PRINCIPLES OF EXTERNAL FIXATION

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Credit Statement

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- Watson JT. Principles of External Fixation. In: Tornetta P, Ricci WM, eds. Rockwood and Green's Fractures in Adults, 9e. Philadelphia, PA. Wolters Kluwer Health, Inc; 2019

- Journal of Orthopaedic Trauma

Objectives

- **Historical Perspective**
- **Indications**
- **Frame Types and Components**
- **Mechanics**
- **MRI Compatibility**
- **Biology**
- **Complications**

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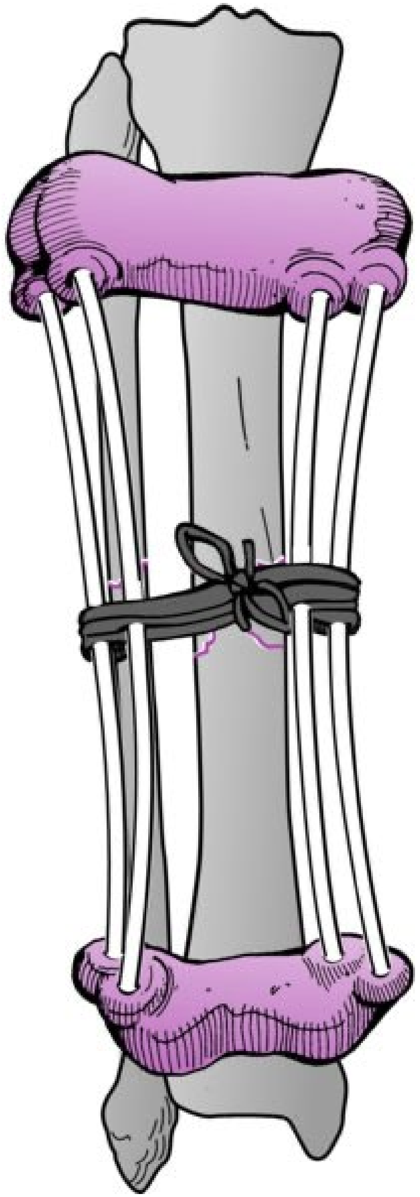
Historical Perspective

- Hippocrates 2400 years ago
  - Shackle external device for maintaining tibia fracture at length
  - Four flexible rods, made of the cornel tree (European dogwood) of equal length
  - Leather wraps on proximal and distal tibia
  - Allowed inspection of soft tissue injury



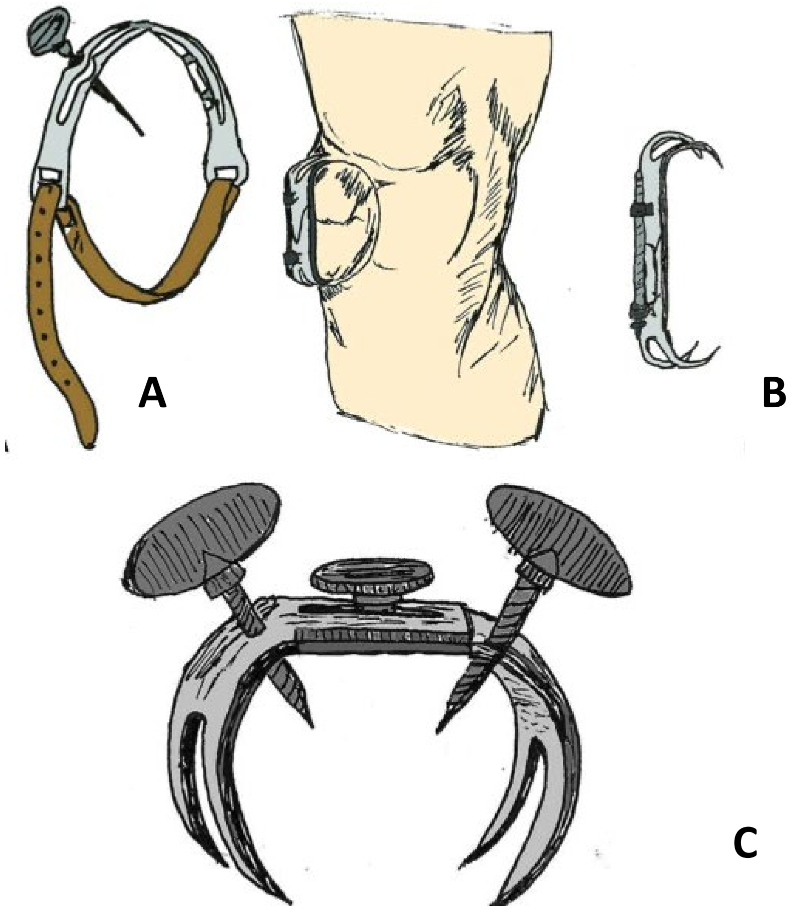
Historical Perspective

- Malgaigne's 1843

  A point metalliqué

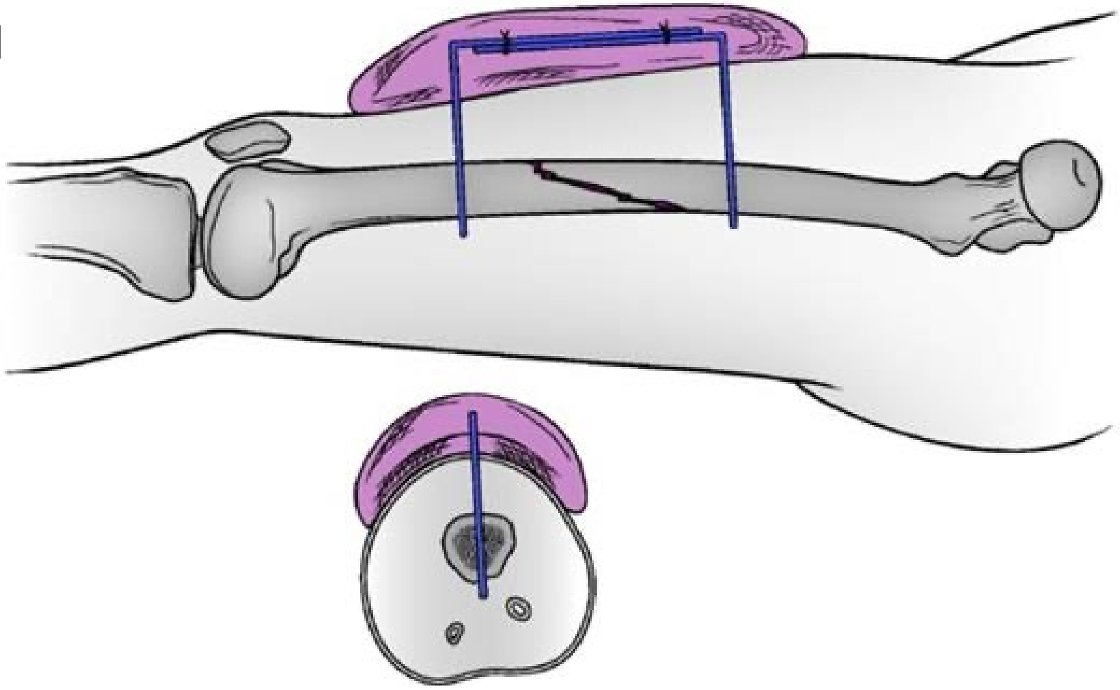
  B griffe metalliqué or metal claw

  C Chassin’s modification of claw for
  Clavicle fixation 1852



Historical Perspective - Monolateral External Fixation

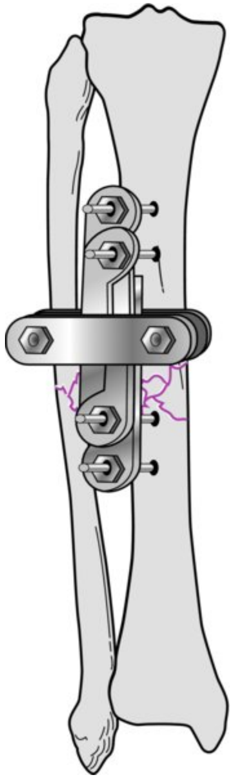
- British surgeon Keetley 1893
  - Implanted pins connected with twists of wire
  - Covered with Iodoform gauze



Historical Perspective - Monolateral External Fixation

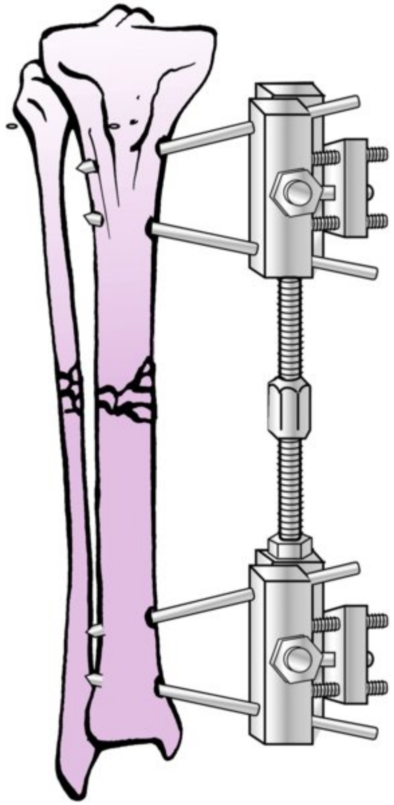
Parkhill 1897

Silver coated threaded Pins to prevent infection



Otto Stader 1937

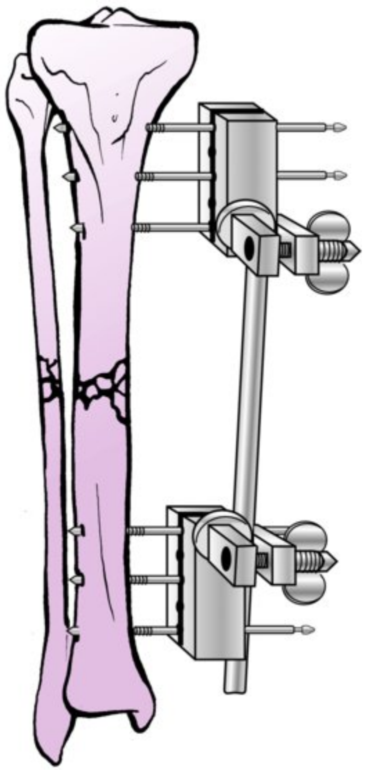
- Pins widely spread
- Pins at an angle



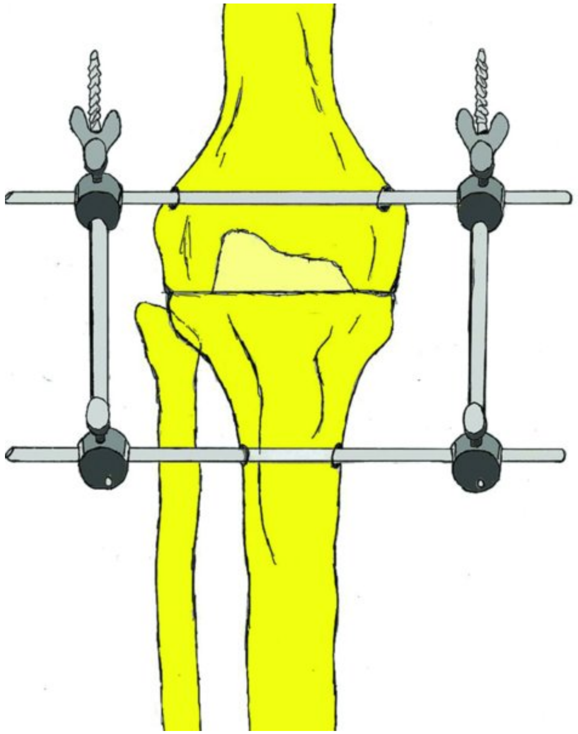
Historical Perspective - Monolateral External Fixation

