The Pattern Of Bone Mineral Density In The Human Calcaneus

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Abstract:
The present study was performed on 21 pairs of cadaveric human calcaneal bones to determine the pattern of bone mineral density (BMD) and to correlate it with the biomechanical function of the calcaneal bone. The present results have demonstrated variations in the BMD in the defferent regions of the calcaneus. In lateral projection the anterosuperior region presented the highest BMD. The posterior region had the second highest BMD. The intermediate and anteroinferior regions presented the lowest BMD. The dorsal aspect of the whole calcaneus appeared denser than the planter aspect.
In the dorsoplantar projection, the middle region had the highest BMD. The anterior region had the lowest BMD and the posterior region was nearly similar to that of the lateral projection. The lateral aspect of the whole calcaneus was denser than the medial aspect and the posterior aspect of the calcaneus was denser than the anterior aspect. The relationship between the bone density distribution of the calcaneal bones and their biomechanical function in the gait cycle is discussed.

Introduction:

The calcaneus, being a short bone, as for the other tarsal bones comprises a peripheral cortical layer of compact tissue coating a framework of spongy tissue whose laminae are oriented to fulfill the functional requirements of the foot.[1] Its structure is thus related to load transmission and to bone strength.[2,3] Weidenreich (1923)[4] in his study on the ontogeny and phylogeny of the human foot, showed that the external and internal patterns of the calcaneus were a response to normal static and dynamic functions.

The association between mechanical stress and bone mass was first recorded by Galileo in 1683 who noted the relationship between body weight and bone size. The First study of the pattern of heal stress was performed by Meyer (1867),[5] but it was not until 1892 that Julius Wolff, a German anatomist realized that changes in the mechanical stresses applied to a bone influenced bone strength.[6] This analysis has remained applicable to the present, in spite of evolution of research techniques.[7]

Bone tissue in the appendicular skeleton is actively model and remodel during development and throughout the life to resist the repeated mechanical loads to which it is exposed.[8] The mechanical loads result in both pressure and tension changes within the bone stimulate bone formation and remolding[9] including changes in bone density.[10,11]

Measurement of bone density has been an important tool in the assessment of bone strength. A well-established method of assessing bone mineral density (BMD) is the use of dual energy X-ray absorptiometry (DEXA).[12,13] Bone mineral density (BMD) tests such as dual X-ray absorptiometry (DXA) are widely available, easy to perform and correlate highly and significantly with bone strength in many modes of failure.[14]

Several authors[15-18] studied the calcaneus by densitometry to assess the effect of physical activity or inactivity in adults.

The present study was undertaken to analyze the densitometric pattern of the human calcaneus and to correlate it with the biomechanical function of the bone. The calcaneus was chosen because of its important biomechanical function within the foot, being a major weight bearing structure.

Materials And Methods:

Human specimens:

Twenty one pairs of calcaneus (excluding those bones, which presented any alterations or damage) were selected from larger sample cadavers available in a medical gross anatomy laboratory. All soft tissue except cartilage were carefully removed from the calcaneus.

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Dual X-ray absorptiometery:

Measurements of the a real bone mineral density (BMD) in g/cm^2 were made with a DEXA system using a lunar DPX-7289 densitometer in both the lateral to medial and dorsal to plantar projections. This technique has high accuracy and precision approaching.[19] For the densitometric analysis of the human calcaneus structure two projections were performed: dorsoplantar and lateral projections according to Camacho et al., (1996)[16] regarding to the concentration of trabeculae. In the dorsoplantar projection, four bone regions were selected, total, anterior (A), middle (M) and posterior (P). The total region corresponded to the area limited by the maximum dimension of the bone i.e total length and width. This region was divided into medial and lateral regions by a plane passing through the middle of the width and perpendicular to it. In the lateral projection five regions were selected: total, anterosuperior (As), intermediate (I), posterior (P) and anteroinferior (AI). The total region corresponded to the area of the full length and height of the bone. This region was divided into dorsal and ventral portions by a plane pass through the middle of the height and perpendicular to it. To obtain (As) region we took the anterior half of the total length and 2 dorsal thirds of the height, being the plantar third occupied by the (AI) region with the same length. The posterior half was divided into three equal parts, from which the 2 anterior thirds corresponded to (I) region and the remaining third to the (P) region, being the height of these two regions that corresponded to the bone at these zones.

Statistical Analysis:

The mean (M), standard deviation (SD) and range of bone mineral densities (BMD) of various regions of the calcaneus were calculated. The differences between dorsal, ventral, lateral and medial aspects of different parts of the calcaneus were compared for statistical significance using the student's T test.

