Ilizarov Pathophysiology

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Introduction

- The Man
- The Frame
- The Law
- The Method
- Experimental Background
- Clinical Applications
- Problems, Obstacles, Complications
- Other Methods
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Gavriil Abramovich Ilizarov [1921-1992]
All-Union Centre for Restorative Traumatology & Orthopaedics, Kurgan, Siberia

- 1000 beds, 18 different departments
- 300 Orthopaedic Surgeons
- 60 post doctoral scientists
- 1500 support staff, 100 machinists
- Over 2000 publications
- Centres in 11 other cities of the old USSR
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The Frame
Ilizarov Frame 1

- Developed in 1951 - Awarded Soviet Inventors Certificate
- Circular
- Hinges, Plates, Threaded rods
- Thin, Smooth or Beaded K-Wires, 1.5-1.8mm diameter
- Unlimited assembly variations
- Human erector (mechano) set
Ilizarov Frame 2

- Wires Tensioned
- Tension provides stiffness
- More rings increase stiffness
- Stiff to bending loads
- Flexible to axial loads
- Allows axial micromotion
- Like walking on trampoline
Tensioning

- One end of wire fixed to ring while other end is tensioned using dynamamometric wire tensioner, to between 80 & 130kg
- Stiffness increases with tension
Ilizarov Frame - Versatile

- Limb segments
- Lengthened
- Rotated
- Angulated
- Translated
- Compressed
- Distracted
- Bone transport
The Law of Tension - Stress

Gradual traction on living tissues creates stresses that can stimulate and maintain the regeneration and active growth of certain tissue structures.
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The Method

- Apply Frame
- Osteotomy [Corticotomy]
- Latency Period
- Distraction Phase
- Consolidation Phase
- Remove Frame
The Method

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Principles of Frame Application

- Stability
- Wire insertion
- Securing Wires to Rings
- Relation of Rings
- Check x-ray
- Periodic retensioning
Principles - Stability

- Fundamental for new bone formation
- Decreases discomfort
- Decreases likelihood of wire sepsis
- Allows limb use
- Wt. bearing & active muscle function enhance local circulation - good for new bone
Principles - Wire insertion

- Anatomy - Consider vessels, nerves, muscles, tendons, and synovium
- Prevent thermal injury to soft tissues & bone
- Introduce wire through soft tissues to bone
- Drill through bone
- Hammer through soft tissues on the other side
Principles - Wire insertion

- Maximum stability when wires are perpendicular to each other
- Stretch muscle during insertion - allow joint movement
- Consider differences in muscle resistance e.g. lower leg, soft tissues on lateral side have greater resistance to elongation - slant wires medially to prevent valgus on lengthening
Principles - Securing wires to rings

- Affix the ring to wire & not wire to ring
- To prevent bending of wires
- Bent wires can cause displacement of attached bone fragments and cause soft tissue necrosis
Principles - Relation of Rings

- All rings should be related to their bone fragments in identical manner
- To have same mechanical axis
- Connecting rods in corresponding holes in rings
- Otherwise - incorrect lateral, rotational, or combined displacement can occur during lengthening
Principles - Check x-ray

- At end of frame application
- Reapply frame if necessary
- For the reasons above
Principles - Relation of Rings

- All rings should be related to their bone fragments in identical manner
- To have same mechanical axis
- Connecting rods in corresponding holes in rings
- Otherwise - incorrect lateral, rotational, or combined displacement can occur during lengthening
Principles - Retensioning

- To insure stability
- Tension can decrease due to wire deformation, or osteoporosis
The Method

- Apply Frame
- **Osteotomy [Corticotomy]**
- Latency Period
- Distraction Phase
- Consolidation Phase
- Remove Frame
Osteotomy [Corticotomy]

- **Open** - Periosteum, cortex, endosteum transected
- **Percutaneous** - Most of periosteum and endosteum preserved
- **Closed** - No damage to periosteum or endosteum [Closed osteoclasis]
Site of Osteotomy

- Metaphyseal
- High osteogenic potential
- At end of osteotomy bone ends should be completely undisplaced
- As initial diastasis is harmful to new bone formation - more fibrous tissue
The Method

- Apply Frame
- Osteotomy [Corticotomy]
- Latency Period
- Distraction Phase
- Consolidation Phase
- Remove Frame
Latency Period

- Time between osteotomy and distraction
- Allows inflammatory phase of healing to settle
- Allows distraction to begin in the reparative phase when early osteogenesis is seen
- 5-7 days usually [10-14 days DeBastiani]
- 3-5 days in children
- More in older patients
- Thus distraction is of early callus [Callotasis - DeBastiani]
The Method

- Apply Frame
- Osteotomy [Corticotomy]
- Latency Period
- Distraction Phase
- Consolidation Phase
- Remove Frame
Distraction Phase

- Variable period
- Rate 1mm/day in 4 steps [Autodistractor best]
The Method

- Apply Frame
- Osteotomy [Corticotomy]
- Latency Period
- Distraction Phase
- Consolidation Phase
- Remove Frame
Consolidation Phase

