THE INFLUENCE OF BONE LOSS ON THE THREE ADULT AGE MARKERS OF THE INNOMINATE

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ABSTRACT

To evaluate the influence of bone loss on the three adult age markers of the innominate, thirty males and thirty females aged between 16 and 80 years coming from the British Coventry Collection were analyzed. The pubic symphysis, auricular surface and acetabulum age variables were evaluated following the descriptions of Schmitt, Buckberry-Chamberlain and Rissech respectively. The second metacarpal cortical index was used to evaluate bone loss. Possible sexual differences in metrical variables were explored by a Student-T test taking into account the entire sample. The possible relationships between the cortical index and the three age methods' stages were assessed by the Kruskall-Wallis test and Spearman's correlation coefficient. There were no sexual differences in the cortical index. In general, we observed no significant differences between the cortical index in the different stages of the pubic symphysis, auricular surface or acetabulum variables in men and women. Most correlation coefficients are negatives and their absolute values are between 0.001 and 0.44, indicating an extremely low influence of bone loss on the analysed variables. Our findings suggest little influence of bone loss in the three ageing methods. However further research on this topic is necessary. This is the first study to analyse the influence of bone loss in the ageing changes undergone by the variables of the three adult age indicators of the innominate taking into account both sexes.

Keywords: Adult ageing; Os coxa; Pathology; Osteoporosis, Adult individuals, Adult age indicators

INTRODUCTION

Accurate age estimation of skeletal remains is fundamental to any anthropological and forensic study. Biological and cultural interpretation of the remains depends on the age estimation results. Most methods of adult age estimation are based on morphological changes associated with the ageing process in different skeletal articulations. Current adult ageing methods based on the innominate take into account the morphological changes of the pubic symphysis [1,2,3], the auricular surface [4,5,6] and the acetabulum [7,8]. The morphological changes observed in these articular surfaces are usually small modifications such as porosities, striations, granulations, ridges, furrows, undulations and roughness, which appear or disappear gradually with age. The presence, absence and degree of expression of these characteristics are what determine a specific estimated age for an individual when a phase system method is used. In methods based on Bayesian inference the estimated age depends on the combination of features, specifically on the probability of finding a specific combination of traits taking into account their distribution in the reference sample. Due to bone plasticity, the influence of environmental, cultural and genetic factors can modify the specific combination of traits in an individual (increasing or diminishing the expression of some features), which in turn affects estimated age. Although health status is usually taken into account during age estimation of an individual and many pathological changes can be easily detected, slight modifications which seem totally normal, but which are related to pathological processes (for example increases in porosity) may potentially be confounding results.

Age markers can be affected by different pathologies and each marker is susceptible in a different way to those pathologies, depending on the type of articulation, the anatomy of the innominate area where the marker is located, and anatomical relationships with other bodily structures [9]. In fact, there is good evidence that most adult age markers are only weakly associated with age [10,11], and other factors appear to be responsible for a substantial proportion of the variation seen in them. Therefore, it is of vital importance to understand the biological and physiological behaviours of each age indicator and the factors upon which they depend. In addition, it is necessary to quantify the influence of different pathologies on different methods of adult age estimation. Extremely few studies thus far have attempted to do this [9,10,12,13]. San-Millán et al. [13] analysed acetabulum and acetabular fossa shape changes due to age and sex in 355 males and 327 females from the Iberian Peninsula. Mays [10] evaluated the influence of the general tendency toward bone formation (by DISH), and occupation on Rissech's acetabular variables in 74 males and 87 females from Great Britain. Schmitt et al [12] evaluated the possibility of distinguishing between bone loser and bone former individuals by radiogrametry of the 2nd metacarpal and the presence of osteophytes in 65 males and 65 females from

Portugal. Rissech et al. [9] examined the patterns of occurrence of several pathologies which can affect the three age markers of the innominate (pubis, auricular surface and acetabulum) and evaluated the influence of bone loss on the auricular surface and acetabulum in 43 Portuguese males.

Some of the traits scored by innominate ageing methods are related to micro and macro porosity. For example, variables 3 (microporosity) and 4 (macroporosity) of the auricular surface method of Buckberry and Chamberlain [6], and variables 3 (acetabular rim porosity) and 7 (porosity of the acetabular fossa) of the acetabular method of Rissech et al. [7] involve recording porosity. Although, Rissech et al. [9] analysed the effect of bone loss on the auricular surface and acetabulum based on a documented Portuguese male sample constituted by 43 individuals, it is necessary to know the influence of bone loss on the three innominate age markers in both males and females. Therefore, the objective of this study was to evaluate the possible influence of bone loss in the three age innicators of the innominate (pubic symphysis, auricular surface and acetabulum). The ageing methods used to evaluate this possible influence were those of Schmitt [3] for the pubic symphysis; Buckberry and Chamberlain [6] for the auricular surface and Rissech et al. [7] for the acetabulum. We have chosen these three methods because of their recent popularity (Buckberry-Chamberlain and Rissech methods) and because each variable in these three methods appear to develop independently of each other [14,3,6,7]. This independent development of the variables allows these three methods be based on Bayesian inference and allows us to analyse the variables in relation to other parameters.

