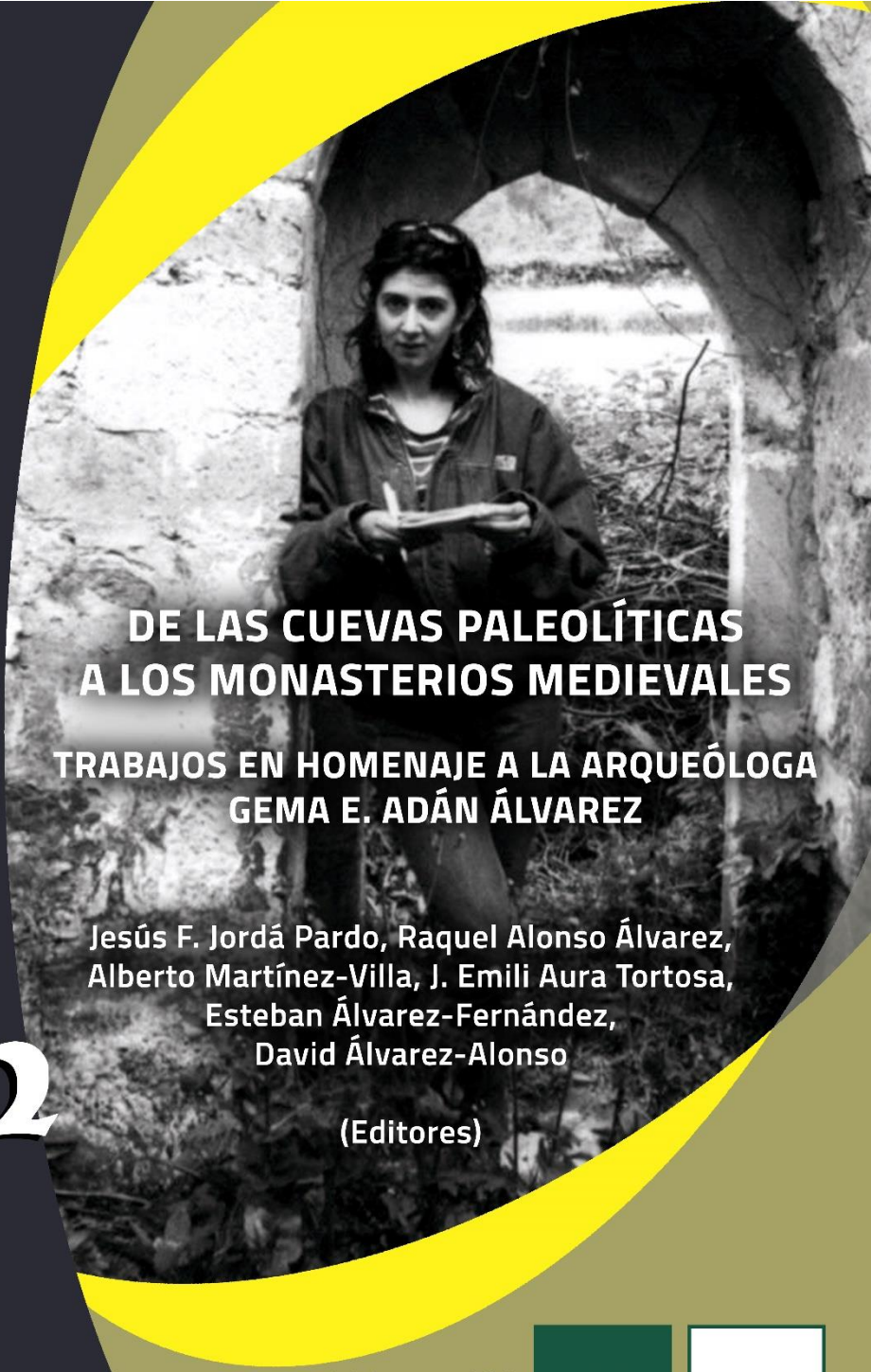
e n t e m u



DE LAS CUEVAS PALEOLÍTICAS A LOS MONASTERIOS MEDIEVALES

TRABAJOS EN HOMENAJE A LA ARQUEÓLOGA GEMA E. ADÁN ÁLVAREZ

Jesús F. Jordá Pardo, Raquel Alonso Álvarez,
Alberto Martínez-Villa, J. Emili Aura Tortosa,
Esteban Álvarez-Fernández,
David Álvarez-Alonso

