Effect of aging on sexual dimorphism of the human skeleton. A multivariate analysis

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Summary

The well-known pubertal acceleration of growth leads to the high morpho-physiological differentiation between males and females, allowing them to fit the requirements of biological reproduction and specifically adult activities. In human beings, pubertal differentiation process ends at about 20 years of age. Further studies suggest that secondary diverse activities related to differential growth and sexual dimorphism – differential growth in soft tissues, physiologically or pathologically conditioned osseous modifications etc. – are evident. The aim of the present study is to find out whether a "late sexual dimorphism" – specifically in the maturity-elderly transition – actually exists in humans. Ninety-nine skeletons of Caucasoid subjects, well registered as to age and sex at the time of their death, were studied. The sample was divided into four groups: 1) twenty-six mature 40-59 year-old males; 2) twelve mature 40-59 year-old females; 3) forty-six senile 60-90 year-old males; 4) twelve senile 60-90 year-old females. The femoral, tibial, fibular, humeral, radial, cubital, neurocranial, and facial lengths; the neurocranial, facial, orbitary, and nasal widths; and the neurocranial, facial and orbital heights were measured. The mandibular bi-goniac and bicondyleon widths, and the ramus height were also measured. Discriminant (backward stepwise) and canonical analyses were made, and Euclidian distances for hierarchical clusters were calculated. After data standardization, the lowest multivariate F value was found in the senile male-mature female comparison and the highest in the mature male-senile female comparison. They were followed by the senile male-senile female, mature female-senile female, mature male-senile male, and mature male-senile male ones. The most sensitive variables were the cubital length, nasal width and orbit height. Changes in size and shape affected late sexual dimorphism. When the size effect was gone, new sexually dimorphic phenomena based on growth/decrease rates could be observed in elderly subjects. The dynamics of the late sexual dimorphism is different from that of puberty. The main subject is the nonlinear reduction of variables linked to bones (shape changes), which, in turn, may obey the selective bone resorptions associated with the catabolic estrogeny of the senile female crania.

Key words *sexual differences, elderly, osteology, menopause troubles*

Introduction

Several studies were made on human sexual dimorphism during the infantile-adolescent period of growth (1-4). According to Humphrey (5), there is a considerable diversity in the genetic background of the skeletal sex differentiation in humans, which gives sex dimorphism a character of non uniformity. According to this, we wanted to find out what happens at the late age stages of human life. It is commonly believed that growth ends at the be-

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ginning of early adulthood. Modern Auxology has however, shown that changes in skeletal growth and sexual dimorphism may be detected in later periods. Several authors still believe that growth is a continuous nonlinear process, ending when the individual dies.

Kiebzak (6) suggests that several quantitative and fair changes occur during aging. They include:

- alterations in the population dynamics of the cells, giving altered rates in osseous resorption/deposition processes;
- changes in the osseous structure;
- accumulation of micro-fractures;
- troubles in mineral deposit concentrations, where hypo-mineralization occurs in some zones and hyper-mineralization in others;
- changes in the crystalline properties of the mineral deposits;
- changes in the matrix protein content.

Chandler and Bock (7) found, among others, significant sex differences in humans older than 40 years of age, due to a statural decrement in females.

The aim of the present study is to determine:

- whether any kind of sex dimorphism is still present in the adult and senile human skeletons; if so:
- whether such variation is evoked by size and /or shape effects.

Materials and methods

Ninety-nine skeletons of Caucasoid subjects, well-registered as to sex and age at the time of their death were studied. The sample was divided into four groups:

1. twenty-six mature 40-59 year-old males;
2. twelve mature 40-59 year-old females;
3. forty-six senile 60-90 year-old males;
4. twelve senile 60-90 year-old females.

All skeletons belonged to modern Caucasoid individuals (Composite collection) coming from different places, with well registered sex and age at death and absence of pathologies. The following variables were measured on each skeleton: tibial, fibular, femoral, radius, cubital, neurocranial and facial lengths; neurocranial, facial, orbitary, nasal, bi-goniac and bicondyleon mandibular widths; and neurocranial, facial, orbitary, and mandibular ramus heights. Measurements were made by electronic Mitutoyo calipers, 0.05 mm precision, and repeated twice by two independent observers (ELA; JAS). The intra and inter-observer errors were evaluated by the Dahlberg's technique. Reliability was not less than 94% in all cases. Raw and standardized (double z) data were used for calculating between-sex size and shape differences. The one-sample Kolmogorov-Smirnov (K-S) test was first performed to calculate frequency distribution normality (table I). Since most variables were normally distributed, the backward stepwise discriminant analysis was used. The multivariate signification matrices among groups and the canonical scores for the hierarchical Euclidian clusters were employed for the analyses. Calculus was done at the Departamento Cientifico de Antropologia of the Museo de la Plata (Facultad de Ciencias Naturales of the Universidad Nacional de la Plata), employing the statistical Systat 7.0 program.

