Patient Specific Modeling of Stage II Flatfoot Deformity Before & After Surgery

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Patient Specific Modeling of Stage II Flatfoot Deformity Before & After Surgery

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My disclosure is in the Final AOFAS Program Book. I have a potential conflict with this presentation due to:

CW Hayes: “Board member/ committee appointments for a society”
JS Wayne: “Other financial or material support from a company or supplier;
           “Board member/ committee appointments for a society”
RS Adelaar: “Board member/ committee appointments for a society”
Introduction

• Adult Acquired Flatfoot Deformity (AAFD)
  – Chronic & degenerative disease characterized by loss of normal arch function
  – Often secondary to PTT dysfunction
  – Causes static stretching of medial support structures of the arch, namely:
    o spring, talocalcaneal interosseous, fibers of the anterior deltoid, & long /short plantar ligaments
  – Presents clinically as a drop in medial longitudinal arch, forefoot abduction, & hindfoot valgus as well as significant pain & dysfunction

• Competing surgical treatments should be tailored to the individual patient’s presentation

Objective

Develop and validate a patient specific computational model to describe foot/ankle function preoperatively and predict outcome of surgical correction
Study Design & Imaging

• With IRB approval, lower leg & foot of a 64yo ♀ imaged with MRI & X-ray
  – Pre-Op:
    1. 1.5T MRI using a T2 SPGR fat-saturated sequence, yielding 0.7mm³-isovolumetric scan
    2. Weight-bearing single-leg X-rays in the ML & oblique AP planes; Hindfoot photos
  – Post-Op:
    1. Weight-bearing single-leg X-rays in the ML & oblique AP planes; Hindfoot photos

• All bony tissue was isolated and extrapolated from the MRI scans, then triangulated to yield accurate patient-specific anatomy
Model Setup & Testing

- Full body weight axial load
- All ligaments of the foot & ankle included as tensile vectors
- Muscle loading included as ratios of body weight according to Thordarson et al.\textsuperscript{6}
  - Achilles = 50% BW
  - FHL = 10% BW
  - FDL = 6% BW
- Specific ligaments associated with AAFD were evaluated through MRI by CWH\textsuperscript{†} & graded according to a scale of attenuation proposed by Deland et al\textsuperscript{1-3}.

<table>
<thead>
<tr>
<th>Ligament of Interest</th>
<th>Grade\textsuperscript{†}</th>
<th>Stiffness Attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuperoMedial Spring</td>
<td>1</td>
<td>25.0%</td>
</tr>
<tr>
<td>InferoMedial Spring</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Anterior Deltoid</td>
<td>1</td>
<td>25.0%</td>
</tr>
<tr>
<td>Posterior Deltoid</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Deep Deltoid</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>TaloCalcaneal Interosseous</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Plantar Fascia</td>
<td>1</td>
<td>25.0%</td>
</tr>
</tbody>
</table>
1. PTT augmentation by FHL transfer through bony tunnel in the navicular

2. 5mm Medializing Calcaneal Osteotomy (MCO or ‘Slide’ Osteotomy) Fixed with cancellous screw
Validation Against Patient Radiographs

- 6 angular measures used to evaluate AAFD recorded for pre- & post-Op
  - ML ($\theta_1$-$\theta_3$)
    1. calcaneal pitch (ML-CP)
    2. talo-1st metatarsal (ML-T1MT)
    3. talocalcaneal angle (ML-TC)
  - Oblique AP ($\theta_4$, $\theta_5$)
    4. talo-1st metatarsal angle (AP-T1MT)
    5. talo-navicular coverage (AP-TN)
  - Hindfoot ($\theta_6$)
    6. PA hindfoot valgus (PA-HFV)

- Model compared to patient data as well as AAFD population averages
  - Coughlin & Kaz\textsuperscript{7}
  - Krans et al.\textsuperscript{8}
  - Murley et al.\textsuperscript{9}
Results:
Model to Patient Comparisons

- **Pre-Op**
  - All but 1 angle within 5°
- **Post-Op**
  - all measures within <5°

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- Patient angles within 6.5° of published AAFD averages

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![Graph showing model and patient comparisons for various angles with data points and error bars.](graphic)
Conclusions

• A patient-specific flatfoot model was faithfully recreated *in silico*
• Foot and ankle biomechanical function was dictated solely by:
  – 3D articular anatomy
  – Ligaments
  – Muscle loading
  – & Body weight
• Model predictions of joint angles were very similar to patient radiographs & correctly predicted changes due to surgical treatment

Future Work

• Future investigations can be used to assess changes in biomechanical factors such as articular contact force / location or ligament strain as a means of predicting future patient outcome
• Additionally, these models could investigate new devices or surgeries in order to better tailor patient treatment