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TRENDS IN BODY PARAMETERS (BODY MASS AND STATURE) OF ADULT INDIVIDUALS FROM THE OSTEOLOGICAL COLLECTION OF THE MEDIEVAL DOMINICAN CONVENT OF SAN PABLO (BURGOS, ESPAÑA)

Parámetros corporales, peso y estatura de los individuos adultos de la colección osteológica del convento medieval dominico de San Pablo (Burgos, Spain)

Laura Rodriguez[1, 2]
Rebeca García-González[3]
Gema E. Adán-Álvarez[4]
José Miguel Carretero Diaz[3, 5, 6]

[1] Área de Antropología Física. Departamento de Biodiversidad y Gestión Ambiental. Universidad de León. Facultad de Ciencias Biológicas y Ambientales. Campus de Vegazana. Avda. Emilio Hurtado s/n. 24071 León, Spain.
[2] Laboratorio de Evolución Humana. Universidad de Burgos. Edificio I+D+i-CIBA. Plaza Misael Bañuelos s/n. 09001 Burgos, Spain.
[3] Área de Paleontología. Laboratorio de Evolución Humana. Universidad de Burgos. Edificio I+D+i-CIBA. Plaza Misael Bañuelos s/n. 09001 Burgos, Spain.
[4] UNED Asturias. †
[5] Centro UCM-ISCIII de Investigación sobre Evolución y Comportamiento Humanos. Avda. Monforte de Lemos 5 (Pabellón 14). 28029 Madrid, Spain.
[6] Unidad Asociada de I+D+i al CSIC Vidrio y Materiales del Patrimonio Cultural (VIMPAC).

Abstract: The Dominican Convent of San Pablo in Burgos provides key insights into the study of the health and disease of humans between the 13th and 18th centuries. The individuals buried there are concentrated in three areas, with two of them showing clear chronological differences: the cloister from the 14th to the 16th century and the church from the 17th to the 18th century. These two areas are used in this study to determine if there are differences in the quality of life during these two periods through two bioanthropological parameters, height and weight. The study reveals that there are no differences among women in both chronologies, but there are differences in the heights of men, which may imply the detection of male vulnerability in this population.
Key words: *Stature, Body mass, secular change, little ice age, plague, male vulnerability*.

Resumen: El Convento dominico de San Pablo de Burgos proporciona claves para el estudio de la salud y la enfermedad de los humanos de entre los siglos XIII y XVIII. Las personas allí enterradas se concentran en tres áreas teniendo dos de ellas cronologías diferenciales claras, el claustro entre el siglo XIV y el XVI y la iglesia desde el siglo XVII al XVIII. Estas dos zonas son las que se utilizan en este estudio para comprobar si existen diferencias en la calidad de vida en estas dos épocas a través de dos parámetros bioantropológicos, como son la estatura y el peso. En este estudio se ve que no existen cambios entre las mujeres de ambas cronologías, pero si que existen diferencias en las estaturas de los varones, lo que puede implicar la presencia de vulnerabilidad masculina en esta población.

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Palabras clave: *Estatura, Masa corporal, cambio secular, Pequeña Edad del Hielo, peste, vulnerabilidad masculina*.

1 Introduction

Through the analysis of the stature and body weight of archaeological populations, not only descriptive anthropological data of the population are recovered, but also biological values that reveal living conditions and adaptations to specific environments (SHEPARD 1991). The explanation for temporal variations in stature and weight among human populations is based on the fact that the human growth process is genetically influenced but is also marked by changes in environmental conditions. Therefore, these two variables are useful for establishing the health and nutrition status of a population.

