Rev. Esp. Antrop. Fís. (2012)
Vol. 33: 1-6

The relationship between the observed body mass and the dimensions of femoral head – A hip MRI case study

PACHÓN L.P.[1], NIINIMÄKI S.[1,2], JUNNO J.A.[1], NISKANEN M.[1], NIINIMÄKI J.[3] Y NÚÑEZ M.[1]

[1] Laboratory of Archaeology, University of Oulu. Finland.
[2] Department of Biology, University of Oulu. Finland.
[3] Department of Radiology, Oulu University Hospital. Finland.

Corresponding author: laura.perezp@estudiante.uam.es

Keywords:

Body weight estimation
MRI
Femoral head
Lean body weight
Biomechanics

ABSTRACT

Body mass reconstruction from postcranial skeletal elements is a common method in Osteology and various fields of Anthropology. As a weight-bearing element, the femoral head is often considered as a relatively straightforward tool for body mass analyses. Mechanical methods explore the relationship between skeletal elements and weight as a stable trait through adulthood. However, gaining and losing mass, especially fat mass, can occur without direct influence on articular dimensions. This study tests how accurate weight estimations can be in living populations with considerable amount of variation in both size and age. In addition we assess whether modern hospital materials and imaging methods could be utilized to improve body size estimations based on the size of skeletal elements. A clinical sample is utilized of 75 individuals (36 males and 39 females) belonging to a population of modern Finns from the Oulu University Hospital records. Our results clearly demonstrate that lean weights are more tightly associated with femur head size than the observed weights.

Recibido: 09-08-2011
Aceptado: 12-02-2012

Palabras clave:

Estimación peso corporal
IRM
Cabeza femoral
Peso corporal magro
Biomecánica

RESUMEN

La reconstrucción de la masa corporal a partir de los elementos óseos postcraneales es un método común en Osteología y diversos campos de la Antropología. La cabeza femoral es una herramienta útil en los análisis de masa corporal. Esta metodología explora la relación entre los elementos óseos y el peso como una característica estable en la etapa adulta. Sin embargo, la pérdida o aumento de masa ocurre sin una influencia directa sobre las dimensiones articulares. En este estudio se pretende probar la fiabilidad de las estimaciones del peso corporal en poblaciones vivas con amplia variación de talla y edad, así como la aplicabilidad del material clínico y técnicas de imagen en la mejora de las estimaciones de talla corporal basadas en las dimensiones de los elementos óseos. Se emplea una muestra clínica de 75 individuos (36 hombres y 39 mujeres) de una población finlandesa moderna del registro del Hospital Universitario de Oulu. Se encontró mayor relación de las dimensiones de la cabeza femoral con el peso magro que con el peso observado.

Introduction

The importance of body mass estimations for skeletal samples relies on the fact that body size is directly involved in weight-bearing elements (Ruff et al. 1993), thus it allows one to study the effects of mechanical loadings on skeletal components, and to compare relative body size between populations from a single derived variable (Ruff, 2000). Therefore, there is a growing interest on developing new and more accurate methods of body weight estimation.

ISSN: 2253-9921 © 2012 Sociedad Española de Antropología Física

Applicability of clinical material for physical anthropology and osteology – a pilot study

Most of the weight estimations are based on the information obtained from anatomical collections or archaeological samples (Ruff et al. 2005; Smith, 2002; Ruff, 2003). There are limited numbers of studies that also utilize living individuals and radiographic methods, mainly x-rays (Geraghty et al. 2003). In this study we wanted to test whether it would be possible to use clinical magnetic resonance image (MRI) data to improve weight estimations. Clinical material has been utilized before, for example in facial tissue thickness studies (Niinimäki et al. 2007).

The strength of the hospital samples lies in that they offer very large sample sizes from a wide variety of geographical locations. This would allow us to develop formulae to estimate more accurately body weights for archaeological samples originating from certain environmental conditions. The main limitations of the hospital material are laid on the circumstances that lead to radiological analysis. MRI subjects usually present a variety of medical problems. MRI subjects are also elderly, which may have a major effect on their body weight.

