Biomechanical Comparison Of Spatial Frames With Different Strut Models And Ilizarov Type External Fixators

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(The Smart Correction® Computer-Assisted Circular External Fixator System)
Background of Ilizarov and Hexapod

• Ilizarov and Spatial Circular ExFix (CEF) used same indication
  – First generation – Ilizarov
  – Second generation – Taylor’s Spatial Frame (TSF), Smart Correction (SC) act.

• Main differences:
  – Connection devices between rings (threaded rods, hinges, translation device vs. Six oblique struts)
  – Angulation, rotation and translation simultaneously
Background of Strut Models

• Initial models contain double universal joint and classic body
  (TSF Standard Telescopic Strut / SC Dual Joint Strut)
Background of Strut Models

• Fast fracture reduction
  
  (TSF FastFx Strut / SC Dual Joint Express Strut)
Background of Strut Models

• Ball and socket joint for fast strut change and three axis motion

(SC Dual Varijoint Strut and Dual Varijoint Express Strut)
Comparison of Ilizarov and Spatial Fixators

• Questions:
  – How do the connection units (rod vs. strut) change the biomechanical performance of first and second generation CEF?
  – How do strut models which contain different joint and body design, affect the biomechanics of hexapod system?

• However, in the literature, there is no biomechanical comparison of this parameters
Biomechanical Characteristics

Conformational Instability of the Taylor Spatial Frame
A Case Report and Biomechanical Study

Eric R. Henderson, MD,* David S. Feldman, MD,† Craig Lusk, PhD,‡ Harold J. van Bosse, MD,† Debra Sala, MS, PT,‡ and Frederick J. Kummer, PhD‡

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• Ring strut angle most important parameter

➢ > 30° axial lowest displacement (axial central load)
➢ 25 to 40° lowest, 65 to 70° greatest bending displacement
➢ Torsional displacement similar to bending
Aim

• Comparison of the biomechanical performances between four different strut models which are used in hexapod spatial frame and Ilizarov threaded rods with identical frame height
Methods

• Frames
  – Single ring blocks
  – Equal height
  – Parallel rings
  – Bone model fixed center axis of the rings
  – Fixation levels were identical
Methods

- Hexapod spatial fixator groups: Medium size one type of four strut models used each group

<table>
<thead>
<tr>
<th>Group</th>
<th>Struts</th>
<th>Functional Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td><strong>Dual Joint Strut</strong></td>
<td>175 mm</td>
</tr>
<tr>
<td>Group 2</td>
<td><strong>Dual Joint Express Strut</strong></td>
<td>175 mm</td>
</tr>
<tr>
<td>Group 3</td>
<td><strong>Dual Varijoint Strut</strong></td>
<td>170 mm</td>
</tr>
<tr>
<td>Group 4</td>
<td><strong>Dual Varijoint Express Strut</strong></td>
<td>170 mm</td>
</tr>
</tbody>
</table>
Methods

• Hybrid Ilizarov type fixators:
  – Four threaded rods
    Stainless-steel, 6 mm DIA, 220 mm length
Methods

• Rings:

  180 mm inner diameter

  Dual hole full ring

  Holes numbered 1 to 42

  Aluminium
<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual joint strut</td>
<td>Dual joint express strut</td>
<td>Dual varijoint strut</td>
<td>Dual varijoint express strut</td>
<td>Rod - Ilizarov</td>
</tr>
</tbody>
</table>
Methods

• Bone Model:

Cylindrical Polyethylene (PE)

  Elastic modulus 850 Mpa
  Density 0,95 g/cm³
  Length 350 mm
  Diameter 30 mm
Methods

- **Fixation devices:**
  - Half pins
    - 6.0mm DIA, 150 mm shank
    - 30 mm threaded, Ti
  - K wire
    - 1.8 mm DIA
    - Stainless-steel
  - Cubes, 2 hole
  - Pin Clamps
  - Bolts
  - Nuts
Methods

PE models fixed centre axis of the rings
Methods

Fixation guides
Methods

• Proximal ring block

2 Half-pins and a K-wire (tightly 125 kg)
Methods

• Distal ring block

3 Half-pins
Methods

• Gap zone: 30 mm (equal distance to both rings)
Methods

• 15 frames prepared for each group
• 3 separate tests:
  – Axial loading
  – Four point bending
  – Tortion
• 5 frames from each groups used for each test
• Non of frame did not used more than a test
### Methods

<table>
<thead>
<tr>
<th>Group</th>
<th>AL (n)</th>
<th>Bend. (n)</th>
<th>TL (n)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Group 2</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Group 3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Group 4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Group 5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>