Results

The mean and standard deviations are shown in table II. The raw-data multivariate F matrix (table III) showed significant differences ($F \geq 4.0$; $p < 0.01$) in all comparisons, being of lower intensity in mature-senile females ($F = 4.1$) and males ($F = 5.6$), followed by the sexual ones in senile ($F = 5.0$) and mature ($F = 7.0$). The age/sex interaction reached its greatest values in the mature male-senile female ($F = 8.1$) and senile male-mature female ($F = 12.4$) samples. The F matrix for standardized data gave non-significant differences for the mature male-mature female ($F = 2.3$) and the mature female-senile male interactions ($F = 0.8$). Age

Table I *Normality of frequency distributions (K-S)[1] for standardized data*

	Mature		Senile	
	MD	**p**	**MD**	**p**
Males				
Femur length	0.22	0.153	0.16	0.171
Tibia length	0.28	0.034 *	0.13	0.414
Fibula length	0.22	0.162	0.14	0.327
Humerus length	0.14	0.730	0.15	0.246
Cubit length	0.31	0.013 *	0.27	0.003 **
Radius length	0.16	0.511	0.12	0.505
Neurocranial length	0.18	0.394	0.13	0.438
Neurocranial width	0.14	0.707	0.19	0.062
Neurocranial height	0.27	0.049	0.09	0.871
Facial length	0.26	0.057	0.12	0.502
Facial width	0.29	0.027 *	0.18	0.106
Facial height	0.17	0.440	0.12	0.553
Nasal width	0.17	0.471	0.18	0.090
Orbit height	0.39	0.001 **	0.22	0.021 *
Orbit width	0.18	0.378	0.16	0.207
Bi-goniac width	0.11	0.907	0.08	0.936
Bi-condyleon width	0.14	0.656	0.11	0.674
Mandibular height	0.20	0.234	0.12	0.558
Females				
Femur length	0.21	0.570	0.31	0.088
Tibia length	0.27	0.309	0.26	0.225
Fibula length	0.22	0.552	0.26	0.221
Humerus length	0.19	0.737	0.41	0.009 **
Cubit length	0.23	0.473	0.25	0.261
Radius length	0.29	0.214	0.23	0.352
Neurocranial length	0.42	0.022 *	0.25	0.261
Neurocranial width	0.30	0.199	0.33	0.058
Neurocranial height	0.23	0.465	0.34	0.046
Facial length	0.25	0.379	0.14	0.877
Facial width	0.21	0.609	0.21	0.443
Facial height	0.22	0.556	0.15	0.867
Nasal width	0.33	0.126	0.29	0.130
Orbit height	0.26	0.352	0.44	0.004 **
Orbit width	0.24	0.444	0.15	0.865
Bi-goniac width	0.23	0.490	0.28	0.152
Bi-condyleon width	0.27	0.294	0.16	0.802
Mandibular height	0.21	0.568	0.22	0.392

Legend: [1]One-sample Kolmogorov-Smirnov test
*p < 0.05, **p < 0.01

differences were significant for the mature male-senile male (F = 5.8), mature female-senile female (F = 7.1), senile male-senile female (F = 8.0), and the mature male-senile female interactions (F = 12.6).

The non standardized discriminant backward stepwise analysis showed the following significant variables: neurocra-