Estimating body mass from femur head

Articular surfaces reflect the mechanical forces they have to face. They form in growing children through modeling and remodeling (Pearson et al. 2004). In adults this process still occurs in micro-crack repair, but external dimensions do not change substantially (Ruff et al. 1988) except for some pathological conditions. Femur head is an articular surface with an important role in supporting body weight and transmitting force while walking, thus a correlation between this skeletal element and body weight is expected.

Body mass estimation from femur head size has to be carried out into the context of mechanical loading (Ruff et al. 1991; McHenry, 1992; Grine et al. 1995). Changes occur in the skeleton to adapt bone tissues to their mechanical environment (Ruff et al. 2006; Fricke et al. 2007). Previous studies concerning body mass estimation (Ruff, 2003, 2007) indicate that the femoral head breadth (FHB) is a relatively reliable predictor of body mass in adults when compared with other body mass estimation methods, as those developed from bi-iliac breadth or stature (Auerbach et al. 2004).

Lean body weight reconstruction

Previous studies have demonstrated that femur head size is associated with body mass at the reach of skeletal maturity (Ruff et al. 1991). In later years of life, femur head size and body mass become less tightly associated as body weight increases without substantial changes in femur head dimensions.

Lean body weight (LBW) correlates with several postcranial elements (Burr, 1997). Despite this, little information is available to clarify the role of LBW in the reconstruction of weight from skeletal elements. It is known that LBW experiences less change than adipose tissue during adulthood (Hughes et al. 2002), from which we formulate the hypothesis that LBW could be more useful than total weight (TW) in reconstructing body size. This could also work for undocumented archaeological samples, as there is no possibility to figure out the adiposity values of such populations.

Material and Methods

Sample characteristics and patient selection

Our sample belongs to a high latitude population of Finns (65º 1’ N) (Table 1). Digital image archive was queried for hip MRI between September 1st, 2009 and August 30th, 2010. Patients with neoplastic disease or trauma affecting hip region were excluded. A total of 75 successive cases (36 males and 39 females) were selected for analysis. The most typical imaging indication was non-specific hip pain. Weight values at the date of imaging could be extracted from the images because patients were weighted before MRI.

Imaging and measurements

MRI scans were obtained using a 1.5-T unit (Signa, General Electric, Milwaukee, WI). For the analysis coronal T1-weighted (520/12 [repetition time msec/echo time msec]) spin echo and transverse fat saturated T2-weighted (5100/69) fast spin echo of the

Table 1: Sample characteristics: number of patients, average values, standard deviation and values range for each variable

	n		Mean		S.D.		Minimum		Maximum	
	M	F	M	F	M	F	M	F	M	F
TW	36	39	81.03	68.00	11.5	10.5	64.00	54.00	110.00	97.00
LBW	34	38	63.49	48.10	5.9	6.2	55.22	35.75	77.76	60.47
FHB	36	39	48.96	44.39	3.3	2.8	41.90	40.50	54.80	51.3
Age	36	39	47.70	50.10	15.0	15.5	19.00	18.00	73.00	73.00

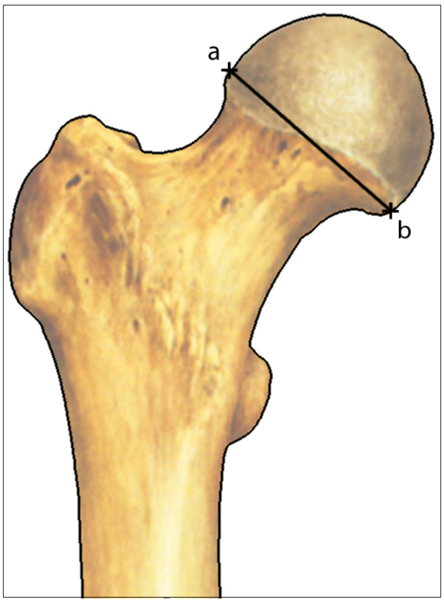
M = Males, F = Females, TW = Total weight, LBW = Lean body weight, FHB = Femoral head breadth

hips were used. The image matrix was 384 x 192 for T1-weighted images and 448 x 224 for T2-weighted images. Field of view was 38 x 38 cm for T1-weighted images and 38 x 28 cm for T2-weighted images. Slice thickness was 4 mm with a 0.5 mm interslice gap. Measurements were performed on a clinical radiology workstation (neaView Radiology version 2.21, Neagen, Finland).

