Bone Density Distribution of the Talus and its Effect on the Response of the Talus to Simulated Weight-Bearing Loads

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INTRODUCTION

Knowledge internal bone structure of the talus is important to the effective design of implants that require anchoring to the talus, such as total ankle replacements and suture anchors. The bone density can be obtained through computed tomography (CT) data through segmentation and through conversion from Hounsfield Units respectively. The purpose of this study is to observe and quantify the variation talar bone density and evaluate the effect of talar bone density distribution on its response to simulated weight-bearing loads is examined.

METHODS

Weight-bearing CT scans of the legs of 60 subjects without any pathologies were collected in bilateral standing posture. Three-dimensional computer models of the left talus were created, and the Hounsfield Units of each CT voxel were extracted and converted into local density values.[1,2] To describe the statistical variation in bone density, the talus was discretised into a finite number of spherical volumes at consistent, standardized locations. Then the average density in each of these volumes was calculated.

Two FE analyses were conducted on this talus, one with heterogeneous local density assignment as described herein, and one with each element assigned the same density value equal to the overall average density (i.e., a homogeneous density), to evaluate the effect of heterogeneity on the mechanical response of the talus under load. Body weight was simulated via a 710N axial load applied to the talar dome. The talus was considered fixed at the interface between the inferior talar surface and the calcaneus.

The statistical variation in bone density was analysed using principal component analyses (PCA). Non-parametric statistics were also performed to test for significant differences between: 1) age groups (younger ≤35, middle 36-54, older ≥55), 2) males and females, and 3) average density in specific talar regions.

RESULTS

Significant differences in bone density existed between the older group and both the younger and middle groups and between males and females. (Table 1).

The PCA showed that most of the variation in density (71% of variance) corresponds to the average variation in density across the entire talus. This was observed for the analysis of the first principal component. (PC1)

The bone density of the talar dome, head, and lateral regions were found to be significantly higher than the density in the other regions ($p<0.05$ for all regions). Strain is higher in the heterogeneous model than in the homogeneous model, especially at base of the talus, as seen in the central sagittal slice and posterior-most coronal slice.

DISCUSSION

Older subjects have a statistically significant reduction in density in comparison to younger subjects. Female subjects also have a statistically significant reduction in bone density compared to male subjects, which is also critical to design of bone fixation features, as less dense bone in female tali may result in poor fixation of implants to the talus if not addressed in design.

The FEA illustrates the effect of heterogeneous versus homogeneous density variation on stress and strain response of the bone. In particular, the increase in strain in the less dense cancellous bone in the interior of the talus, as seen in Figure 2E and 2G, may indicate significant bone weakness regions that may go undetected in a homogeneous analysis.

CONCLUSIONS

This study shows that there is significant variation in talar density. Knowledge of this variation is an important factor to consider for optimizing the design of anchoring systems for talar implants. Accounting for this variation in FE analyses of the talus is also critical when modelling the load response.

REFERENCES

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2. Xu B, Zhang B, Wang X, et al. 2017. Heterogeneous modelling and finite element analysis of the femur. MATEC Web of Conferences 139.

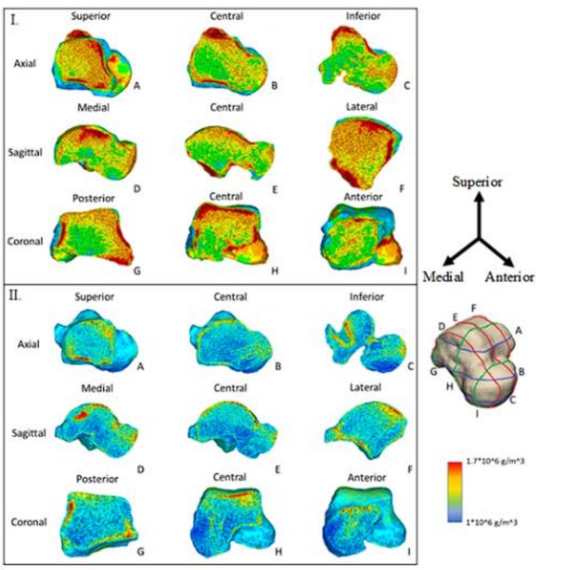

Figure 1: Statistical Variation in Bone Density of the First Principal Component (+/-2 sd)

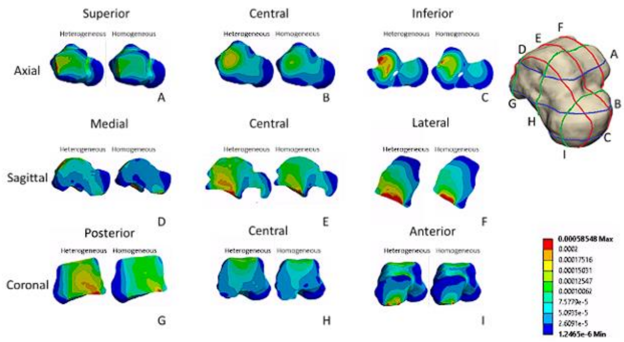

Figure 2: Strain in Talus Closest to the Average Bone Density

Table 1: Statistical Differences in Shape and Density

	Density p-value
Female vs. Male	**0.001**
Young vs. Older	**0.003**
Young vs. Middle	0.618
Middle vs. Older	**0.002**