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Analysis of bone density of the human first metatarsal bone

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Abstract

This study was performed on 38 Pairs of cadaveric human 1st metatarsal bones in an attempt to establish the pattern of bone mineral density and to correlate it with the biomechanical function of the bone. The results show that the head is denser than the base, the dorsal portion of the whole metatarsal is denser than the planter portion and the lateral portion of the whole metatarsal is denser than the planter portion and the lateral portion of the whole metatarsal is denser than the medial aspect. The same pattern of bone density with respect to dorsal vs planter and Lateral vs medial was also seen in the head and compared with same portions of the metatarsal as a whole. The relation-ship between the bone density distribution of the 1st metatarsal bone and their biomechanical function in the gait cycle was discussed.

Introduction

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 *(1)*. The mechanical loads result in both pressure and tension changes within the bone which will stimulate bone formation and remolding *(2)*, which include changes in bone density *(3-8)*.

Measurement of bone density has been an important tool in the assessment of bone strength. A well established method of assessing areal bone mineral density (BMD) has been dane through the use of dual energy x–ray absorptiometry (DEXA) *(3,9-11)*.

Camacho et. al. *(12)* related the densitometric profile across the human calcaneus to the previously described distribution of trabecular bone strength within that bone *(13)*. They found that regions of highest BMD correlated with regions of greatest trabecular bone strength.
The present study was undertaken to analyse the densitometric pattern of the human 1st metatarsal bone. The 1st metatarsal bone was chosen because of its important biomechanical function withen the foot, being a major weight bearing structure. Because it is a long bone, it has a different architecture than the calcaneus bone.

Material and Methods

Human Specimens

Thirty-eight pairs of cadaveric 1st metatarsals were selected from a larger sample cadavers available in a medical gross anatomy laboratory. After removal from the cadavers, the 1st metatarsals were stored for two weeks prior to testing in a 1% Phenoxyethanol in water solution to retain moisture. Medical histories and causes of death were available on the cadavers and they were screened and eliminated if they had a premortem history of prolonged immobilisation, or endocrine and metabolic disorders and other conditions affecting bone. All soft tissue except cartilage, was carefully removed from the metatarsals.

Dual X- ray absorptiometry

Measurements of the areal bone mineral density (BMD) in g/ cm^2 were made with a dual x- ray absorptiometer (model DPX- L, Lunar Radiation, Madison, WI) in both the Lateral to medial and dorsal to planter projections.

Analysis of DEXA scans

Scans were then analysed for areal BMD of the dorsal and plantar portion, the medial and lateral portion of the whole metatarsal, the head, shaft and base region of the bone. In determining the medial vesus Lateral portions *(Figs. 1,2,5)* and dorsal versus plantar portions *(Figs. 3,4,6)* on the DEXA scans, the narrowest portion of the shaft was bisected longitudinally, extending through the head and base regions. The medial versus lateral and the dorsal versus plantar portions of the head were determined by using the previously established bisecting line for the whole metatarsal and then drawing a dorsal to plantar bisecting line proximal to the plantar extension of the articular surface of the head at the surgical neck *(Figs. 5,6)*. The head, shaft and base regions were determined on lateral to medial scans by drawing a dorsal to plantar bisecting line proximal to the planter extension of the articular surface of the head at the surgical neck, and a dorsal to plantar bisecting line just proximal to the insertion of the peroneus longus tendon to base *(Fig .6)*.

Statistical analysis

The data of the bone densities (BMD) of the various regions of the 1st metatarsal bone were analysed by using the student's T test for paired samples. The mean (M), standard deviation (S.D.) and standard error of the mean (S.E.M.) were obtained.

Results

The means of all measurements taken from the right foot were not significantly different than the equivalent measurements from the left foot (P= 0.05). Results are summarised in Table 1& 2.

Dorsal vs plantar distribution of BMD within the whole 1st metatarsal:

A highly significant difference in mean BMD was found between the dorsal and plantar portions of the whole metatarsal bone with the dorsal portion being denser (P< 0.001). For the whole metatarsal, the mean difference in BMD was an approximately 31% denser dorsal portion. (Table 2).

Lateral vs medial distribution of BMD within the whole 1st metatarsal:

A highly significant difference in mean BMD was found between the lateral and medial portions of the whole metatarsal bone with the lateral portion being denser (P = 0.002). For the whole metatarsal, the mean difference in BMD was an approximately 25% denser lateral portion. (Table 2).