It is well-established that stature is largely genetically determined and does not vary significantly once maturity is reached (PREECE 2008; RUFF 2002), providing valuable information about an individual's biological profile (CARRETERO *et al*. 2012; CHRISTENSEN *et al*. 2019). However, it also has a significant environmental component that provides information about health and nutrition (SILVENTOINEN 2003). This is why it can be used as a parameter for individual recognition in forensic contexts (DE MENDONÇA 2000). Adult stature is considered a good indicator of the nutritional and health status of the population, signaling potential secular changes in successive generations due to changes in diet and medical care (CARDOSO 2008).

There are two basic methods for estimating stature from skeletal remains: the anatomical method, which requires a complete skeleton, and the mathematical method based on the proportionality between height and bone length. The latter is possible because the length of long bones is highly correlated with stature (DE MENDONÇA 2000; DUPERTUIS and HADDEN 1951; OLIVIER 1963; OLIVIER *et al*. 1978; PEARSON 1899; TROTTER and GLESER 1952, 1958). However, it should be noted that the proportion of stature represented by bone length varies among populations, and therefore, the most desirable equations are those belonging to a population similar to the one being studied (DE MENDONÇA 2000; HOLLIDAY and RUFF 1997; RAXTER *et al*. 2008; RUFF and WALKER 1993).

On the other hand, body mass has been and is seen as a simple parameter to measure in living beings, as a simple scale is sufficient. It can be used to analyze other more complex biological parameters of interest for inferring the biology of species described through the fossil record, archaeological populations, or individuals in forensic contexts. However, estimating the body mass of a species from its bone remains faces numerous challenges, as it is a parameter that varies significantly throughout an individual's life (DAMUTH and MACFADDEN 1990). Despite its limitations, the estimation of body mass in human remains are important, and it is accepted that the lower limb is preferred, providing the most accurate estimate of body mass (JUNGERS 1988; MCHENRY 1992; PORTER 2002; RUFF 1990; RUFF *et al*. 1991, 1997; TRINKAUS and RUFF 2012). Additionally, SHEPARD (1991) states that the weight closest to the ideal weight, i.e., the mass an individual must have to minimize the risk of death or maximize life expectancy, is reached in the young adult stage. In this regard, the size of the femoral head, whose size stabilizes at 18 years (CHRISTENSEN *et al*. 2019;

SCHEUER and BLACK 2000) and no longer responds to changes in mechanical load, is highly correlated with an individual's "ideal" body weight (RUFF *et al*. 1991).

In this study, a continuation of the work on the paleodemography of San Pablo Convent (GARCÍA-GONZALEZ *et al.* in press), we estimate the stature and "ideal" weight of adult individuals from the Dominican convent of San Pablo (Burgos) to determine both sexual and population differences. We aim to explore variations in health conditions in these two chronological populations and discern any potential secular changes.

2 Materials and methods

2.1 Materials: San Pablo Convent

The Dominican Convent of San Pablo was located outside the medieval city of Burgos on the banks of the Arlanzón River. It was founded during the 12th century, although the major structures of the convent were built during the 14th century, and the church was completed in 1430 (CASILLAS 2014). During the War of Independence, the French converted it into a barracks (1808-1814), and later it definitively lost its status as a convent in Mendizábal's well-known confiscation (1835-1844), transforming into a prison, hospital, and barracks (ADAN-ALVAREZ 2003).

Due to the construction of the Human Evolution complex, a historical-archaeological study of the site was conducted from September 2002 to June 2003 by Dr. Gema E. Adán (ADAN-ALVAREZ 2003). During this intervention, the remains of the convent's foundations and the human remains of around 500 individuals (both non-adults and adults) buried in three completely differentiated areas were recovered.

Over the 6 centuries of its existence as a convent, the first cloister area (dating from the 14th to the 16th centuries) and the church with its chapels later were used as a burial place for the local population (ADAN-ALVAREZ 2003). This practice continued until the 18th century when, by order of King Carlos III in 1787, burials within churches were prohibited, with some exceptions, and extramural burials began (SANTONJA CARDONA 1999). The chapter house was used as a burial place for the monks continuously (ADAN-ALVAREZ 2003).