**Legend:**
- AL (n): Aluminum
- Bend. (n): Bend
- TL (n): Total Length
Methods

MTS 858 Mini Bionix® II Biomaterial Testing System
Methods

3-Dimensions Digital Imaging Correlation (3D DIC)
Methods

• Axial Loading Test
  – Frame adapted to MTS by pots
  – Paper containing high contrast pattern (HCP) aligned to 15-16 numbered holes anteriorly
Methods

- **Axial Loading Test**

  - **Initial loading**
  
    Between 0-300 N at 2 Hertz for 10 times (Force control)

  - **Cyclic loading**
  
    Between 0-300 N at 2 Hertz for 1000 times x 10

G3A3 video
Methods

• Axial Loading Test

After every 1000 cycle stiffness values (linear regression) and gap site displacements (vertical - y, horizontal - x and anteroposterior - z) were calculated.
Methods

- Four Point Bending Test
  - Support platform and the fork apparatus for load transmission
  - Papers containing HCP aligned to 28-29 numbered holes
Methods

• Four Point Bending Test
  – Bending moment just applied one plane (oblique) to the bar between 36-37 numbered holes
  – Hexagonal diamond shape structure
Methods

• Four Point Bending Test

  – Initial loading
  Between 0-300 N at 2 Hertz
  for 10 times (Force control)

  – Cyclic loading
  Between 0-300 N at 2 Hertz
  for 1000 times x 10

G2B2 video
Methods

- Four Point Bending Test
  After every 1000 cycle stiffness (linear regression) and gap site angle of bending ($\alpha$ angle) were calculated.
Methods

• **Torsional Loading Test**

  Fixators placed to MTS

  similar to axial loading test
Methods

• Torsional Loading Test
  – Initial loading
  Between 0.5-10 Nm at 2 Hertz for 10 times (Force control)
  – Cyclic loading
  Between 0.5-10 N at 2 Hertz for 1000 times x 10

G4T1 video
Methods

- Torsional Loading Test
  After every 1000 cycle stiffness (linear regression) and gap site angle of rotation (β angle) were calculated.
Statistical Analysis

• SPSS (Statistical Package for the Social Sciences) 15.0 for Windows

• One-way analyses of variance (ANOVA) with a significance level of 0.05
  – If warranted, post hoc multiple comparisons were made with Tukey’s range test between groups

• Paired Samples Test with a significance level of 0.05
  – Used to compare repeated measurements of every thousands cycles for within each group
Results (Axial Loading)

Axial Loading Mean Stiffness Values - Cycle Graph

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10,000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>70.2 ± 7.9</td>
<td>71.3 ± 8.5</td>
</tr>
<tr>
<td>G 2</td>
<td>76.8 ± 3.5</td>
<td>77.5 ± 4.8</td>
</tr>
<tr>
<td>G 3</td>
<td>75.1 ± 5.5</td>
<td>76.0 ± 5.4</td>
</tr>
<tr>
<td>G 4</td>
<td>75.0 ± 2.4</td>
<td>77.4 ± 3.3</td>
</tr>
</tbody>
</table>
| G 5   | 96.2 ± 3.6     | 95.85 ± 3.3     | *(p<0.05)*
Results (Axial Loading)

Y – Direction Mean Displacement - Cycle Graph

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10.000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>4,4 ± 0,5</td>
<td>4,3 ± 0,5</td>
</tr>
<tr>
<td>G 2</td>
<td>4,0 ± 0,2</td>
<td>4,0 ± 0,2</td>
</tr>
<tr>
<td>G 3</td>
<td>4,0 ± 0,3</td>
<td>4,0 ± 0,3</td>
</tr>
<tr>
<td>G 4</td>
<td>4,0 ± 0,1</td>
<td>3,9 ± 0,2</td>
</tr>
<tr>
<td>G 5</td>
<td>3,0 ± 0,1</td>
<td>3,1 ± 0,1</td>
</tr>
</tbody>
</table>

(p<0,05)
Results (Axial Loading)

X – Direction Mean Displacement - Cycle Graph

<table>
<thead>
<tr>
<th></th>
<th>1000 cycle</th>
<th>10.000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>0.8 ± 0.3</td>
<td>0.9 ± 0.2</td>
</tr>
<tr>
<td>G 2</td>
<td>1.1 ± 0.2</td>
<td>1.1 ± 0.2</td>
</tr>
<tr>
<td>G 3</td>
<td>1.1 ± 0.04</td>
<td>1.1 ± 0.02</td>
</tr>
<tr>
<td>G 4</td>
<td>1.1 ± 0.1</td>
<td>1.1 ± 0.1</td>
</tr>
<tr>
<td>G 5</td>
<td>0.4 ± 0.1</td>
<td>0.4 ± 0.1</td>
</tr>
</tbody>
</table>

