Coll. Antropol. 35 (2011) 1: 55–59
Original scientific paper

Antropological Measurement of the Calcaneus

Vlado Krmek[1], Nikola Krmek[2], Ana Jo-Osvatić[3] and Vasilije Nikolić[3]

[1] Health Centre Metković, Metković, Croatia
[2] University of Zagreb, »Sestre milosrdnice« University Hospital, Department of Pediatrics, Zagreb, Croatia
[3] »J.J. Strossmayer« University, School of Medicine, Department of Anatomy, Osijek, Croatia

A B S T R A C T

Transfer of the forces from the trunk to the lower extremities end on calcaneus which transports these forces to the pad, and that is why it is very important to research this bone. This study was done on 57 calcaneal bones of the osteological collection of the Department of Anatomy »Drago Perović« Zagreb School of Medicine and Department of Anatomy Osijek School of Medicine. The intention was to notice the regularity of the relations between specific dimensions and bone mass and structure, which is of great importance for understanding interrelation between biomechanical parameters of calcaneus and development of involutive changes. In this study geometrical parameters of the calcaneus have been defined, so length of the whole bone and especially frontal and back part, width, height, weight of dry bone, volume, geometrical surface of lateral and longitudinal cross section have been measured on every anatomical specimen. – Mean value, standard deviation and standard error have been calculated for every measured parameter. Positive correlation between most of the parameters of the calcaneus and negative correlation between specific weight and surface of cross section have been found. Coefficient of variation is the highest for weight, and the smallest for width.

Key words: *calcaneus, heel bone, osteometry*

Introduction

Calcaneus is, from the functional morphology and biomechanical point of view, one of the most interesting parts of skeleton. It is the biggest of so called short squared bones. It is entirely filled up with spongy bone and surfaced with compact bone. This bone is exposed to strong tensile and compressive forces. Calcaneus receives the main, but variable, part of the body weight, depending on antropological caracteristics of the foot and shape of the shoes, and transmits it to the heel, the back anchorage of the body. Part of the body weight is transmitted to the front, thru the cuboid bone. Calcaneus is affected, not only by compressive, but also by tensile forces of the Achilles tendon, ligaments and muscles of the foot. All these forces are in static balance when the foot is at rest, but never the less, inside the bone they result in strong inner stress distribution. In movements, for example walking, running, jumping, many changes occur in dynamic impact of forces and momentum resulting in changes of inner dynamic stress distributions in the bone. That is why the shape, the dimension and the structure of the spongy bone is changing in filogenetic, ontogenetic and postnatal life. They are adjusting, so they can accommodate average and maximal needs of the individual, with the minimum spent material. This is also in accordance with general Roux's minimum-maximum principle. Therefore structure of calcaneus meets its function. However, calcaneus also, as the rest of the skeleton, acts according to general laws determining age changes in skeleton. In the fifth decade in women and in the sixth in men, the involutive changes of organism start, especially skeleton. This is the process that brings to osteoporosis in the older population. Osteoporosis and osteopenia bring many difficulties, and if we consider number of people affected, it is not hard to notice sociological and medical importance of this subject, so it is understandable that many medical and technical experts show great interest in finding the best ways to see changes in bone mass as early as possible and to quantitatively evaluate it[1]. There are many densitometric methods available today, that are based on dual-energy X-ray absorptiometry, singlephoton apsorptiometry, ultrasound etc.[2–6]. Lately, studies of ultrasound densito-

Received for publication June 1, 2008

metry of calcaneus are very often[2,4–6] and that is why we chose calcaneus as the subject of our study. Our intention was to see correlations between dimensions, bone mass and structure which is of significance for insight in relations between biomechanical properties of that bone and involutive changes. We believe that, although researching of modern technologies have gotten far, studies in basic anatomy are always needed[7,8] so that we would have a firm basic on which we can create and prove. Many measurements and calculations to which one came in the past are often taken as absolute truths, and today one is witness of demolishing many dogmas, especially in medicine.

Methods

We carried our investigation on model of 57 bones of the osteological collection of Department of Anatomy »Drago Perović« of School of Medicine in Zagreb. The point of this research is to establish dependence of geometrical parameters and bone density of calcaneus. To achieve that, we first defined geometrical properties of calcaneus, so these parameters were defined on every specimen:

A) Average length – l, smallest width – d, height – h, length of posterior part of bone, from Tuber Calcanei to anterior part of facies articularis talaris posterior – l_1, and length of anterior part of bone which we marked as $v=l-l_1$ (Figure 1 and 2).

B) After those measurements we calculated nondimensional parameters of calcaneus as index:
   1. height (h)x100 / average length (l)
   2. height (h)x100 / length of posterior part of bone (l_1)
   3. width (d)x100 / average length (l)
   4. width (d)x100 / length of posterior part of bone (l_1)

C) Weight of dry bone – G, which is measured with common druggist's scale after drying in thermostat and keeping in excitator for 48 hours.

