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Abstract: Today we are witnessing a genuine revolution in diagnostic imaging techniques. Dual X-ray Absorptiometry (DEXA) quantifies bone mineral density (BMD) and bone mineral content (BMC). This technique has rarely been used in Forensic Anthropology, although its practical application has been demonstrated by various authors. In this article, we look into the conduct of bone mineral density in the Femoral Neck, the Trochanter, the Intertrochanter, the Proximal Femur and Ward's Triangle, in relation to anthropometric age and sex parameters. The research was carried out on 70 persons—38 men and 32 women—and the results obtained show significant correlations between bone mineral density measurements and anthropometric values. The research demonstrates bone mineral density to be a useful technique for sex and age data in forensic anthropology, particularly in the measurements observed in the Ward's Triangle area.

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Abstract

Today we are witnessing a genuine revolution in diagnostic imaging techniques. Dual X-ray Absorptiometry (DEXA) quantifies bone mineral density (BMD) and bone mineral content (BMC). This technique has rarely been used in Forensic Anthropology, although its practical application has been demonstrated by various authors. In this article, we look into the conduct of bone mineral density in the Femoral Neck, the Trochanter, the Intertrochanter, the Proximal Femur and Ward's Triangle, in relation to anthropometric age and sex parameters. The research was carried out on 70 persons—38 men and 32 women—and the results obtained show significant correlations between bone mineral density measurements and anthropometric values. The research demonstrates bone mineral density to be a useful technique for sex and age data in forensic anthropology, particularly in the measurements observed in the Ward's Triangle area.

Introduction

Dual X-ray Absorptiometry (DEXA) has rarely been used in Forensic Anthropology. The determination of Bone Mineral Densitometry (BMD) currently bases its application in the medical field, as a diagnostic technique for high impact pathologies, such as osteoporosis, osteopenias and osteomalacias. This technique in particular has undergone rapid growth over the last few years. Absorptiometry techniques measure the absorption of photonic energy in a skeletal region. Dual X-ray absorptiometry (DEXA) uses two energy peaks; this feature makes it possible to measure bone regions with unequal soft tissues, such as the lumbar spine, the hip or the forearm. DEXA measurement has become the chosen method for assessing bone mass thanks to its speed, accuracy (minimum error around the current value) and precision (minimum error around repeated measurements), and it is currently considered the gold standard for measuring bone mass (1). DEXA equipment uses an X-ray tube as a source of photons, which are targeted at the area of interest. This photon source is mechanically linked to a detector. The amount of bone mineral in the tissue through which the photon ray passes is calculated by the amount of energy of the photons which reach the detector; the photons which are not detected are assumed to have been absorbed by the bone. The skeletal areas of interest are selected by the operator and a computer assesses the bone mineral density in said area. DEXA measurements can determine bone mineral density in the spine, hip, distal radius and the whole body. The presence of vertebral fractures, however, can be a problem since a collapsed vertebra can have greater bone mineral density than a normal one. Variations in the fat content of the bone marrow or the thickening of the soft tissues covering the bone can also cause aberrant results, but this only occurs in very obese individuals.

The use of bone densitometry has many advantages: skeletal length calculations (2), body mass index calculations (3), dating of skeletal remains (4), neutral density measurement techniques in femur and humerus X-rays in relation to age (5), body weight calculations (6), body structure and composition calculations (7), and, although its use is not very widespread in Forensic Anthropology, a field of research is opened up for the dating and identification of human skeletal remains.

Densitometry of the femoral neck and proximal femur is the chosen field of research, which is only natural since this is the region that supports a greater body weight load and is subject to more bone remodelling changes. Moreover, it is directly related to sex, since men are usually stronger than women. Body weight is an important determinant of bone mass and greater body weight is associated with greater skeletal mass and therefore with lower bone loss (8). As this effect occurs in all weight ranges, the influence of body weight on bone mass is relevant for all subjects. Moreover, low weight is considered a serious risk factor for low bone mass (9). Furthermore, with age, there is usually a gradual loss of bone mass, a fact which is aggravated by a decrease in size of the individual due to the progressive wear of the intervertebral discs (10).

The intention of this research is to discover the behaviour of bone mineral density in relation to age and sex parameters. The aim is to assess and record the differences in bone mass in the study population by means of measurements taken in the femoral neck, trochanter, intertrochanter, 1/3 proximal femur and Ward's triangle (Picture 1), and their application as a dating and identification method in forensic anthropology.

Methods

Subjects:

The sample was made up of 70 individuals. They were not selected by means of any random sampling method and their participation in the experiment was determined by chance through their attendance at the hospital on the dates during which the research was carried out (May 2007 to December 2008). Ages ranged from 32 to 83 years, 38 men and 32 women. The women's weight was 64.01 ± 12.64 kg., ranging from 44 to 101 kg. and the men's, 67.021 ± 12.13 kg., ranging from 47 to 113Kg. The women's height was 1.50 m. ± 0.064, ranging from 1.41 to 1.65 m., and the men's, 1.65 m ± 0., ranging from 1.50 to 1.80m. 12.3% had had some kind of fracture, as opposed to 87.7% who had not. The individuals had not been hospitalized over the last 2 years.

Methods:

The measurement of bone mineral content and BMD of the proximal femur was carried out by means dual X-ray absorptiometry (DEXA) with a Hologic DQR-4500 X-ray bone densitometry unit. This unit measures the bone mineral content in a fast, precise way by means of quantitative digital X-rays, making it possible to obtain both the bone mineral content measurement in grams and the BMD in gr./cm². The precision is greater than 1% with a variation coefficient of 1%, for a BMD = 1 gr/cm^2, the spatial resolution being 1.5%. Measurements were taken of the femoral neck, trochanter, intertrochanter 1/3 total femur and Ward's triangle.

All patients had anthropometric weight and height measurements taken. Weight was measured in kilograms and height in centimetres using a Perperson 113481 scales-stadiometer. The BMI was calculated using the formula, $weight/height^2$, and grouped according to the WHO classification: BMI < 20 slim, 20 to 25 overweight type 1, 26 to 30 overweight type 2, >30 obese.

Statistical Analysis.

Analysis was carried out using the statistical package, SPSS 15.0.1. Simple correlations were made using the anthropometric and BMD measurements, age regression measurements and sex. All data are expressed in mean value + standard deviation (X ± SD), statistical significance being considered to exist with values of $p < 0.05$.