The accuracy of MRI measurements is limited by the in-plane resolution of the images (FOV divided by image matrix). With the used imaging parameters, voxel size was 1.0 x 1.98 mm for the T1-weighted images, and 0.85 x 1.25 mm for the T2-weighted images. Because the measurements were obtained from the equator of the spherical femoral caput, the volume averaging effect due to 4 mm slice thickness is less than in-plane resolution, and therefore the slice thickness should not have an effect on the accuracy of the measurements. In our earlier study (Junno et al. 2009) the reliability of the MRI measurements was tested as the dimensions of 12 archaeological and cadaveric vertebrae were measured utilizing MRI ruler function and standard measurement calipers. MRI scans were obtained and analysed following the protocols mentioned above. The slice thickness was 4 mm with intersection gap of 0.8 – 1.0 mm. The measurements were found to be similar regardless of the measuring technique (r = 0.985).

The inclinations of the coronal and transverse planes were determined before taking the measurements of each individual from the MRI. Supero-inferior FHB was measured following the recommendations of Martin & Saller (1957) in the right femur (Figure 1). Ventral fat breadth measurements were taken from the axial plane of the pelvis at the level below femoral head suture. These linear measurements are expressed in millimetres.

Figure 1: Measurement of supero-inferior femoral head breadth (Modified from Gilroy et al., 2008)



Lean body weight estimation

To calculate LBW we standardized TW with a linear measurement of the abdominal panniculus. This new variable was then used to obtain Pearson's correlations and the regression equations. Measurements of adipose tissue have previously shown significant correlation with body mass index (BMI) ($R^2 = 0.436$) and body fat percentage (e.g. Hunter et al. 1998). Several studies have also investigated the correlations between anthropometric measurements, BMI and percentage body fat (Lahiri et al. 2006). Although not a direct representation of BMI, adipose tissue at abdominal area (visceral adipose tissue and waist circumference) correlates highly with BMI (Barreira et al. 2011; Kerwin et al. 2011; Bastos et al. 2011). MR images allowed us utilize "raw" body fat values by direct measurements of abdominal panniculus instead of relying on further estimates of body fat level. We believe that in case of MR images, this variable will provide a reliable estimate of an individual's level of body fat, similar to BMI or approximated body fat percentage. Further investigations are needed to explore new methods of LBW calculation, appropriated to these material and sample characteristics, in body composition analyses.

Statistical analysis

Bivariate analyses were performed to examine the correlation between body mass and proximal femur parameters. We used Pearson's correlations since the data were normally distributed.

Since the results from log transformed data did not present major differences, multiple regression analyses were performed for raw data to develop body mass prediction equations from FHB. Log transformed data have been used to solve non-linear relationships between body mass and FHB caused by allometry (Ruff et al. 1993). However, the back-transformation in this process may be problematic, and previous studies show that log transformed and raw data provide similar relative errors (Ruff et al. 1991). The correlation coefficients were quite low for all bivariate comparisons, so we tested Ordinary Least Squares (OLS) and Reduced Major Axis (RMA) regression methods for both data sets to choose the model giving more reliable estimates of body mass (Aiello and Dean, 1990). The results obtained from multivariate analyses led us to consider OLS as the most accurate method to do body weight estimations in this sample. Therefore, OLS will be the estimation method taken in further considerations to discuss the biological relationship between FHB and body mass.

The statistical analysis was made separately for each sex (Table 1) as there are considerable differences in body weight and skeletal parameters between them. Although age affects LBW (Janssen et al. 2000), all analyses were carried out without age grouping due to the sample size. Thus, a linear correlation between LBW and FHB is not expected a priori.