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Results:

The means of all measurements taken from the right foot were not significantly different from those of the left foot (P> 0.5). The results of BMD of different aspects of the calcaneus are illustrated in Tables 1- 4.

In the lateral projection:

The As region presented the highest BMD. The posterion region had the second highest BMD. The I and AI regions presented the lowest BMD. All the differences were statistically significant (P^O.05) (Table 1), (Fig. l).

In the dorsoplantar projection:

The M region had the highest BMD, the posterior region had the second highest BMD and was nearly similar to that of the lateral projection. The anterior region presented a lower BMD. All the differences were statistically significant (P<0.05) (Table 2), (Fig. 2).

Dorsal versus plantar distribution of BMD within the whole calcaneus (in the lateral projection):

A highly significant difference (P0.001) in mean BMD was found between the dorsal and plantar portions of the whole calcaneus with the dorsal portion being denser (Table3), (Fig3). For the whole calcaneus, the mean difference in BMD was 27% denser dorsal portion (Table 4).

Lateral versus medial distribution of BMD within the whole calcaneus (in dorsoplanter projection).

The lateral portion was significantly denser (P<: 0.05) than the medial portion (Table 3, Fig3). For the whole calcaneus, the mean difference in BMD was 6% denser lateral portion (Table 4).

Distal to proximal distribution of BMD within the whole calcaneus.

A highly significant difference (P< 0.001) in mean BMD was found between the posterior and anterior portion with the posterior portion being denser (Table 3, Fig 3). For the whole calcaneus, the mean difference in BMD was 25% (Table 4).

Table 1: Ranges, means and S.D for all measurements in the human calcaneus (lateral projection).

	Range (g/cm^2)	Mean	S.D
Total	0.72-1.15	0.85	0.13
A.S.	0.90-1.4	1.06	0.17
P	0.68-1.16	0.81	0.14
Intermediate	0.64-1.06	0.78	0.125
A.I	0.46-0.82	0.57	0.123

Table 2: Ranges, means and S.D for all measurements in the human calcaneus (dorsoplantar projection).

Region	Range (g/cm^2)	Mean	S.D
Total	0.71-1.26	0.88	0.15
Middle	0.80-1.51	1.02	0.212
Posterior	0.80-1.3	0.92	0.151
Anterior	0.46-0.95	0.67	0.14

Table 3: Ranges, means and S.D for all measurements compared.

Region	Range (g/cm^2)	Mean	S.D
Dorsal aspects of whole calcaneus	0.78-1.34	0.97	0.15
Planter aspects of whole calcaneus	0.68-1.16	0.81	0.14
Lateral aspects of whole calcaneus	0.80-1.30	0.92	0.15
Medial aspects of whole calcaneus	0.66-1.35	0.86	0.18
Posterior aspects of whole calcaneus	0.70-1.2	0.92	0.14
Anterior aspects of whole calcaneus	0.46-0.95	0.67	0.15

Table 4: Percentage of mean differences:

	Mean difference	% Mean difference
Dorsal aspects Vs planter aspect	0.27	0.27/1X100=27%
Lateral aspects Vs Medial aspect	0.06	0.06/1X100=6%
Posterior aspects Vs anterior aspect	0.25	0.25/1X100=25%

Fig. I: Measurements of the human calcaneus (lateral projection).

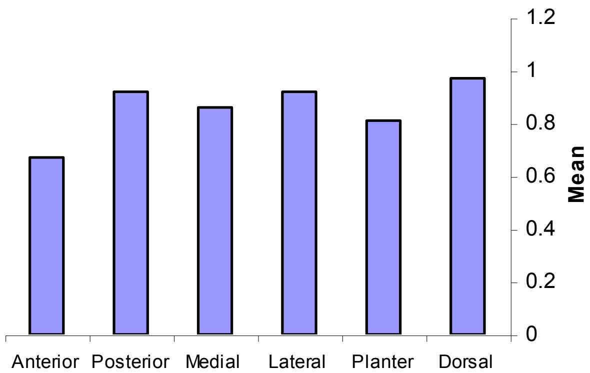


Fig.2: Measurements of the human calcaneus (Dorsoplanter projection).