Results.

Weight and height were greater in men than in women, as can be observed in Table 1. Men showed greater bone mineral density than women in all the areas measured (Table 2).

Men showed a higher bone mineral density than women in all the zones measured, as shown in Table 3. When comparing the BMD with the BMI categories, it was found that as the BMI values increased so did the BMD values, as shown in Table 4.

The age of the sample also shows a high rate of negative correlation with BMD, and weight and height show a positive correlation with BMD, as can be observed in Table 5.

When classifying the group under study according to age and zones of BMD measurements, it was found that the bone density was lower in all the areas measured within the subject group under 40 years old (with the exception of the trochanter zone, where BMD decreased progressively in subjects from 40 to 61 years old). BMD increased again in the group from 41 to 50 years old and then it decreased progressively from 51 to 60 years old and from 61 upwards, as shown in Table 6 and Graphics 1,2,3,4,5.

Linear regression analysis shows that, when body weight is considered as a dependent variable, there is a substantial coefficient of determination (R^2) with the areas measured, with the exception of Ward's triangle (Table 7). When this same analysis is carried out considering height as a dependent variable, we also observe a significant linear relationship between this (height) and the areas measured, with a high probability, also with the exception of Ward's triangle (Table 8). On the other hand, when we take age as a dependent variable, it is Ward's triangle that shows a higher level of significance (Table 9).

If we separate the independent variables, weight, height and age, by sex, we can observe how the variable, weight, shows a greater relationship with BMD in men than in women, in all the areas measured (Table 10). On the other hand, when we observe height, the areas presenting greater linearity are the Trochanter, Intertrochanter and 1/3 proximal femur, greater significance being shown by women than men (Table 11). With regard to age, men show a high correlation with BMD in all the areas measured. The same is not true of women, but we do observe that the area of greatest interest is Ward's triangle (Table 12). This area shows a high correlation. Table 13 and Graph 6 and 7 show how the combination of age and BMD in Ward's triangle increases precision for calculating chronological age in men and women, as independent predictive variables, based on their respective coefficients of determination (R^2), the standard error of the estimate is appropriate to be use in women and men.

Discussion

The femur is formed by cortical bone and cancellous bone, the latter being the most dependent on changes. With the passage of time, it is possible to observe how the structure of the cancellous bone gradually disintegrates, with loss of bone trabeculae, cavitation in the head, neck and greater trochanter in the femur, or greater tuberosity in the humerus, advance of the medullary cavity from the shaft of the long bone to the head of the same and, finally, thinning of the cortex. It has generally been assumed that growth of the femoral diaphysis is dependent on mechanical load factors, which is confirmed by the non-existence of differences between the sexes if it is correlated with body size; as opposed to the differences found in cases of endochondral ossification, such as vertebral bodies, the mineralization of which does not appear to be influenced by the mechanical loads they support (11). In this investigation, it can be observed that the group of subjects studied show a positive correlation between weight and BMD, a correlation which had already been described in previous research (12,13), the same occurring with height, showing the importance of the mechanical action of weight and height over the mineral content of the skeleton. Both weight and height will condition the BMI (BMI = Weight / Height^2), which, in turn, will condition the BMD. In Table 4, we can observe how as the BMI increases, so does the BMD. Recent research shows this association between BMI and BMD (14,15). Therefore, the body mass index appears to be the anthropometric measurement which has most influence over the determination of bone mass. High correlations have been found between muscular strength and BMD (16), and this is likely to reflect the importance of the mechanical action of muscles on the skeleton as a determinant of the latter's mineral content.

Decades ago, Frost developed a model which explains the influence of mechanical load over bone development (17). As we can observe in Table 6, the study of age with regard to the quantification of bone mineral density enables us to confirm the tendency for bone mass to decrease with increasing age, bone mass reaching a peak at approximately 30 to 35 years of age and starting to decline at around the age of 40, its lowest level being reached at about 80 years. These results agree with those of the research of other authors (18,19), using radiological and imaging techniques. With regard to regression analyses, we can observe how there is a high correlation between body weight, height and bone mineral density in all the areas measured and, by sex, we can see that it is more accentuated in men than women, this being due to a greater amount of muscle mass in men than women. In 1995, Warhafting (20) found greater muscular strength in the quadriceps to be associated with a higher bone mineral content (BMC) in the femur, suggesting that muscular strength can increase the BMC of a specific area, which would make it possible to establish a relationship between muscular strength and BMC. In 2005, Zhang (21) points out that men have larger bones than women, which implies a greater amount of muscle mass and, therefore, greater weight. With regard to age, men lose less bone during the aging process, such that bone mineral density is greater in men than women at any age (22). This may be caused by sex hormones such as oestrogens and testosterone and play an important role in the maintenance of bone strength and decrease in old age. In conclusion, this research demonstrates the usefulness of DEXA technology in forensic anthropology; in the analysis of the femur, it is a useful tool for determining sex and age and assessing weight and height, as shown by the results obtained. The regression equation, for men and women, is highly reliable for inferring chronological age in the sample studied. On the other hand, it would be useful to increase the sample size and carry out more extensive research regarding these results.

Our study demonstrates the usefulness of DEXA technology on the BMD of Ward's triangle in the proximal femur in sex and age determination, found by other authors (Wheatley Bruce P). There is a wide scope for the use of Dual X-ray Absorptiometry (DEXA) in forensic anthropology.