(p<0.05)
Results (Axial Loading)

Z – Direction Mean Displacement - Cycle Graph

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10.000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>0.3 ± 0.1</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>G 2</td>
<td>0.4 ± 0.1</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>G 3</td>
<td>0.4 ± 0.1</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>G 4</td>
<td>0.4 ± 0.1</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>G 5</td>
<td>0.1 ± 0.1</td>
<td>0.2 ± 0.1</td>
</tr>
</tbody>
</table>

(p<0.05)
Results (Bending)

Four Point Bending Mean Stiffness - Cycle Values

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10,000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>182.7 ± 11.4</td>
<td>188.0 ± 11.2</td>
</tr>
<tr>
<td>G 2</td>
<td>199.9 ± 27.9</td>
<td>210.3 ± 36.4</td>
</tr>
<tr>
<td>G 3</td>
<td>207.5 ± 5.2</td>
<td>206.3 ± 15.2</td>
</tr>
<tr>
<td>G 4</td>
<td>207.3 ± 21.3</td>
<td>210.6 ± 20.5</td>
</tr>
</tbody>
</table>
| G 5   | 267.7 ± 13.6     | 277.3 ± 25.6      | *(p<0.05)*
Results (Bending)

Mean $\alpha$ - Angle of Bending - Cycle Graph

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10.000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>5.1 ± 0.7</td>
<td>4.9 ± 0.6</td>
</tr>
<tr>
<td>G 2</td>
<td>4.5 ± 0.3</td>
<td>4.4 ± 0.3</td>
</tr>
<tr>
<td>G 3</td>
<td>4.6 ± 0.2</td>
<td>4.5 ± 0.2</td>
</tr>
<tr>
<td>G 4</td>
<td>4.6 ± 0.2</td>
<td>4.4 ± 0.3</td>
</tr>
<tr>
<td>G 5</td>
<td>3.3 ± 0.4</td>
<td>3.2 ± 0.3</td>
</tr>
</tbody>
</table>

(p<0.05)
Results (Torsion)

Torsional Loading Mean Stiffness - Cycle Values

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10,000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>3139,7 ± 124,7</td>
<td>3219,6 ± 291,7</td>
</tr>
<tr>
<td>G 2</td>
<td>3100,8 ± 152,7</td>
<td>3016,4 ± 136,1</td>
</tr>
<tr>
<td>G 3</td>
<td>3165,8 ± 209,9</td>
<td>3083,4 ± 242,9</td>
</tr>
<tr>
<td>G 4</td>
<td>3092,8 ± 199,0</td>
<td>3026,2 ± 105,7</td>
</tr>
<tr>
<td>G 5</td>
<td>2551,7 ± 224,7</td>
<td>2473,6 ± 150,1</td>
</tr>
</tbody>
</table>

(p<0.05)
Results (Torsion)

β – Angle of Rotation - Cycle Graph

<table>
<thead>
<tr>
<th>Group</th>
<th>1000 cycle</th>
<th>10,000 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>0.9 ± 0.1</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>G 2</td>
<td>0.9 ± 0.2</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>G 3</td>
<td>0.9 ± 0.1</td>
<td>0.9 ± 0.03</td>
</tr>
<tr>
<td>G 4</td>
<td>1.0 ± 0.2</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>G 5</td>
<td>1.2 ± 0.2</td>
<td>1.2 ± 0.2</td>
</tr>
</tbody>
</table>

(p<0.05)
Conclusion

• Different strut models which have different joint and body combination, do not change about
  – Axial, torsional and bending stability of SF
  – Gap zone movements of SF

• No superiority to each other as mechanically
Conclusion

• Using four threaded rods instead of hexapod struts
  – Increasing axial and bending stability
  – Decreasing torsional stability
  – Gap zone movements compatible with stability
    • Axial movement decreases (directed vertical, horizontal and anteroposterior)
    • Bending angulation decreases
Conclusion

• Four threaded rods vs. six struts
  – Less number
  – Greater stability of axial and bending
    • Force vector creates rotational moment at the level of joints
    • Requiring longer functional size of strut causes bending
  – Lesser gap zone movement
    • Clinical significance ???
    • Needed experimental animal study / histological investigation
Home Message

• According to the our study
  – Using different strut models do not change biomechanical performance of hexapod CEF
  – Transformation of spatial fixator to Ilizarov via four threaded rods improves axial and bending stability however, decreases torsional stability
  – Better during consolidation !?