D) Volume – V, of every specimen was measured in gauge glass. However, we encountered a problem, because bones are leaky and water got into all cavities. After few measurements we got significant differences that we could not ignore. We solved this problem in two ways. First we closed all openings on the bones and then measured them. Second way was that we put bones into water, and after they were filled with water we measured their volume in gauge glass. By measuring repeatedly by both ways we reduced possibility of mistake to minimum.

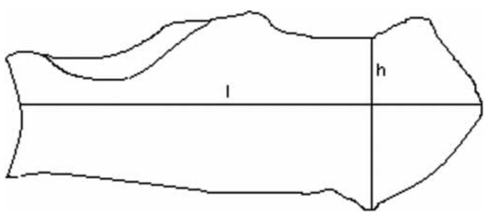

Fig. 1. Latero – lateral projection of calcaneus. l – length, h – height.

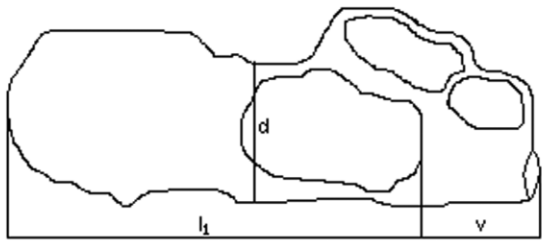

Fig. 2. Calcaneus – view from above. l_1 – length of posterior part of bone, d – smallest width, v – length of anterior part of bone.

E) We calculated specific density (G/V) of calcaneus by dividing the weight with the volume.

F) We calculated geometrical surface of longitudinal and transversal cut from linear measures of parameters, so we multiplied width and height (d x h) for surface of transversal cut, and average length and height (l x h) for longitudinal cut. Geometrical surface of posterior part is also calculated (l_1 x h).

Results

Every single parameter was statistically evaluated to get average value with standard error and standard deviation (Table 1). Correlation between these measured parameters was statistically significant at the significance level of 1% and 5% (Table 2). Insignificant correlations are not in the table because of the simplicity. Statistically significant positive correlations were between most of the parameters of calcaneus, and negative correlations

TABLE 1
RESULTS OF MEASUREMENTS

	Max	Min	$\overline{X}$±stand.error	SD
l (mm)	84	63	74.4±0.60	4.49
h (mm)	46	32	40.2±0.35	3.13
d (mm)	33	22	27.5±0.41	2.63
l_1 (mm)	65	45	55.3±0.35	3.81
v (mm)	26	11	18.9±0.50	2.62
G (g)	38.25	7.06	23.6±1.46	6.14
V (cm^3)	84	33.5	55.8±0.81	10.98
G/V (g/cm^3)	0.646	0.179	0.423±0.01	0.095
h · d (mm^2)	1518	768	1108.7±22.66	166.58
h · l (mm^2)	3647	2016	2997.6±47.67	359.89
h · l_1 (mm^2)	2730	1440	2227.3±35.59	271.43
h · 100/l	61.5	46.3	54.1±0.47	3.57
h · 100/l_1	88.9	64.4	73.0±0.76	5.73
d · 100/l	46.4	30.6	37.2±0.48	3.53
d · 100/l_1	66.7	40.6	50.0±0.70	5.27

l – length, h – height, d – width, l_1 – length of posterior part of bone, v – length of anterior part of bone, G – weight, V – volume

TABLE 2
COEFFICIENTS OF CORRELATION AT THE SIGNIFICANCE LEVEL OF 1% AND 5% (WHICH ARE MARKED WITH^{X}). INSIGNIFICANT CORRELATIONS ARE NOT IN THE TABLE

l	v	h	d	l_1	$\frac{h\times100}{l}$	$\frac{h\times100}{l_1}$	$\frac{d\times100}{l}$	$\frac{d\times100}{l_1}$	V	G	$\frac{G}{V}$	hxd	hxl	
0.4136														v
0.5438														h
0.4733		0.4891												d
0.8448		0.4396	0.3192^{x}											l_1
		0.6742												$\frac{h\times100}{l}$
		0.6167		–0.4283	0.8610									$\frac{h\times100}{l_1}$
			0.6621			0.2750^{x}								$\frac{d\times100}{l}$
	0.2690^{x}		0.7094	–0.4147	0.3143^{x}	0.5598	0.7585							$\frac{d\times100}{l_1}$
0.8307	0.3004^{x}	0.7198	0.6744	0.7148										V
0.5673		0.3040^{x}	0.3300^{x}	0.5911					0.6220					G
						–0.301^{x}				0.6825				$\frac{G}{V}$
0.5763		0.8303	0.8900	0.4271	0.4469	0.4707	0.4710	0.5435	0.804	0.3594	–0.266^{x}			hxd
0.8382	0.3334^{x}	0.9121	0.5505	0.6927	0.3139^{x}	0.3162^{x}			0.8758	0.4740		0.8215		hxl
0.8057		0.8687	0.4900	0.8250	0.2955^{x}				0.8521	0.5211		0.7616	0.9545	hxl_1