Distal to proximal distribution of BMD within the whole 1st metatarsal:

There was no significant difference in BMD between the head and shaft or between the shaft and base. The head was significantly denser than the base. The difference in BMD between base and head was significant but of smaller magnitude (P= 0.026). (Table 2).

Dorsal vs plantar distribution of BMD within the head:

A significant difference in mean BMD was found between the dorsal and plantar portions of the head, with the dorsal portion being denser (P= 0.019). The mean difference in BMD was an approximately 19% denser dorsal portion. (Table 2).

Lateral vs medial distribution of BMD within the head:

A highly significant difference in mean BMD was found between the lateral and medial portions of the head, with the lateral portion being denser (P< 0.001). The mean difference in BMD was an approximately 32% denser lateral portion (Table 2).

Table 1: Ranges, means and S.E.M for all measurements compared

	Range (g/cm^2)	Mean (M)	S.E.M.
Whole metatarsal.	0.126 –0.580	0.370	0.016
Whole head.	0.129 –0.686	0.401	0.020
Whole shaft.	0.130 – 590	0.372	0.016
Whole base	0.116 –0.561	0.344	0.016
Dorsal portion of whole metatarsal	0.152 –0.671	0.428	0.019
Plantar portion of whole metatarsal	0.106 – 0.671	0.428	0.015
Latera portion of whole metatarsal	0.182 –0.695	0.444	0.016
Medial portion of whole metatarsal	0.116 – 0.594	0.355	0.016
Dorsal portion of head.	0.151 –0.689	0.440	0.022
Plantar portion of head.	0.110 – 0.663	0.372	0.019
Lateral portion of head	0.121 – 0.727	0.398	0.020
Medial portion of head.	0.077 – 0.546	0.300	0.016

Table 2: Mean differences, mean percentage differences and probabilities for all comparisons.

	Mean difference (g/cm^2)	% Mean difference (nearest 1%)	P
Whole metatarsal:			
Head vs shaft.	0.029	8	0.254
Shaft vs base.	0.028	9	0.219
Head vs base.	0.066	16	0.026
Dorsal vs planter.	0.101	31	< 0.001.
Lateral vs medial	0.090	25	0.002.
Head:			
Dorsal vs plantar.	0.069	19	0.019
Lateral vs medial.	0.098	32	< 0.001.

Legend of Figures

Fig. 1: Densitometric image of the 1st metatrsal bone, dorsal view.
Note: The lateral aspect is more dense than the medial one and the head is more dense than the base.
Fig. 2: Densitometric image of the 1st metatarsal bone, plantar view.
Note: - The degree of the head density (lateral more than medial).
- The lateral aspect is more denser than the medial one.
Fig. 3: Densitometric image of the 1st metatarsal bone; medial view.
Note: Although the dorsal aspect is more denser than the plantar one; the density is less in the medial aspect than in the lateral aspect .
Fig. 4: Densitometric image of the 1st metatarsal bone; lateral view; showing the dorsal and plantar aspects, the head, shaft and base.
Note: The density is more in the dorsal than the plantar and in the head than the base .
Fig. 5: Plane X – ray; lateral view of the 1st metatarsal showing the dorsal portion, plantar portion, head, shaft and base of the bone.
Fig. 6: Plane-X ray; plantar view of the 1st metatarsal showing medial and lateral aspects of the bone.

