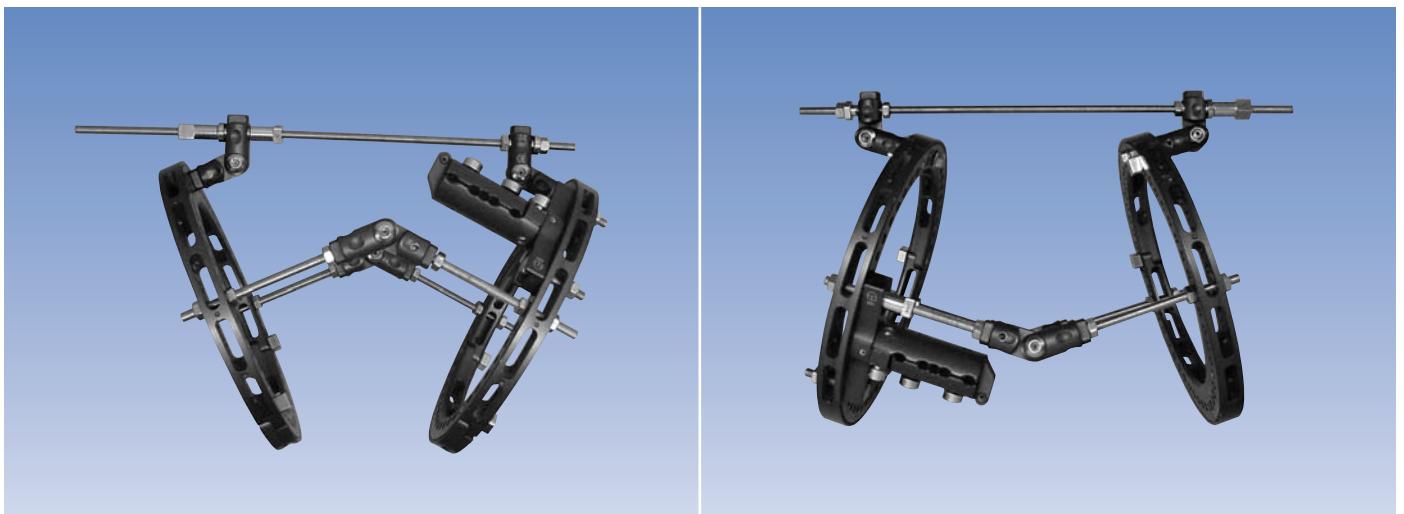
### Fixator Construction (Diaphyseal or Metaphyseal)

Two full rings are assembled. One is used as a template, and laid over the pre-operative plan to determine the hinge and motor positions. Since there are 48 holes in the rings there are 7 H degrees between each two holes. Avoiding the holes required for the hinges and motors, three temporary 200 or 300 mm threaded bars are inserted, to fix the rings in relationship to each other. The hinges and motors may now be applied. The position of the hinges and motors on the circumference of the ring, i.e. the ring holes, is identified, and the position of the hinge calculated by identifying the CORA. A motor should be positioned at 90 degrees to the hinge axis, and may be on either side, in compressing or distracting modes. The positioning of motors in the medial or posterior quadrants should be avoided for patient comfort.

The position of each component in relation to the ring holes must be determined but also the position of the hinge in relation to the top or bottom ring. The CORA is described in mm from the joint surface so that the ring is positioned in a constant relationship to the joint line. The position of the hinge with respect to the ring may be calculated. The minimum distance from the tibial plateau joint surface to the bottom of the ring should be 35 mm, if a wire is used above the ring, to prevent capsular penetration and allow for the thickness of the ring.

The outer aspect of the metaphyseal ring must be 16-20 mm from the tibial joint line at the knee and at least 5 mm from the ankle joint line. Two hinges are selected, making sure to position the hinge locking screw hexagons outwards, and the locking screws and screw sleeves are removed. An appropriate length threaded bar is inserted into each side of the hinges and secured with a nut and washer. They are now applied to the rings, and locked into place with a nut and washer at each end, using predetermined hole positions.

