OSSTF-Target 3

Junctional failure prevention

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Adjacent level failure

01
Proximal junctional kyphosis (PJK)
Is characterized by increased kyphosis at the upper instrumented vertebra segment
(Glatter Spine 2005)

02
Proximal junctional failure (PJF)
Is the next step that usually requires surgery
Proximal junctional kyphosis

- Radiographic finding with $>10^\circ$ increase of vertebral body kyphosis
- Short-term complication of adult spinal deformity (ASD) surgery
- Not always symptomatic and does not always require additional surgery
Proximal junctional failure

- Clinical presentation with pain, deterioration of balance, and neurological impairment
- Short- to mid-term complication after ASD surgery
- More surgery frequently necessary
Risk factors

- Fixation length
- Sagittal alignment
- Poor bone health
- High BMI
- Age
Fixation length

Proximal junctional kyphosis and proximal junctional failure are common problems after long-segment (>5 levels) thoracolumbar instrumented fusions in the treatment of ASD.
Sagittal alignment

Multifactorial issue, but

Flatback with decrease of **pelvic incidence minus lumbar lordosis (PI-LL) and pelvic tilt (PT)**
→ significantly higher risk of PJK
Flatback with increase of **thoracic kyphosis (TK)**
→ significantly higher risk of PJK
Preventing PJK and PJF

Evaluation of stresses in the upper adjacent levels by preoperative finite element analysis of the future instrumentation

Initial set-up and experience by Osmar JS de Moraes (Sao Paulo)
Construction of geometric models

- Computed tomography images imported into Mimics software (Materialise, Belgium)
- Vertebral bodies segmented according to the different gray-scale values of the vertebral bone and surrounding tissue
- 3D reconstruction using 2D imaging data of the segmented vertebral bodies to produce T1-S1 3D geometric models
Reconstructed Model of T1-S1

+ Ribcage, ligaments, and discs
## Material properties used in the model

<table>
<thead>
<tr>
<th>Component</th>
<th>Young's modulus, MPa</th>
<th>Poisson's ratio</th>
<th>Cross-section, mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>12,000</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>100</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>End plate</td>
<td>3,000</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Anterior longitudinal</td>
<td>15</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Posterior longitudinal</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Ligamentum flavum</td>
<td>8</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Interspinous</td>
<td>10</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Ligamentum flavum</td>
<td>15</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Intertransverse</td>
<td>10</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Capsular</td>
<td>7.5</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Nucleus pulposus</td>
<td>1.0</td>
<td>0.499</td>
<td></td>
</tr>
<tr>
<td>Annulus fiber</td>
<td>4.2</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Fusion mass (Ti)</td>
<td>110,000</td>
<td>0.28</td>
<td></td>
</tr>
</tbody>
</table>
Young’s modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material.
Poisson’s Ratio = \frac{Lateral Strain}{Longitudinal Strain}
Stresses at upper end of different constructs

Example of top ending of construct
Selection of nine fusion models and comparison of the maximum von Mises stresses on the pedicle screw

<table>
<thead>
<tr>
<th>Fusion model</th>
<th>Max. screw stress, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2-L5 fusion</td>
<td>106.50</td>
</tr>
<tr>
<td>T4-L5 fusion</td>
<td>48.14</td>
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<tr>
<td>T10-L5 fusion</td>
<td>45.50</td>
</tr>
<tr>
<td>T11-L5 fusion</td>
<td>44.68</td>
</tr>
<tr>
<td>T12-L5 fusion</td>
<td>42.66</td>
</tr>
<tr>
<td>L1-L5 fusion</td>
<td>49.97</td>
</tr>
<tr>
<td>L2-L5 fusion</td>
<td>48.71</td>
</tr>
<tr>
<td>L3-L5 fusion</td>
<td>47.59</td>
</tr>
</tbody>
</table>
Opportunities using construction of geometric models

- New materials for reinforcement
- Expandable screws
- Local measure of pressure/axial load using cheap chips
- Mechanical models suitable for clinical practice
Next steps

Proposal by Osmar de Moraes

Feasible technique, not expensive and reproducible in ASD surgery group

• Build a tool to prevent PJF? Customized? Algorithm planning? Better construction/screws/anterior support size?
Surgical strategy

No specific surgical strategy has definitively shown to lower the risk of PJF as the result of a multifactorial etiology.

Different technical options:

• Rod stiffness
• Prophylactic polymethylmethacrylate (PMMA) augmentation
• Bands, tethers, and ligaments
• Soft-landing solutions
Rod stiffness

The use of CoCr rods is effective in ensuring stability of the posterior spinal construct and accomplishment of spinal fusion. Furthermore, results indicate that junctional kyphosis may occur more frequently in CoCr systems than in Ti systems.

Increasing the rod stiffness by using CoCr rods can prevent rod breakage but adversely affect the occurrence and the time of PJK.
Prophylactic PMMA cement augmentation

- Aim is to decrease the incidence of PJK and PJF in patients treated with prophylactic PMMA cement augmentation at the uppermost instrumented vertebrae (UIV) and rostral adjacent vertebrae (UIV+1)
- Is one of the most popular solutions today
- Needs cannulated and perforated screws
- Drawback—PMMA leaks
Upper level PMMA supplementation

- Stent
- Vertebroplasty
- Kyphoplasty
Bands tethers ligaments

Sublaminar band placement has been suggested as a possible technique to prevent PJK and PJF but carries the theoretical possibility of a paradoxical increase in these complications as a result of the required muscle dissection and posterior ligamentous disruption.
Soft-landing solutions

Aim
Avoid excessive stress at the instrumentation level upper part of the construct and at the non-instrumented upper levels

Solutions
- Less rigid rods
- Change of rod diameter at upper part of instrumentation
- Flexible device at upper part of instrumentation
Two different diameter rods at the upper level

Option 1:
3.5 mm diameter proximal Ti rod instrumentation and 5.5 mm thoraco lumbar rod instrumentation connected with dominos end-to-end or lateral/lateral
Two different diameter rods at the upper level

Option 2:
Rod with two different diameters
3.5–5.5 mm
Upper levels flexible devices

Option 1:
Cable
Upper levels flexible devices

Option 2: Bumper
Other flexible devices