- Variable period
- Until mature callus
- Allows bone ends to consolidate
- Corticalization on x-rays
The Method

- Apply Frame
- Osteotomy [Corticotomy]
- Latency Period
- Distraction Phase
- Consolidation Phase
- Remove Frame
Principles - Frame Removal

- Neutralize tension
- By gradual and balanced rotation of nuts on connector rods
- X-rays before and after
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Experimental Evidence

- Evaluate optimum conditions for osteogenesis during limb lengthening
- Stability of fixation - effect of rigidity
- Soft tissue preservation
- Direction of traction
- Rate and Frequency of distraction
Materials and Methods

- Canine tibiae
- Varying rigidity, osteotomy, rate, frequency
- Vets, Animal care specialists
- All dogs walked daily
- Special meals
Method

- Osteotomy
- 5-7 day latency period
- Distraction phase
- Period of neutral fixation, 3-6 wks
- Further observation for 6 mths.
- Weekly x-rays
Within each experimental group

- Animals sacrificed:
  - Immediately, 7, 14, 21 days
  - 6 weeks
  - 2, 3, 4 and 6 months after osteotomy
From each sacrificed animal

- Osteotomized and contralateral (control) limbs removed
- Histology
- Biochemistry
- Angiography
- Radiography
- Transmission & Scanning EM
- Compare marrow & peripheral blood
- Soft tissues, capillaries, nerves, muscle
Experimental Evidence

- Evaluate optimum conditions for osteogenesis during limb lengthening
- Stability of fixation - effect of rigidity
- Soft tissue preservation
- Direction of traction
- Rate and Frequency of distraction
Experiments - Effects of Rigidity

- 480 dogs
- Open transverse osteotomy of diaphysis, periosteum and marrow
- Longitudinal distraction
- 3 Groups
Rigidity - Group 1

- 2 rings
- 1 pair of crossed wires in each fragment
- Loosely attached wires
Rigidity - Group 2

- Same as group 1 but wires tensioned
Rigidity - Group 3

- Even more rigid with two pairs of wires in each fragment
Rigidity - Results

- Group 1 [Least rigid] - had least osteogenic activity
- Group 3 [Most rigid] - had most osteogenic activity
- Connective tissue fibres and osseous trabeculae in the bone forming region all had longitudinal orientation in Group 3
Experimental Evidence

- Evaluate optimum conditions for osteogenesis during limb lengthening
- Stability of fixation - effect of rigidity
- Soft tissue preservation
- Direction of traction
- Rate and Frequency of distraction
Experiments - Soft tissue preservation

- 2 groups
- Varying degree of soft tissue damage at time of osteotomy
Soft tissue preservation - Group 1

- 4 rings
- open osteotomy of periosteum, bone, and transection of 1/3 of the marrow diameter
Soft tissue preservation - Group 2

- 4 rings
- Maintain maximum integrity of periosteum, bone marrow, and nutrient vessels
- Osteotomy by closed osteoclasis
- Using tension curved wire to crack cortex
Soft tissue preservation - Results

- Most osteogenesis with least soft tissue damage
- Periosteum most important
- Marrow damage not significant - Kojimoto
Experimental Evidence

- Evaluate optimum conditions for osteogenesis during limb lengthening
- Stability of fixation - effect of rigidity
- Soft tissue preservation
- Direction of traction
- Rate and Frequency of distraction
Experiments - Direction of Traction

- Longitudinal osteotomy
- Gp. 1 through cortex
- Gp. 2 Through cortex & marrow
- Lateral traction
Direction of traction - Results

- Osteogenic activity less in Group 2, where bone marrow had been damaged
Experimental Evidence

- Evaluate optimum conditions for osteogenesis during limb lengthening
- Stability of fixation - effect of rigidity
- Soft tissue preservation
- Direction of traction
- Rate and Frequency of distraction
Experiments - Effects of Rate and Frequency of Distraction

- 120 dogs
- Group 1 - open osteotomy
- Group 2 - closed osteoclasis
- Varying Rates and Frequencies
### Distraction Rates and Frequencies

<table>
<thead>
<tr>
<th>Rate [mm]</th>
<th>No. Steps</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1</td>
<td>1mm/24hrs</td>
</tr>
<tr>
<td>1.0</td>
<td>4</td>
<td>0.25mm/6hrs</td>
</tr>
<tr>
<td>1.0</td>
<td>60 [autodistractor]</td>
<td>0.017mm/24hrs</td>
</tr>
<tr>
<td>0.5</td>
<td>4</td>
<td>0.125mm/6hrs</td>
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<tr>
<td>0.5</td>
<td>60 [autodistractor]</td>
<td>0.0085mm/6hrs</td>
</tr>
<tr>
<td>2.0</td>
<td>4</td>
<td>0.5mm/6hrs</td>
</tr>
</tbody>
</table>
Rate and Frequency - Results 1