Raul Hoffmann 1938

- Universal Ball Joint
- Fracture reduction in 3 planes
- Inter fragmentary compression
- Limb length restoration



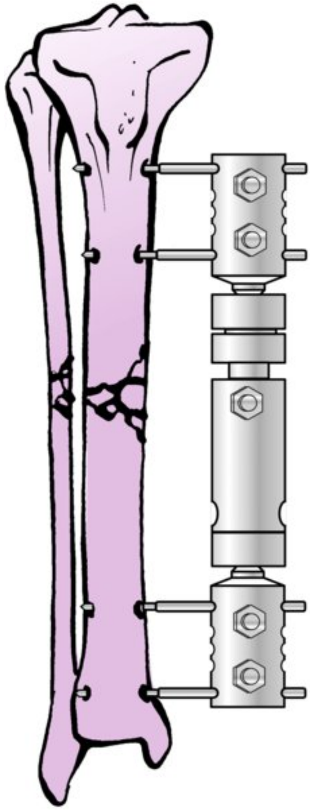
Charnley's Compression fixator



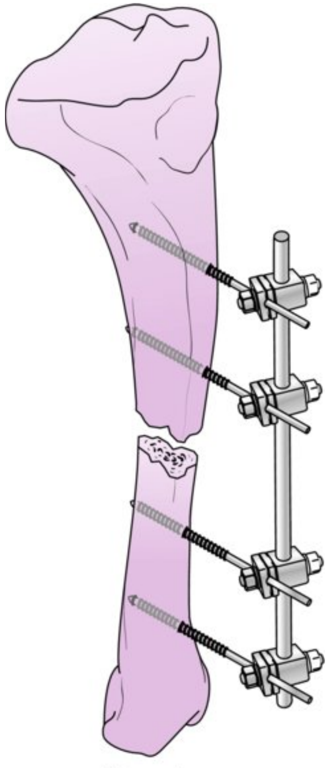
Contemporary Monolateral External Fixation Evolution

De Bastiani, Gotzen 1970

- Large body Monotube external fixator
- Axial loading with full WB
- Micromotion
- Fracture dynamization

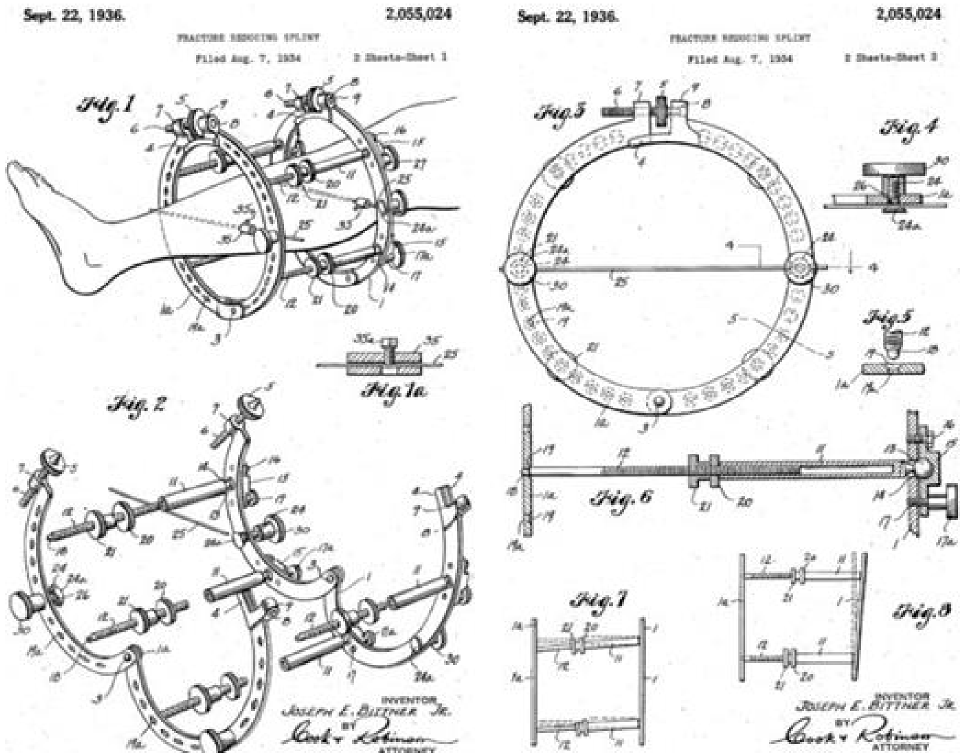


AO Manual 1977



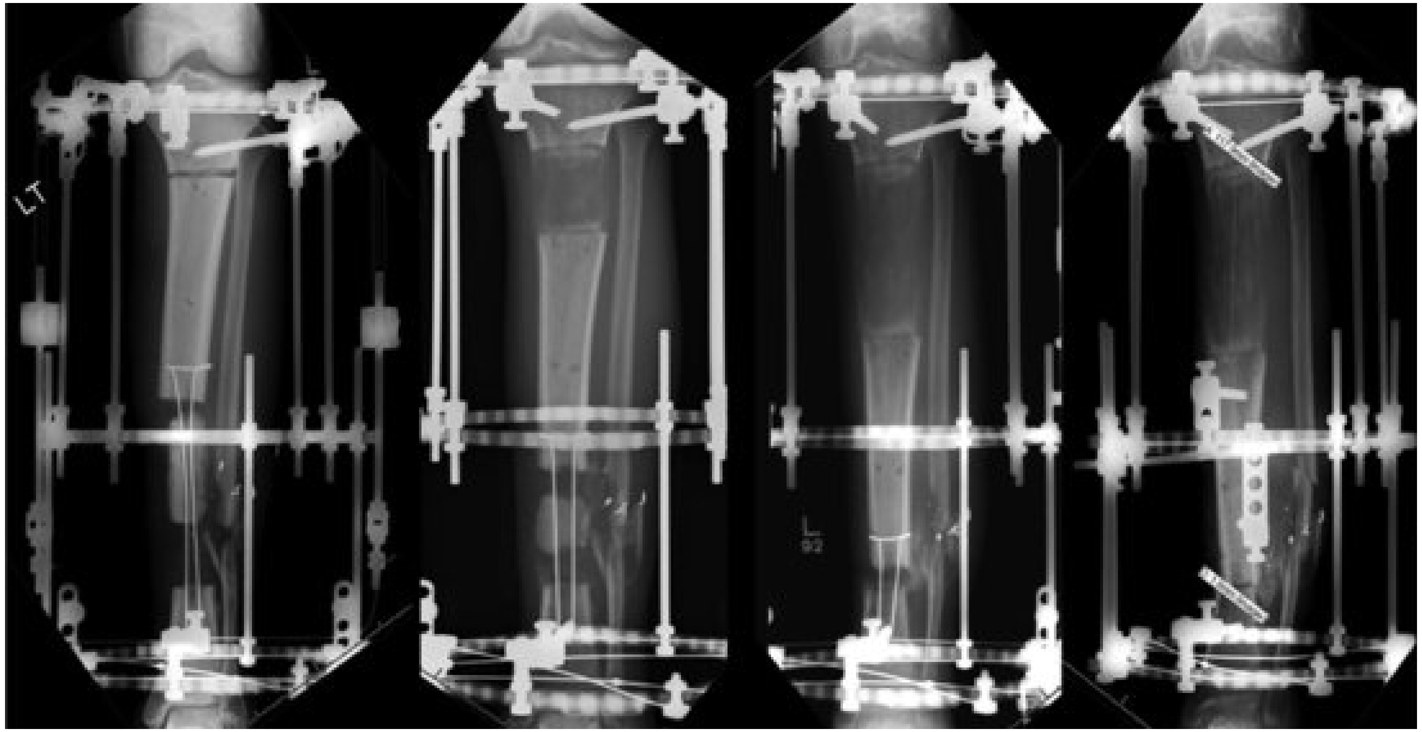
Circular External Fixation

- Joseph E. Bittner, Washington 1933
  - Circular rings
  - Transfixion wires
  - Wires tensioned by expanding a hinged ring with the wire attached between the hinges
- Russian and European circular Fixators followed



Circular External Fixation

- Gavril Abramovich Ilizarov 1948
  - Distraction technique
  - 3 Dimensional correction
- Carlo Mauri 1980
  - Introduced the technique to west



Indications of External Fixation - 1

- Open Fractures
- Closed fractures with high grade soft tissue injury, Vascular injury with acute repair
- Multiple long bone fractures in Critically ill patients - Damage Control
- Complex periarticular fractures with extensive comminution, bone loss or critical soft tissue injury e.g.
    - High energy Tibia plateau fractures
    - Distal Tibia pilon fractures

Indications - 2

- Pelvic ring injury
- Compartment syndrome
- Nonunion particularly infected nonunions
- Osteomyelitis
- Bone transport for the reconstruction of bone defects
- Limb lengthening
- Deformity correction
- Arthrodesis

Frame Types

- Unilateral
- Bilateral
- Multiplanar e.g. Delta configuration
- Ring fixator

Frame Designs

- Standard Frame
- Joint Spanning Frame
  - Non Articulated
  - Articulated
- Distraction or Correction Frame

Frame Components

- Pins
- Rods
- Clamps
- Rings & Transfixion wires

Pin bone Interface

- Stability of the Pin bone interface is most important factor in overall stability of an external fixator construct
- Factors affecting Pin bone interface
  - Pin geometry and thread design
  - Pin biomaterials and biocompatibility
  - Pin insertion technique

Moroni, Antonio; Vannini, Francesca; Mosca, Massimiliano; Giannini, Sandro State of the Art Review: Techniques to Avoid Pin Loosening and Infection in External Fixation, Journal of Orthopaedic Trauma: March 2002 - Volume 16 - Issue 3 - p 189-195

Pin Design

- Core diameter
  - Bending stiffness of a pin (S) = pin radius ^{4}
  - Pin hole greater than 1/3rd of the bone's diameter will substantially increase the risk of pinhole fracture after removal of the pin

Pins

Pin Biomaterials - Titanium

- Stainless steel pins- Traditional
- **Titanium alloy pins**
  - Much lower modulus of elasticity
  - Less pin bone interface stress
  - Lesser risk of pin site infection and better Osteointergration