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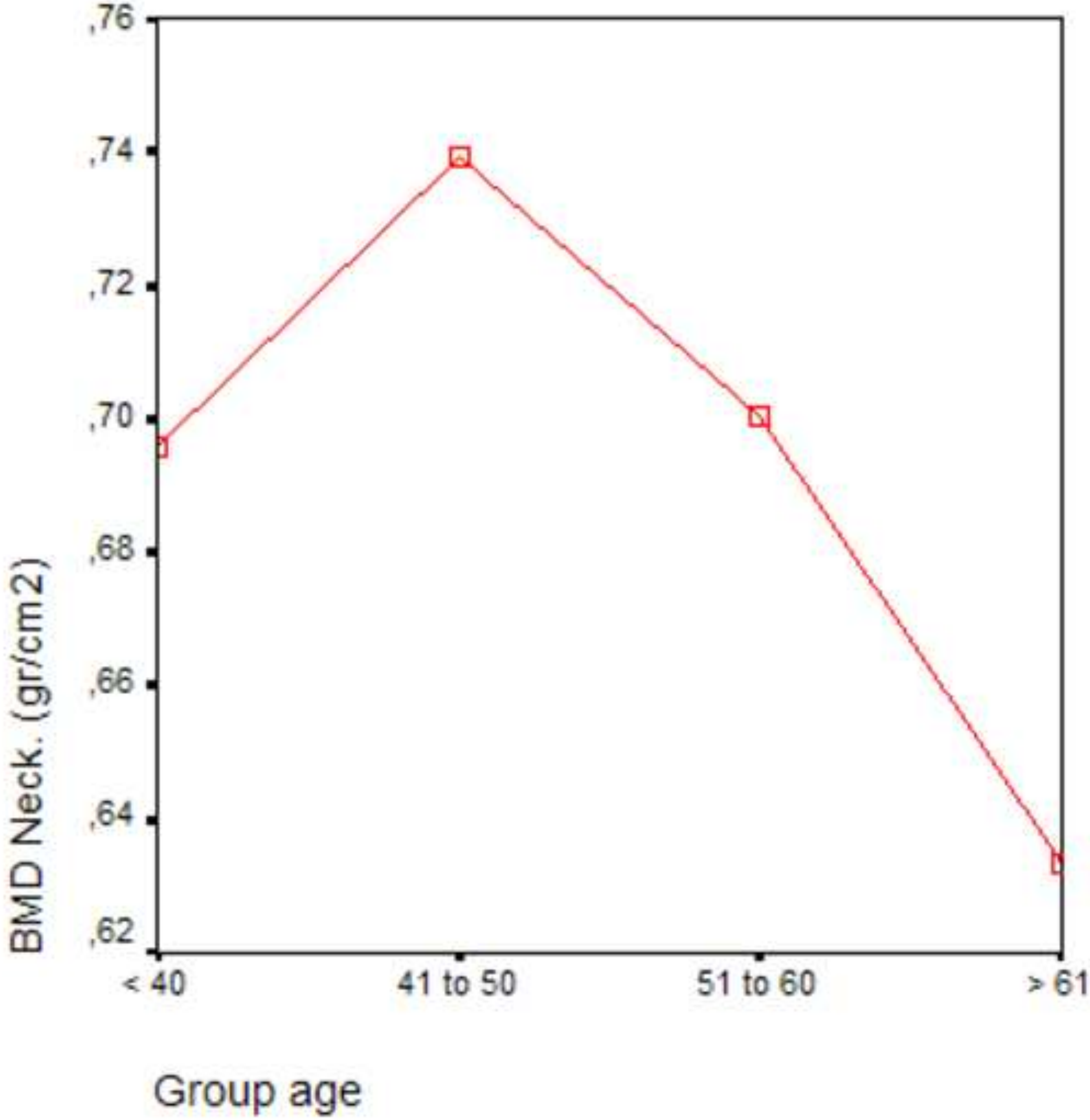

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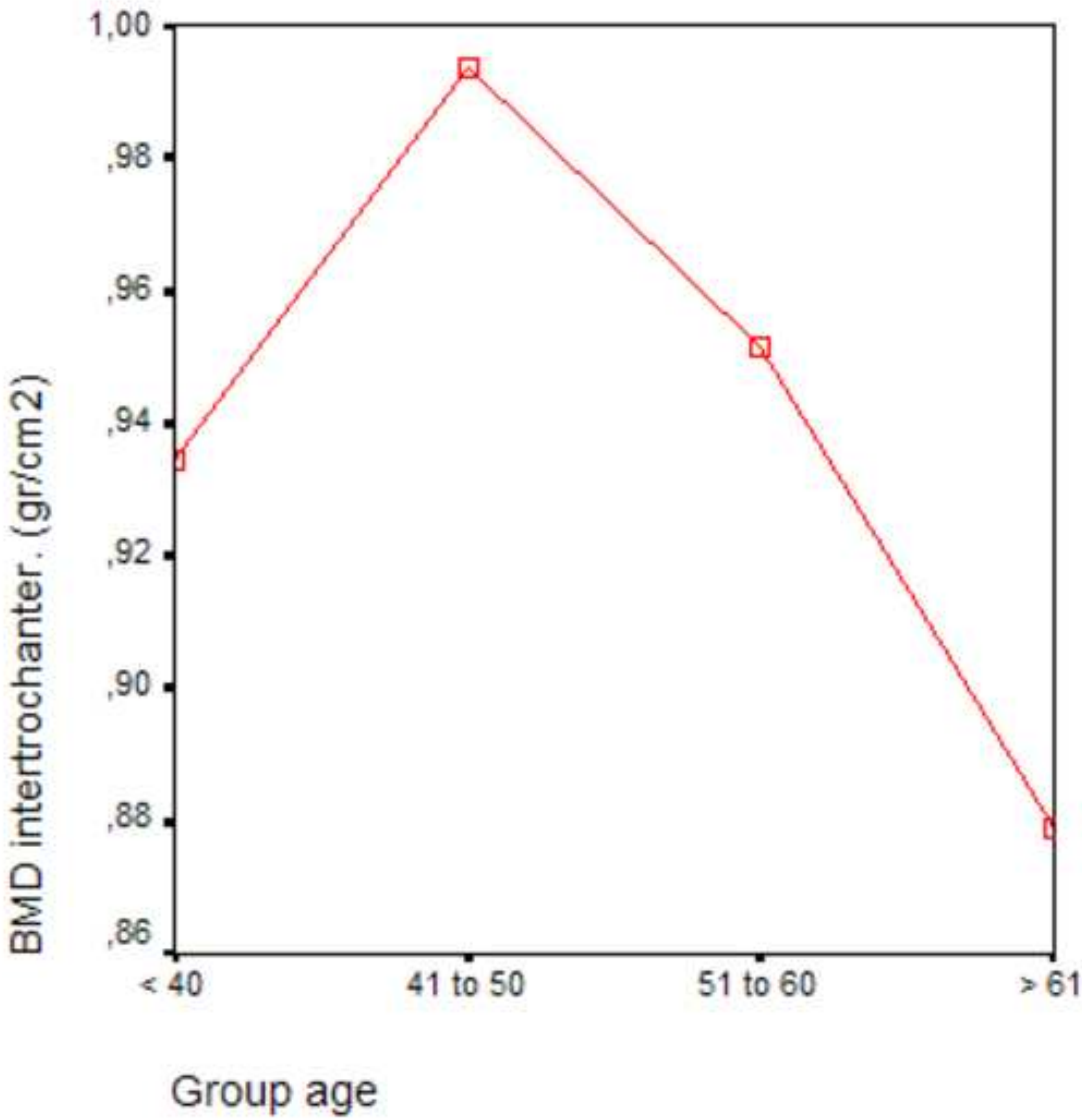