Table II *Mean (X) and Standard deviation (SD) values*

	Mature		Senile	
	X	**SD**	**X**	**SD**
Males				
Femur length	447.8	27.2	455.3	20.5
Tibia length	369.6	21.4	381.3	30.6
Fibula length	357.4	21.3	363.5	21.3
Humerus length	321.4	17.0	326.2	15.8
Cubit length	255.4	15.8	263.0	23.0
Radius length	236.7	15.1	243.0	16.4
Neurocranial length	180.2	8.6	180.0	6.3
Neurocranial width	138.8	7.5	139.5	6.4
Neurocranial height	123.8	5.6	121.2	6.0
Facial length	73.1	3.2	71.7	4.4
Facial width	120.4	7.9	116.3	6.9
Facial height	68.1	6.1	69.2	4.0
Nasal width	25.5	1.5	24.7	1.9
Orbit height	36.2	2.6	38.0	2.1
Orbit width	38.3	2.9	37.4	1.9
Bi-goniac width	100.9	5.9	103.1	6.6
Bi-condyleon width	123.5	6.9	123.8	4.8
Mandibular height	65.7	6.9	63.8	5.6
Females				
Femur length	445.2	29.7	436.7	22.7
Tibia length	368.2	21.6	361.3	21.3
Fibula length	354.1	22.9	349.7	17.5
Humerus length	317.7	22.9	309.2	14.6
Cubit length	254.9	17.8	267.9	26.7
Radius length	236.9	15.8	235.7	17.3
Neurocranial length	170.9	5.6	173.3	7.7
Neurocranial width	136.7	3.0	139.0	4.6
Neurocranial height	119.7	3.9	117.5	5.5
Facial length	71.2	3.9	70.1	5.1
Facial width	114.6	3.2	115.0	7.3
Facial height	66.8	6.7	66.1	4.0
Nasal width	23.3	1.4	25.3	2.4
Orbit height	35.6	2.2	38.0	1.9
Orbit width	36.0	1.3	36.7	2.1
Bi-goniac width	98.8	3.7	97.5	7.6
Bi-condyleon width	120.6	7.9	120.8	7.7
Mandibular height	61.5	7.3	60.6	5.7

nial length (F = 7.7; T = 0.99) and orbit height (F = 6.3; T = 0.99). The remaining ones were non-significant and ranged from the neurocranial (F = 0.1) to the nasal widths (F = 3.2). After standardization, three significant variables were obtained: cubital length (F = 7.6; T = 0.9), orbit height (F = 6.8; T = 0.9), and nasal width (F = 5.2; T = 0.9). The remaining variables gave non-significant results, ranging from facial height (F = 0.3) to facial width (F = 3.4) (table IV).

Table III *Multivariate F matrix of significations*

	Female		Male	
	Mature	**Senile**	**Mature**	**Senile**
Raw-data				
Mature female	0.0			
Senile female	4.119	0.0		
Mature male	6.958	8.072	0.0	
Senile male	12.355	4.949	5.589	0.0
Wilk's Lambda coefficient = 0.6638; F = 7.1256; $p < 0.01$				
Canonical scores of the group means				
I	6.390	8.197	-2.865	-2.721
II	0.470	-0.289	1.081	-0.639
III	1.284	-0.864	-0.281	0.105
Standardized data				
Mature female	0.0			
Senile female	7.101	0.0		
Mature male	2.316	12.628	0.0	
Senile male	0.836	7.950	5.806	0.0
Wilk's Lambda coefficient = 0.6114; F = 5.6269; $p < 0.01$				
Canonical scores of the group means				
I	-0.064	1.868	-0.815	-0.132
II	0.378	0.456	0.787	-0.692
III	1.097	-0.195	-0.279	-0.065

Discussion

Differences are seen in the human skeleton of males and females through several discontinuous characters and metric traits. Size (males are often greater than females), and genetically linked morphological differences given during growth and development (8) are good indicators of sexual differences. Humphrey (5) considers that sex dimorphism in variables of later growth rate is greater than found in variables of early growth rate. According to Antoszewska and Wolanski (9), the differences between males and females increase with age, at least until adulthood. The present results showed that the differentiation process continues during the late stage of human life. In fact, two different physiologic processes are playing a role in human sexual skeletal dimorphism. The former, anabolic and linked to growth and reproduction, lasts from birth (8) to the beginning of adulthood (10). The latter, catabolic and linked to osseous deposition-resorption processes, lasts from adulthood to senility.

In figure 1, the size and shape influences on dimorphism are shown by the F value bars. Sex dimorphism (S1, S2) is slightly greater than age dimorphism (A1, A2) but both are significant since the senile male-mature female interaction (T2) was greater than the mature male-senile female one (T1). The effect found in T2 can be explained only by a whole reduction in size of the senile females. The hierarchical cluster

