Biometry of bone components in the talonavicular joint: A cadaver study

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\textbf{KEYWORDS}
Talus; Navicular; Biometry; Biomechanics; Foot

\textbf{Summary}
Introduction: Exhaustive biometric data of the talus and the navicular bones have not been reported in the classical anatomy treatises.

Hypothesis: The radiographic measurements, being variable according to the X-ray beam inclination, have no real value. This biometric analysis aimed to specify the characteristics of the constitutive bone components of the talonavicular joint.

Material and methods: This anatomic study investigated the biometry of the talus and the navicular bones separated from anatomic specimens with no previous disease history from adult subjects whose sex was unknown. It was completed by in situ dissection and evaluation of talonavicular and talocalcaneal joints conducted to gain an understanding of the bone specimens in three dimensions. The measurements were taken using a highly precise measuring tape and a comparator providing the length and the width of the articular surfaces. The comparator determined the surface pattern and the radii of curvature in the two main axes.

Results: The results emphasize the variations in the bone specimens. Three morphotypes emerged, which had never been identified before.

Discussion and conclusion: These biometric data make up a database designed to improve clinical exploration. They can be used as landmarks for fundamental comparative research between all the bone structures of the hindfoot and thus provide a logical classification of the different pathological conditions and a reasoned adaptation of therapeutic protocols.

Level of evidence: Experimental study, level IV.

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Introduction

The talus is the bone connecting the tibial pilon and the foot, with three-dimensional mechanical imperatives. Its role as a constitutive component of the medial arch of the foot is currently under debate. Although some authors refer to the talus as the keystone of this arch, others refute this role, allocating it to the navicular [1–4]. Better knowledge of the joint components increases the comprehension of static disorders of the foot and thus improves their management. The objectives of this study were to determine the morphology of the bony components of the talonavicular joint at the root of the mechanical behaviour of the foot’s medial arch responsible for static disorders.

Material and methods

The present study entailed observation and measurement of 40 individual taluses and 35 naviculars (dry bone) from adult subjects from the anatomy laboratory whose sex was unknown, who had no lesions apparent on macroscopic examination of the bony structures and with no scars that would suggest traumatic lesions. The analysis was completed by dissection and evaluation in the anatomic position of the joints of the hindfoot including the talus, the calcaneus, the navicular, and the cuboid so as to determine the lengths and measure the true axes between the talus, the calcaneus, and the navicular. This was a study on bony segments and anatomic specimens of laboratory subjects.

Figure 1  Angle measurement method. A. Declination angle (body-neck-head horizontal angle). B. Inclination angle (body-head angle in the sagittal plane). C. Rotation angle.

Figure 2  Measurement of the surface pattern of the articular surface of a navicular bone according to its two axes using a specific comparator. A. Main oblique axis. B. Secondary axis.
Figure 3  Comparative study of the talar head (A) and the posterolateral plantar articular surface (B) of the same talus.

Figure 4  A. The two large types of inclination angles of the talar head. B. The types of declination angle of the talus, angle directed laterally, angle directed neutrally, angle directed medially. C. Example of a horizontal view of a talus with the angle directed laterally and the arrangement of the bone trabeculae of the neck and head.
preserved in a mixture of formol-, alcohol-, and glycerin-based liquid and dissected with the objective of harvesting the bones of the hindfoot.

The calcaneocuboid joint was not taken into consideration in this study. The arrangement of the ligaments was noted but none were measured.

For the talus, the inclination angle (body-neck-head sagittal angle), the declination angle (body-head-angle in the horizontal plane), and the rotation angle were analysed. The talar rotation angle was measured along the anteroposterior axis in relation to the horizontal plane of the articular surface of the talus (Fig. 1A, B). For each surface of the talonavicular joint space, the length of their largest axis was measured. The surface pattern and the radius of curvature of the joint surfaces were measured using a specific comparator (Fig. 2A, B). For each talus, the main radius of curvature of the talar head was compared to its posterolateral plantar joint surface (Fig. 3).

Figure 5  The three types of torque angle of the talus.