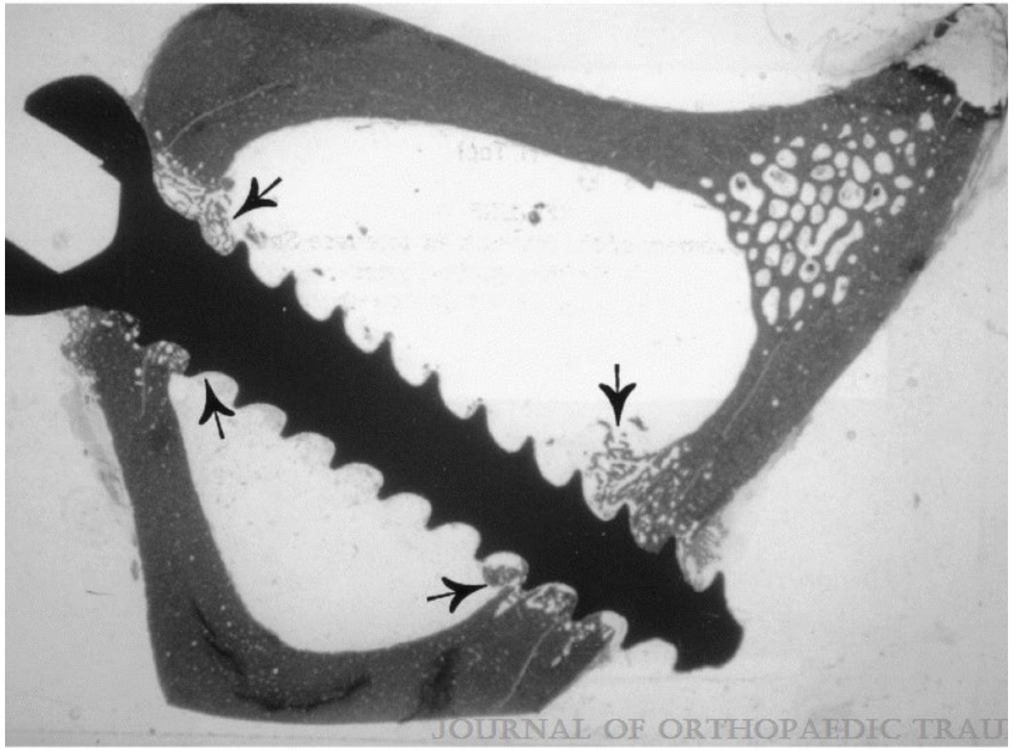
Pieske O, Geleng P, Zaspel J, Piltz S. Titanium alloy pins versus stainless steel pins in external fixation at the wrist: a randomized prospective study. J Trauma. 2008 May;64(5):1275-80

Pin Biomaterials - HA Coated

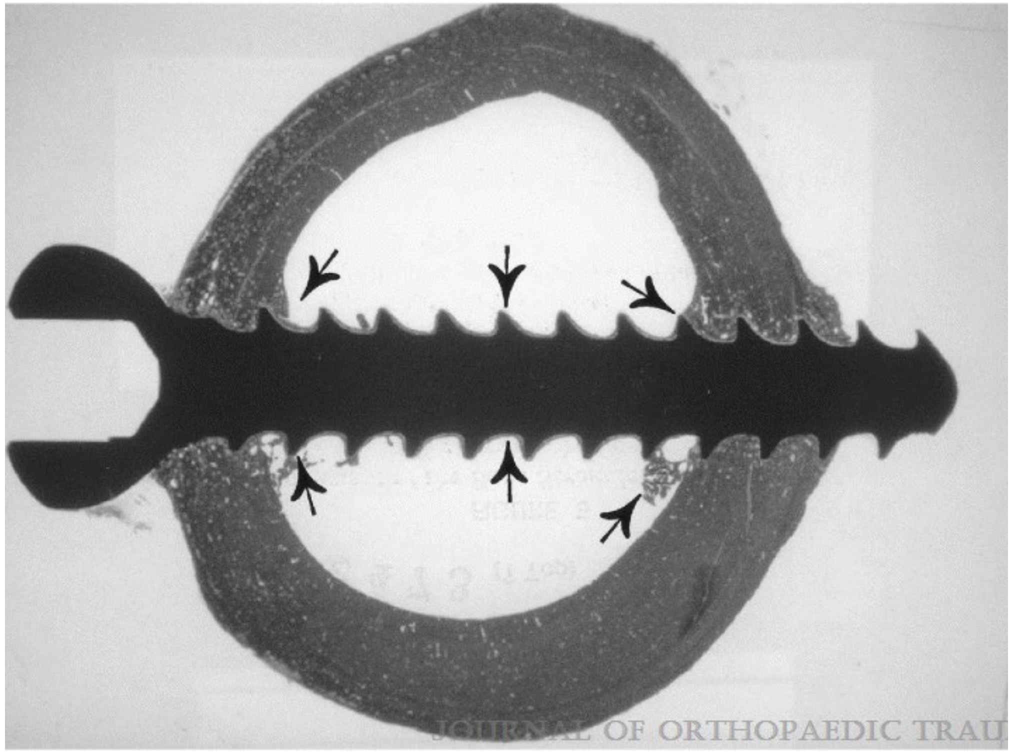
- **HA Coated Pins**
  - Best pin bone interface fixation
  - Less fibrous tissue interposition at the pin–bone interface
  - Less loosening
  - More relevant in cancellous, Osteoporotic bones

Moroni A, Toksvig-Larsen S, Maltarello MC, et al. A comparison of hydroxyapatite-coated, titanium-coated, and uncoated tapered external-fixation pins. J Bone Joint Surg Am 1998; 80:547–55

Bone Screw interface - Standard Vs HA Coated



A



B

Pre drilled pins: Radial Preload

- Pre drilled pins require a pilot hole to be drilled prior to insertion of the pin
- Pilot hole diameter should be equal to or slightly less than pin core
- Radial preload pre stresses the pin–bone interface in a circumferential fashion
  - Lower peak insertion temperature
  - Less thermal necrosis and bone damage
  - Lesser chance of loosening *Controversial*

Biliouris, Timothy L; Schneider, Erich; Rahn, Berton A.; Gasser, Beat; Perren, Stephan M. The Effect of Radial Preload on the Implant-Bone Interface, Journal of Orthopaedic Trauma: December 1989 - Volume 3 - Issue 4 - p 323-332

Self drilling pins

- **Self drilling Pins**
  - Risk of stripping of near cortex as drill tip spins to cut the far cortex
  - More depth of insertion required to pass sharp drilling portion beyond far cortex
  - More heat on insertion
  - Risk of micro fractures in both near and far cortices
  - Lesser pull out strength

Pin Insertion Technique - 1

- Incise the skin directly at the site of pin insertion
- Dissect down to bone and incise periosteum if feasible
- Care must be taken to avoid neurovascular structures etc
- Advance trocar and drill sleeve directly to bone to avoid soft tissue entrapment
- Avoid transcortical drilling

Pin Insertion Technique - 2

- Pre drill with a sharp drill of diameter equal to or slightly less than pin core
- Insert appropriate sized pin < 1/3rd bone shaft diameter
- Slow insertion speed & Low torque
- Use irrigation

https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/17165336/ankle-spanning-ex-fix

Anatomic Considerations

- Safe Corridors: Must avoid major Nerves, Blood vessels and Organs (Pelvis)
- Avoid Joint and Joint capsules
- Minimise muscle/tendon impalement (especially those with large excursions)

Caption

Anatomy - Pin placement Upper Limbs

- Proximal Humerus - Anterolateral
  - Avoid damage to the axillary and radial nerves
- Distal Humerus - Posterolateral
  - Avoid the olecranon fossa
- Forearm
  - Ulna - Subcutaneous border
  - Radius - Distally, Protect Superficial Radial nerve

Anatomy - Pin placement Lower Limbs

- Femur - Anterolaterally or Direct lateral
- Tibia - Subcutaneous anteromedial surface of the tibia
  - Pins placed perpendicular to either the anteromedial or posterior tibial cortex
- Periarticular Ankle
  - Trans calcaneal pin
  - To prevent equinus & to provide more stability - additional pins into Talus neck, Cuneiforms, First metatarsal base medially or laterally Cuboid or Fifth metatarsal base laterally

Monolateral Frames

- Components
  - Schanz Pins, Bars - Metal, Carbon fibre
  - Clamps - pin to pin, bar to bar or Universal
- Versatile, Wide range of flexibility
- **Place pins out of the zone of compromised skin and away from the fracture haematoma i.e. Zone of injury**
- Pins should be inserted in safe corridors
- Should be aligned with the bending axis of the bone

