TITLE: Smartmesh: An Automatic 3D Meshing Algorithm for Tibiotalar Joint FEA

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INTRODUCTION: Accurate mesh generation for 3D assessment, including Finite Element Analysis (FEA) of the tibiotalar joint, has been crucial for simulating ankle function, especially under weightbearing conditions. Existing mesh generation methods have had issues with consistency and reproducibility, were time-consuming, and were not optimized for orthopedics. This study aimed to compare existing mesh creation strategies with a novel automatic method (Smartmesh™) to identify the optimal solution for bones in the foot and ankle.

METHODS: The automatic mesh generation process was performed using Python (v3.9), consisting of hole filling, edge smoothing, island removal, voxelization, and decimation. Smartmesh was compared with 103 manually generated meshes in terms of element quality (EQ) and aspect ratio (AR) via Wilcoxon signed-rank tests. Acceptable FEA meshes have mean EQ > 0.70 and mean AR < 4. Smartmesh was evaluated by comparing these FEA metrics to these EQ and AR benchmarks via one-sided t-tests. The Jaccard Index, Dice Coefficient, Hausdorff Distance, sensitivity, and specificity were calculated.

RESULTS: Thirty-three tibias, 38 fibulas, and 32 talus bones from weightbearing computed tomography (WBCT) scans were processed and compared to manually generated meshes. Element quality (EQ) and aspect ratio (AR) for tibia, fibula, and talus were above 0.70 ($P < 0.01$) and below 4 ($P < 0.01$)--within acceptable ranges. However, manual meshes outperformed Smartmesh by a difference in EQ of 0.12 on average and a difference in AR of 0.35 ($P < 0.01$). Differences in mesh quality are stratified by bone in Table 1.

DISCUSSION: Smartmeshes of the tibia, fibula, and talus had inferior performance metrics to manual meshes, yet had acceptable EQ and AR. The Smartmeshes also were similar to manually generated meshes based on Jaccard, Dice, sensitivity, and specificity scores.

SIGNIFICANCE/CLINICAL RELEVANCE: Given the extensive time and effort required to manually generate meshes, Smartmesh may be a more efficient yet satisfactory alternative in the context of FEA in orthopedics. Smartmesh is the first step in enabling scientists and physicians to rapidly and objectively assess the 3D alignment and stress distribution of load bearing in lower extremity joints.

IMAGES and TABLES: Table 1. Descriptive statistics for quality and overlap for Smartmesh meshes (Python) and manual meshes for the tibia, fibula, and talus of the right ankle

Metric	**Right Tibia**	**Right Fibula**	**Right Talus**
Element Quality (Smartmesh)	0.77 ± 0.01	0.78 ± 0.01	0.78 ± 0.01
Element Quality (Manual)	0.88 ± 0.01	0.89 ± 0.01	0.93 ± 0.01
Aspect Ratio (Smartmesh)	1.40 ± 0.05	1.65 ± 1.36	1.46 ± 0.25
Aspect Ratio (Manual)	1.18 ± 0.15	1.19 ± 0.27	1.08 ± 0.01
Sensitivity (Smartmesh vs Manual)	0.96 ± 0.003	0.96 ± 0.004	0.96 ± 0.003
Specificity (Smartmesh vs Manual)	0.99 ± 0.004	0.995 ± 0.002	0.99 ± 0.002
Dice Score (Smartmesh vs Manual)	0.98 ± 0.001	0.98 ± 0.002	0.98 ± 0.001
Hausdorff Distance (mm) (Smartmesh vs Manual)	1.53 ± 0.08	1.15 ± 0.06	1.59 ± 0.06
Jaccard Index (Smartmesh vs Manual)	0.96 ± 0.002	0.95 ± 0.003	0.96 ± 0.002