PRINCIPLES OF EXTERNAL FIXATION

Dr. Ritesh Khokhar
Consultant Orthopaedic Surgeon
FRCS Ortho
India
Credit Statement

Figures in this presentation are used with permission


• Journal of Orthopaedic Trauma
Objectives

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

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 métalliqué
B griffe métalliqué 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
Pin Design

• Core diameter
  • Bending stiffness of a pin \( (S) = \text{pin radius}^4 \)

• 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 Osteointegration

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

Bone Screw interface - Standard Vs HA Coated
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

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)
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
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
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

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

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

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
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

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

Caption

A

B
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 2\textsuperscript{nd} 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

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

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

## Pin Track Infection - Classification*

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

• Hoffmann R. Osteotaxis: Transcutaneous Osteosynthesis by Means of Screws and Ball and Socket Joints. Paris, France: Gead; 1953
• Aro HT, Chao EY. Bone-healing patterns affected by loading, fracture fragment stability, fracture type, and fracture site compression. Clin Orthop Relat Res. 1993;293:8–17
• Green SA. Complications of External Skeletal Fixation: Causes, Prevention, and Treatment. SpringField, IL: Charles C Thomas; 1981