The motor is constructed by taking two hinges and removing the end screws. The wire clamp end is connected to the appropriate ring hole on each ring. The hinges are turned through a 90 degree angle away from the centre of the ring. A threaded bar long enough to pass through both hinges with the rings parallel, is inserted through each of two screw sleeves with nuts and washers on each side, one being a Counter Nut. Using a distracting motor the hinges should be on the inner aspect of the frame, and with a compressing motor on the outside of the frame, to avoid threaded bar impingement.



For deformity correction the motor hinge clamps may be placed on the inner or outer aspects of the frame, to avoid risk of the bar impinging on a ring.

The three temporary bars are removed, and the hinge orientation adjusted until smooth movement is achieved between both rings. The hinges are then locked by tightening the nuts at the angle determined from the pre-operative plan, which reflects the degree of the deformity.

In the most frequently used ring sizes the Sheffield Clamp occupies 7 holes, usually antero-medially. Hinge placement should not be compromised and different options for Sheffield Clamp placement may need to be considered.

### **Action Required if the Ideal Hinge Position is Blocked by the Position of the Sheffield Clamp**

- a) If one of the outer two holes covered by the clamp is required for hinge placement, the bolt can be replaced by a threaded bar with a counter nut, which is used to lock the Sheffield Clamp to the ring. The hinge can then be positioned at the correct level.
- b) If the hinge position lies over one of the four inner holes, the clamp can usually be moved so that the option above with the threaded bar and counter nut is available. Because the clamp can be rotated, diaphyseal screw position should not be compromised.
- c) If the ideal hinge position is over the central hole covered by the Sheffield Clamp, it is better to move the clamp to an anterior position, with a single orthogonal screw medially from an independent screw clamp.

### **Selection of Ring Size**

For small angulations, select a ring in the normal way. For angulations of more than 25 degrees, select a ring one size larger than would normally be needed.

### **Operative Technique**

- 1) Fibular osteotomy: If a fibular osteotomy is required it should be done first by dividing the fibula at the junction of the middle and lower thirds, using a 4.8 mm drill bit with a drill guide, completing the osteotomy with an osteotome under X-ray control.

### **Référencement et position de charnière**

- 2) Skin marking: the joint line, anatomical axis, CORA and postero-medial edge of the tibia are identified. The frame is applied over the leg, which is suspended in the middle of the rings with rolled up towels or a kidney dish under the knee and heel.
- 3) A long threaded post is inserted temporarily in the antero-central hole and centred over the tibial tuberosity. If the joint line is clearly identifiable a transfibular reference wire is inserted in the coronal plane, at least 15 mm from the proximal joint line, or 5 mm from the distal joint line.
- 4) The Image Intensifier is adjusted so that the proximal ring is seen as a single bar. It is lined up at right angles (3 degrees varus) to the joint line so that a wire passing just proximal to the ring is below the epiphysis, or in the mature patient, below the joint capsule (15-20 mm below the joint line). The level of this wire should also be just above the head of the fibula. In the immature skeleton the epiphysis of the fibula is proximal to that of the tibia and transfibular wire placement may not be possible. In such a case a 2 mm K-wire is inserted into the head of the fibula, transfixing it to the tibia.
- 5) A proximal metaphyseal reference wire is inserted into a wire securing pin, placed so that the tip is facing upwards through the middle hole of the last group of three. The first wire is inserted above the tip of the fibula exiting through the anterior surface of the tibia, antero-medial to the patellar tendon. The fixator should be parallel to the limb in the sagittal plane with the reference post anterior. A second wire is inserted parallel to the first using the wire guide. It should exit through the second slot from the midline of the ring.