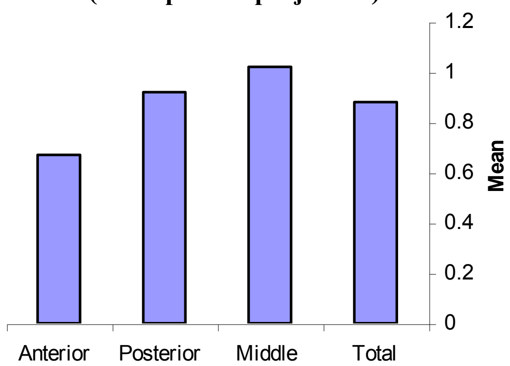
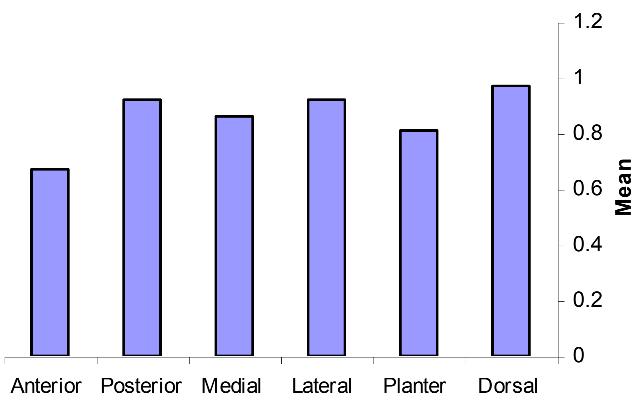


Fig.3: Comparison of the measurements of calcaneus.



Discussion:

The regional distribution of BMD in the human calcaneus was examined in the present study in an effort to determine the change of the morphological patterns of the bone in response to the stresses during the normal gait cycle. The bone density of cadaveric specimens is highly variable and has a significant effect on the results of biomechanical testing but it is not often assessed before testing is performed in the lab.[14] On the other hand, calcaneus BMD is not readily affected by degenerative change or soft tissue.[20]

Wolffs law states that changes in bone function are followed by changes in internal architecture and external conformation. The magnitude of bone strain (the amount of relative change in bone length under mechanical loading) may be responsible for these alterations. Thus, one would expect no change in BMD in a bone that undergoes no loading.[18]

Carter et al., (1991)[9] stated that the mechanical stress played a major role in the regulation of skeletal development. Fischer et al., (1997)[21] stated that the sites of maximum density in the femur corresponded to those areas that exhibit the greatest compressive and tensile strength. In the present study, the posterior portion of the calcaneus located in the hind foot is denser than the anterior portion, which is located in the midfoot. This could be explained by examining the pressure distribution patterns on the plantar foot, this agrees with the functional importance of these two regions with respect to load support and to the insertion of Achilles tendon.[7,22]

Arcan and Brull (1976)[23] found that in 4 out 5 subjects, 45 to 65% of body weight was under the heel, 30 to 47% was under the forefoot and the remainder was under the midfoot. Cavanagh et al. (1987)[24] had shown that, in barefoot standing, the highest peak pressure is located under the heel with the next highest pressure under the forefoot, generally under the second metatarsal head. Bennett and Duplock (1993)[25] and Rozema et al (1996)[26] mentioned that, during walking maximum loads are distributed under the heel initially and later, as weight is transferred forwards, across the forefoot. These findings are not in agreement with Perry et al. (1995)[27] in their study on peak pressures during walking. They found that the highest pressure was under the second metatarsal head, located in the forefoot with the next highest pressure under the heel.

In the present study, the dorsal and lateral portions of the whole calcaneus were denser than the plantar and medial portions. These changes could be explained by observing the dynamics of the calcaneus during the gait cycle. The dorsal portion of the calcaneus having a greater BMD than the plantar portion could be explained by the fact that the dorsum is under going compressive stress and strain as a result of ground reactive forces. During normal walking, vertical force initially peaked at the end of the loading response phase of the midstance portion of the gait cycle when there is a transition from double limb to single limb support. At this time weight is being distributed from the heel to the ball of the foot. Weight is shifted towards the lateral portion of the calcaneus as it came to lie in a position closer to the weight-bearing surface than the medical portion of the bone due to inversion of the foot at this time.[28] This correlated to the present finding of a denser lateral portion of the calcaneus than medial portion.

As previously reported,[7,29] there is a close relations between bone mass and bone strength. Our results agree with Jensen et al. (1991)[2] and Camacho et al. (1996)[16] concerning the strength of the different regions of the calcaneus. According to them, the region with greatest strength was the posterior talar articular surface (our M region) in dorsoplantar projection, followed by the tuber calcanei (our P region). The weakest zone was the cubiodal articular surface (our A region).

The present results were based on elderly samples. Although there are osteoporotic specimens within these samples, no differences in density patterns between decades, between individual calcaneus or between the most dense and least dense calcaneus, since this study was concerned with the relative density patterns rather than absolute density values.

In summary, the present study established a bone density pattern for the calcaneus and its relations to the dynamics of this bone during the normal gait cycle.

Conclusion:

The calcaneus has an important biomechanical function within the foot being a major weight bearing structure. The bone mineral density of the cadaveric calcaneal specimens is highly variable and has an effect on the result of biomechanical function of the foot.

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