In this study, only the human remains of adults from the cloister and the church will be analyzed since they represent two chronologically distinct periods. It is in adults where the maximum biological information about individuals during growth can be observed, summarizing the life history of these individuals up to the moment of death and how they adapt and adjust to moments of adversity and prosperity. We define adults as those individuals whose bones are already mature, i.e., not in the growth or epiphysis-diaphysis fusion stage (CHRISTENSEN *et al*. 2019; SCHEUER and BLACK 2000).

2.2 Methods

2.2.1 Sex Estimation

The sex estimation in the adult population used here is the one detailed in the article on paleodemography from this same special issue (GARCÍA-GONZALEZ *et al.* in press).

2.2.2 Stature Estimation

Stature estimation is carried out using formulas created by DE MENDOÇA (2000) for the femur and humerus, as they are based on 200 individuals of both sexes who are of Portuguese nationality and come from autopsies at the Oporto Institute of Legal Medicine, thus representing Iberian Europeans who would be closest to the body proportions of the San Pablo sample. The formulas are shown in Table 1. The measurements used in this section are the maximum length of the femur (M1) and humerus (M1) described by (MARTIN and SALLER 1957) and referred to here for greater agility as Femlength and Humlength, respectively.

	Humerus	Femur
Males	59.41 + 0.3269 x Humlength ± 8.44	46.69 + 0.2657 x Femlength ± 6.96
Females	64.26 + 0.3065 x Humlength ± 7.70	57.86 + 0.2359 x Femlength ± 5.96

Table 1. Formulae for Stature Estimation (MENDOÇA 2000). Humlength: Maximum Length of the Humerus. Femlength: Maximum Length of the Femur. Measurements in millimeters.

2.2.3 Weight Estimation

The estimation of weight is carried out following the recommendations of TRINKAUS and RUFF (2012), in which different formulas are used depending on the size of the femoral head (variable M18 from Martin and Saller, 1957). Initially, these formulas were created for different populations with varying body sizes (GRINE *et al*. 1995; MCHENRY, 1992; C. B. RUFF *et al*. 1997). At this point, it is important to note that weight estimation is more accurate for younger individuals, as they are not affected by age-related weight gain and are less influenced by a sedentary lifestyle. By using the femoral head, which stabilizes in size at 18 years (CHRISTENSEN *et al*. 2019; SCHEUER and BLACK 2000), we assume that the individual's weight is calculated when they have just finished growing, equivalent to the ideal weight (SQUYRES and RUFF 2015), and not the weight at the time of death. The formulas are presented in Table 2.

		Formulae
Femoral head diameter ≤ 38 mm	MCHENRY (1994)	BM=2.239 x FemHdDia – 39.9
Femoral head diameter 38 < x ≤ 47 mm	Male	Mean from MCHENRY (1994) GRINE (1995) and the necessary from RUFF ET AL., (1997)
	Female	
	GRINE ET AL. (1995)	BM=2.268 x FemHdDia – 36.5

		Formulae
Femoral head diameter > 47 mm	Male (RUFF ET AL, 1997)	(2.741 x FemHdDia – 54.9) x 0.90
	Female (RUFF ET AL, 1997)	(2.426 x FemHdDia – 35.1) x 0.90

Table 2. Formulae for body mass estimation following Trinkaus and Ruff (2012). FemHdDia: Vertical femoral head diameter. Measurements in Millimeters.

2.2.4 Comparison

The comparison will be conducted between sexes and populations. To do this, a normality analysis is carried out for both stature and weight calculation results. Once normality and homogeneity of variances are confirmed, a two-factor ANOVA (sex: male and female, and population: cloister and church) is performed to determine if there are any differences between them. In cases where there is no homogeneity of variances, but normality is present, a one-factor ANOVA with Welch's correction is conducted, considering four different populations (female cloister, female church, male cloister, male church). The statistical analyses are performed using the free software JASP (JASP TEAM 2022).