*Note: In the immature patient, coronal plane fixation may be safer if fibular hemimelia or an abnormal tibiofibular relationship exists. The wire is inserted open, watching for twitching of the foot. If the joint line is difficult to discern, a freehand plain wire should be used.*

- 6) Before these wires are fixed to the ring and tensioned, the position of the hinges is checked. The wires are then tensioned to 1400N.
- 7) Checking that the leg is central within the fixator, two cortical Hydroxyapatite-coated screws are inserted through the centre of the diaphysis, as follows: The Sheffield Clamp rotation screw is released; the base of the clamp is applied directly to the ring so that the clamp is at right angles to the medial face of the tibia. Two screw guides are inserted in seats 1 and 5, rotating the screw guide so that a trocar meets the centre of the diaphysis. If it does not, the Sheffield Clamp is repositioned by releasing the locking nuts and sliding the clamp on its slotted holes, or if the distance is too great, moving the whole clamp to an adjacent screw hole on the ring. The screw furthest from the ring is inserted first.
- 8) When the screws are in place the Sheffield Clamp is opened, the screw guides removed, and the screw sites thoroughly irrigated. The leg is carefully positioned in the centre of the ring, and the clamp and rotational locking screw locked.

## Fixation

- 9) The two medial face wires are inserted from the medial side with the knee flexed. Insert a wire securing pin with the tip facing distally so that one wire goes through the ring and the other below the ring. With both wires in position they are tensioned to 1400 Newtons. *Note: If one or two coronal plane wires are used, an additional wire may be inserted from postero-lateral to antero-medial to ensure a 60 or 70 degree crossing angle.*
- 10) A single screw is inserted from the distal ring through a single screw clamp, the safest position being in the anterior tibial crest. The single screw clamp is attached loosely with the black collar rotated to the “template” position, with a screw guide and trocar in position, and gently tightened. If the screw guide is pushed down on to the bone with the handle perpendicular to the line of the crest, the teeth of the guide will sit firmly on each side, ensuring that the drill bit does not slide off the bone.
- 11) After drilling with a 4.8 mm drill bit and drill stop, the required screw is inserted, usually 110/40 or 130/40. The clamp bolt is loosened, the screw guide removed and the black collar rotated to the “screw” position. The screw is irrigated and tightened in position with two spanners.
- 12) The fixator is now firmly secured to the bone and should fit the shape of the particular deformity. 3-5 mm of distraction may be applied to all three bars in order to achieve an osteotomy under tension<sup>18</sup>.
- 13) A 3 cm longitudinal antero-medial incision is made, 1 cm distal from the level of the lowermost wire. A self-retaining retractor is applied and the periosteum exposed. Stay sutures are inserted in the anterior and posterior parts of the periosteum and a longitudinal incision made down to the bone. The periosteum is separated with an elevator from the medial and lateral bone surfaces and bone levers inserted to protect the soft tissues during drilling. A 3.2 mm drill bit is inserted into a drill guide and screw guide, and the drill stop adjusted so that just enough of the drill bit is exposed to perform the osteotomy safely. As many holes as possible are drilled in the exposed medial and anterior surfaces, keeping them close together by engaging one of the teeth of the screw guide in the last drilled hole, and proceeding stepwise round the bone. The holes in the medial cortex are connected with a small osteotome. A larger osteotome is used to divide the postero-medial corner; leaving this osteotome in place, another similar osteotome is inserted vertically along the lateral wall of the tibia until the postero-lateral corner is divided. Usually during this manoeuvre the bone gently divides as the posterior wall separates under the effects of the previously applied distraction.
- 14) Complete bone division is confirmed with the triple test, namely ease of distraction, a palpable gap and a radiological gap, which is best seen if the limb is translated during screening.
- 15) The gap is then closed by compressing the bone ends by tightening the threaded bars; the periosteum is sutured separately before the usual skin closure.