Figure 6  Examples of a navicular with different radii of curvature (A) and identical radii of curvature depending on the two axes (B).
The assessment criteria were based on manual measurements with a measuring tape using a precision caliper ruler. A comparator was used to measure the surface pattern and the radius of curvature. The comparator data were transcribed on millimetre graph paper, allowing measurement of the radius of curvature using the classical method by drawing three parallel lines at the summit of the curve and the perpendicular line at each right angle, which by cross-checking determined the radius expressed in millimetres.

The measurement methods were based on a digital photograph transferred into Adobe Photoshop software. The images were converted to DICOM format using Intrasense Myrian image software, which measured the angles. The software’s measurement tools were specific for measuring angles without projection and therefore without enlargement. This measurement was completed using a protractor for manual measurement. Each measurement was taken three times several days apart by another observer; the difference was on the order of 1 mm and 1°, which was considered valid given the low values found. The reliability of the measurements was facilitated by the presence of marks on the anatomic specimens measured.

Measurement results

The results are presented in Tables 1–4.

Angle variations

The inclination angles varied with a mean predominant angle of 95°. For the talus, an inclination angle less than 95° predisposed to pes cavus with an accentuated medial arch. The declination and rotation angles demonstrated three types (Table 1A–C; Fig. 4A–C, Fig. 5). The pure sagittal direction of the declination angle (0°) and the lateral direction (−20°) was a factor in subtalar and talonavicular joint stability. A +30° angle resulted in a misaligned talar head whose stability was maintained by other factors along with talocalcaneal divergence and the difference in the length of the articular surfaces in contact. A high rotation angle was a factor of rotational stress, which was distributed between the body and the head of the talus, requiring that the ligament and musculoaponeurotic structures maintain stability. The role played by the calcaneocuboid joint could be considered like the Y- or V-shaped bifurcate ligament with fibers at 45°, a true rotational stabilization ligament.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Results of inclination, declination, and rotation angles for 40 taluses (Fig. 5). The results demonstrate multiple individual variations. No correlation between the three angles was found.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talus n=40</td>
<td>Inclination angle: mean (range)\textsuperscript{a}</td>
</tr>
<tr>
<td>n = 31</td>
<td>95° ± 6 (89–105)</td>
</tr>
<tr>
<td>n = 9</td>
<td>115° ± 4 (111–119)</td>
</tr>
<tr>
<td>Talus n=40</td>
<td>Declination angle: mean (range)\textsuperscript{b}</td>
</tr>
<tr>
<td>n = 29</td>
<td>Medial +30° ± 3 (27–33)</td>
</tr>
<tr>
<td>n = 7</td>
<td>Sagittal 0° ± 2 (−2 to + 3)</td>
</tr>
<tr>
<td>n = 4</td>
<td>Lateral −20° ± 2 (18–22)</td>
</tr>
<tr>
<td>Talus n=40</td>
<td>Torsion: mean (range)\textsuperscript{c}</td>
</tr>
<tr>
<td>n = 28</td>
<td>35° ± 6 (29–41)</td>
</tr>
<tr>
<td>n = 8</td>
<td>50° ± 3 (47–53)</td>
</tr>
<tr>
<td>n = 4</td>
<td>20° ± 2 (18–22)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} The inclination angle shows two main types of talus: one is more frequent with a mean angle of 115° and the other less frequent with a mean angle of 95°.

\textsuperscript{b} Three types of talus are demonstrated with the declination angle.

\textsuperscript{c} Three types of talus exist for torsion.
Variations of the radii of curvature and the surface patterns

The results of the surface pattern and the radius of curvature measurements for 40 taluses confirmed that the articular surfaces were asymmetrical, in accordance with the joint classification (Tables 2 and 3; Figs. 6A, B, 7 and 8A, B). Clearance for mobility predominated in the horizontal plane. The differences noted between the surface pattern and the radius of curvature of the navicular compared to the talus allowed functional adaptation of the medial arch. The joint surface measurements of the navicular confirm its condylar type (ellipsoid). The main oblique axis of the navicular in its medial and plantar parts with a large radius of curvature was found with a bony tubercle of the posterior tibial tendon located in the medial plantar quadrant, which has a dynamic supination function.