Monolateral Frame

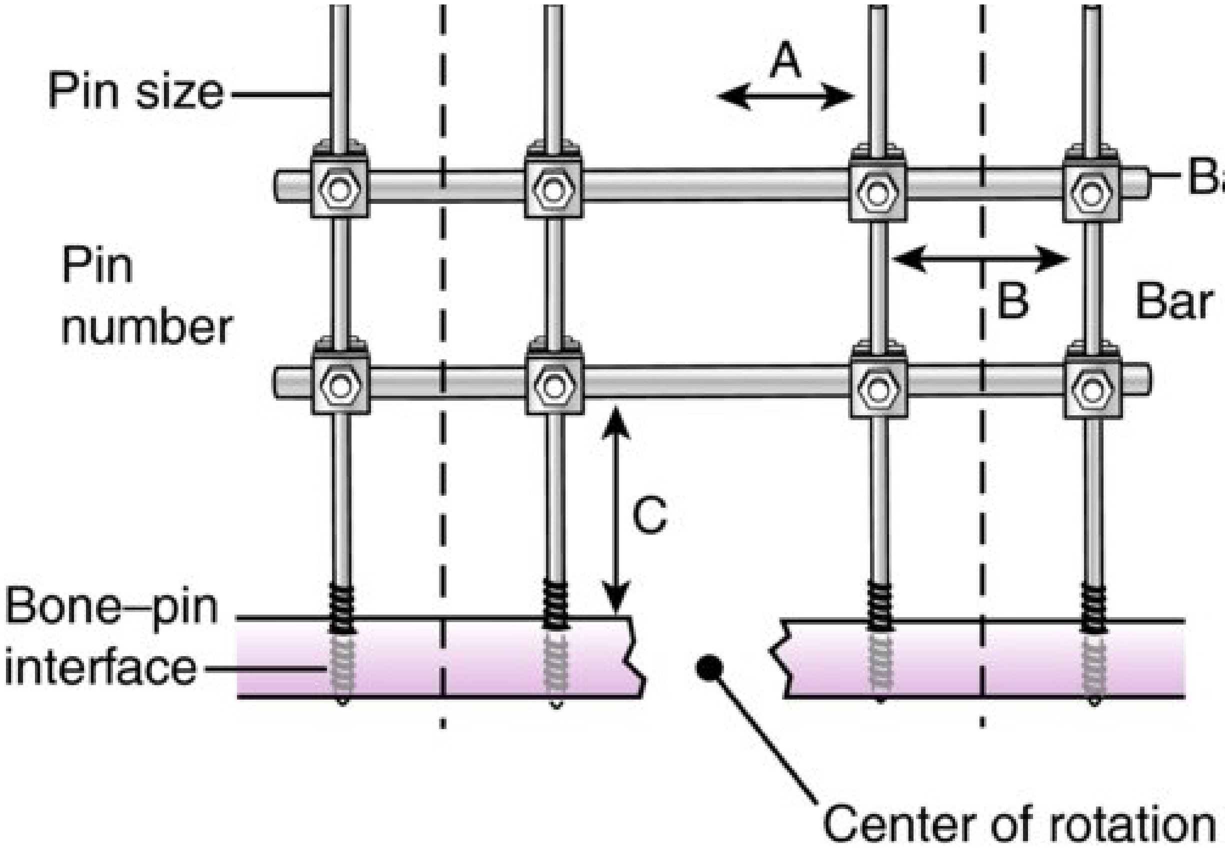
A

B

C

MonoLateral Frame

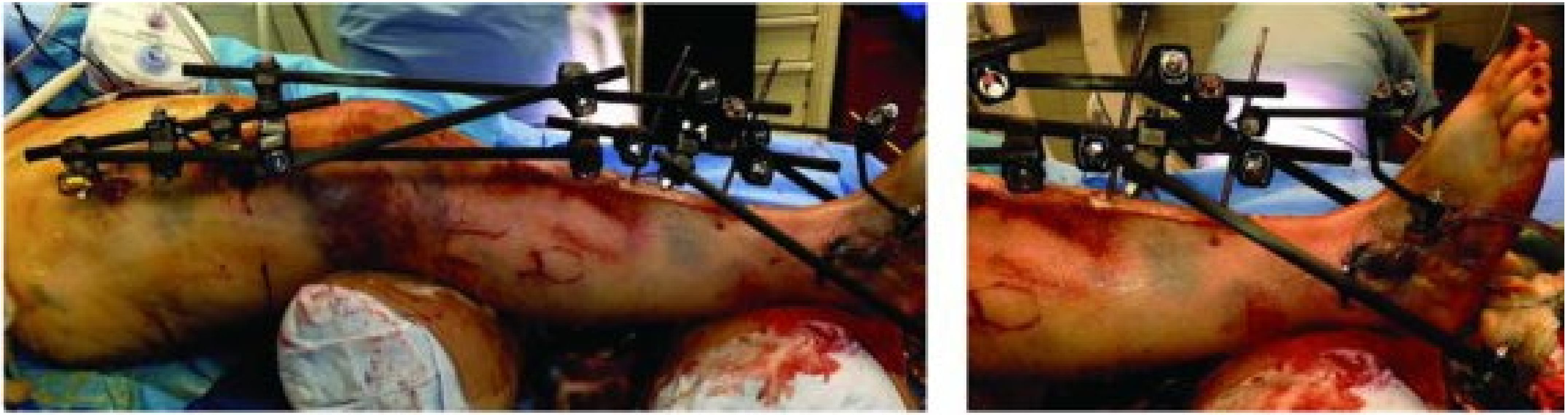
Factors affecting Stability of Monolateral Frame



Caption

A Pin to centre of fracture
B Pin separation
C Bone–bar distance.

Joint Spanning External Fixator - Knee



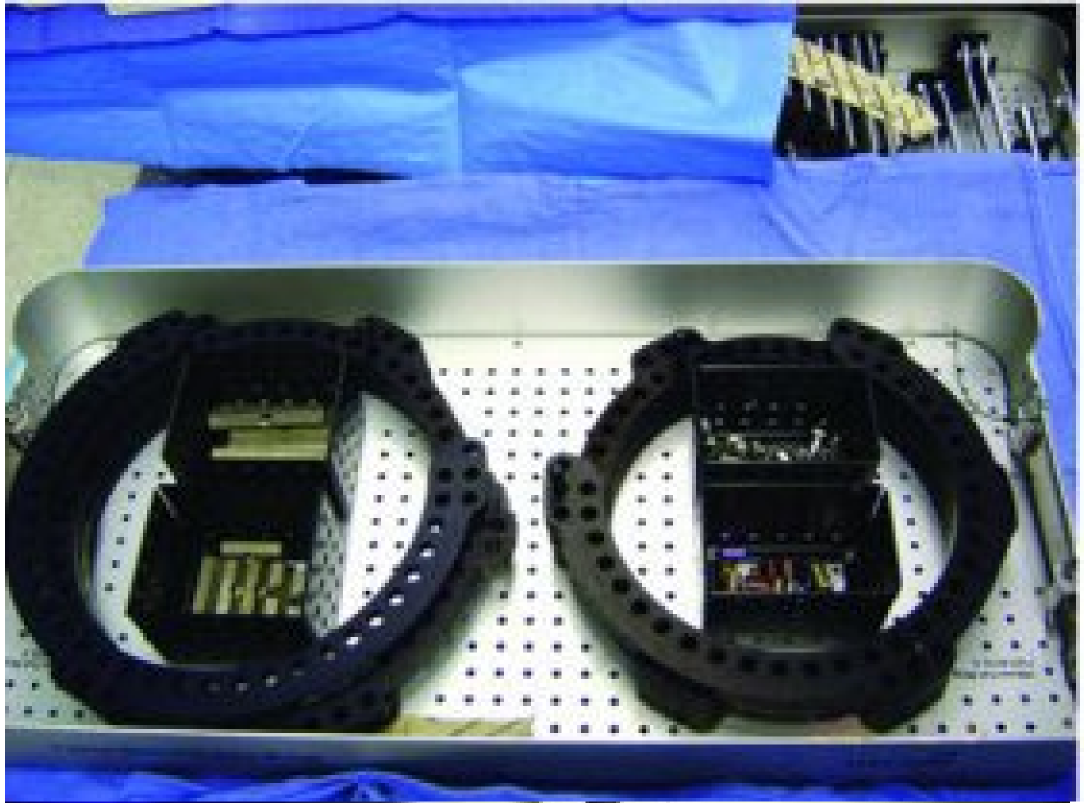
Monotube Fixators

- Higher degree of constraint
- Telescoping tube allows axial compression or distraction
- Useful for Lengthening & Deformity correction
- Particularly in Humerus and Femur

Circular (Ilizarov) Frames

- Allow multiplaner fixation/correction
- Minimises cantilever loading and shear forces as compared to the monolateral system
- Support axial micromotion and dynamization
- Beaded (Olive) wires help in
  - Fracture reduction
  - Inter-fragmentary compression
  - Deformity correction in malunions or nonunions
  - Better resistance to shear forces

Circular Frames - Wires, Bars and Rings



Circular Frames - Wire tensioning device

- Used to increase overall rigidity of the frame construct
- Usually tensioned to 90 - 130 Kg

How to enhance Stability of Circular Frames

- Increase diameter of wires and half pins
- Decrease ring size (distance of ring to bone)
- Use olive wires/drop wires
- Additional wires or half pins
- Cross wires or half pins at 90 degrees
- Increase wire tension, upto 130 Kg
- Place central 2 rings closer to either side of the fracture site
- Reduce space between adjacent rings

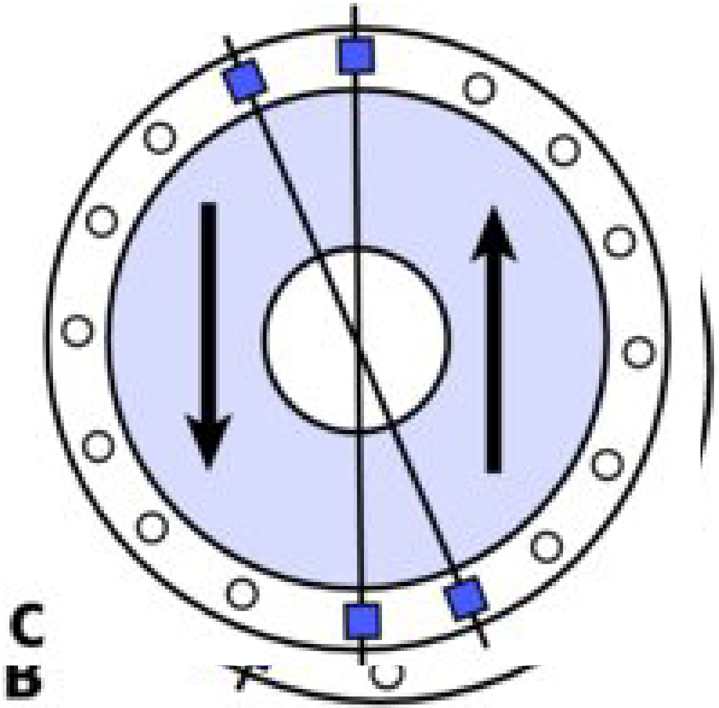
Circular Frames - Stability

- Reasons for loss of wire tension and consequent frame instability
  - **Slippage between wire and fixation bolt**
  - Plastic deformation and material yielding
- To reduce wire slippage
  - > 20 Nm Torque should be applied on the bolt
  - Roughening the wire–bolt interface
  - Additional wires
  - Achieve bone to bone contact

Circular Frames

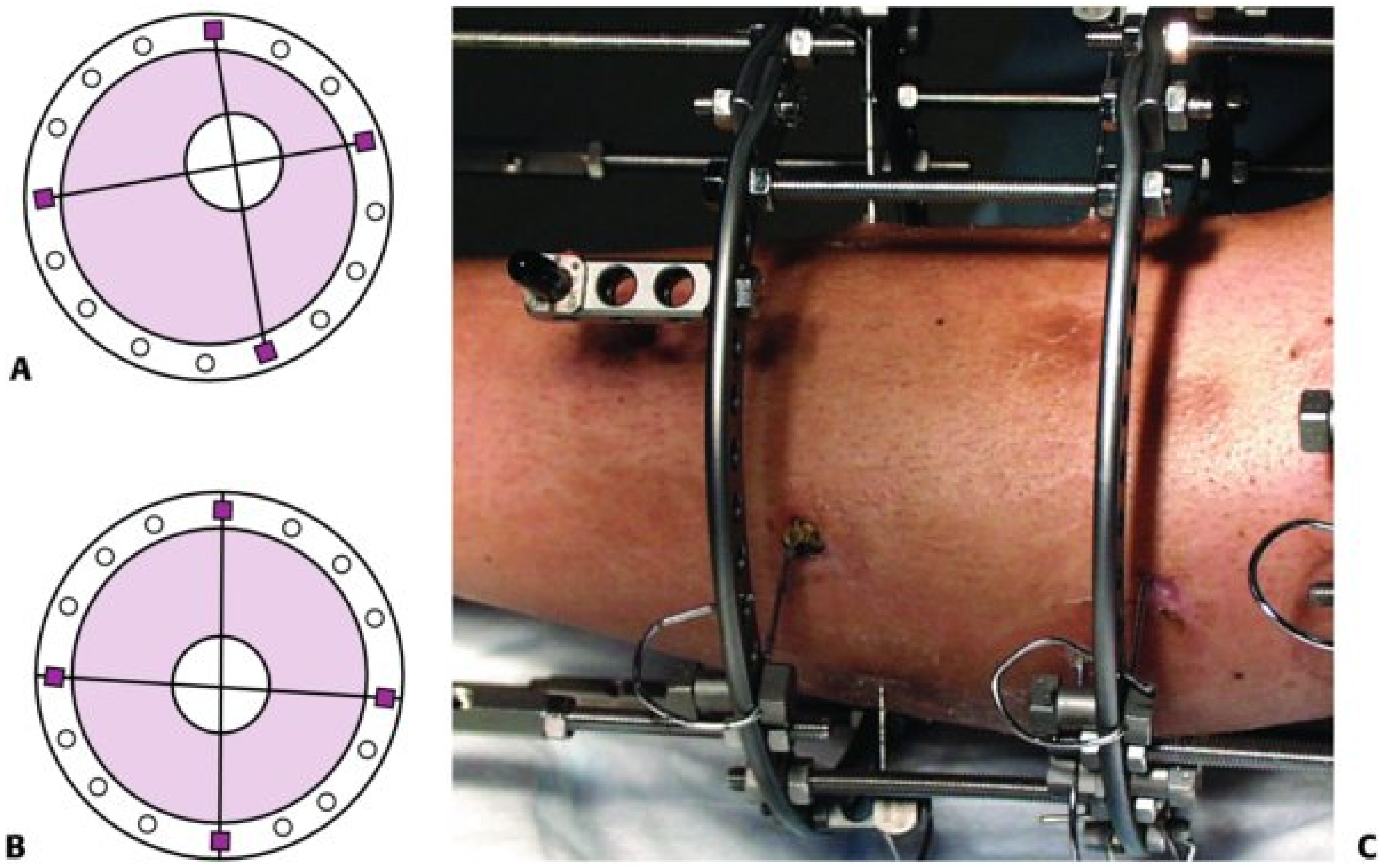
- Simple two rings frame is recommended for the upper extremity
- Optimal number of rings for lower extremity is four. The rings have to be allocated by two to each bony segment above and below fracture/nonunion
- Half-rings are mostly used for the upper and lower arm frames and for the foot component of a leg frame
- At least four rods must be used to connect two neighbouring rings, affixed at equal distance both vertically and horizontally on the rings

