NEW OBSERVATIONS ON THE MORPHOLOGY OF THE TALAR DOME AND ITS RELATIONSHIP TO ANKLE KINEMATICS

[1] Sorin Siegler, PhD; [1]Jason Toy, PhD; [1]Damani Seale, MS; [2] David Pedowitz, MD

[1]Department of Mechanical Engineering, Drexel University, Philadelphia, PA, USA
[2]The Rothman Institute, Thomas Jefferson University, Philadelphia, PA, USA
Email of corresponding author: ssielger@coe.drexel.edu

INTRODUCTION

The kinematic properties of the ankle are the result of a complex interaction between bony articular morphology, ligament constraints and muscle balance. However, the basic patterns of motion are primarily determined by the geometric features of the articulating surfaces of the trochlea and the tibial mortise. Detailed knowledge of the geometric features of these articulating surfaces is especially important for such applications as designing the components for total ankle replacement surgery. Some of the first detail studies of the functional morphology of the talar dome were conducted more than 60 years ago by Inman and Close and their co-workers [1,2]. Inman regarded the talocrural joint as a one-degree of freedom joint with a fixed axis of rotation. Inman and his co-workers then performed detailed cadaveric measurements to determine the curvature of the medial and lateral facets of the talar dome using different techniques such as a specially built contourometer, a Formagage a modified precision divider. Although different in their specific features, all these techniques had one common denominator. They were all based on Inman's assumption of a fixed axis of rotation approximated by the intermalleolar axis - the line connecting the tips of the medial and lateral malleolus. On the basis of these in vitro measurements Inman observed, after fitting circular arcs to the medial and lateral facets of the talus, that the medial facet had a smaller radius of curvature than the lateral facet. On the basis of these results he then argued that the trochlear surface could be approximated by a frustum of a cone, whose apex is directed medially and whose major axis serves as the axis of rotation of the ankle joint, coinciding with the intermalleolar axis. Inman noticed that such a shape (conic surface with apex directed medially) is incongruent with the observed coupled motion of the ankle referred to as supination (internal rotation and inversion coupled with plantarflexion) and pronation (external rotation and eversion coupled with dorsiflexion). He explained this incongruity by the restraining and guiding action of the surrounding ligaments. Since Inman's original studies, the concept of a fixed axis of rotation for the ankle has been refuted by many modern studies [3,4]. However, the idea of a truncated cone with the apex directed medially, which was based entirely on an assumed fixed axis of rotation, is still to a large extent accepted by the majority of experts in this field. In fact, this idea has been implemented recently in the design of some total ankle replacements. The main goal of this study was to revisit Inman's truncated cone idea and other functional geometric concepts by conducting a detailed functional morphology study of the talar dome based on combining modern 3D image processing and engineering software tools.

METHODS

The study was performed on CT data of healthy ankles obtained from 26 young subjects (age range 18-35). A commercial Image Processing software (Analyze Direct^{TM}) was used to create 3D models of the talus by the process of segmentation (identifying the boundaries of objects of interest – Figure 1a) followed by 3D rendering. (Combining 2D segmented slices to produce a surface representation of the object of interest – Figure 1b).

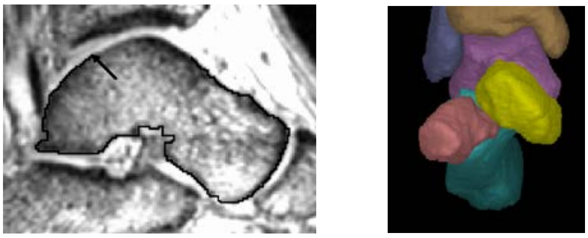
1a – Segmenting the talus 1b – 3D rendering

Figure 1: Creating 3D surface models from CT data

The 3D surface rendering of the talus was then exported into a commercial, 3D CAD and reverse engineering software - Geomagic^{TM}. All the subsequent 2D and 3D processing and measurements were performed in this software environment. (Figure 2).

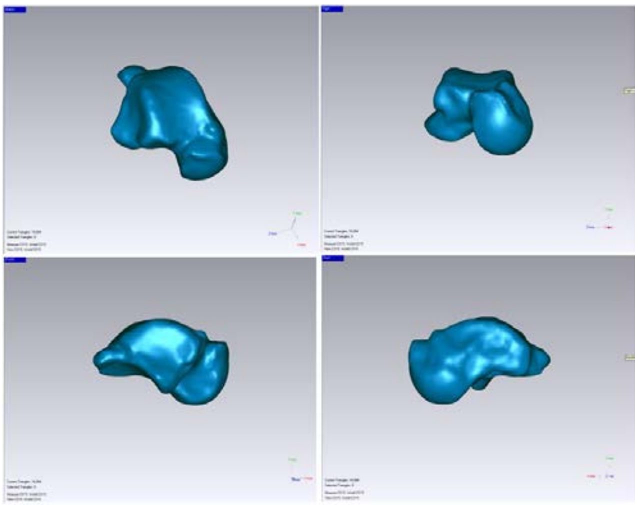
Figure 2 – Views (clockwise from top left: superior, frontal, medial and lateral) of the talus in the Geomagic^{TM} environment.

Sagittal sections were created through the talar dome coinciding with the lateral, central, and medial facets and optimal circles (in the least-square error sense) were then fitted to the medial, central and lateral contours of the talar facets and the radius and location of the centers of the optimally fitted circles were recorded (Figure 3).

