Bilateral Symmetry, Sex Differences, and Primary Shape Factors in Ankle Bone Morphology

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Introduction

Background
• Over 35,000 foot and ankle fractures or dislocations occur per year in the US.
• Functional outcomes after traumatic ankle injury and ankle arthroplasty are poor
• Poor outcomes may be related to failure to restore native ankle bone morphology.

Aims
• (1) Determine side-to-side differences (SSD) in ankle bone morphology, (2) identify differences between males and females, and (3) identify the bone shape factors that are associated with variability in ankle bone morphology among individuals.

Hypotheses
• (1) Ankle bones are symmetric, (2) male ankle bones are larger than female bones, and (3) shape variability is primarily due to bone size and bony prominences.

Methods

Data Collection
• 20 healthy individuals (age 30.7±6.3 years; 10 Males: avg. BMI 24.2, height 179.2 cm, weight 171 lbs; 10 Females: avg. BMI 23.9, height 165.2 cm, weight 144 lbs) with no history of major ankle injury or surgery were imaged using computed tomography (CT) from 10 cm above the ankle joint down through the toes with an average voxel size of 0.63 mm x 0.63 mm x 1.25 mm.

Data Processing and Analysis
• 3D surface models of each distal tibia, talus, and calcaneus were created (Materialise, Luven, Belgium).
• Corresponding surface nodes were identified on each bone model (Figure 1).

Results

Table 1: Symmetry in Ankle Bone Morphology. There were no significant SSD’s in ankle bones.

<table>
<thead>
<tr>
<th>Bone</th>
<th>Average SSD (mm)</th>
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<tbody>
<tr>
<td>Tibia</td>
<td>0.76 ± 0.31</td>
</tr>
<tr>
<td>Talus</td>
<td>0.76 ± 0.29</td>
</tr>
<tr>
<td>Calcaneus</td>
<td>0.79 ± 0.32</td>
</tr>
</tbody>
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Figure 1: Work flow for generating bone models with corresponding points. A) An average bone model, comprised of 4000 evenly distributed surface nodes, was created based upon all 40 3D surface models. The average bone model was non-rigidly registered to each individual bone model, B) resulting in bone models with the geometry of the individual bone and corresponding surface points across individuals.

Figure 2: Sex Differences in Ankle Bone Morphology. The average male tibia was larger than the average female tibia in the most medial and lateral portions of the bone. The average male and female talus were within a voxel size of each other (0.49 mm). The average female calcaneus was longer (~2mm) and thinner (~3 mm) than the average male calcaneus.

Figure 3: Average Bones and ±3 SD of the Primary Shape Factor. Variability in the Tibia was focused in the overall length of bone (45.4% variability), the size of medial malleolus (11.6%), and the shape of tibia shaft (8.9%). Variability in the Talus was due to the length of the talar neck and height of the talar dome (20.9%), concavity of the talar dome (13.9%), and prominence of the posterior process (11.1%). Calcaneus variability was due to length and height (23.6%), and the size of anterior process (12.4%), the size of sustentaculum tali and peroneal tubercle (11.9%).

Discussion

Main Findings
• Symmetry: Ankle bones are generally symmetric within an individual.
• Sex Differences: Tibia: males are larger overall; Talus: similar in size; Calcaneus: Longer in females, wider in males.
• Shape Variability: The primary shape differences were related to bone size and bony prominences.

Clinical Significance
• In patients with ankle trauma, the contralateral ankle can serve as an accurate guide for restoring ankle morphology. Knowing that the talar dome height and concavity are two of the primary factors that vary among individuals suggests that replicating patient-specific talar dome morphology is important if ankle prostheses are to restore native anatomy.

References and Acknowledgements


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