Data are presented as groups of means ± SD and maximum and minimum values. The statistical program used for the analyses was SPSS Statistics 17.0. Standard error of estimate (SEE), as well as percentage prediction error (% PE), and absolute percentage prediction error (| % PE |) were used to compare all the estimates. We also calculated the correlation coefficients of residual values for each variable to review the importance of the bias.

Results and Discussion

Body weight and lean body weight correlations and estimation analyses through MRI

The applicability of MRI to TW reconstruction was found to be feasible. Femoral head parameters from MRI demonstrated similar results to other studies. Means for body weight and FHB are similar to those presented in previous articles (Ruff et al. 1991; McHenry, 1992; Grine et al. 1995). Females exhibit a stronger relationship between femoral head dimensions and body weight than males, showing a moderate correlation between FHB and TW (r = 0.406), as well as LBW (r = 0.487) (Table 2). These values for TW fall near those found in Ruff et al. (1991). On the other hand, males do not show the expected results, with no statistically significant correlations. This might be a consequence of the gradual decrease in LBW in later stages of life, as males show a strong decline in LBW at advanced ages in this sample, which is in agreement with other studies (Janssen et al. 2000). To illustrate this we obtained the correlation between LBW and age, significant only for males (r = -0.467). However, this lack of correlation between FHB and body mass in males is not consistent with the general pattern seen in previous studies (Ruff et al. 1991; McHenry, 1992; Grine et al. 1995), possibly due to the age range of this sample. The relationship between FHB and LBW in males and females is represented in Figure 2.

Results in this study are consistent with the hypothesis that LBW is more useful in reconstructing body size than TW. Correlation coefficients suggest this association in females, showing a stronger association between LBW and FHB. This might be explained by the lower shifts produced in LBW versus TW throughout life (Hughes et al. 2002). It has been documented that the proximal articular surface area of

Table 2: Relationships between FHB and body mass, and comparison between regression methods for body mass estimation

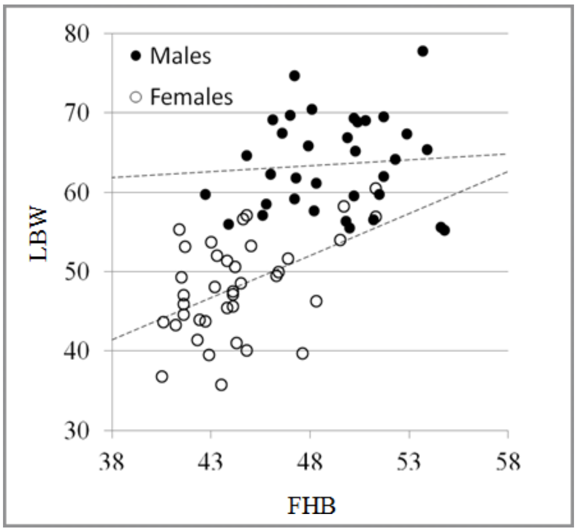
Gender	Comp	Equations				Bias		
		Intercept	Slope	r	SEE	%PE	∣PE%∣	r (res)
Males	TW	32.287	0.995	0.281	11.206	-1.715	11.334	0.960
Males	LBW	56.083	0.151	0.077	6.002	-0.857	7.443	0.997
Females	TW	1.265	1.503	0.406	9.684	-1.788	11.114	0.914
Females	LBW	1.121	1.060	0.487	5.460	-1.325	8.639	0.873

TW, Total weight; LBW, Lean body weight; r, Correlation coefficient between dependent and independent variables; SEE, Standard error of estimate; %PE, Percent prediction error; ∣%PE∣, Absolute percentage prediction error; r (res), Correlation coefficient for residual values

hind limbs (e.g. femoral head or tibial condyle) experience a negligible increase in size in adult animals when they are placed under increasing mechanical forces, (Lieberman et al. 2001). This demonstrates their resistance to change under environmental pressure, and justifies the inference that the most pronounced variations in TW will reduce their correlation to FHB.