- Rate of 0.5mm/day - Premature union
- Rate of 1mm/day in one step - poor bone formation
- Rate of 2mm/day in 4 steps - poor bone formation, gap filled with more fibrous tissue
Rate and Frequency - Results 2

- Optimum bone formation at a rate of 1mm/day with autodistractor
- Most usually distract at 1mm/day over 4 steps
- Closed osteotomy group better at all rates and frequencies
• Fascia, Capillaries, Arterioles, Nerves, ALL developed best at a rate of 1mm/day with the autodistractor

• With the autodistractor histology of the nerve tissues resembled that of developing foetal nerve trunks
Effects of Tension - Stress on Fascia

- 1. Reorientation of collagen network along direction of traction
- 2. Neohistiogenesis - increased fibroblastic activity
1. Recruitment of cells - growth in length of new muscle
2. Addition of sarcomeres to existing cells
For 1st 20% of growth & length - even lengthening of muscle
After 20% greater lengthening at bone distraction site
Between 20% & 25% increased damage to muscle structure
If double bone cuts - no damage until up to 30% lengthening
Effect of Tension - Stress on Peripheral Nerves

- New Schwann cells
- Active myelination
- Ilizarov claimed that tension-stress stimulates tissues to regress to foetal state
- Nerve regeneration under distraction was faster
Conclusions

- New bone [Regenerate] formation is affected by:
  - Stability of fixation
  - Type of osteotomy - degree of damage to bone & soft tissues
  - Location of osteotomy - metaphysis
  - Presence of diastasis between bone ends
  - Latency period
  - Rate of distraction
  - Frequency [Rhythm] of distraction
Conclusions

- Regenerate bone develops without formation of an intermediate cartilaginous layer, similar to intramembranous ossification.
- Minimal soft tissue damage at time of osteotomy - Corticotomy / Compactotony.
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Clinical Applications

- Limb lengthening
- Treatment of non-union
- Bone & soft tissue defects
- Osteomyelitis
- Correct Bony deformity
- Joint contractures
- Limb deformity
- Arthrodesis
- Fractures
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Problems, Obstacles, Complications [Paley]

- **Problems** - Difficulty resolved by non-operative means by end of treatment
- **Obstacles** - Difficulty resolved by operative means
- **Complications** - Difficulty unresolved at end of treatment, minor & major. Goal of treatment not achieved
Problems, Obstacles, Complications [Paley]

- Muscle contractures
- Joint subluxation
- Axial deviation
- Neurologic injury
- Vascular injury
- Premature consolidation
- Delayed consolidation
Problems, Obstacles, Complications [Paley]

- Pin-site problems
- Refracture
- Joint stiffness
- Psychological - loss of appetite, depression
- Chronic pain
- RSD
- Compartment syndrome
- Oedema
Problems, Obstacles, Complications [Paley]

- Rates vary
- DeBastiani - 14%
- Wagner - 45%
- Ilizarov - 5%
- A learning curve
- Up to 80% in some series
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Other Methods

- Hopkins 1889, osteotomy & bone spacer
- Codivilla 1905, osteotomy, plaster cast, traction, change plaster every few days
- Putti 1921, osteotomy, skeletal traction, Osteoton
- Abbott, Carrell, Dickson & Diveley
- Wagner 1970s
- Callotasis - DeBastiani 1987
- Ilizarov variants
Other Methods

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Wagner Technique

- Apply rigid, uniplanar fixator
- Middiaphyseal osteotomy
- Rapid distraction - 1.5mm/day in 1 or 2 increments to desired length
- Following distraction, plate & bone graft the distraction gap
- Remove Fixator
- Remove plate & screws about 18mths later
Other Methods

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Callotasis

- Callotasis means stretching of bony callus (tasis is derived from Greek teino ‘to stretch’)
- Term 1st used by DeBastianini in 1987
- Ideal age for performing callotasis is the period immediately following end of growth (Risser 4-5), although no real age parameters - Aldegheri 1988
- Similar to Ilizarov
DeBastiani - Callotasis Technique

- Apply fixator
- Metaphyseal corticotomy - open, drill holes
- Latency period 10-14 days
- Distract at 1mm/day in 4 increments
- Consolidation phase
DeBastiani - Callotasis Technique

- Any significant deformity or angulation that occurs during lengthening usually requires separate surgery
- Only can be used for distraction or compression
- Good regenerate if half pins used, rather than transfixation wires for lengthening
Other Methods

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Ilizarov Variants

- **Lombardy** - Hoffman half pins in proximal femur & circular frame distally
- **Monticelli-Spinelli** - Addition of ball joints at the point where the rods connect to rings, thicker connecting rods
- **Brive** - Rings tubular in cross section, springs to maintain uniform tension
- **Rancho** - Titanium half pins
The Ilizarov Technique

- Bone and soft tissues can be made to regenerate in a controlled, reliable, and reproducible manner.
- Regenerated bone resembles intramembranous ossification, no intermediate cartilaginous phase.
- Confirmed by Tajana in humans by taking biopsies from patients undergoing lengthening.
Thank You