3D GEOMETRICAL OPTIMIZATION OF THE TALAR DOME

[1]Andrew R. Fauth, [1,2]Neil A. Sharkey, and [3]James Michelson
[1]Dept. of Kinesiology, The Pennsylvania State University, University Park, PA
[2]Dept. of Orthopaedics and Rehabilitation, The Pennsylvania State University, Hershey, PA
[3]Dept. of Orthopaedic Surgery, The George Washington University, School of Medicine and Health Services
email: nas9@psu.edu url: http://www.biomechanics.psu.edu

INTRODUCTION

The human ankle joint presents a complicated mix of geometry and anatomy that together create an intricate, multi-axis joint capable of complex motions. Past cadaveric and radiographic examinations of the ankle joint have attempted to assess the radii of curvature of the talus by assuming the talar dome to be cylindrical, at least in the 2D sagittal view.[1,4,5,6] Recent studies focused on total ankle arthroplasty applications suggest that the talar dome has a more complicated polyradial and polycentric shape.[2,3] There is little, if any, literature regarding assessments of the surface of the talus with respect to 3D geometry using a numerical optimization approach. The goal of this study was to accurately describe the 3D geometry of the talar dome by combining 3D digitization of cadaveric specimens with numerical optimization.

METHODS

Eight fresh, frozen, non-paired cadaver lower extremities with a mean age of 61.3 years (range 25-80) were used for this experiment. The group was composed of four male and four female specimens equally divided between right and left. Prior to testing, the specimens were thawed, radiographed, and subjected to a number of anthropometric measurements. Each specimen was then dissected and the talus was removed, potted in bone cement (PMMA), and secured in a rigid fixture. A 1mm x 1mm grid was drawn onto the entire articular surface of each talus and a Microscribe 3D digitizing tool (Immersion Corp., CA, USA) was used to collect points along the gridlines.

Following digitization, the data were analyzed in Matlab (V.7.0, Mathworks, MA, USA) using a least-squares optimization approach with the Levenberg-Marquardt algorithm to assess the accuracy of fitting a cylinder to the native shape of the articular surface. First, the superior articular surface of the talar dome was isolated from the medial and lateral walls. Next, a best-guess axis was established by finding the direction vector that connected the most superior point on both the medial and lateral edges of the surface data. This line was then inferiorly offset to provide an initial guess for the cylinder axis. The unit direction vector of this guess axis, a point on the axis, and a radius was provided as an initial estimate to the optimization routine, which then determined the best fit cylinder to all the data points on the superior articular surface of the talus. The resulting output of the optimization was a new axis point, axis direction vector, and a radius that described the best-fit cylinder (Figure 1). The accuracy of the cylinder fit was described by the mean-square error (MSE) of the optimization.

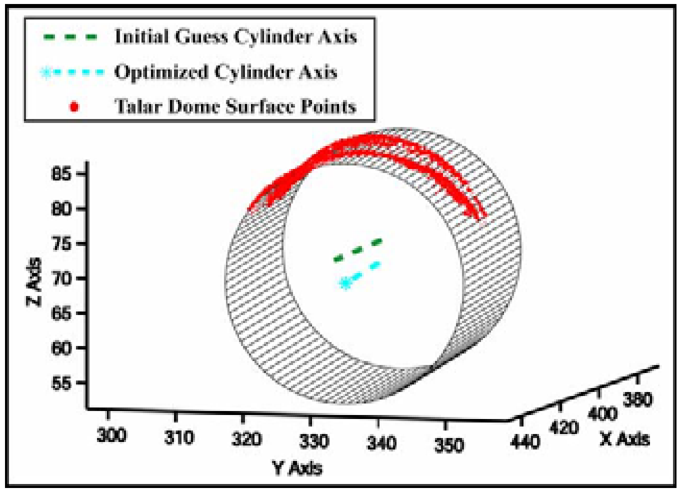

Figure 1. Talar dome surface points for one specimen and the cylinder fit to the points by numerical optimization.

RESULTS AND DISCUSSION

According to the results, a cylinder accurately describes the geometry of the superior talar dome (Table 1). MSE for the optimizations ranged from less than 0.1 mm to 0.43 mm. These data confirm that the overall shape of the superior talar dome can be accurately represented by a cylinder in 3D. The optimized cylinder radii were found to be similar for all males (~22mm) and all females (~18mm) respectively, and the difference between the two groups was significant. The calculated radii of curvature are in the range of previous 2D estimates of talar dome radii of curvature.[2,4,6] Examinations of the anthropometric data showed low variance in foot size, however, limiting statistical power. Further examinations are necessary to draw any conclusions regarding predictors of talar dome radii, such as foot size and gender. These data have direct applications to numerical models of the ankle as well as to the design of components for ankle arthroplasty.

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Table 1: Output Radii and Mean-Square Error of the Cylinder Optimizations

Specimen #	1	2	3	4	5	6	7	8	Mean	St.dev.
Gender	*Male*	*Male*	*Male*	*Male*	*Female*	*Female*	*Female*	*Female*	--	--
Optimized Radius (mm)	22.54	22.40	21.68	21.30	17.79	18.12	18.72	17.20	20.36	2.073
Cylinder Fit MSE (mm)	0.234	0.424	0.199	0.093	0.184	0.092	0.090	0.189	0.188	0.120