The produced prediction equations are presented in Table 2. LBW and TW were regressed on FHB to examine the relationship between femoral head dimensions and changes in body weight. SEE is low compared to the results from other studies obtained from clinical material (Ruff et al. 1991). SEE is lower for LBW rather than TW estimations. The directional bias and ∣ %PE ∣ are lower as well. The most accurate estimations are produced for males. Results in LBW estimations suggest that this variable could be useful tool for further body size reconstructions.

Figure 2: Differences in the relationship between LBW and FHB in males and females



LBW, lean body weight expressed in kilograms;
FHB, femur head breadth expressed in millimeters.

Conclusions

This study clearly demonstrates that clinical samples could be useful for improving body weight estimations. An increasing number of diagnosis via MRI are being performed every day, providing us with more data for further analysis. Quite probably there are also hip MRI cohort studies available worldwide, which could provide us with a baseline for further studies.

Our results clearly indicate that LBW could provide more reliable estimates of body mass than TW, as body fat percentage can fluctuate greatly during adulthood. LBW could provide more accurate body size predictions by considering mostly muscle mass. In our view, estimates of body fat are essential when clinical materials are utilized for the development of new methods to reconstruct body size and shape in archaeological and forensic remains. Several body density formulae include the abdominal skinfold (e.g. Wilmore et al. 1969). However, skinfolds are not accessible measurements when MR images are used but other estimates, such as the abdominal panniculus thickness introduced in this study, can be utilized. This variable can be improved with other information provided in patients' clinical reports, as well as with other measurements on MR images.

Acknowledgements

Thanks to the Oulu University Hospital for providing us with the access to a clinical sample. Thanks for funding to the Department of Archaeology of the University of Oulu, and to the Goya-Mundus and Erasmus-Mundus programs.

References

Aiello L. & Dean C. (1990) *An Introduction to Human Evolutionary Anatomy*. Ed. Elsevier Academic Press. London. pp 260-262.

Auerbach B.M. & Ruff C.B. (2004) Human body mass estimation: a comparison of "morphometric" and "mechanical" methods. *Am. J. Phys. Anthropol*. 125(4): 331-342.

Barreira T.V., Harrington D.M., Staiano A.E., Heymsfield S.B. & Katzmarzyk P.T. (2011) Body adiposity index, body mass index, and body fat in white and black adults. *JAMA*. 306(8): 828-830.

Burr D.B. (1997) Muscle strength, bone mass, and age-related bone loss. *J. Bone. Miner. Res.* 12(10): 1547-1551.

Fricke O. & Schoenau E. (2007) The 'Functional Muscle-Bone Unit': probing the relevance of mechanical signals for bone development in children and adolescents. Growth Horm. *IGF. Res*. 17(1): 1-9.

Gonçalvez F.B., Koek M., Verhagen H.J., Niessen W.J. & Poldermans D. (2011) Body-mass index, abdominal adiposity, and cardiovascular risk. *Lancet*. 378(9787): 227.

Geraghty E.M. & Boone J.M. (2003) Determination of height, weight, body mass index, and body surface area with a single abdominal CT image. *Radiology*. 228 (3): 857-863.

Gilroy A. (2008) *Atlas of Anatomy*. Ed. Thieme. N. York. 656 pp.

Grine F.E., Jungers W.L., Tobias P.V. & Pearson O.M. (1995) Fossil Homo femur from Berg Aukas, northern Namibia. *Am. J. Phys. Anthropol*. 97(2): 151-185.

Hughes V.A., Frontera W.R., Roubenoff R., Evans W.J. & Singh M.A. (2002) Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. *Am. J. Clin. Nutr*. 76(2): 473-481.

Hunter B., French D., Warner J. & Remick D. (1998) Correlation of body mass index with thoracic and abdominal panniculus. *J. Forensic Sci*. 43 (2): 427-430.

Janssen I., Heymsfield S.B., Wang Z.M. & Ross R. (2000) Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J. Appl. Physiol*. 89(1): 81-88.