l – length, h – height, d – width, l_1 – length of posterior part of bone, v – length of anterior part of bone, G – weight, V – volume

were between specific density (G/V) and index of surface of transversal cut (hxd) and index h x $100/l_1$, also between length of posterior part of bone (l_1) and index hx100/ l_1, and index dx100/ l_1. Coefficient of variability was calculated so it would be possible to compare all parameters of calcaneus to each other. Every minimal value was expressed as percentage of maximal value (Min/Max x100). These results are shown in Tables 3 and 4. Parameters in these tables are lined up by size of coefficient of variation. One can see that weight (G) shows most variation, then specific density (G/V), volume (V), surface of transversal cut (hxd), length of anterior part of bone (v), surface of longitudinal cut of posterior part (hxl_1), surface of longitudinal cut (hxl), width (d), height (h), while the least variability shows length of posterior part of bone (l_1) and average length (l).

From non dimensional parameters, index $dx100/l_1$ shows the most variability, and others follow: index dx100/ l, index hx100/ l_1 and index hx100/l. The most deviations of all calculated areas shows area of transversal cut (hxd), then area of longitudinal cut of posterior part of the bone (lxl_1) and area of longitudinal cut (hxl).

Discussion

Osteometrical values, measured on our material (Table 1) are probably not a good representative model, due to the fact that specimen was not appropriate, and it wasn't chosen for wider anthropometrical research of calcaneus. Because of that, comparison of these values with the values in other publications in the field of anthropology, can give only approximate orientation. Never the less we can see that our values are within the borders that other researchers got. For example Laidlaw (1904) measured 750 heel bones, and he got that the longest length of that bone is between 48 mm and 94 mm, and width between 26 mm and 53 mm. Range of results we got on our material is smaller but fits in his. In the same way other osteometrical parameters are similar. In comparative anatomy we can see that heel bone in human is wider than in smaller animals, which is best seen by index calculated from smallest width and average length of calcaneus (dx100/l). Values of this index match datas from Martin[9]. In humans this index is significantly larger than in monkeys. If we consider width and height we can differentiate three types of calcaneus:

1. Narrow and long with small index (dx100/l), less than 33
2. Middle size with index (dx100/l) between 33 and 41
3. Short and wide heel bone with index larger than 41.

Index between height and width is similar. Average value of that index (hx100/l) in our study is a bit higher than in studies from authors cited by Martin[9] as average values for Europeans. However, all these values are within interval of one standard deviation from average value in this study. If we concentrate on index of height and width, we can see that, except the middle size type

TABLE 3
COEFFICIENTS OF VARIABILITY

	C.V.
G	26.02
$\frac{G}{V}$	22.46
V	19.68
v	13.86
d	9.56
h	7.79
l_1	6.89
l	6.03
$\frac{d \times 100}{l_1}$	10.54
$\frac{d \times 100}{l}$	9.49
$\frac{h \times 100}{l_1}$	7.85
$\frac{h \times 100}{l}$	6.60
hxd	15.02
hxl_1	12.19
hxl	12.01

C.V. – coefficient of variability, l – length, h – height, d – width, l_1 – length of posterior part of bone, v – length of anterior part of bone, G – weight, V – volume

TABLE 4
INDEX MIN/MAX x100

	Min/Max x100
G	18.4
$\frac{G}{V}$	27.7
V	39.8
v	42.3
d	66.7
l_1	69.2
h	69.5
l	75.0
$\frac{d \times 100}{l_1}$	60.8
$\frac{d \times 100}{l}$	65.9
$\frac{h \times 100}{l_1}$	72.4
$\frac{h \times 100}{l}$	75.2
hxd	50.6
hxl_1	52.7
hxl	55.3

which includes values between 50 mm and 58 mm, there are two extreme types – type of low long calcaneus and type of high and short. In humans evolved strong tuber and corpus of calcaneus, as calcaneus evolved to be suporter carrier of the foot, and the whole body, due to forces in the calcaneus. According to Martin[9], width is smaller in highlanders than in people that live in valley. If we cross examine data, we can see that indexes between length and width, and length and height have coefficients of correlation on the level of significance of 1%, while correlation of these indexes with length, logically negative, is statistically insignificant. It means that these indexes change, not on behalf of length, which is the least variable parameter, but on behalf of the remaining two dimensions. Length of calcaneus is consisted of two parts: length of posterior part of bone and anterior, which change independently.