## Post-operative Care

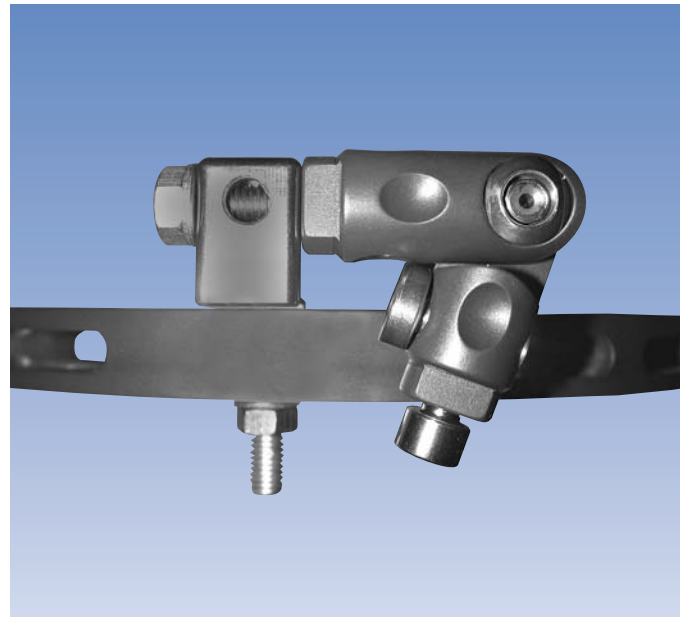
The same protocol is carried out as for lengthening (pages 35-36).

Correction of the deformity commences usually on day 8-10 by loosening the relevant hinges, and by gradually compressing or distracting the motor. Occasionally it is necessary to obtain some initial clearance at the osteotomy site by distracting the motor and both hinges simultaneously for a week, before commencing with deformity correction. Follow-up visits should be scheduled every 2 weeks initially with radiographic and clinical evaluation. Once the deformity correction has been completed, it is assessed radiographically with a parallel beam scanogram<sup>19</sup>. Clinically the rings should end up parallel to each other at the end of correction. The nuts on the threaded bars are locked securely and the neutralisation period is commenced.

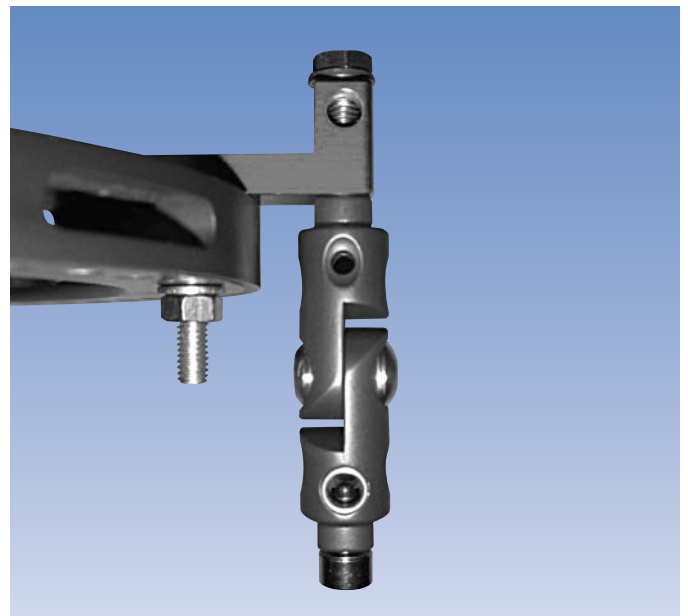
The details of the management of the remaining phases of treatment are the same as for lengthening.

## Different Options

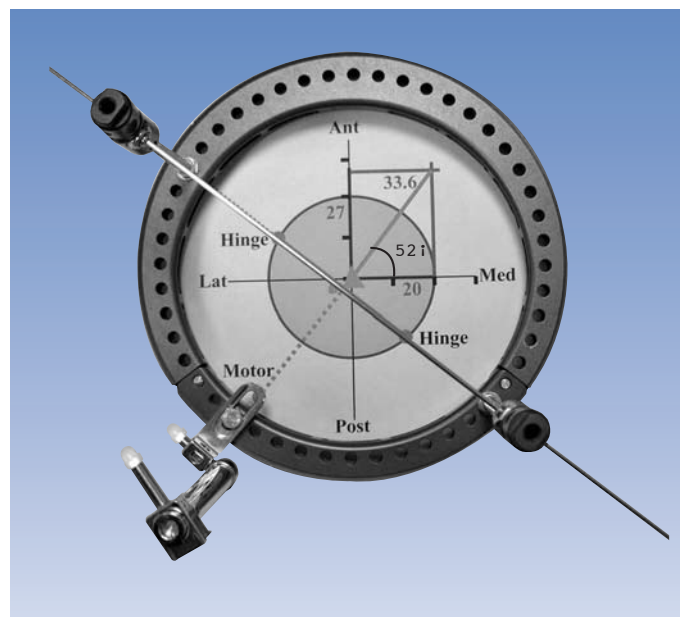
1) Juxta-articular frame constructs for intra articular and juxta-articular deformity correction with the extension plate. Deformity close to the joint is commonly seen in arthritis, or growth plate injuries such as Blount's disease.