Table 2 Results of the surface pattern and the radius of curvature for 40 taluses (dry bones).

<table>
<thead>
<tr>
<th>Talus n = 40</th>
<th>Mean ± SD (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface pattern</td>
<td>Main axis</td>
</tr>
<tr>
<td></td>
<td>Perpendicular axis</td>
</tr>
<tr>
<td>Radius of curvature</td>
<td>Main axis</td>
</tr>
<tr>
<td></td>
<td>Perpendicular axis</td>
</tr>
</tbody>
</table>

This table demonstrates two broad groups of naviculars, the largest with different surface patterns and radii of curvature (n = 33) and two identical (n = 2).

Table 3 Results of the surface pattern and the radius of curvature for 35 naviculars (dry bone).

<table>
<thead>
<tr>
<th>Navicular n = 35</th>
<th>Mean ± SD (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface pattern n = 33</td>
<td>Main axis</td>
</tr>
<tr>
<td></td>
<td>Perpendicular axis</td>
</tr>
<tr>
<td></td>
<td>n = 2 Main axis</td>
</tr>
<tr>
<td></td>
<td>Perpendicular axis</td>
</tr>
<tr>
<td>Radius of curvature n = 33</td>
<td>Main axis</td>
</tr>
<tr>
<td></td>
<td>Perpendicular axis</td>
</tr>
<tr>
<td></td>
<td>n = 2 Main axis</td>
</tr>
<tr>
<td></td>
<td>Perpendicular axis</td>
</tr>
</tbody>
</table>

The variations of the talar surface pattern with a high standard deviation between the two axes demonstrated a wide range in the range of motion. The highest radius of curvature was correlated with the largest surface pattern. An identical radius of curvature of the talus head and the posterolateral plantar articular surface of the same talus was a fundamental, logical factor in the transmission of rotational stresses. This similarity of the radii of curvature was within the functional rotational continuity of the inverted double trochoid of the subtalar joint. A different radius of curvature led to excessive stress at the neck, source of a risk of stress fracture. The rotational angle was an indispensable adaptive factor for the same bone structure.

Table 4 Biometric results of length of 70 taluses and calcanei based on continuous anatomic specimens (Fig. 9A, B).

<table>
<thead>
<tr>
<th>70 specimens</th>
<th>Talus</th>
<th>Calcaneus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (cm)</td>
<td>6.12 ± 0.27</td>
<td>8.8 ± 0.10</td>
</tr>
<tr>
<td>Width (cm)</td>
<td>4.26 ± 0.31</td>
<td>3.2 ± 0.10</td>
</tr>
</tbody>
</table>

Figure 8 A. Arrangement of the main oblique axis of the talar and navicular head on a continuous anatomic joint specimen; note the true obliquity of the articular surfaces. B. Posterior view of the articular surfaces of the navicular and the cuboid with presence of an accessory navicular bone in the inferomedial quadrant, which gives insertion to fibers of the posterior tibial tendon.
meant a high level of adaptability of the first fixed point of the coxa pedis and better distribution of stresses [4]. Analysis of the talonavicular articular surfaces with continuous cartilage shows the same biometric values with greater precision because of the presence of cartilage. The fundamental point of this analysis was the distinction of three morphological types depending on the talocalcaneal joint congruence with a potentially more or less stable talar head. During growth, a complex joint formed around the talar head such as a deformed spheroid joint (Pisani’s coxa pedis) [5]. This was fundamental in the closing mechanisms (locking lever arms) and the opening mechanisms (adaptation) of foot and pelvis kinematic chains in terms of coordination and transmission.

Length and width asymmetry between the talus and the calcaneus

The length of the talus compared to the calcaneus demonstrated three types: type I with an identical joint length, type II with the length of the talus exceeding the width by at least 1 cm compared to the calcaneus, and type III with a talus length greater than or equal to 2 cm (Table 4; Fig. 9). In types II and III, this difference was compensated by the contact of the anterior plantar surface of the talus with the calcaneonavicular ligament and its glenoid fibrocartilage, providing an additional possibility for stability and mobility during gait. The width of the sustentaculum tali of the calcaneus was a mean 1.5 cm. The width of the talus was less so as to adapt to the calcaneal surface. This difference in talar width was compensated by its continuity with the navicular bone, which confirms that the talus is the transmission bone for the medial and lateral parts. The absence of the two arches would result in a talus bone with identical talar and calcaneal width.