Circular Frames - Wire Orientation



Increasing ← Stability → Decreasing

Circular Frames - Limb position in Rings



Circular Frames - Olive Wires

A Fracture extending over distal one-third of tibia with large medial butterfly fragment

B Olive wires used as a “lag screw” to achieve additional stability of the medial butterfly fragment and distally in the metaphyseal region

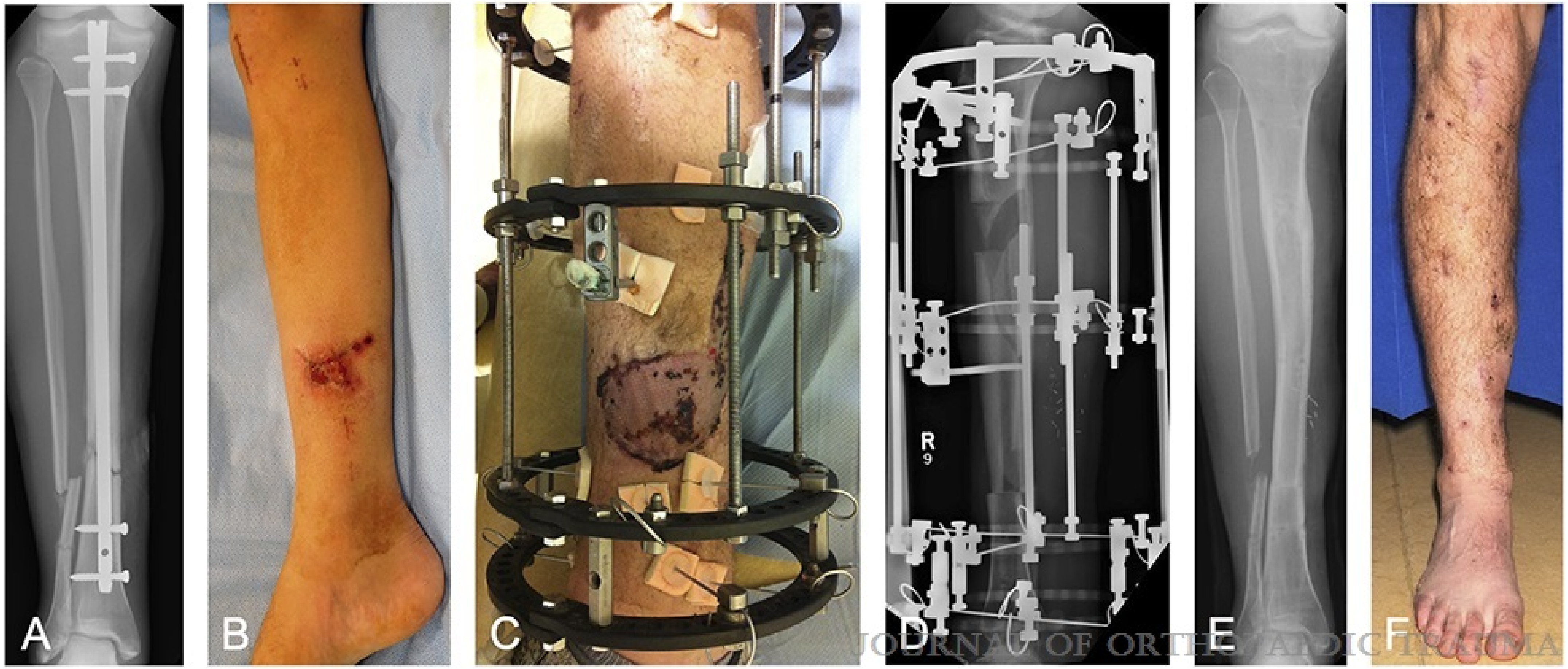
A B

Steerage Pins

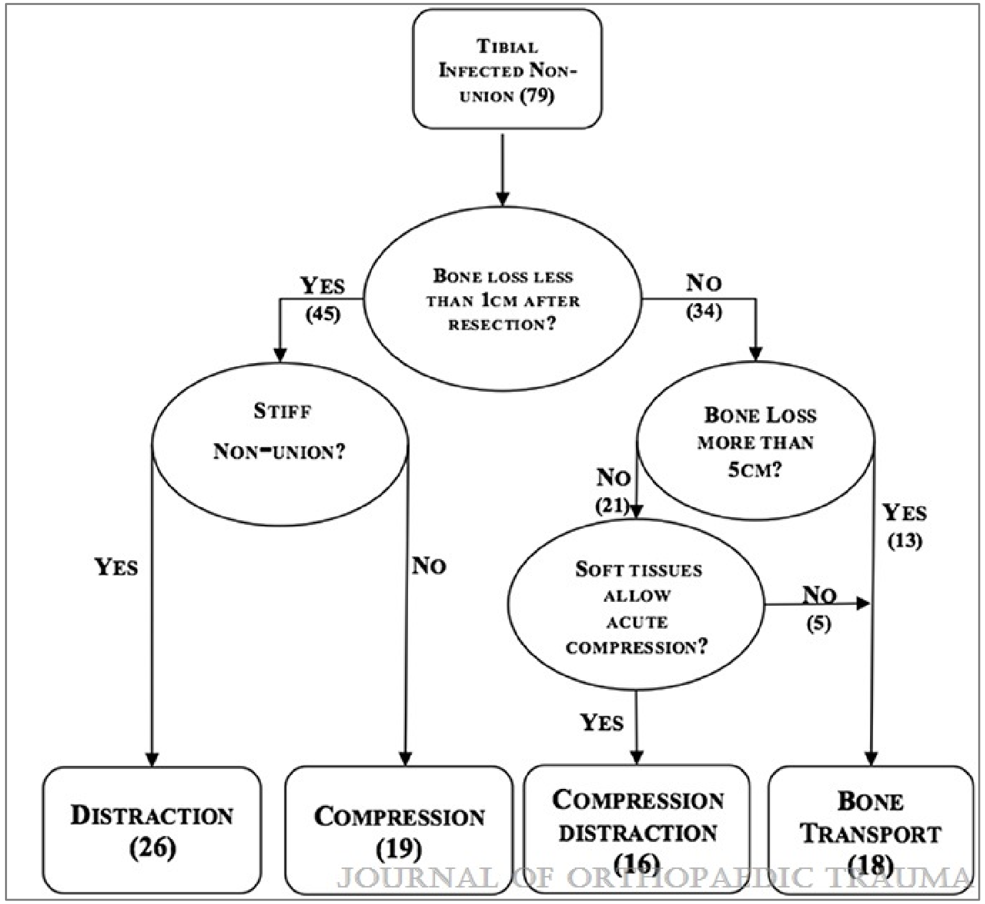
- Half pins placed parallel to the fracture line
- Shear force is actively converted into a dynamic compressive moment directed to the edge of the fracture fragments
- Shear phenomenon is dramatically reduced

Hierholzer G, Ruedi Th, Allgower M, et al., eds. Manual on the AO/ASIF Tubular External Fixator. Berlin, West Germany: Springer-Verlag; 1985

Ilizarov Frame in Infected Non - Union



Ilizarov Treatment algorithm in Infected Non - Union Tibia

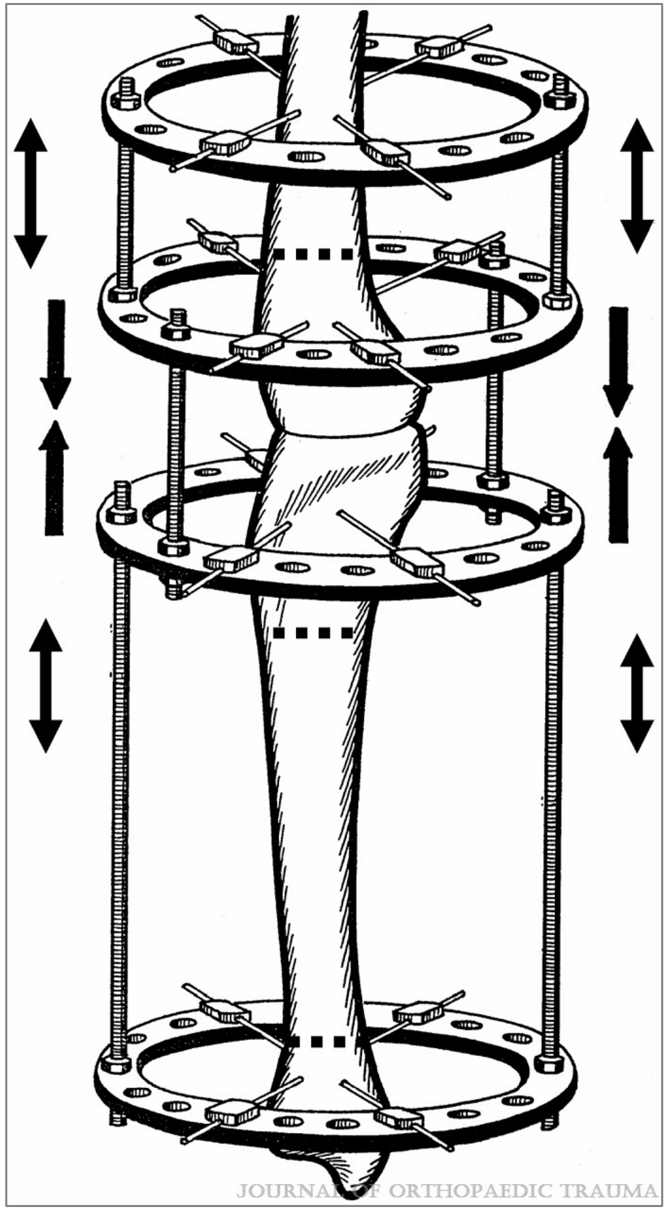


Based on the degree of stiffness of the nonunion after excision and the size of the segmental bone defect