The distance from the ring can be varied by changing the way the extension plate is used. Compare this configuration with the one shown above.



2) **Oblique plane correction:** Laying the ring over a drawing of the deformity can define the holes to be used for the hinges and motor.  
**Tibial mechanical axis planning:** This is a graph of a deformity in an antero-medial oblique plane, consisting of 27 degrees of antecurvatum and 20 degrees of valgus. This resolves into a deformity of 33.6 degrees in a single antero-medial plane, 52 degrees anterior to the coronal plane.



## 5. CROSS JOINT AND FOOT FIXATION

Cross Joint fixation is indicated where knee or ankle stabilisation is required during limb lengthening, and where a second level of fixation is required for a low tibial or femoral non-union. It is also indicated for severe tibial plateau or pilon fractures. It may be used for arthrodesis, contracture correction (for example a flexion deformity of the knee or equinovarus foot) and articulated distraction of the ankle.

Additional rings are required, and hinge clamps are used to facilitate contracture correction or for articulation, when they should be placed at the centre of rotation of the joint.

When crossing the knee from the tibia, for example for an unstable tibial plateau fracture, the femoral ring is normally fixed with a Sheffield Clamp and two lateral screws. In distal femoral fixation with an LRS or SRF, a ring may be fixed in the proximal tibial metaphysis with wires or mid-diaphysis with a Sheffield Clamp and screws.

Hinge placement in the distal femur for articulation of the knee is posterior to the midline in the sagittal plane, at the level of the adductor tubercle. Correct placement is confirmed by flexing the knee. Wires may be used to support the distal femoral ring, but transfixion of gliding tissues in the shortened position must be avoided.

At the ankle, for example for a difficult pilon fracture, a complete distal tibial ring is used, with a foot ring to hold the hindfoot and forefoot. Midfoot fixation is achieved with two wires crossing at 45 degrees in the os calcis. Forefoot fixation is achieved with 1 or 2 wires; additional wires, or wires with a central olive, may be used to increase stability. The hinge clamp is positioned with the centre of the hinge aligned with the sinus tarsi, with the lateral hinge slightly behind the medial one reflecting a 10 deg external rotation of the ankle. A talar wire may be required to protect the ankle in contracture correction or for differential distraction of the ankle and subtalar joint. The talar wire is placed slightly anteriorly in the head of the bone to avoid the fibula and neuro-vascular structures. The frame may be applied to fuse the ankle and subtalar joints, for triple fusion and foot contracture. In most instances a foot ring is selected; however where correction of the midfoot is required with respect to the hindfoot, two 2/3 rings are selected. Hinges, threaded bars and extension plates may be used to connect the hindfoot and forefoot rings. Where wires are placed in the forefoot using the foot ring, the technique is described below. However, when 2/3 rings are used, the ring is applied perpendicular to the foot and wires may be inserted using wire securing pins and wire slider clamps. Occasionally, an olive wire inserted from the medial side is required to prevent metatarsus adductus.

The 81500 Foot Ring can be used directly with a 150 mm ring, or connected to larger rings with extension plates or translation/rotation hinges. The Foot Ring can be used for procedures involving the foot which include fractures, arthrodesis, deformity correction, and correction of joint contractures.

### A. Frame assembly

The Foot Ring is positioned around the foot with the open end toward the toes, and can be connected to other rings with threaded rods placed through the holes in the posterior half of the ring. The rings are secured to the threaded rods with nuts and washers. At least three threaded rods should be used, spread as far apart as possible to maximise frame stability. Two rods with hinges may be used to permit ankle movement. Care should be taken to maintain equal distance between the rings to ensure that they remain parallel. The front of the ring may be connected to the front of the tibial ring for additional stability.