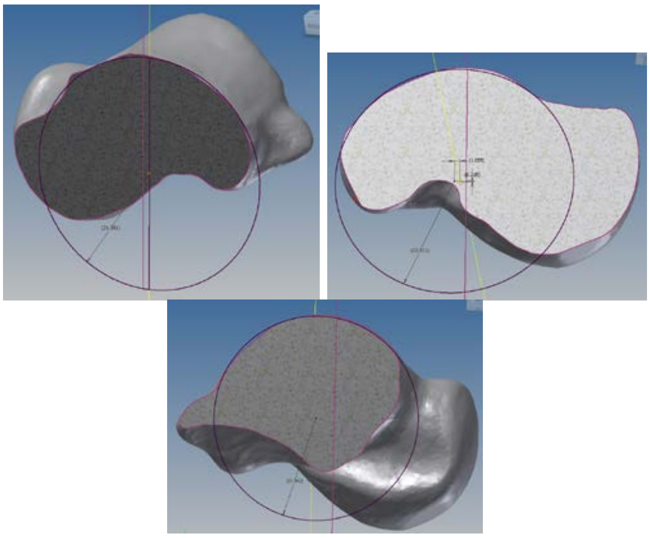

Figure 3: Medial (top left) central (top right) and lateral (bottom) sagittal sections through the talar dome and the best fitted circles to the talar dome contours.

In addition to the above, five equally spaced coronal sections through the talar dome were created by rotating coronal planes through the axis connecting the centers of the medial and lateral circle facets (Figure 4). The curvature of the talar dome contour produced in each of these five planes was recorded.

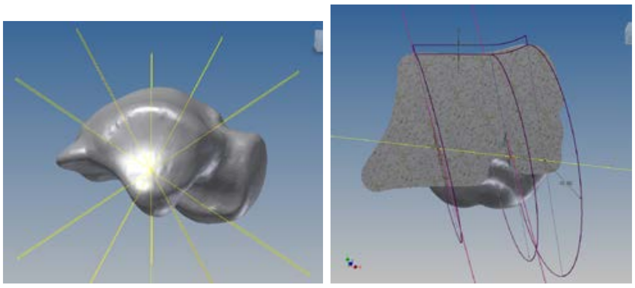

Figure 4: Five equally spaced coronal sections through the talar dome (left) and an example of the talar dome contour produced through such section (right)

RESULTS AND DISCUSSION

Analysis of the data obtained from all subject show that the radius of a circle fitted to the medial facet of the talar dome (Average = 25.7mm, Standard Deviation = 4.8mm) is larger than the central radius (Average = 24.7mm , Standard Deviation = 3.8mm) and on average 4 mm larger than the radius fitted to the lateral facet (average = 21.7mm, standard deviation = 2.9mm). These results, an example of which is shown in Figure 5, indicate that the talar dome can be considered as a truncated cone with its apex directed laterally. This finding is opposite to the finding of Inman and his co-workers who indicated a truncated cone with its apex located medially. The reason for this contradiction is that while Inman relied on an assumed fixed axis of rotation to perform the radius of curvature measurements, no such assumption was applied in our study which relied solely on the 3D geometrical features of the talar dome obtained through CT imaging. The functional importance of our findings is that a truncated cone with its apex located laterally is consistent and compatible with the well-known ankle coupling of internal rotation and inversion coupled with plantarflexion (known as supination) and external rotation and eversion coupled with dorsiflexion (known as pronation). In contrast Inman's conic model was contradictory (as Inman himself observed) to this well-known kinematic behavior. In the coronal plane, our study indicates that the radius of curvature of the talar dome increases from anterior, where it is the smallest to posterior, where it is almost flat (Anterior: 31.6 ± 23mm; anterio-central: 63.6 ± 26mm, central: 70.2 ± 26 mm; postero-central: 87 ± 39mm; and posterior: 111.9 ± 43mm). These results indicate that in the coronal plane the talar dome is concave with a varying radius of curvature. This concavity provides the ankle with a stable surface for mobility in inversion/eversion.

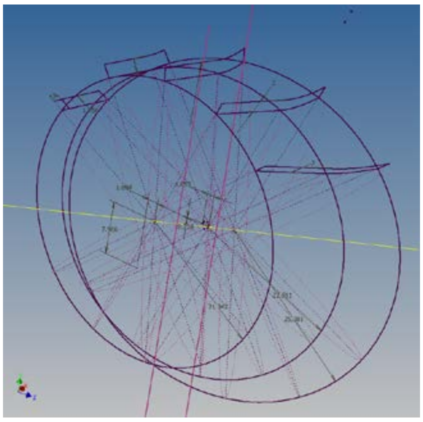

Figure 5: Example obtained from one subject showing the talar dome as a truncated cone with its apex oriented laterally and a concave surface in the coronal plane resulting in a truncated conic saddle shape.

CONCLUSIONS

From the results of this image-based morphological study it was concluded that the talar dome can best be modeled as a truncated conic saddle shape with its apex oriented laterally. This conclusion is compatible with the observed pronation/supination motion of the ankle and provides a stable congruency in movements of inversion/eversion. The results of this investigation and the conclusion based on them challenge the fundamental theory of functional morphology of the ankle pioneered by Inman of a truncated cone with apex oriented medially and suggest that these new findings should be considered in future biomechanical research and in clinical applications such as design of total ankle replacements.

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