Ilizarov - Knee Arthrodesis

- Schematic illustration of an Ilizarov construct for knee arthrodesis and lengthening
- Note the compression across the arthrodesis site and distraction at osteotomy sites (dotted lines) of the distal femur, proximal tibia and/or distal tibia

Rozbruch, S. Robert MD; Ilizarov, Svetlana MD; Blyakher, Arkady MD Knee Arthrodesis With Simultaneous Lengthening Using the Ilizarov Method, Journal of Orthopaedic Trauma: March 2005 - Volume 19 - Issue 3 - p 171-179



Ilizarov - Limb Lengthening

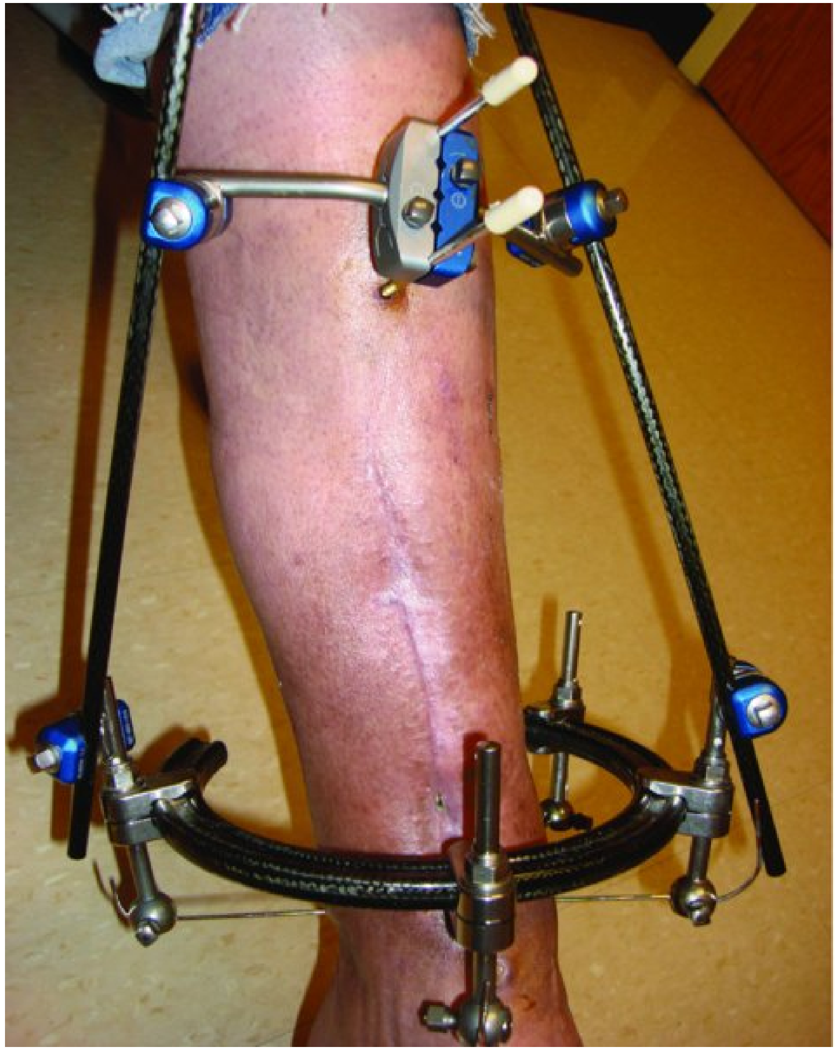
A

B

Hybrid Fixators

- Mechanically inferior
- Much less axial and bending stiffness compared to a standard Ilizarov fixator
- Most of these devices tend to lose reduction with progressive-weight bearing

Pugh KJ, Wolinsky PR, Pienkowski D, Banit D, Dawson JM. Comparative biomechanics of hybrid external fixation. J Orthop Trauma. 1999 Aug; 13(6):418-25

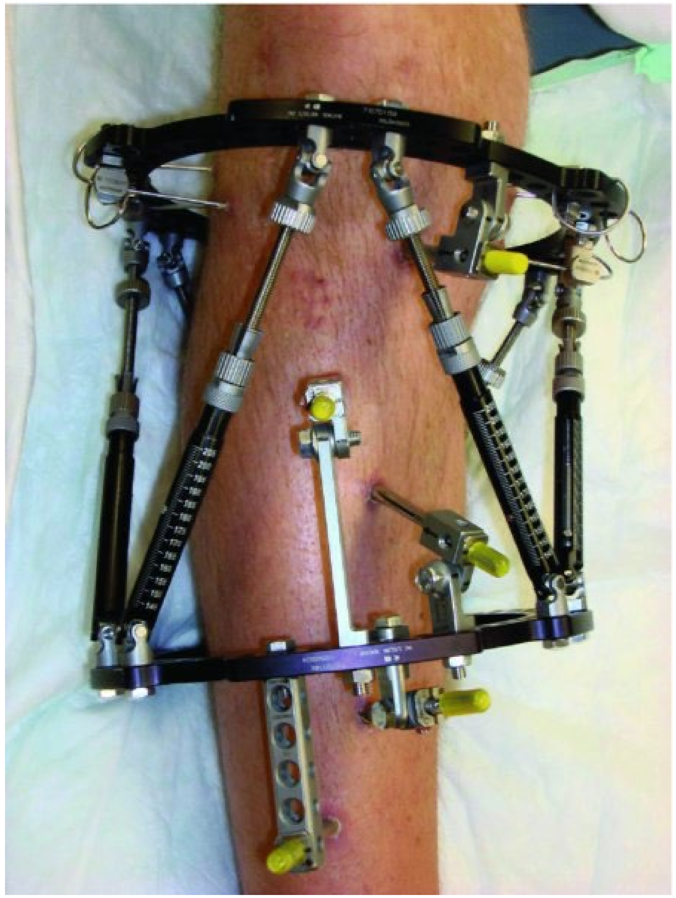


Hexapod Frames

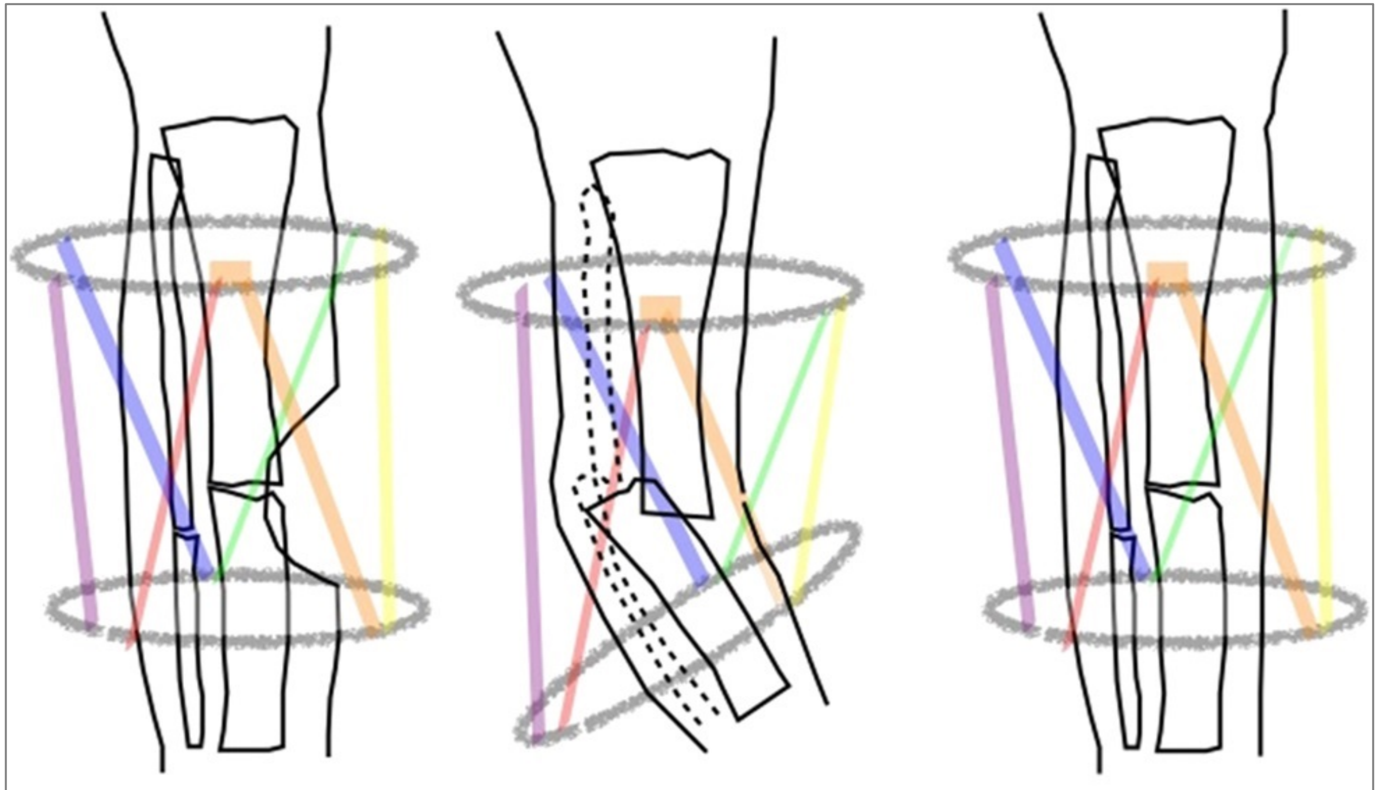
- Taylor Spatial frame (TSF)
- Allows simultaneous correction in 6 axes
  - Coronal angulation and translation
  - Sagittal angulation and translation
  - Rotation and length
- Uses web-based software interfacing with digital x-rays*
- Allows rings to be positioned in any orientation within their respective limb segment

Taylor Spatial frame (TSF)

- Transfixion wires or a minimum of three half-pins on either side of the fracture
- Particularly useful in
  - Stiff hypertrophic nonunion
  - Infection
  - Bone loss
  - Limb length discrepancy (LLD)
  - Poor soft tissue envelope



TSF - Intentional Deformation and Closure of Soft Tissue Defect in Open Tibial Fractures