Junno J.A., Niskanen M., Nieminen M., Maijanen H., Niinimäki J., Bloigu R. & Tuukkanen J. (2009) Temporal trends in vertebral size and shape from Medieval to Modern-Day. *PLoS ONE* 4(3): e4836.

Kerwin D.R., Gaussoin S.A., Chlebowski R.T., Kuller L.H., Vitolins M., Coker L.H., Kotchen J.M., Nicklas B.J., Wassertheil-Smoller S., Hoffmann R.G. & Espeland M.A. (2011) Interaction between body mass index and central adiposity and risk of incident cognitive impairment and dementia: results from the Women's Health Initiative Memory Study. *J. Am. Geriatr. Soc*. 59(1): 107-112.

Lahiri A., Duff C., Brown T. & Griffiths R. (2006) Anthropometric Measurements and Their Value in Predicting Complications Following Reduction Mammaplasty and Abdominoplasty. *Ann. Plast. Surg*. 56(3): 248-250

Lieberman D.E., Devlin M.J. & Pearson O.M. (2001) Articular area responses to mechanical loading: effects of exercise, age, and skeletal location. *Am. J. Phys. Anthropol*. 116 (4): 266-277.

Martin R. & Saller K. (1957) *Lehrbuch der Anthropologie in Systematischer Darstellung*. Band I, 3. Ed. Stuttgart, Fischer. Jena. 1181 pp.

McHenry H.M. (1992) Body size and proportions in early Hominids. *Am. J. Phys. Anthropol*. 87: 407-431.

Niinimäki S. & Karttunen A. (2007) Study on the facial tissue thickness of the Finns. In: Buzug TM., Sigl K., Bongartz J & Prüfer K. (Eds). *Facial Reconstruction - Forensic, Medical and Archaeological Methods of the Reconstruction of Soft Facial Parts*. Bundeskriminalamt, Luchterhand Publishers, München. 677 pp.

Pearson O.M. & Lieberman D.E. (2004) The aging of Wolff's "law": ontogeny and responses to mechanical loading in cortical bone. *Am. J. Phys. Anthropol*. 39: 63-99.

Ruff C.B. & Hayes W.C. (1988) Sex differences in age-related remodeling of the femur and tibia. *J. Orthop. Res*. 6 (6): 886-896.

Ruff C.B., Scott W.W. & Liu A.Y. (1991) Articular and diaphyseal remodelling of the proximal femur with changes in body mass in adults. *Am. J. Phys. Anthropol*. 86 (3): 397-413.

Ruff C.B., Trinkaus E., Walker A. & Larsen C.S. (1993) Postcranial robusticity in Homo. I: Temporal trends and mechanical interpretation. *Am. J. Phys. Anthropol*. 91 (1): 21-53.

Ruff C.B. (2000) Body mass prediction from skeletal frame size in elite athletes. *Am. J. Phys. Anthropol*. 113 (4): 507-517.

Ruff C.B. (2003) Long bone articular and diaphyseal structure in Old World monkeys and apes. II: Estimation of body mass. *Am. J. Phys. Anthropol*. 120 (1): 16-37.

Ruff C.B., Niskanen M., Junno J.A. & Jamison P. (2005) Body mass prediction from stature and bi-iliac breadth in two high latitude populations, with application to earlier higher latitude humans. *J. Hum. Evol*. 48 (4): 381-392.

Ruff C.B. (2006) Who's afraid of the big bad Wolff? "Wolff's law" and bone functional adaptation. *Am. J. Phys. Anthropol*. 129 (4): 484-498.

Ruff C.B. (2007) Body size prediction from juvenile skeletal remains. *Am. J. Phys. Anthropol*. 133(1): 698-716.

Smith R.J. (2002) Estimation of body mass in paleontology. *J. Hum. Evol*. 43 (2): 271-287.

Wilmore J.H. & Behnke A.R. (1969) An anthropometric estimation of body density and lean body weight in young men. *J. Appl. Physiol*. 27(1): 25-31.