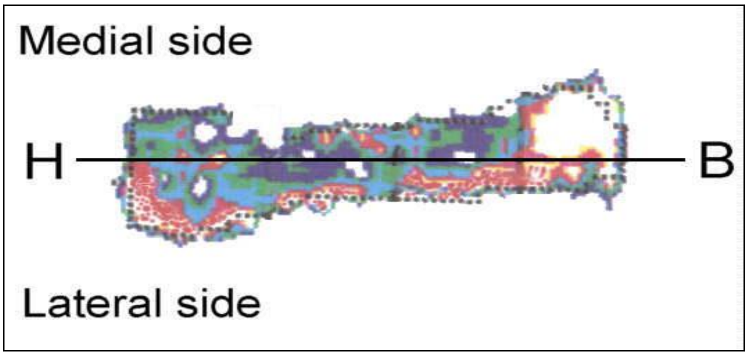

Fig. 1

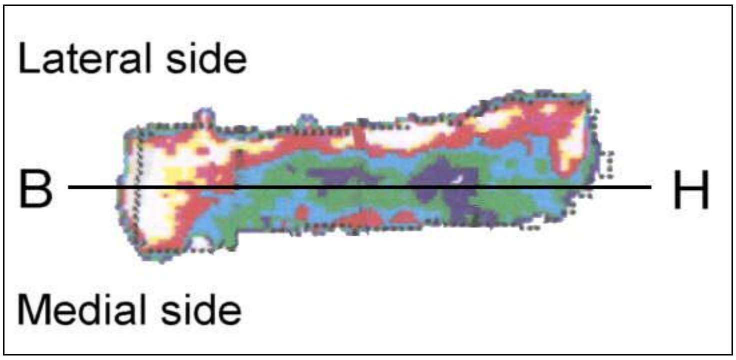

Fig. 2

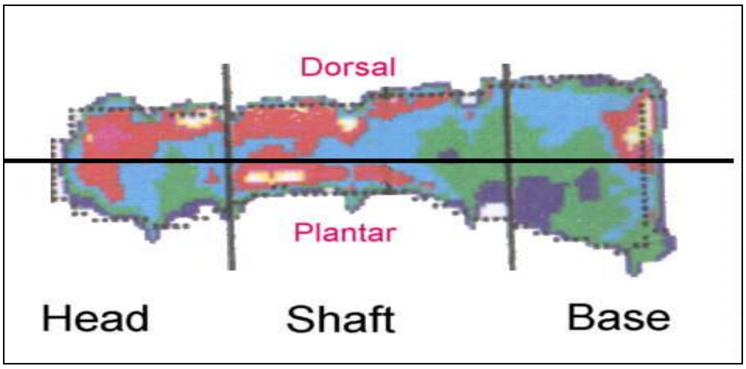

Fig. 3

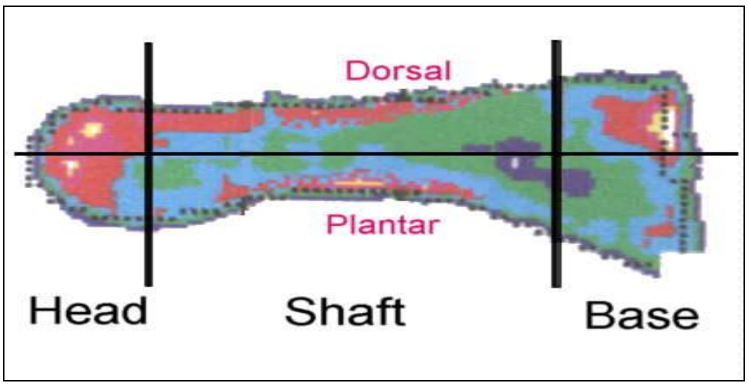

Fig. 4

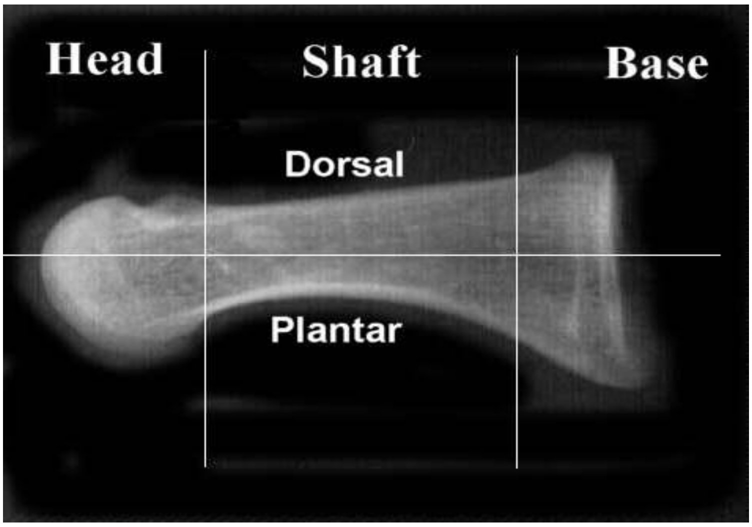

Fig. 5

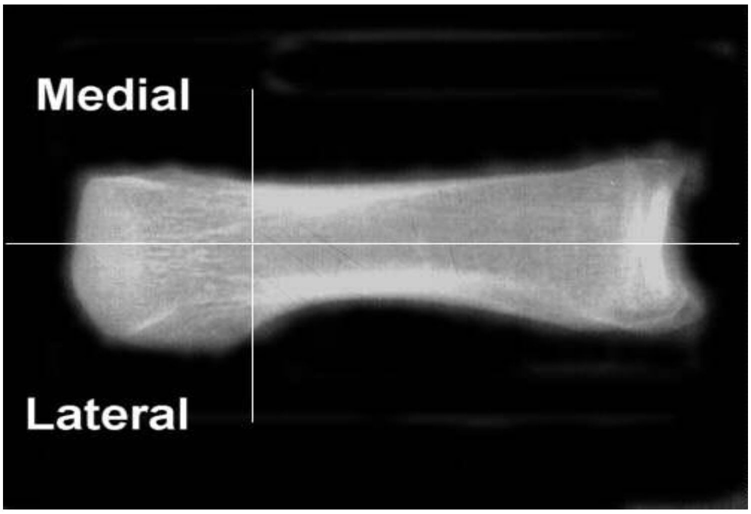

Fig. 6

Discussion

The Present study examines the regional distribution of BMD in the 1st metatarsal bone in an effort to determine the change of the morphological pattern of the bone in response to the stresses during the normal gait cycle.

Carter *et al. (2)* stated that mechanical stress played a mojor role in the regulation of skeletal development which resulted in a system modified for the function it performs.

It had previously been shown that the sites of maximum density in the femur correspond to those areas that exhibit the greatest compressive and tensile strength *(16,17)*. In the present study, the head of the 1st metatarsal bone, located in the forefoot, is denser than the base, which is located in the midfoot. This could be explained by examining the previously reported pressure distribution patterns on the plantar foot. Arcan and Brull *(18)* found that in 4 out 5 subjects, 45to 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. (19)* 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 2nd or lesser metatarsal heads. Perry *et al. (20)*, in their study on peak pressures during walking , found that the highest pressure was under the 2nd metatarsal head, located in the forefoot. Though the lateral midfoot had slightly higher pressure than the medial midfoot, these pressures were significantly lower than those found under the metatarsal heads, including that of the 1st. Other studies, (21,22) concur that, during walking, maximum loads are distributed under the heal initially and later, as weight is transferred forwards , across the forefoot. The load at the normal midfoot is low. At the time of propulsion during walking, vertical force peaks under the ball of one foot and it is at this time that the metatarsal is maximally loaded, and in comparison with the base of the metatarsal, the head is subjected to far greater peak pressure.