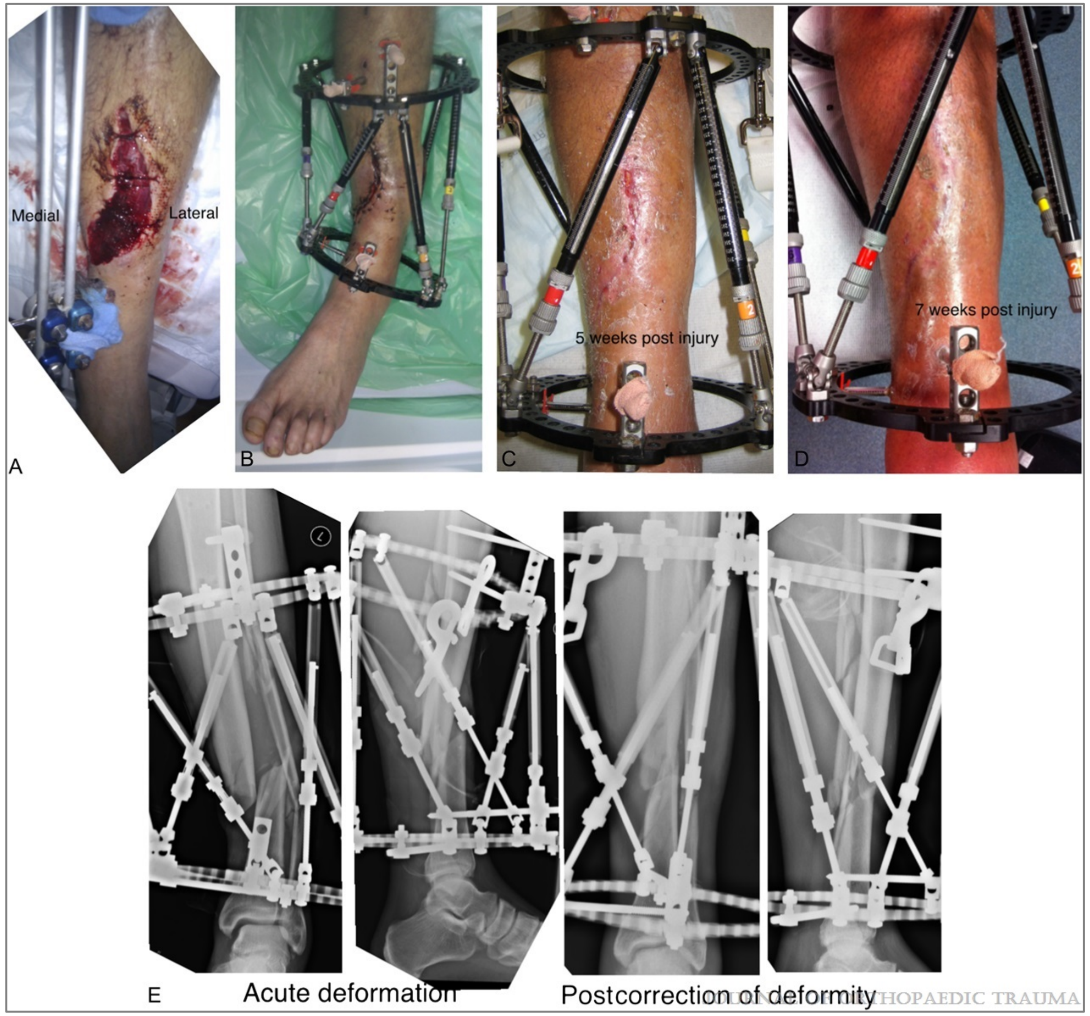


Anatomically aligned fracture after wound debridement - ring sizes and strut length readings are recorded (Aligned frame strut lengths)

Acutely deformed the limb to approximate the wound edges - strut length readings are recorded (Deformed frame strut lengths)

Gradually the frame is returned to 'Aligned Frame Strut Lengths to restore length and normal alignment of the leg. Soft tissue defect healed without plastic procedure.

TSF - Intentional Deformation and Closure of Soft Tissue Defect in Open Tibial Fractures



Locking Compression Plate External Fixators

- Applied outside the soft tissue envelope following closed reduction
- Angle stable screw fixation
- Lower profile
- Higher torsional stiffness with similar axial rigidity as standard external fixator

MRI Compatibility

- Safety Concerns
  - Ferromagnetism
    - Significant linear forces, torque
    - Radio frequency (RF) heating within both metallic implants and biological tissues
- Image distortion
- Ferromagnetism lesser with Titanium, Aluminium and Carbon fibre components as compared with Stainless Steel components

MRI Compatibility

- Almost all are safe if the components are not directly within the scanner (subject to local policy)
- Consider use of MRI safe external fixator when the area of interest is spanned by the frame and prefer titanium pins

Hayden, Brett L. MD; Theriault, Raminta MD; Bramlett, Kasey PA-C; Lucas, Robert BA; McTague, Michael MPH; Bedi, Harprit Singh MD; Flacke, Sebastian MD, PhD; Weaver, Michael J. MD; Marcantonio, Andrew J. DO, MBA; Ryan, Scott P. MD. Magnetic Resonance Imaging of Trauma Patients Treated With Contemporary External Fixation Devices: A Multicenter Case Series, Journal of Orthopaedic Trauma: November 2017 - Volume 31 - Issue 11 - p e375-e380

Modes of Fixation

- Compression
  - When bone stock good and bone ends are in contact
  - Typically used to complete union of a fracture and in Arthrodesis
- Neutralisation
  - In presence of comminution or bone loss
  - To maintain length and alignment & to resist external deforming forces
- Distraction
  - Reduction through ligamentotaxis
  - Distraction Osteogenesis

Biology

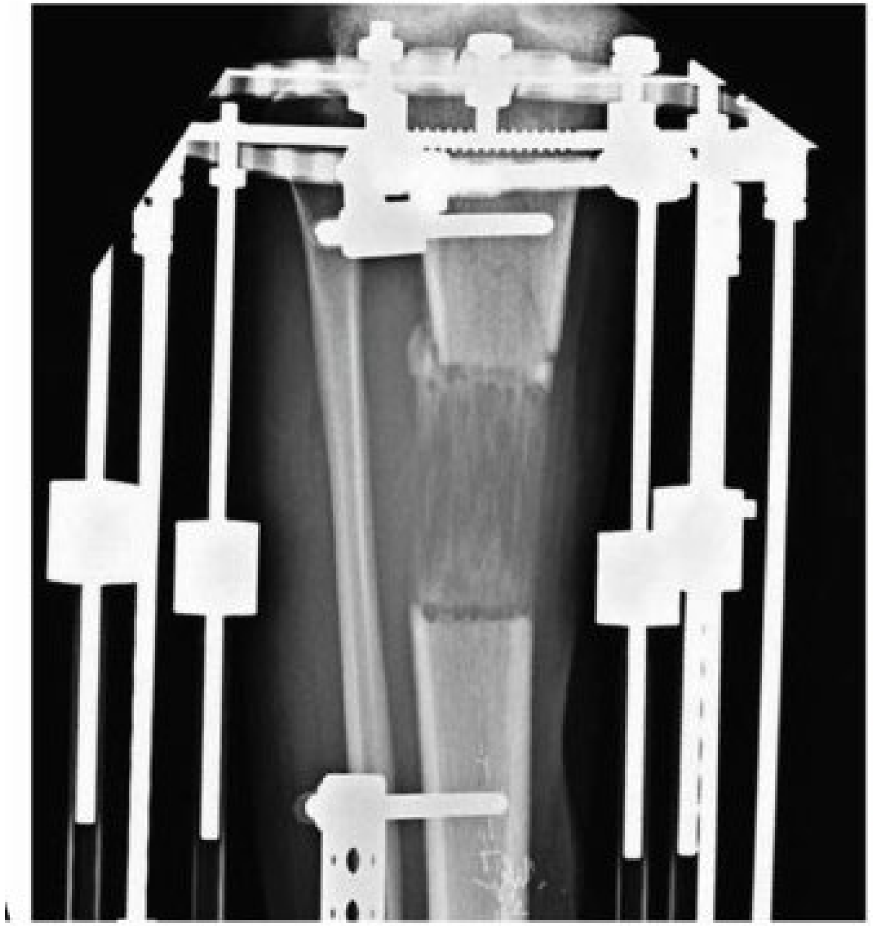
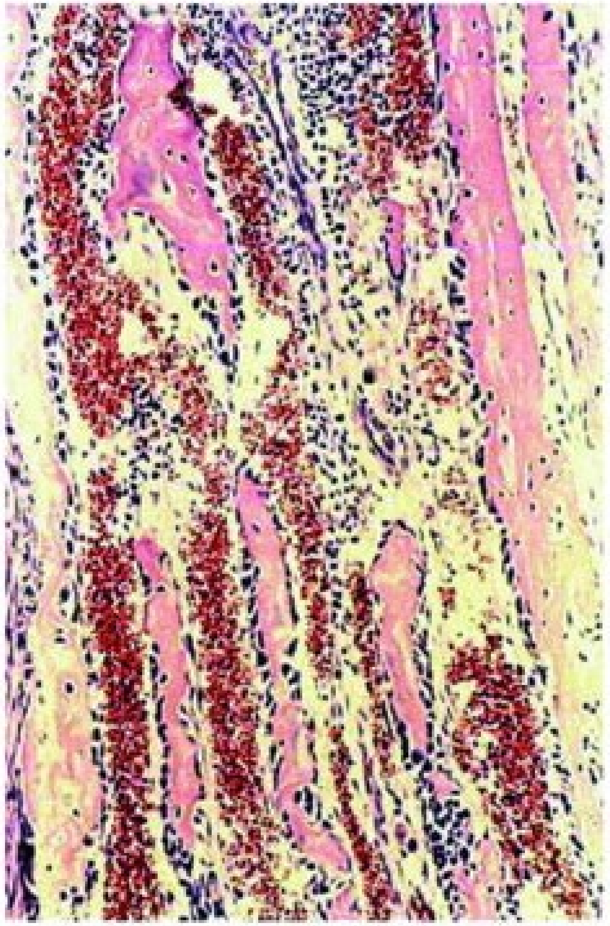
- External fixation facilitates external bridging callus
- Highly dependent upon the integrity of the surrounding soft tissue envelope
- Ability to bridge large gaps and very tolerant of movement

Ilizarov GA (1992) The tension stress effect on the genesis and growth of tissues. The influence of blood supply and loading upon the shape-forming processes in bone and joints. In: SA Green (ed) The transosseous osteosynthesis. Theoretical and clinical aspects of the regeneration and growth of tissue. Springer, Berlin Heidelberg, pp 137–257

Distraction Osteogenesis

- Mechanical induction of new bone that occurs between bony surfaces that are gradually pulled apart
- **Ilizarov's "Tension Stress Effect" - Stimulates biosynthetic activity in tissues**
- Osteogenesis takes place by formation of a physis like structure in the gap
- Interzone - Central growth region, from which new bone forms in parallel columns extending in both directions
- Cells for Interzone are recruited from periosteum

Distraction Osteogenesis

A   B

Caption

Distraction Osteogenesis

- Rate and rhythm of distraction are crucial
- Distraction rate should be 0.5 to 2 mm per day
- Ilizarov recommendation: 1 mm distraction in 4 divided doses in 24 hrs
- Constant distraction over a 24-hour period produces a significant increase in the regenerate quality
- Tissues respond to slow application of prolonged tension with metaplasia and differentiate into the corresponding tissue type
    - Bone responds first -> Muscle -> Ligament -> Tendons -> NV structures