Table IV *Discriminant analysis (backward stepwise)*

Variable	Significant F	Tolerance	Variable	Non-significant F	Tolerance
Raw-data					
Neurocranial length	7.68	0.993	Femur length	1.59	0.965
Orbit height	6.26	0.993	Tibia length	1.83	0.967
			Fibula length	0.88	0.943
			Humerus length	2.73	0.982
			Cubit length	1.29	0.979
			Radius length	0.85	0.987
			Neurocranial width	0.11	0.896
			Neurocranial height	2.91	0.877
			Facial length	0.46	0.850
			Facial width	2.03	0.928
			Facial height	0.75	0.829
			Nasal width	3.21	0.905
			Orbit width	2.43	0.952
			Bi-goniac width	2.73	0.979
			Bi-condyleon width	0.22	0.927
			Mandibular height	1.44	0.909
Standardized data					
Cubit length	7.57	0.884	Femur length	0.72	0.898
Nasal width	5.24	0.933	Tibia length	2.09	0.849
Orbit height	6.82	0.944	Fibula length	0.85	0.821
			Humerus length	1.93	0.875
			Radius length	1.08	0.775
			Neurocranial length	2.55	0.945
			Neurocranial width	0.76	0.927
			Neurocranial height	1.89	0.978
			Facial length	0.79	0.933
			Facial width	3.37	0.844
			Facial height	0.27	0.933
			Orbit width	1.32	0.978
			Bi-goniac width	0.31	0.984
			Bi-condyleon width	0.47	0.960
			Mandibular height	0.74	0.959

of figure 2 showed that female differentiation was greater than the male one. While the males joined in one subcluster at the lowest distance (d = 1.0), the females joined in two different subclusters, at the highest distance (d = 1.4). Moreover, the senile male-female differentiation process (d = 1.4) was fairly greater than the mature male-female one (d = 1.2).

When the size effect was gone, the F bars (figure 3) showed that age and sex differences are mainly due to the senile female group (E2 and S2 are greater than E1 and S1, respectively). The senile male-mature female interaction (T2), however, is non-significant with respect to the high mature male-senile female one (T1). The standardized cluster showed that, when the size effect is gone, the "senile-female effect" becomes clearer than when size is present. Now the senile female group separates at the greatest distance (d = 1.4), while the

"mature sex dimorphism pattern" shows the lowest separation level (d = 0.9) (figure 4). The triggering effect of the senile female differentiation was the behaviour of the senile females. The skeletal size was involved in the differentiation although only few isolated variables were significant. The affected ones were the optic, the nasal, and the upper-arm regions. Accordingly, Doual et al. (11), who studied humans between 21 and 101 years of age, found that while the anterior-posterior cranial length was not affected by age, the components of the upper face were, the posterior height being greatly altered. Also, bone density was increased with skeletal growth, reaching ts top in the late adolescence or early adulthood (12). This means that during puberty, androgens stimulate bone growth. Studies made on androgen-resistant animals showed that the sexual dimorphism of the skeleton depends upon the androgenic receptors. In adults, the androgens also participate in keeping the male skeleton well structured (13).

Age evokes changes in the concentrations of hormones which regulate calcium and phosphates. While the parathyroid hormone increases, several active metabolites of the D3 vitamin decrease. According to Kiebzak (6), such hormonal changes affect the normal bone homeostasis. It is known that aging evokes bone loss in both sexes, but in females this process is particularly accelerated after menopause, leading to osteoporosis (6,12). According to Doual et al. (11), the structures of intramembranous origin favour a greater osteoporotic activity, compared with those of endochondral origin. With the loss of the osseous mass (expressed in

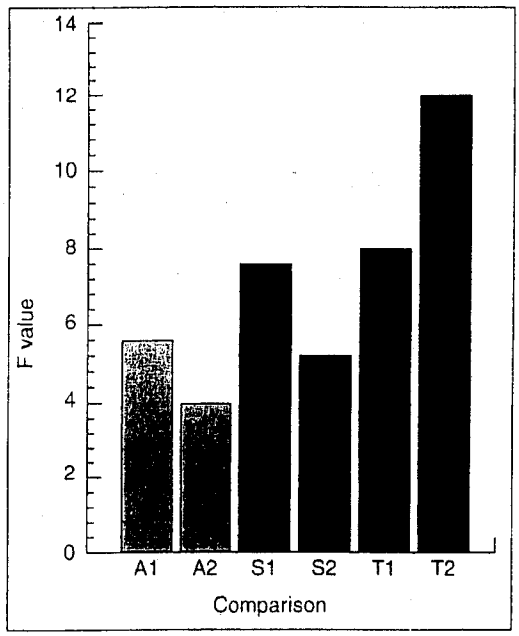

Figure 1 *Between-group multivariate F values for raw-data. Each bar belongs to a comparison. Age factor: mature male – senile male (A1), mature female-senile female (A2). Sex factor: mature male-mature female (S1), senile male-senile female (S2). Age/sex interaction: mature male-senile female (T1), senile male-mature female (T2).*

