EVALUATION OF THE TRANSVERSE METATARSAL ARCH OF THE FOOT

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INTRODUCTION

The existence of the transverse metatarsal arch (TMA) of the foot is controversial, with some researchers [1, 2, 3] historically describing either an arch, or a foot that rests on the floor on the heel, 1st and 5th metatarsal heads. Biomechanically, this configuration has been considered to be a shock absorber. More recently – largely due to the emergence of pressure measurement technologies – researchers have disputed the arch concept by showing that during gait the highest pressures are found at the 2nd-3rd metatarsal heads (MTH’s) and the heel in midstance [4]. According to these researchers, there cannot be a “tripod” if there are no significant pressures under the 1st and 5th MTH’s.

In this study, we developed a model that could reconcile both the existence of a TMA and the fact that pressure values can be elevated under the 2nd and 3rd MTH’s.

METHODS

A 2D finite element (FE) model was prepared in Abaqus 6.13 based upon a simplified cross-sectional view of the foot at the metatarsal heads (Figure 1). The considered model includes two beams having the mechanical properties of bone tied together at the apex and free to slide horizontally at the medial and lateral edges of the foot.

The triangular free space between these two beams was filled with an elastic material representing soft tissue. Material properties used for different parts are listed in Table1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Young’s Modulus (MPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone Beams</td>
<td>1750</td>
<td>7300</td>
<td>0.3</td>
</tr>
<tr>
<td>Soft Tissue</td>
<td>1050</td>
<td>2000</td>
<td>0.33</td>
</tr>
<tr>
<td>Ground</td>
<td>7800</td>
<td>200,000</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Fillets were applied at all edges of the soft interior portion of the model in order to avoid excessive distortions. The coefficient of friction between the soft triangle and ground was set 0.5 [5]. Moreover, the angled sides of the soft tissue were tied to the beams leading to ensure no relative movement. A 10 mm vertical displacement was applied to the apex for observing the effect of applying bodyweight to the forefoot. Boundary conditions were established by setting the lower horizontal surface of the rectangular modeled ground to have no displacement or rotation in any direction. Furthermore, the beam ends in contact with the ground were constrained to translate only in the horizontal (medio-lateral) direction.

Meshing involved using beam elements for the “bone” structures and plane stress elements for soft tissue and ground since the assumed cross section with a small thickness would have negligible stresses in the perpendicular direction. Finally, the conducted analysis was modelled as Dynamic-Explicit. Of note is the fact that for quasi-static problems, Dynamic-Explicit analysis requires attention to the static status of the problem during
the iterative modelling process. Accordingly, the values of internal and kinetic energies were compared throughout the loading process. Finally, in order to verify the meshing process, a convergence study was performed to assess the influence of element sizes.

RESULTS AND DISCUSSION

The model was assessed and found to exhibit consistently lower magnitude of kinetic energy in comparison with internal energy. This implies the model was acceptable from a quasi-static point of view.

The convergence validation showed that predicted pressures at the ground-foot interface changed by only 1% when the elements were increased by a factor of four (i.e., from 2mm to 0.5mm). These results supported the decision to select elements 1mm in size.

The primary finding of this study is that the model showed that pressures can be elevated in the MTH2 and MTH3 regions – simply by virtue of the fact that as the arch flattens, the soft tissue is compressed in a matter that leads to pressure build-up in the central forefoot region (Figure 2).

CONCLUSIONS

This study has shown that a “controversy” in whether or not there is a transverse arch can be reconciled through the use of a simple model. What the model shows is that pressures can be elevated in MTH2 and MTH3 regions even when there is a bony “tripod” made up of osseous elements within the foot. The fact that loads may be distributed through the calcaneus and 1st and 5th rays may not be at odds with elevated pressures in the central forefoot region.

REFERENCES


Figure 2: Results showing elevated pressures at the foot-ground interface at the MTH2 and MTH3 region. Mesh Size: 1 mm, maximum MTH pressure = 309 Pa