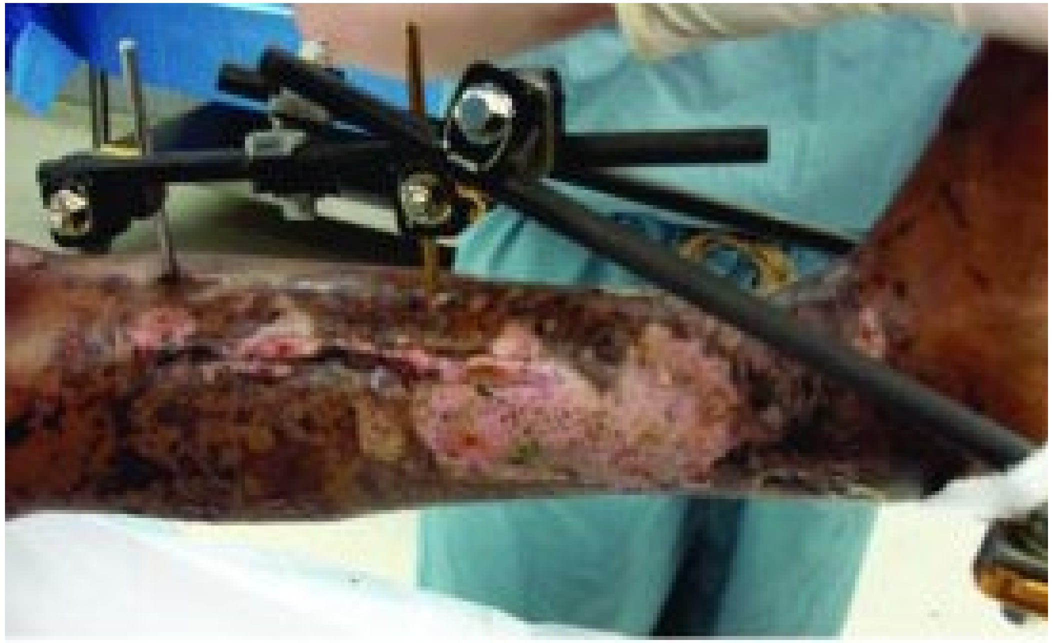
Damage Control External Fixation

- To focus on initial resuscitation and treatment of higher priority injuries
- To minimise 2nd hit
- Aims
  - To rapidly stabilise Long bone and Pelvis fractures
  - To maintain length, alignment, and rotation of the extremity
  - Initial stabilisation of periarticular fractures using a joint spanning external fixator

Damage Control External Fixation

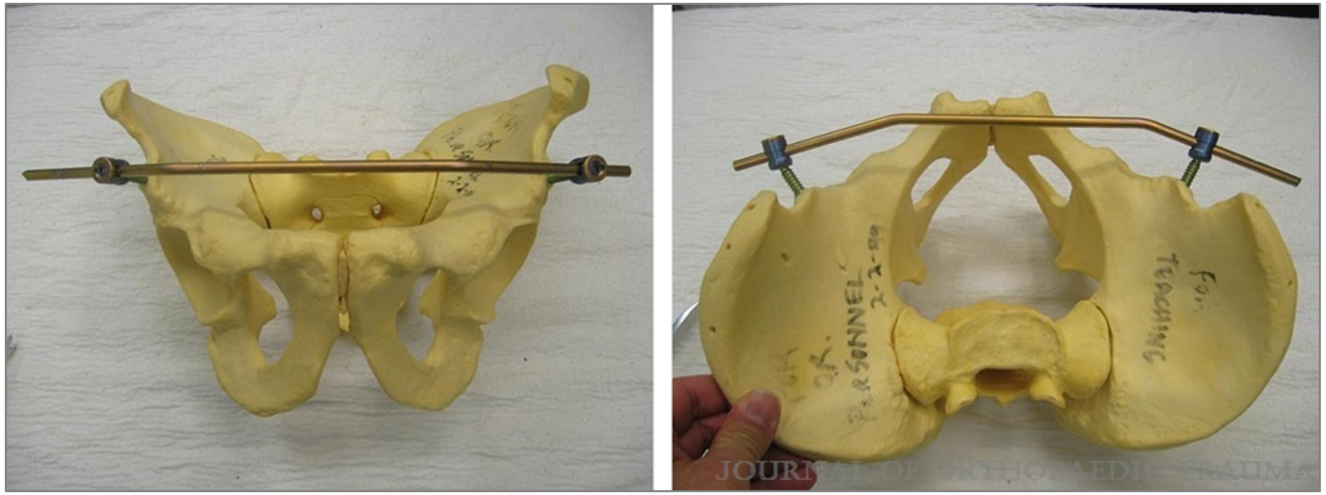
- Ligamentotaxis reduction of complex articular fractures
  - Reduces injury-related swelling and oedema
  - Delay of more than few days can cause difficulty in disimpaction and reduction of displaced metaphyseal fragments
- Risk of Fixator “creep” or gradual loosening of fixator components
  - Check radiographs should be done if delay in definitive fixation anticipated
  - May require frame adjustment if loss of reduction

Damage Control External Fixation



Percutaneous Supra-Acetabular External Pelvic Fixation

- Used in Unstable Pelvic ring injuries
- To close an anterior-posterior compression injury, Open a lateral compression injury or to stabilise a vertical shear injury



Percutaneous Supra-Acetabular External Pelvic Fixation

- Incision 2 cm distal and medial to Anterior Superior Iliac Spine (ASIS) & find Anterior Inferior Iliac Spine (AIIS)
- Do blunt dissection up to the bone and protect Lateral femoral cutaneous nerve
- Pins are inserted between the inner and outer tables of Ilium in posteromedial direction

https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731357/percutaneous-supra-acetabular-external-pelvic

Conversion to Internal Fixation

- Early definitive stabilization minimises complications
- Generally safe within 2-3 weeks
- Staged conversion
  - If pin sites infected
  - Remove the fixator, debride the pin sites, place the extremity in a splint or traction and antibiotics
  - Definitive fixation once infection settled

Bible, Jesse E. MD, MHS; Mir, Hassan R. MD External Fixation, Journal of the American Academy of Orthopaedic Surgeons: November 2015 - Volume 23 - Issue 11 - p 683-690

Complications

- **Pin loosening, Pin tract infection - Most Common Complication**
- NV Injury - Use safe corridors for pin/wire insertion
- Soft-tissue impalement
- Malunion
- Nonunion
- Compartment syndrome
- Metal fatigue failure

Pin loosening and Infection

- Aetiology - Multifactorial
- Thermal and mechanical damage of the bone during pin insertion
- Formation of fibrous tissue at the bone-pin interface
- Excessive pin site tissue motion

Green, Stuart A. M.D. Complications of External Skeletal Fixation, Clinical Orthopaedics and Related Research: November 1983 - Volume 180 - Issue - p 109-116

Pin Track Infection - Classification*

Grade	Appearance	Treatment
1	Slight erythema, Minimal discharge	Improve Pin care
2	Erythema, discharge and pain in soft tissues	Topical and/or oral antibiotics
3	Grade 2 but no improvement with antibiotics	Remove pin and change antibiotic regimen
4	Soft-tissue infection involving several pins	Remove any loose pins
5	Grade 4 and radiographic evidence of bone involvement	Remove entire fixator construct and curettage pin tract
6	Infection after fixator removal (clinical and radiographic)	Débridement, irrigation, and systemic antibiotics

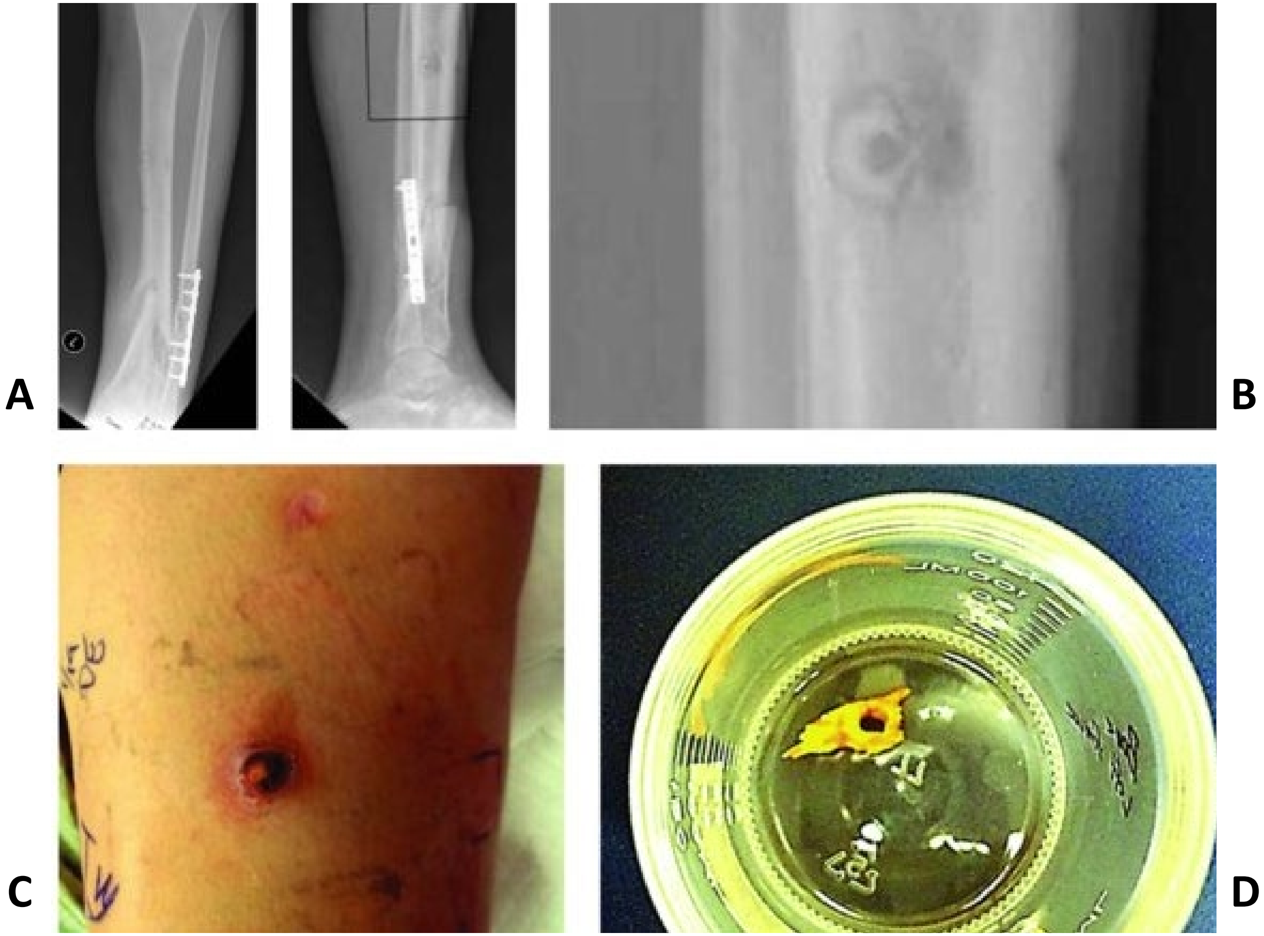
Pin Track Infection

Pin site infection - Chronic, with Sequestrum

A, B Self-drilling pin used in the diaphysis resulted in a ring sequestrum

C Clinical appearance of chronic pin site infection

D Ring sequestrum removed



Caption

Summary

- Minimally invasive and flexible tool
- Can be applied quickly
- Can be used for both temporary as well as definitive stabilisation
- Appropriate frame type use as per clinical indication can lead to excellent clinical outcome
- Early recognition and treatment of complications is vital

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