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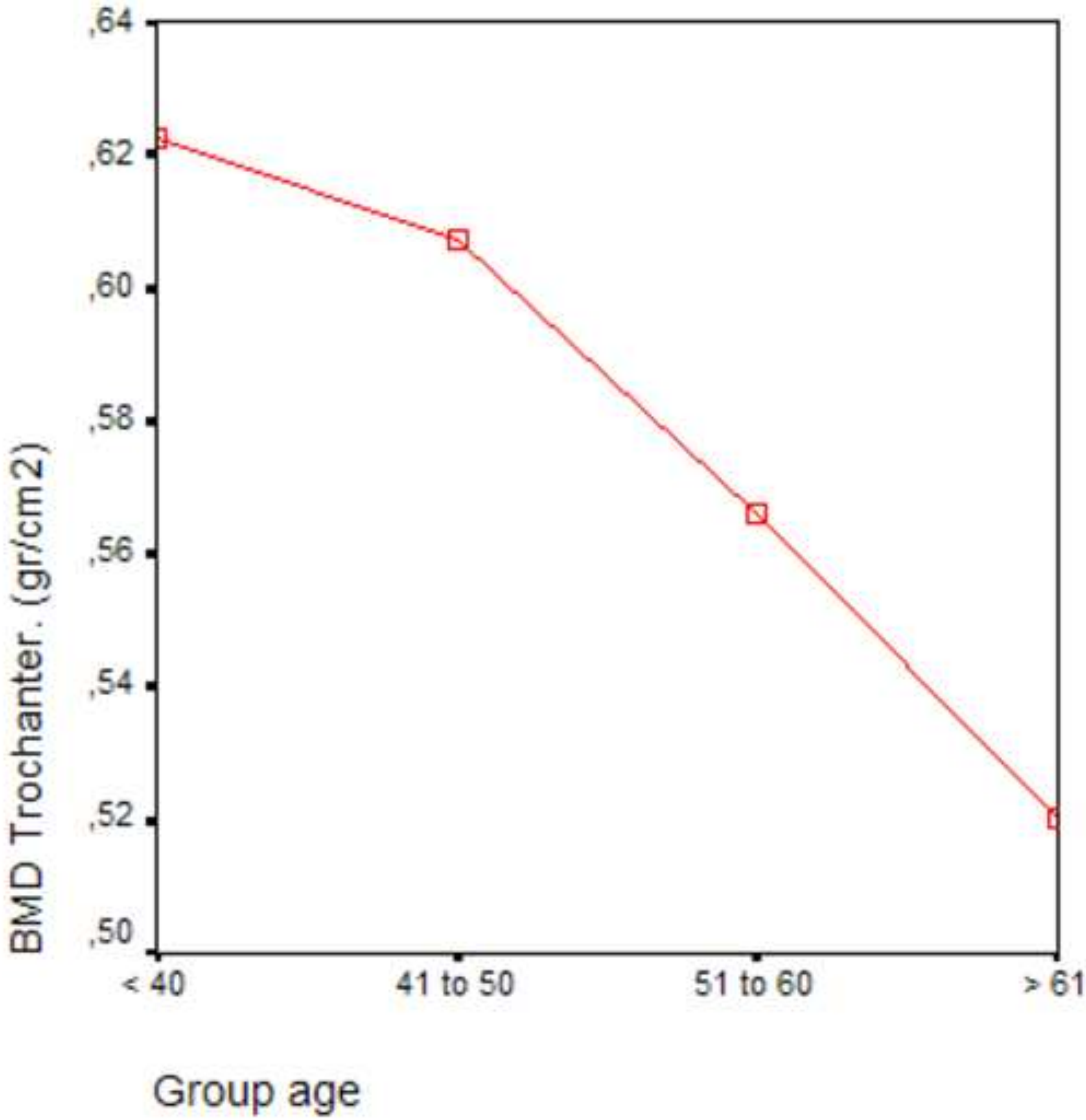

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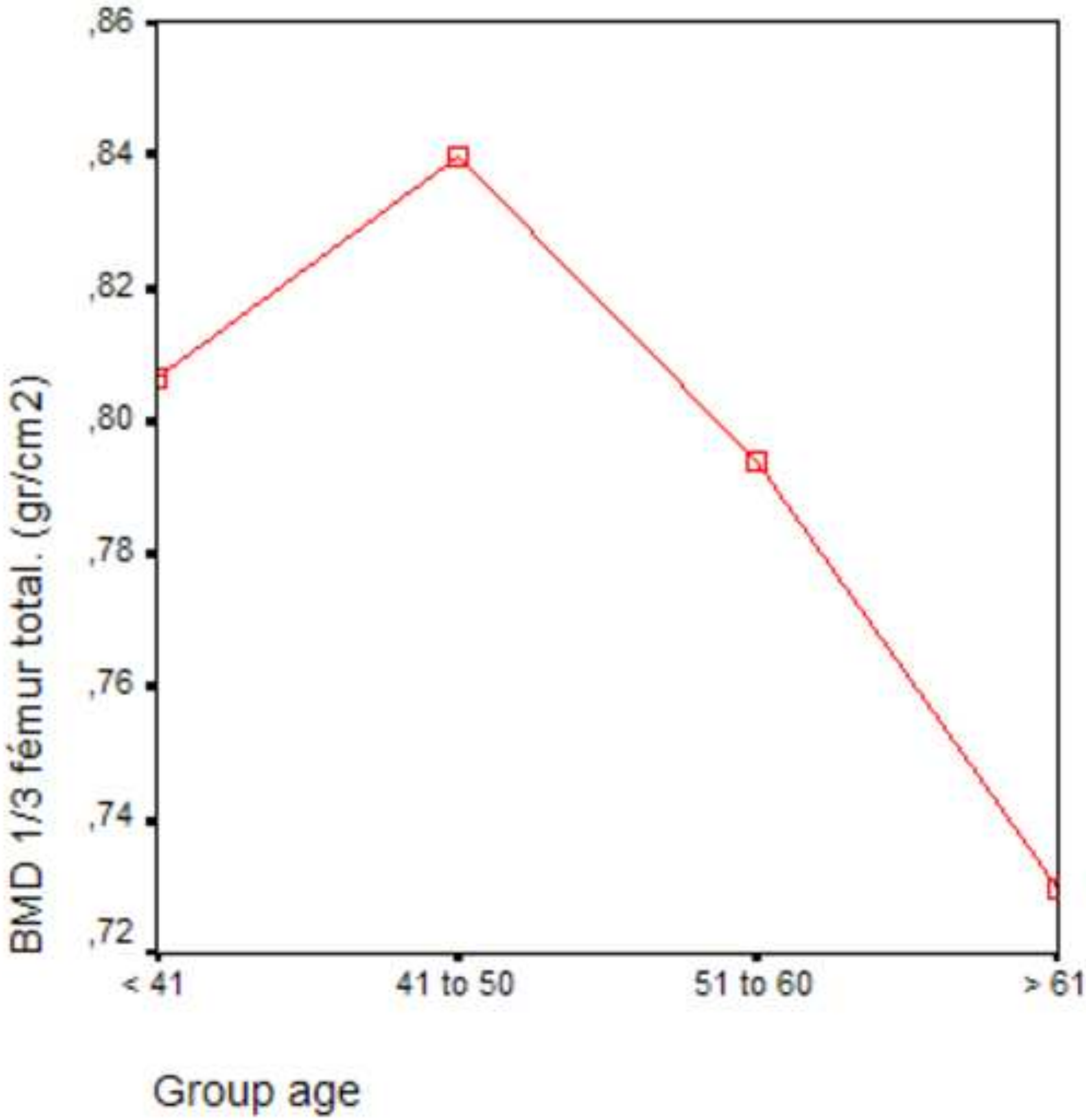