### B. Wire placement

For wires in the hindfoot, the Two-Hole Securing Pins and the Three-Hole Wire Slider Units can be used to form a crossed wire configuration. In this case, a Lateral Olive Wire must be used and inserted from anterior to posterior through the Two-Hole Securing Pin. Care should be taken to avoid neurovascular structures. Talar wires should be placed above the neurovascular bundle and calcaneal wires below it.

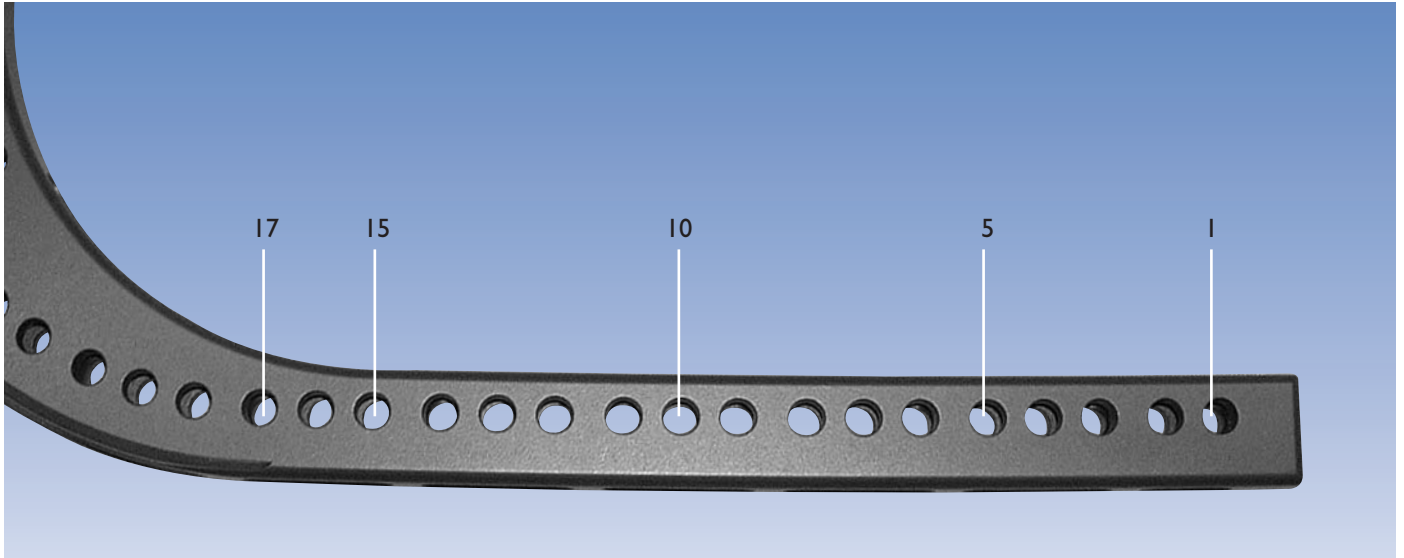
For wires in the mid-foot or forefoot, independent wire fixation should be used along the two straight arms of the Foot Ring on either side of the foot, using angled wires in hinge clamps or slotted washers.

**C. Wire tensioning**

Because the foot ring has an open end with long arms extending along either side of the foot, the maximum tension possible on the wires in the forefoot and mid-foot is less than for a normal ring.

For additional stability, the two ends of the Foot Ring can be connected by a bridge of a 6 mm rod crossing over the toes, anchored on either side with a Supplementary Screw Clamp and Post, or a single screw clamp, or a hinge clamp.

Generally, hindfoot wires are tensioned to 800-1000N, and forefoot wires to 600N.



Using the hole numbering shown in the image below, i.e. with hole No. 1 at the end of each arm, maximum wire tensions should be as follows:

Holes 1 - 3: 500N

Holes 4 - 7: 700N

Holes 8 - 11: 1000N

Holes 11 - 17: 1200N

Beyond hole 17: as normal ring.

If the open end of the Foot Ring is reinforced as described above, tensions can be greater than detailed here.

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- CN-0703-OPT The Centronail Titanium Supracondylar and  
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