Discussion

Data from the literature

Are the classical anatomical data sufficiently informative on the factors predisposing to static disorders? Is a morphological classification possible? Observations make it possible to determine the anatomical causes responsible for deformities and in particular pes valgus. These biometric notions may be a complement to radiographic assessment with three-dimensional reconstruction and angle calculations of the radii of curvature of the talus and the navicular articular surfaces. The biometric data are an important component with reference to earlier studies [6—8], which did not report such well-developed variations. There is no classification that catalogs the length of the talus in relation to the calcaneus.

Clinical incidence

During the foot’s growth, this new notion of talus and calcaneus length as well as talonavicular joint congruence defines torque stability. During growth, when the talus is longer, the talar head is well supported, and it has not been demonstrated that the proximal side of the navicular bone is hollowed out because of the reduction in pressure (Fig. 10).

In the adult, a longer talus has its head either resting on the calcaneonavicular ligament, which through distension results in pes valgus, or creates hyperpressure resulting in hollowing the proximal surface of the navicular bone, thus enlarging the concave reception cavity with an accessory navicular bone, source of a risk of osteoarthritis. The torque is locked and the talar head is sometimes deformed by pressure. Questions can be raised as to the extent and the more or less vertical position of the sustentaculum tali, orienting toward the unstable form if it is horizontal or
Figure 10 Sagittal view of the talonavicular joint in a fetus, which, possibly indicating that the hollowing of the navicular articular surface, is proportional to the mechanical stress of the talar head.

hyperpressure if it is vertical. The present observations can be used to define variability in the rotational stability profiles of the subtalar joint in relation with the rotational profile of the talocrural joint. This study emphasizes the presence of individual variations, showing significant differences playing a functional role of compensation of the morphologies of the adjacent talocrural, subtalar, and calcaneocuboid joint surfaces. Symmetrical radii of curvature of each reference axis confirm the simple condylar type (two working axes and two degrees of freedom in the joint) with an additional complementary potential of joint freedom in terms of purely axial rotation limited by the V and Y ligaments and the morphology of the calcaneocuboid joint (saddle joint), a true mechanical brake. The talus remains the cornerstone of the medial arch’s transmission. The functional repercussions of the radii of curvature, angles, and lengths of the bony segments require further study; it would be wise to take these phenomena into consideration in cases of chronic laxity of the talocrural joint or in the implantation of ankle prostheses. Measurement methods should be developed with adapted computerized tools.

The morphology of the posterolateral plantar articular surface of the talus in relation to the articular surface of the talar head demonstrates a variable orientation that will be the subject of later biometric development for the talocalcaneal and calcaneocuboid joints. These results compared to previous publications can be used to determine the bases of a better comprehension of the complex functioning of the hindfoot’s joints with future possibilities for modeling these structures. Separating out the pathologies of the hindfoot with their therapeutic implications requires more precise morphological analysis of the bone structures and the development of high-performance 3D analysis. Conventional AP and lateral radiographic measurements are highly questionable from a scientific point of view. Treating pes valgus requires considering the morphology of the calcaneocuboid joint. Data on the participation of the muscle and fascia structures are totally unknown and excluded in management of pathological feet.

Conclusion

Precise biometric measurements have contributed to analysis of the functional consequences of the talonavicular joint. A summary is proposed while recognizing its limitations in that the biometric data of the other calcaneocuboid joint component have not been considered in this study.

An understanding of the functioning of these joints would require integrating all the joints of the kinematic chain. Over the long term, this study will aid in developing the notion of individual at-risk morphotypes for particular activities. The characteristic mode of locomotion of the species and its anatomy are complementary: bipedality requires a complex osteoarticular system that has perhaps not completed its adaptation.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Participations: P. Teissier, intern, assisted in dissections; E. Toulec, discussion of pes valgus; M. Maestro, worked on this topic with personal measurements; B. Ferré, discussion on radii of curvature with methodology.

References