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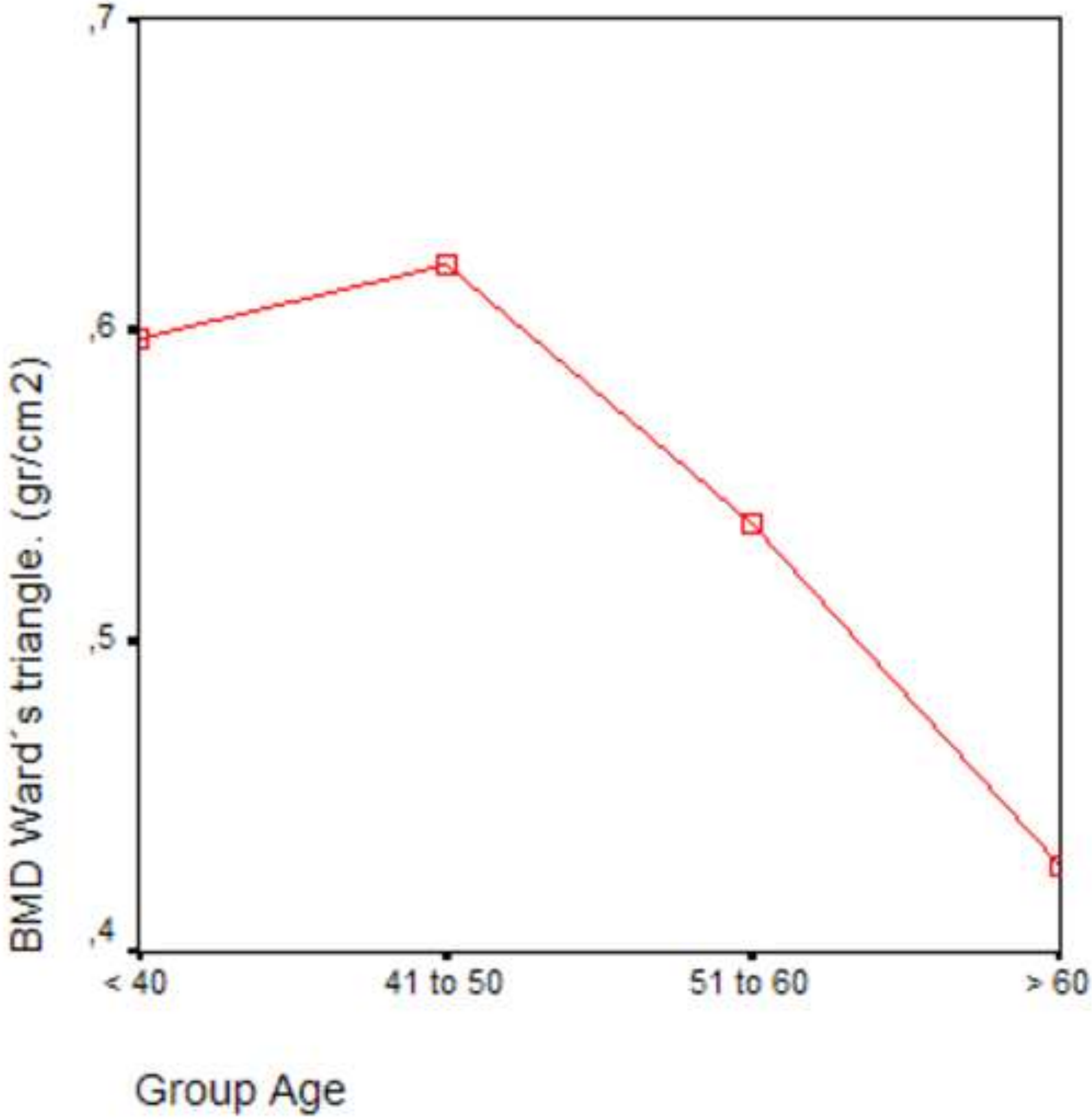