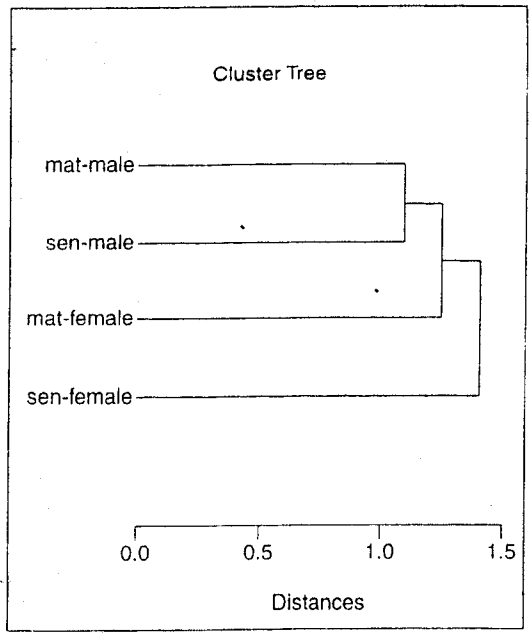

Figure 2 *Euclidian hierarchical clusters based on the canonical scores of raw-data from the four human samples. A slightly greater female differentiation (d = 1.4) than the male one (d = 1.0) is evident.*

diminished bone mineral content), osteoporosis is accompanied by deformities in the vertebral column and loss of stature (6).

Conclusions

Sex dimorphism is still present in the adult and senile human skeletons. Such "late sexual dimorphism" is different from that of the spurt at adolescence in etiology and consequences.

The senile females were more affected than the remaining ones because of the reduction in size by several variables (size effect) and variations in growth rate in other cases (shape effect). Late sexual dimorphism may be caused by the intensive catabolic processes suffered by the senile females, one of its consequences being bone resorption processes linked to aging.

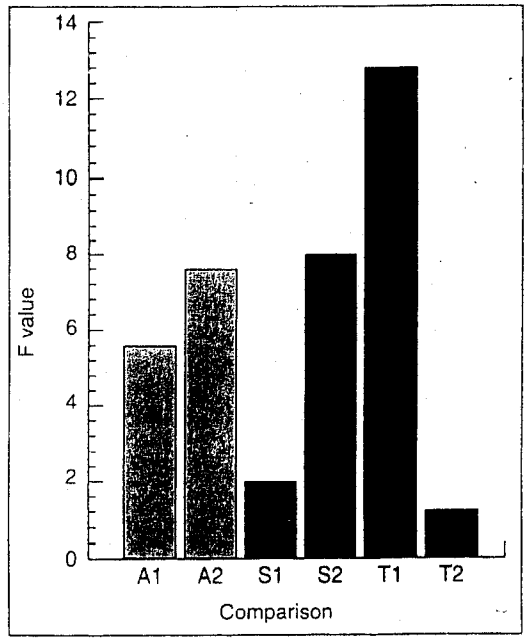

Figure 3 *Between-group multivariate F values for standardized data. Each bar belongs to a comparison. Age factor: mature male–senile male (A1), mature female-senile female (A2). Sex factor: mature male-mature female (S1), senile male-senile female (S2). Age/sex interaction: mature male-senile female (T1), senile male-mature female (T2).*

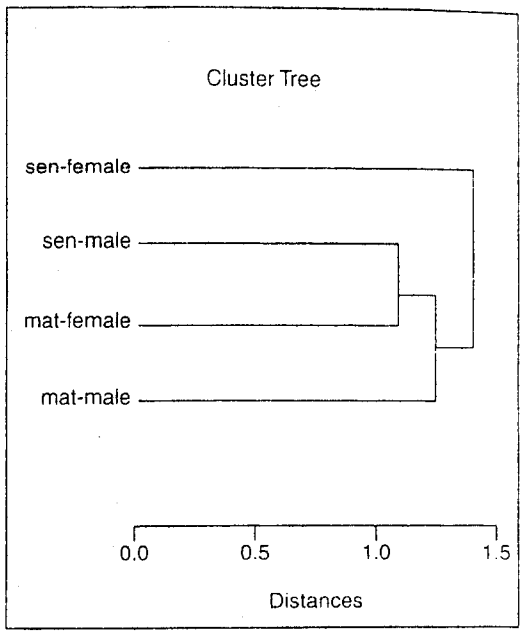

Figure 4 *Euclidian hierarchical clusters based on the size-free canonical scores of raw-data from the four human samples. A clearly differentiated subcluster for the senile females is evident (d = 1.4), the remaining samples being differentiated at lesser distances (dx = 0.9).*

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