To compare these two populations from the San Pablo collection (Burgos) with others from Castilla y León from different periods, the work of López-Martínez (2000) is utilized, where statures of modern populations (up to the 18th century) and medieval populations (up to the 14th century) from Castilla y León were calculated. They will also be compared with the Portuguese populations analyzed by Cardoso (2008). Cardoso (2008) calculates stature using the same formulas as in this study, allowing for a direct comparison. However, in the populations of Castilla y León, the formulas used are those of Pearson (1899). Lin's concordance tests are employed to determine if stature estimations with both formulas can be considered consistent with each other.

3 Results

The basic statistics for the raw variables used in the calculation of body parameters are presented in Table 3. The basic statistics for height and weight calculations are provided in Table 4 and Table 5. These tables reveal that individuals from the cloister show higher means than those from the church. However, after confirming normality and making the necessary corrections due to the lack of variance homogeneity, it can be concluded that there are no statistically significant differences between both populations in weight for both women and men, nor for women in stature. However, differences do exist among men regarding stature in different chronological periods and between men and women, both within and between populations (Table 6 and Table 7).

Upon conducting congruence tests between the formulas of Pearson (1899) and MENDOÇA (2000) for individuals from San Pablo, it is observed that there is significant congruence between the two formulas, yielding a Lin correlation coefficient of 0.94 (0.91-0.95). However, systematically, the Mendoça (2000) formula provides a higher estimation than the Pearson formula, with a mean difference of 2.20 ± 1.5 cm ($p < 0.01$).

	Femur maximum length				Femoral head SI diameter				Humerus maximum length			
	fc	mc	fch	mch	fc	mc	fch	mch	fc	mc	fch	mch
N	14	15	49	60	14	18	54	59	10	11	22	29
Mean	415.8	454.6	404.5	436.8	43.3	47.5	42.4	47.3	294.1	322.6	288.9	306.0
Standard Desv.	18.3	20.4	18.6	23.9	1.6	3.5	2.5	2.8	12.6	17.8	16.2	15.9
Minimum	390	420	368	385	40.8	38.4	37.4	41.7	278	295	268	270
Maximum	448	494	440	512	46.0	52.8	48.8	55.6	315	360	334	331

Table 3. Basic statistics for the maximum length of the femur and humerus and for the superoinferior (SI) diameter of the femur are presented by sex and population for stature, concerning both the femur and humerus, in relation to sex and population. The four groups are as follows: Fc: females of the cloister, mc: males of the cloister, fch: females of the church, mch: males of the church. Measurements in millimeters.

	Stature			
	fc	fch	mc	mch
N	14	49	15	60
Mean	156.0	153.3	166.7	162.4
Standard Desv.	4.4	4.5	5.6	6.2
Shapiro-Wilk	0.9	1.0	1.0	1.0
P-value (Shapiro-Wilk)	0.4	0.2	0.9	0.5
Minimum	150.3	144.9	157.4	148.4
Maximum	163.8	163.8	177.6	182.9

Table 4. Basic Statistics for the stature for the four groups are as follows: Fc: females from the cloister, mc: males from the cloister, fch: females from the church, mch: males from the church. Stature in centimeters.

	Body mass			
	fc	**fch**	**mc**	**mch**
N	14	54	18	59
Mean	60.7	58.4	75.1	70.7
Standard Desv.	4.6	5.6	7.5	6.6
Shapiro-Wilk	0.9	1.0	1.0	1.0
P-value (Shapiro-Wilk)	0.6	0.3	0.6	0.7
Minimum	54.1	48.3	59.9	54.1
Maximum	69.2	71.0	93.6	85.5

Table 5. Basic Statistics for the body mass for the four groups are as follows: female cloister (mc), female church (mi), male cloister (vc), and male church (vi). Body mass in kg.