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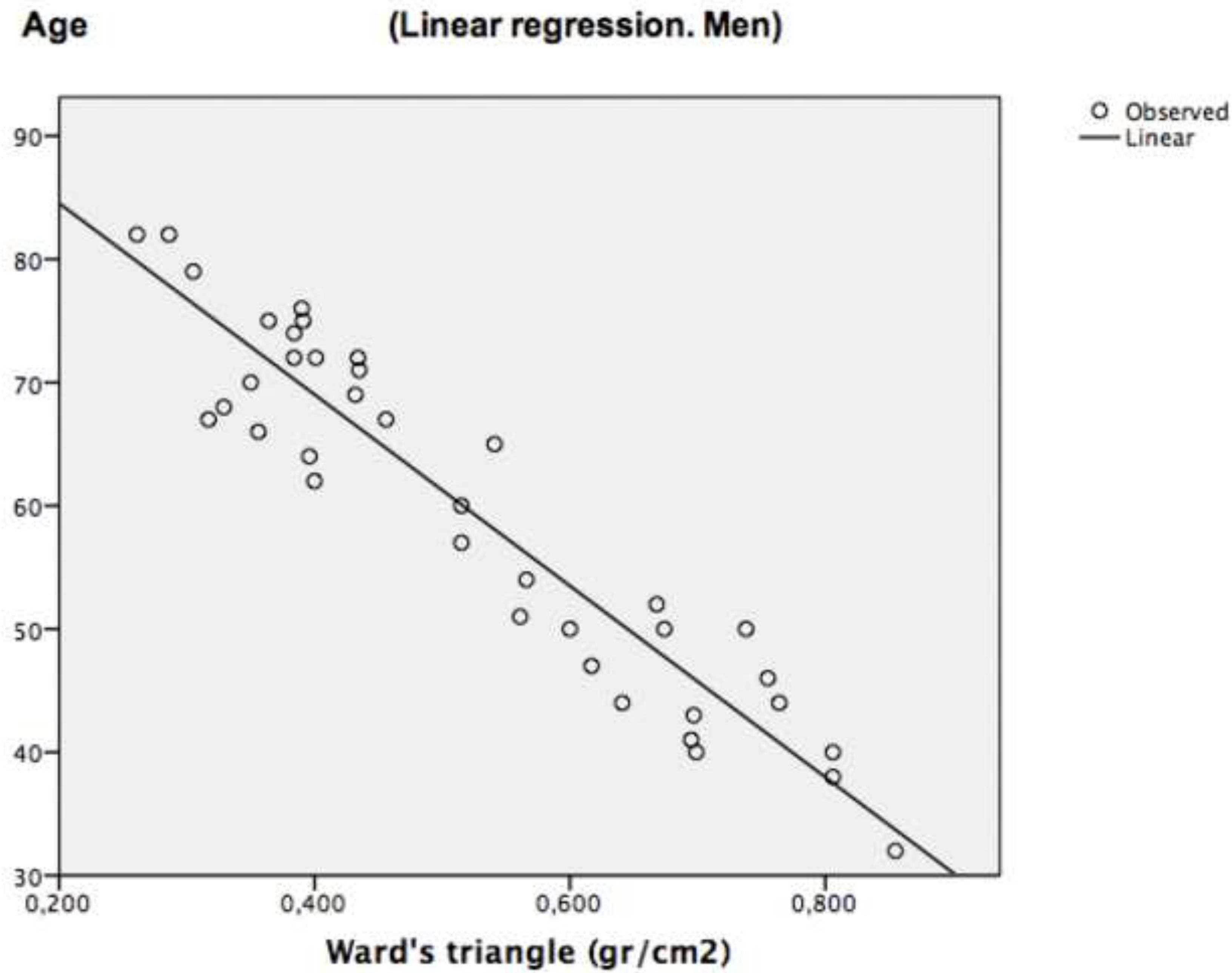

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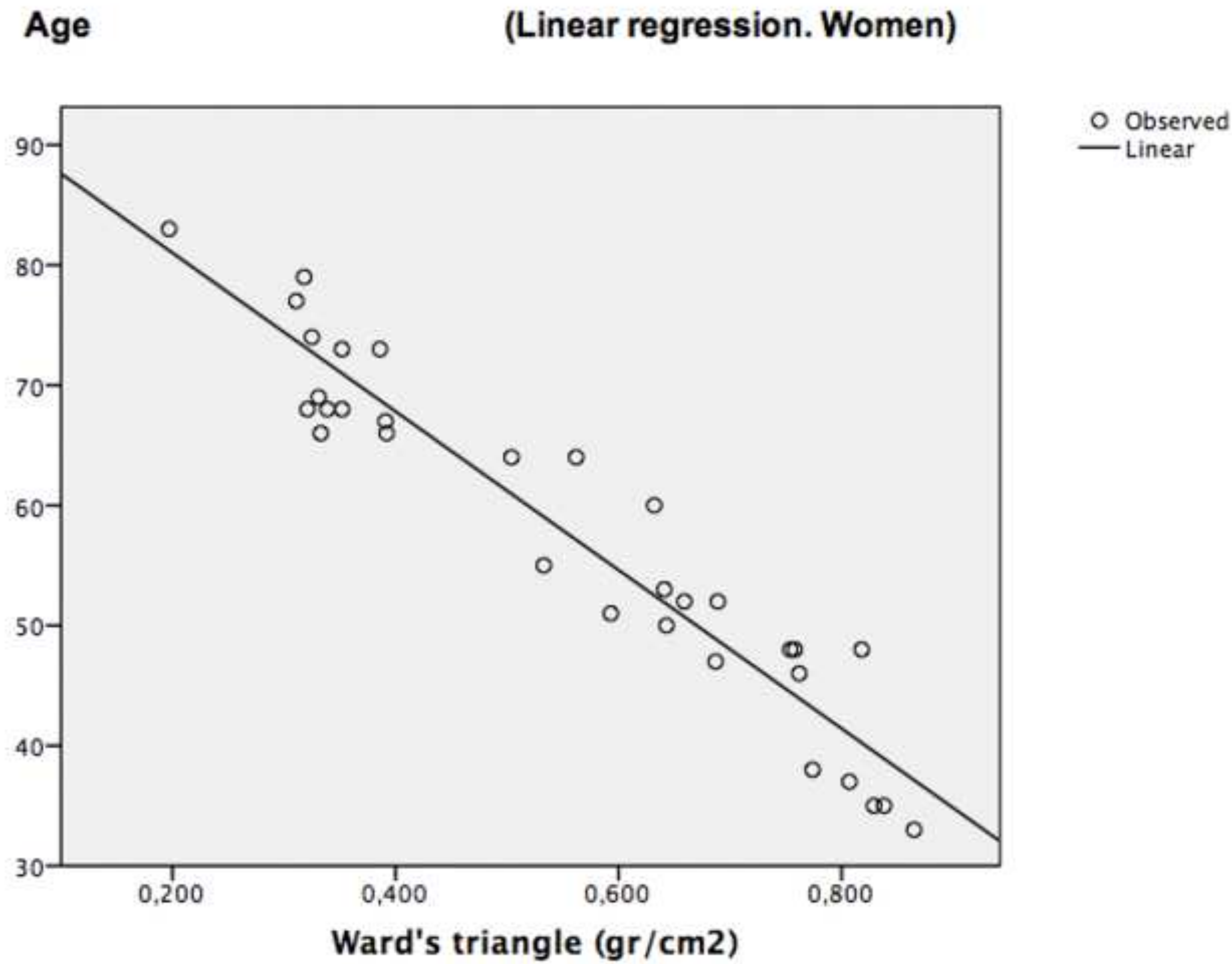