Volume only slightly depends on length of anterior part, but it's in high correlation with length of posterior part of calcaneus. Weight of heel bone is the most variable parameter. This is understandable, since it includes a new variable, a bone density. Weight of calcaneus is in high correlation with volume and specific density, little less with linear dimensions, except for length, especially length of posterior part of the bone.

Very high variability of weight and specific density is an indicator that osteoporosis greatly effects calcaneus. Regressive changes of heel bone, meaning that calcaneus looses its weight within its volume, are very expressed, although this bone is mehanicaly weighted.

Weight of calcaneus is in correlation with its dimensions, but not with nondimensional indexes, which means that constitutional shape of bone does not influence the weight. Specific density (G/V) is in positive correlation only with weight, and in negative with index of height and posterior length ($hx100/l_1$) and surface area of transversal cut (hxd). It means that specific density of heel bone decrease with the increase of transversal cut, and that is in accordance with general biomechanical laws in the area of locomotor system. This result also points out that involutive changes in loss of bone weight usually do not go under minimal level which is conditioned with biomechanical construction of heel bone.

Conclusion

The fact that coefficient of variation of density of calcaneus exceeds 22% and that maximal value of density is more than three times bigger than minimal value shows that the heel bone can be taken for densitometry. Adjustment of the heel bone to biomechanical conditions does not disturb osteoporosis so much that it would influence results of densitometry. On the other side, calcaneus has all topographical and anatomical advantages to be chosen as one of the places for measuring level of osteoporosis, because that bone is easily accessible to densitometry and it is covered with relatively thin layer of soft tissues. It is useful for epidemiological and screening studies, especially in field conditions, in which this method has its advantages compared to DEXA. In this study many parameters of calcaneus were measured, calculated, and divided into groups to show different types of calcaneus, which will be helpful in future studies of this bone.

REFERENCES

1. BONNICK SL, Topics in Geriatric Rehabilitation, 21 (2005) 30. — 2. TAKEDA N, MIYAKE M, KITA S, TOMOMITSU T, FUKUNAGA M, Calcified Tissue International, 59 (1996) 84 — 3. ROSENTHALL L, Journal de L'Association Canadienne des Radiologistes, 48 (1997) 38 — 4. LANGTON CM, LANGTON DK, British Journal of Radiology, 73 (2000) 31 — 5. MOHR A, BARKMANN R, MOHR C, ROMER FW, SCHMIDT C, HELLER M, GLUER CC, ROFO-Fortschritte auf dem Gebiet der Rontgenstrahlen und der Bildgebenden V, 176 (2004) 610 — 6. IKEDA Y, IKI M, MORITA A, AIHARA H, KAGAMIMORI S, KAGAWA Y, MATSUZAK T, YONESHIMA H, MARUMO F, Journal of Bone & Mineral Metabolism, 22 (2004) 248 — 7. KRMEK N, JO-OSVATIĆ A, NIKOLIĆ T, KRMEK V, ŠALAMON A, Coll Antropol, 30 (2006) 811 — 8. SALAMON A, SALAMON T, SEF D, JO-OSVATIĆ A, Coll Antropol, 28 (2004) 221 — 9. MARTIN R, Lehrbuch der Anthropologie. Zweiter band, Kraniologie, Osteologie (Jena, Gustav Fischer, 1928).

N. Krmek

Ante Topić Mimare 30, 10000 Zagreb, Croatia
e-mail: knikola@yahoo.com

ANTROPOLOŠKO MJERENJE KALKANEUSA

SAŽETAK

Prijenos tlačne sile s trupa na donje ekstremitete završava na kalkaneusu koji tu silu predaje podlozi, stoga je važno upoznati tu kost jako dobro. Ovo istraživanje provedeno je na 57 maceriranih petnih kostiju iz anatomske zbirke za anatomiju »D. Perović«. Namjera je bila da se uoče zakonitosti odnosa pojedinih dimenzija i koštane mase i strukture, a što je od značaja za uvid u međusobnu povezanost biomehaničkih značajki petne kosti i razvoja involutivnih promjena. Izvršena je definicija geometrijskih svojstava petne kosti, pa su na svakom anatomskom preparatu određeni dužina cijele kosti te posebice prednji i stražnji dio, širina, visina, težina suhe kosti, volumen, geometrijske površine popriječnog i uzdužnog presjeka. Za svaki od mjerenih parametara dobivena je srednja vrijednost, sa standardnom devijacijom i standardnom pogreškom. Ustanovljena je statistički signifikantna pozitivna korelacija između većine parametara petne kosti, dok je negativna korelacija ustanovljena između specifične težine i površine poprijećnog presjeka. Koeficijent varijacije je najveći za težinu, a najmanji za dužinu petne kosti.