In the present study, the dorsal and lateral portions of the whole metatarsal were denser than the plantar and medial portions, and that the dorsal and lateral portions of the head were denser than the plantar and medial portions. These changes could be explaned by observing the dynamics of the 1st metatarsal bone during the gait cycle. The dorsal portion of the 1st metatarsal being had a greater BMD than the plantar portion could be explaind by the fact that the dorsum is undergoing 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 *(14)*. 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 1st metatarsal shaft as it came to lie in a position closer to the weight-bearing surface than the medial portion of the shaft due to pronation of the foot at this time . This correlated to the present finding of a denser lateral portion of the 1st metatarsal than medial portion, a reflection of its loading pattern.

In comparison the same portions of the metatarsal head with the corresponding portion of the whole metatarsal, there was no significant difference in the distributing pattern of BMD. This finding is not in agreement with Muehleman *et al (15)* who stated that in comparison the dorsal vs plantar and lateral vs medial portions of the head with the same portion of the metatarsal as a whole, only the medial portion of the head was less dense than its respective portion of the whole metatarsal bone.

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

In summary, the present study established a bone density pattern for the 1st metatarsal and related it to the dynamics of this bone within the gait cycle.

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تحليل كثافة العظام فىالعظمة الأولى لمشط القدم البشرية

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تمت هذه الدراسة على 38 زوج من عظمة مشط القدم الأولى البشرية فى محاولة لدراسة هيئة كثافة العظام فيها ومقارنته بالوظائف الكيميائيه الحيويه فى العظام.
وقد دلت نتائج هذه الدراسة على أن كثافة العظم يكون أكبر فى رأس العظمه عنه فى قاعدتها كما أن هذه الكثافه أيضا تكون أكثر فى الجزء الظهرى عنه فى الجزءالبطنى لنفس العظمه.
ودلت النتائج أيضا أن كثافه العظم فى عظمة المشط الأولى للقدم تكون أكثر وأعمق فى الجزء الخارجى أو الوحشى للعظمة عنه فى كل من الجزء البطنى أو الأنسى لها.
وقد تمت مناقشه النتائج المختلفة فى هذه الدراسه والتغيرات فى كثافة العظم لعظمة المشط الأولى للقدم البشريه مقرونة بالوظائف البيوكيميائيه فى دورة وهيئة المشى (Gait cycle).