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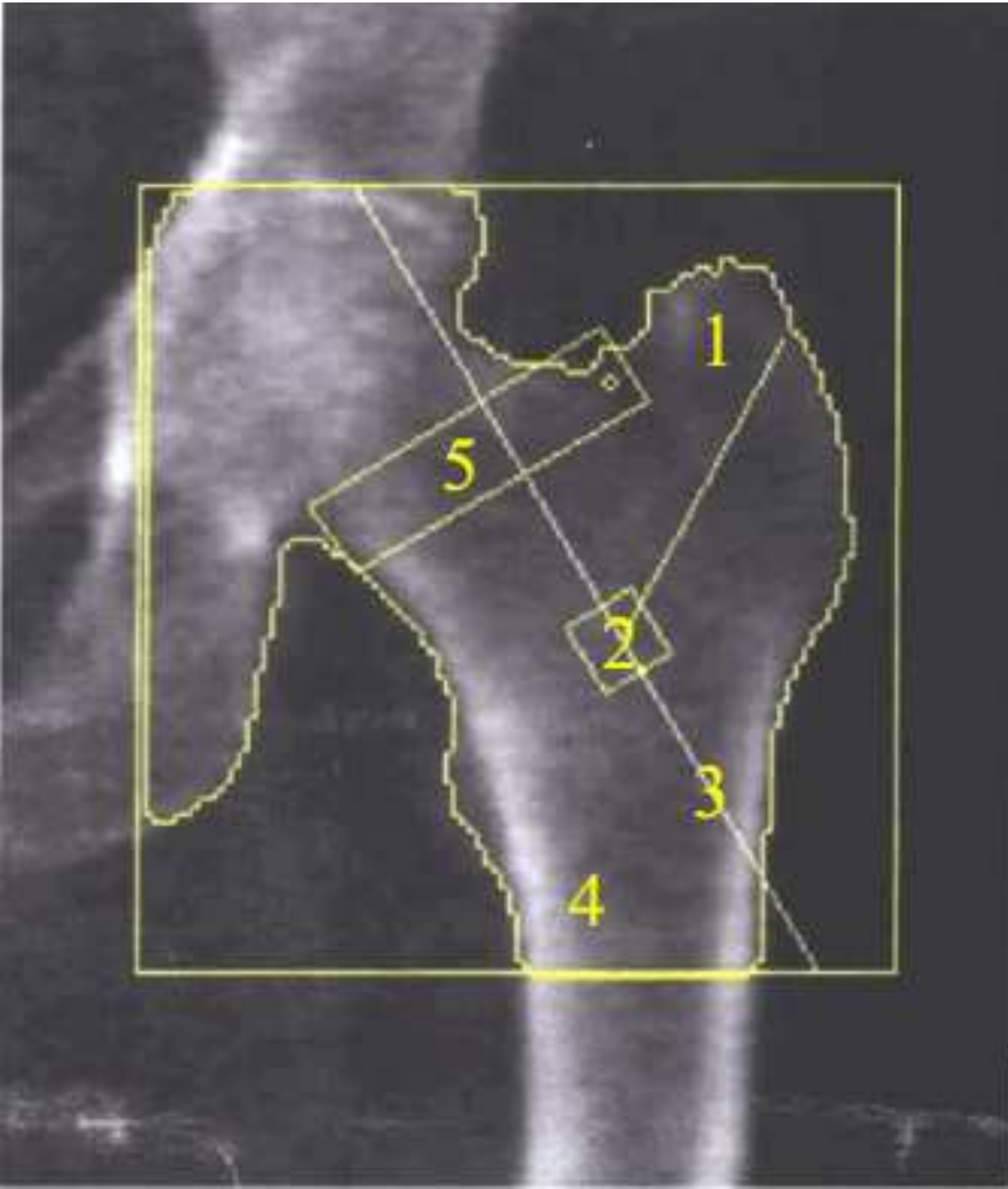

Tables

Table 1: Weight and Height by Sex

Sex	Weight (Kg)	Height (m)
Woman	64.01±12,64	1,50 ± 0,064
Men	67,021 ± 12.13	1,65 ± 0,077

Values are mean ± SD.

Table 2. Comparation BMI by Sex

Sex	BMI
Women	28.065 ± 4.66
Men	24.790 ± 3.70

Values are mean ± SD.

Table 3: Bone Mineral Content measurements between sexes.

BONE MINERAL CONTENT					
Sex	**Neck.**	**Troc.**	**Intertroc.**	**1/3 femur**	**Ward**
Women	0.64 ± 0.11	0.49 ± 0.12	0.88 ± 0.19	0.72 ± 0.15	0.49 ± 0.16
Men	0.70 ±0.14	0.61±0.13	0.95 ± 0.18	0.81± 0.15	0.52 ± 0.14

Values are mean ± SD. Neck: femur's neck; Troc: Trochanter; Intertroc: Intertrochanter; Ward: Ward´s triangle.

Table 4: BMD measurements by BMI categories.

BMD					
BMI	**Neck.**	**Troc.**	**Intertroc.**	**1/3 femur**	**Ward**
<20	0,621 ± 0,15	0,521 ± 0,07	0,866 ± 0,18	0,715 ± 0,14	0,486 ± 0,16
20 to 25	0,666 ± 0,13	0,547 ± 0,14	0,876 ± 0,18	0,748 ± 0,16	0,498 ± 0,17
26 to 30	0,695 ± 0,13	0,576 ± 0,15	0,970 ± 0,19	0,803 ± 0,17	0,516 ± 0,09
>30	0,674 ± 0,15	0,574 ± 0,13	0,976 ± 0,18	0,809 ± 0,16	0,543 ± 0,13

Values are mean ± SD. Neck: femur's neck; Troc: Trochanter; Intertroc: Intertrochanter; Ward: Ward´s triangle.

