Biomechanics of THA Dislocation

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Rationale for Study

- 250,000 THA’s per year
- 2nd leading cause of failure
- 2 - 11% primary cases
- 4 - 25% revision cases
- $75M per year (Morrey, 2000)
- Pain, Incapacitation
Clinical Studies

- Registries
- Limited statistical power
- Conflicting conclusions

- Malposition of cup
- Empirical “safe-zone”
  - 30-50° Tilt & 5-25° AV (Lewinnek et al., 1978)

- Factorial associations, but not actual mechanisms
Experimental

• Cadaveric studies
• Limited observation variables
• Small sample size (statistical power)
• Mainly ROM studies

• Need to examine local deformation and characterize dislocation mechanics
Computational

- $n=1$
- Efficient parametric studies
  - Design
  - Orientation
  - Motion Challenge
- Local deformation & stress
- Many outcome measures (ROM, resistance)

- Historically simplified (model, formulation)
Acetabular Cup:
- Duraloc 22 - 52mm
- Ti shell
- UHMWPE liner

Femoral Component:
- Endurance stem
- 22mm modular head
- CoCr Alloy

DePuy, Inc.
**Software**
- PATRAN 8.5 - IGES
- ABAQUS 5.8

**Acetabular Cup**
- Bonded between UHMWPE liner & Ti shell
- 3920 brick elements

**Femoral Component**
- $E_{\text{CoCr}} \gg E_{\text{liner}}$
- Rigid Bezier surface
Physical Validation

![Graph showing resisting moment vs. angle with experimental and FEA data]
Kinematic and Kinetic Input

• 10 healthy subjects (5 male / 5 female)
  • Age (yrs): 49.7 ± 4.97 (44 - 59)
  • Height (m): 1.71 ± 0.14 (1.50 - 1.96)
  • Mass (kg): 77.3 ± 23.8 (40.9 - 122.7)

• Optotrak

• Pelvic reference frame

• Recessed force plate
7 Maneuvers Tracked

SSN / SSL

XLG

TIE

46 / 39 cm
STOOP

PIVOT

ROLL

ROLL
Kinematic Data

- Cardan angles
  - Flexion
  - Adduction
  - Endorotation

Kinetic Data

- 47-muscle inverse dynamics model
- Temporally varying load vector
The graph represents the relationship between flexion angle (in degrees) and resisting moment (in Newton meters, Nm). Key points on the graph include:

- **Peak Resisting Moment**: Occurs at approximately 100 degrees flexion angle, with a resisting moment of around 9 Nm.
- **Impingement**: Begins at about 90 degrees flexion angle and continues to increase until the peak is reached.
- **Subluxation Regime**: Begins after the peak and continues until a flexion angle of 115 degrees, where the moment begins to decrease.
- **Hooking**: Begins after the subluxation regime and continues until dislocation occurs at 120 degrees flexion angle.
- **Dislocation**: Occurs after hooking, indicating a significant increase in resisting moment.

The graph illustrates the dynamic changes in resisting moment as the flexion angle increases, highlighting critical stages such as impingement, subluxation regime, and dislocation.
UHMWPE Stresses

<table>
<thead>
<tr>
<th>von Mises (MPa)</th>
<th>VMES (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>1.52</td>
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</tr>
<tr>
<td>3.02</td>
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<tr>
<td>4.51</td>
<td>4.51</td>
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<tr>
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</tr>
<tr>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>33.6</td>
<td>33.6</td>
</tr>
</tbody>
</table>

Impingement Site

Egress Site

Stable Articulation

Incipient Dislocation
Influence Factors

Femoral Component Anteversion

Head Size
Head/Neck Ratio

Leg Cross, Rise-from-Seat, Stooping, Shoe-Tying
Pivot, Bed-Rollover

Metal Backing
Polyethylene Liner

Tilt
Anteversion

Z
Y
X

d
θ
b
Femoral Anteversion Effect

Average 0.4° more flexion per degree of femoral anteversion
Dislocation Resistance Improvement

Erectly Seated Leg Crossing

Anteversion (deg)

<table>
<thead>
<tr>
<th>Anteversion (deg)</th>
<th>Inclination (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>0.9%</td>
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<tr>
<td></td>
<td>0.27°</td>
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<tr>
<td></td>
<td>6.4%</td>
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<tr>
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<td>2.9°</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>3.7%</td>
</tr>
<tr>
<td></td>
<td>3.9°</td>
</tr>
<tr>
<td></td>
<td>9.3%</td>
</tr>
<tr>
<td></td>
<td>7.3°</td>
</tr>
<tr>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>10.2%</td>
</tr>
<tr>
<td></td>
<td>12.3°</td>
</tr>
<tr>
<td></td>
<td>16.7%</td>
</tr>
<tr>
<td></td>
<td>16.1°</td>
</tr>
<tr>
<td></td>
<td>23.2%</td>
</tr>
<tr>
<td></td>
<td>20.6°</td>
</tr>
</tbody>
</table>
Head Size Variation
(Constant H/N Ratio)

Head/Neck Ratio Variation
(Constant Head Size)
Design Trade-Offs
## Finite Element Results

<table>
<thead>
<tr>
<th>Maneuver</th>
<th># of Trials</th>
<th># of Dislocations</th>
<th>% of Trials Dislocating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Sit-to-Stand</td>
<td>47</td>
<td>41</td>
<td>87</td>
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<tr>
<td>Normal Sit-to-Stand</td>
<td>55</td>
<td>33</td>
<td>64</td>
</tr>
<tr>
<td>Tie</td>
<td>69</td>
<td>31</td>
<td>45</td>
</tr>
<tr>
<td>Leg Cross</td>
<td>64</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>Stoop</td>
<td>42</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Post. Disloc. Maneuvers</td>
<td>277</td>
<td>133</td>
<td>48</td>
</tr>
<tr>
<td>Pivot</td>
<td>58</td>
<td>23</td>
<td>40</td>
</tr>
<tr>
<td>Roll</td>
<td>19</td>
<td>12</td>
<td>63</td>
</tr>
<tr>
<td>Ant. Disloc. Maneuvers</td>
<td>77</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td><strong>Overall Series</strong></td>
<td><strong>353</strong></td>
<td><strong>168</strong></td>
<td><strong>47</strong></td>
</tr>
</tbody>
</table>
Summary (Placement)

• Femoral Anteversion
  – $\uparrow$ ROM but not resistance

• Acetabular Tilt & Anteversion
  – $\uparrow$ ROM and Resistance

  …. Posterior Dislocations
Summary (Design)

• Head Size ↑ Resistance

• H/N ↑ ROM

• Acetabular: ROM / Resistance Trade-off
  – Inset, Chamfer Angle, Lip Width
Summary (Patient Motions)

- Posterior vs. Anterior Dislocations
  - Similar average risk (48-45%)
  - Posterior maneuvers more frequent?

- Wide variability of risk: 14 - 87%

- Highest risk:
  - Rising from low seat (87%)
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