Test of equality of variances (Levene's)

F	df1	df2	p
1.482	3	134	0.222

ANOVA

Cases	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
Population	276.792	1	276.792	9.496	0.003
Sex	2206.264	1	2206.264	75.688	< .001
Population ✻ Sex.	15.483	1	15.483	0.531	0.467
Residuals	3906.016	134	29.149		

Post-Hoc test

		Mean Difference	**SE**	**t**	**p_{tukey}**
fc	**fch**	2.658	1.636	1.625	0.368
	mc	-10.653	2.006	-5.31	< .001
	mch	-6.348	1.602	-3.961	< .001
fch	**mc**	-13.311	1.593	-8.355	< .001
	mch	-9.006	1.04	-8.663	< .001
mc	**mch**	4.305	1.559	2.762	0.033

Table 6. Two-way ANOVA for comparing stature based on population and sex. Abbreviations: Fc: females of the cloister, mc: males of the cloister, fch: females of the church, mch: males of the church.

Test of equality of variances (Levene's)

F	df1	df2	p
4.689	3	141	0.004

ANOVA

Homogeneity Correction	Cases	Sum of Squares	df	Mean Square	F	p
Welch	2facto	4471.29	3	1490.43	29.68	< .001
	Residuals	7132.25	46.17	154.47		

Post-Hoc test

		Mean Difference	SE	t	ptukey
fc	**fch**	2.26	2.13	1.059	0.715
	mc	-9.87	2.53	-3.896	< .001
	mch	-9.06	2.11	-4.286	< .001
fch	**mc**	12.13	1.94	6.267	< .001
	mch	-11.32	1.34	-8.452	< .001
mc	**mch**	0.81	1.92	0.423	0.974

Table 7. ANOVA with Welch correction for comparing the weight variable between populations and sex. Abbreviations: Fc: females of the cloister, mc: males of the cloister, fch: females of the church, mch: males of the church.

4 Discussion

From the 13th century to the first half of the 16th century, the city of Burgos was prosperous and productive (HILTPOD 1978; ADAN-ALVAREZ 2003; CASILLAS and ADAN 2005; GONZALEZ-PRIETO 2006), with economies based on the primary and secondary sectors at the local level. Wool was a fundamental raw material and played a key role in international trade with Europe. Craftsmen in wood, leather, and esparto were also crucial in maintaining prosperity and independence in the city (ADAN-ALVAREZ 2003; CASILLAS and ADAN 2005; GONZALEZ-PRIETO 2006). However, in the second half of the 16th century, various prolonged adverse events occurred, negatively impacting the population. These included epidemics stemming from transformed diseases (such as the two episodes of the Black Plague in 1565 and 1599, causing high mortality, especially among infants) to poor hygiene or malnutrition due to the high population density emerging in cities (HILTPOD 1978; ADAN-

ALVAREZ2003; CASILLAS and ADAN 2005; GONZALEZ-PRIETO 2006). Public perception varied, and by 1600, the city was described as being inhabited by "old people fighting desperately to save their city" (HILTPOD 1978).

Furthermore, between the 14th and 19th centuries, the world experienced the so-called Little Ice Age, with particularly harsh effects in the Northern Hemisphere (FAGAN 2000). Due to its geographical location, the Iberian Peninsula entered this period in the 16th century, and given the moderate altitude of its mountains, its magnitude was limited and confined to specific areas (ALBEROLA ROMÁ 2014). In the Castilian Plateau, the years 1529 and 30 were especially severe, but the 17th century was particularly harsh (Maunder Minimum), especially from the second half of the century onward. In the 18th century, the decline of this Little Ice Age began, continuously extending into the 19th century (ALBEROLA ROMÁ 2014).