Table 5: Correlation BMD by Age, Weight, Height:

BMD					
	Neck.	**Troc.**	**Intertroc.**	**1/3 femur**	**Ward**
Age	-0,249	-0,269	-0,185	-0,237	-0,506
Weight	0,401	0,456	0,453	0,458	0,295
Height	0,350	0,477	0,318	0,373	0,264

$p < 0.05$ Neck = femur's neck; Troc = Trochanter; Intertroc =Intertrochanter; Ward = Ward's triangle.

Table 6: **Comparison of age groups by areas of measurement of bone density.**

BMD (gr/cm2)	Age Groups	N	Media	Stand. deviation	Typical Error
	Descriptive				
Neck.	< 40	10	,69570	,140015	,044277
	41 - 50	14	,73907	,147224	,039347
	51 - 60	12	,70050	,095936	,027694
	> 61	34	,63329	,135042	,023160
	Total	70	,67489	,136730	,016342
Trochanter	< 40	10	,62240	,128610	,040670
	41 - 50	14	,60714	,111721	,029859
	51 - 60	12	,56617	,136236	,039328
	> 61	34	,52021	,155006	,026583
	Total	70	,56007	,144088	,017222
Intertrochanter	< 40	10	,93450	,157099	,049679
	41 - 50	14	,99350	,172885	,046206
	51 - 60	12	,95167	,175411	,050637
	> 61	34	,87882	,210013	,036017
	Total	70	,92220	,192305	,022985
1/3 fémur	< 40	10	,80650	,139517	,044119
	41 - 50	14	,83979	,145866	,038984
	51 - 60	12	,79383	,148018	,042729
	> 61	34	,72991	,174826	,029982
	Total	70	,77379	,163448	,019536
Ward's triangle	< 40	10	,59740	,153903	,048668
	41 - 50	14	,62071	,139130	,037184
	51 - 60	12	,53800	,104737	,030235
	> 61	34	,42753	,133641	,022919
	Total	70	,50937	,155269	,018558

Table 7: Weight regression analysis with BMD

	WEIGHT		
	R^2	F	P
Neck	0,161	13,020	0,000
Trochanter	0,207	17,803	0,000
Intertrochanter	0,205	17,527	0,000
1/3 Femur	0,210	18,042	0,000
Ward	0,086	6,478	0,003

Table 8: Height regression analysis with BMD

	HEIGHT		
	R^2	F	P
Neck	0,123	9,497	0,000
Trochanter	0,227	20,008	0,000
Intertrochanter	0,101	7,669	0,007
1/3 Femur	0,139	11,008	0,001
Ward	0,070	5,101	0,027

Table 9: Age regression analysis with BMD

	AGE		
	R^2	F	P
Neck	0,062	4,509	0,037
Trochanter	0,072	5,308	0,024
Intertrochanter	0,034	2,404	0,126
1/3 Femur	0,056	4,045	0,048
Ward	0,893	595,014	0,000

Table 10: Weight Regression analysis with BMD regarding sex

	Weight regression, Men		
	R^2	F	P
Neck	0,225	10,445	0,003
Trochanter	0,259	12,58	0,010
Intertrochanter	0,171	7,433	0,010
1/3 Femur	0,215	9,858	0,003
Ward	0,118	4,808	0,035
	Weight regression, Women		
	R^2	F	P
Neck	0,066	2,115	0,156
Trochanter	0,124	4,255	0,048
Intertrochanter	0,213	8,143	0,008
1/3 Femur	0,170	6,152	0,019
Ward	0,051	1,611	0,214

Table 11: Height regression Analysis with BMD regarding sex

	Height regression , Men		
	R^2	F	P
Neck	0,082	3,231	0,081
Trochanter	0,078	3,055	0,089
Intertrochanter	0,031	1,136	0,294
1/3 Femur	0,049	1,865	0,181
Ward	0,071	2,763	0,105
	Height regression, Women		
	R^2	F	P
Neck	0,065	2,082	0,159
Trochanter	0,129	4,459	0,043
Intertrochanter	0,129	4,432	0,044
1/3 Femur	0,109	3,677	0,065
Ward	0,073	2,370	0,134

Table 12: Age regression Analysis with BMD regarding sex

	Age regression, Men		
	R^2	F	P
Neck	0,294	12,469	0,001
Trochanter	0,352	16,282	0,000
Intertrochanter	0,238	9,381	0,005
1/3 Femur	0,302	12,958	0,001
Ward	0,886	294,370	0,001
	Age regression, Women		
	R^2	F	P
Neck	0,006	0,234	0,632
Trochanter	0,006	0,223	0,640
Intertrochanter	0,005	0,183	0,671
1/3 Femur	0,000	0,001	0,975
Ward	0,919	351,525	0,000

Table 13. Equation regression for men and women.

SEX	R^2	Equation regression	Std. Error of the Estimate
Men	0,886	Y= 100,558 – 79,124(X1)	4,149
Women	0,919	Y= 94,488 – 66,391(X1)	4,855

X1= BMD Ward´s triangle

*Revision Notes

Added a correct translation, we have added error estimates were adjusted to the results and have added two new charts, legends of the graphs added on a separate sheet. Have been taken into account all the sound opinions of the reviewers.

Legends:

Figure 1: Femur neck measurements by age groups.

Figure 2: Intertrochanter measurements by age groups.

Figure 3: Trochanter measurements by age groups.

Figure 4: 1/3 femur total measurements by age groups.

Figure 5: Ward's Triangle measurements by age groups.

Figure 6: Graphic and Linear Regression Equation for Men, Predictors: Age - Ward's triangle

Regression equation Age= 100,558 - 79,124 x (X1)

R square = 0,886

Figure 7: Graphic and Linear Regression Equation for Women, Predictors: Age - Ward's triangle

Regression equation Age= 94,448 – 66,391 x (X1)

R square = 0,919

Image 1:

1: Trochanter.

2: The small square samples "Wards Triangle", which represents the lowest BMD in the hip. This area often shows the earliest loss or earliest improvement in the hip.

3: Intertrochanter line.

4: 1/3 of total femur.

5: Femur Neck