The two chronological populations of San Pablo Convent, marked by the place of burial, would be influenced by the Little Ice Age and various health conditions. The population of the church (17th-18th centuries) is the one most affected by the more adverse climate, while the population of the cloister (14th-16th centuries) could be more related to more virulent plague episodes, especially those who lived in the second half of the 16th century, with the outbreak of 1565 having a significant impact on the city's life (LOPEZ-GOMEZ and PARDIÑAS DE JUANA 2000). During this epidemic, the sick was concentrated in the Hospital de la Concepción, just 700 meters from the Convent (LOPEZ-GOMEZ and PARDIÑAS DE JUANA 2000). The plague causes skin ulceration, sores, pustules, spots, petechiae, and gangrene (BARBIERI *et al*. 2020), but due to its virulence, the infection acts very rapidly, leaving no signs in the bone (ALEXANDER *et al*. 2021), known as the Osteological Paradox.

Regarding lifestyle, our preliminary studies show that individuals from the cloister would have occupational stress marks related to agricultural tasks, with no statistically significant differences between sexes. In contrast, individuals from the church show a decrease in agricultural work, with men being more specialized in urban trades and women being engaged in domestic tasks (including agricultural work in urban gardens).

Despite this change in lifestyle and environmental and health conditions, and although there are differences in mean values, there are no significant differences in weight and height among women in these two populations (Tables 4 and 5 and Tables 6 and 7). However, males show statistically lower stature in individuals from the church compared to those from the cloister (Tables 4 and 6). In other words, the change in lifestyle is accompanied by a difference in the quality of life during development, which seems to be more pronounced in males.

This can be explained by the phenomenon called "male vulnerability," where males are more affected by changes in lifestyle than females, leading to delayed growth (THOMPSON 2021). The genetic burden of the X chromosome also influences the individual's immune function; thus, females with a double burden seem to have a stronger immune system than males (LIBERT *et al*. 2010; MARKLE and FISH 2014). Therefore, male individuals from the church population of San Pablo seem to be more affected by lifestyle changes than females. The change in weight can also be considered part of this secular change, but while

the change in height is strongly influenced by the environment (SILVENTOINEN 2003 and CARDOSO, 2008), weight calculated as the product of femoral head size, i.e., ideal weight, is more genetically influenced, and the change is not as noticeable (Table 5 and Table 7) (RUFF *et al*. 1991).

The relative stability of life conditions during the Middle Ages in Burgos until the 16th century (HILTPOD 1978; ADAN-ALVAREZ 2003; CASILLAS and ADAN 2005; GONZALEZ-PRIETO 2006) may explain the greater stature of individuals from the cloister compared to those buried in the church belonging to the Modern Age. When comparing the populations of San Pablo with others from the same chronological periods in the community of Castilla y León (LÓPEZ-MARTÍNEZ 2000), from the Iberian Peninsula, and other European countries, CARDOSO (2008) observes that individuals from San Pablo are slightly taller than their contemporaries in Castilla y León. This may be due to the fact, as demonstrated in this study, that heights calculated with the Pearson formula are slightly (and statistically) lower than those of MENDOÇA (2000). Individuals from Burgos are similar to those from Portugal in the same chronological periods, calculated using the same formulas and undergoing similar secular changes observed in these studies (CARDOSO 2008; LÓPEZ-MARTÍNEZ 2000).

This may imply that living conditions in Castilla y León and the Iberian Peninsula, in general, were common, with great stability and good living conditions during the Middle Ages. However, in the Modern Era, there seems to be a deterioration in overall living conditions. CARDOSO (2008) explains this by a change in lifestyle, with a shift from rural to urban areas, increasing demographic pressure and resulting in poorer living conditions. This is also confirmed by historical studies of the city of Burgos (HILTPOD 1978; ADAN-ALVAREZ 2003; CASILLAS and ADAN 2005; GONZALEZ-PRIETO 2006).

5 Conclusions

The study of the body parameters of individuals recovered in the church and the cloister of the San Pablo convent shows that both populations fall within the variation of populations from the rest of Castilla y León and the Iberian Peninsula for these chronological periods. In the case of weight, there are no differences between the different populations in Burgos, but there are statistically significant differences in the height of males, indicating what can be considered male vulnerability, with less growth in height in the modern era, probably due to the worse health and environmental conditions known to affect the Iberian Peninsula.

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