BONE LOSS INFLUENCE ON AGE MARKERS: BACKGROUND

A literature review by Rissech et al. [9] examined the patterns of occurrence of several pathologies (rheumatoid arthritis, juvenile chronic arthritis, ankylosing spondilylitis, psoriatic arthritis, Reiter's syndrome and tuberculosis) which can affect the three age markers of the innominate (acetabulum, pubic symphysis and auricular surface) and found differences in the patterns of their occurrence. Rheumatoid arthritis, juvenile chronic arthritis, ankylosing spondylitis, psoriatic arthritis and Reiter's syndrome are rheumatisms of unknown aetiology [15,16]. Tuberculosis is an infectious disease induced by *Mycobacterium tuberculosis* [17]. Rissech et al [9] identified two distinct patterns of occurrence of these pathologies in the acetabulum, pubic symphysis and auricular surface: 1) pathologies which more frequently affect the hip-joint, and thus the acetabulum (rheumatoid arthritis, juvenile chronic arthritis and tuberculosis); and 2) pathologies which more frequently affect the auricular surface and the pubic symphysis (ankylosing spondylitis, psoriatic arthritis and Reiter's syndrome). In the case of tuberculosis, the pattern of occurrence is due to the different vascularization and anatomical structures of these joints (different quantity of hematopoietic tissue). In the case of the

other pathologies (ankylosing spondylitis, psoriatic arthritis and Reiter's syndrome), differences appear to be due to the type of joint and its mobility [9]. In addition, within these two patterns, the frequency with which each joint is affected varies according to which disease is present (Figure 1). According to these authors, this means that, where one of these conditions is present, the choice of age marker could affect the accuracy of age estimation.

In addition to their literature review, Rissech et al. [9] examined the influence of bone loss on the ageing of the auricular surface and the acetabulum in a sample of 43 male individuals from the documented collection of Coimbra (Portugal). The ageing methods used were the variables of the auricular surface proposed by Schmitt [3] and the variables of the acetabulum proposed by Rissech et al [18].

Schmitt [3], in her Ph.D. proposed the definition of new variables for the pubis and auricular surface based on the classical ageing methods of McKern et Stewart [19], Meindl et al., [20], Brooks and Suchey [2], Lovejoy et al [4] and Meindl and Russel [21], but simplified and arranged to be used in Bayesian inference.

Rissech et al. [18] outlined 7 variables of the acetabulum to be used in a preliminary acetabular ageing methodology. These 7 variables were later modified and published definitively as the Rissech method [7].

MATERIAL AND METHODS

The material analysed in this study comes from the Coventry Collection, an urban post-medieval skeletal collection dating from the industrial revolution (between the end of the 18th century to the end of the 19th century). This collection consists of human remains exhumed from the Holy Trinity Graveyard (Coventry, West Midlands, England) during its excavation in 1999-2000 [22]. The Coventry collection consists of 97 individuals (34 males, 32 females and 31 immature individuals) ranging from 0 to 80 years, and housed at the School of Archaeology and Ancient History of the University of Leicester (Leicester, UK), where it is used for teaching and research purposes [23]. The Coventry collection is essentially archaeological in nature, as only thirteen of the individuals are of known identity due to associated coffin plates being preserved. None of the parish records prior to 1837 have survived [23]. Sex and age were estimated by several methods [24,25,26,27,28,29,30; among others], specifically for sex estimation we used methods based on the innominate (all the analysed individuals had innominate) and skull, particularly those of Schutkowski [27], Nemeskeri

[31], Rissech and Malgosa [32], Murail et al., [33] and Mays and Cox [34]. Although this collection consists of only a few known-age-and-sex skeletons, it is useful for our purpose because we are not going to evaluate any method for age estimation. The objective of this study is to evaluate the possible relationship between maturation stages and bone loss, which will be done directly from each specific stage of maturation and the bone loss marker used in the study. That is to say, during the analysis we do not need to know neither the chronological age nor estimated age of the individuals. However, sex estimation is important for this reason we estimated sex carefully by the methods quoted previously.

To carry out the study we choose individuals with a good state of preservation. That is to say, we excluded those individuals with observable taphonomic alterations which could affect the evaluation of the innominate age markers and bone loss. All the individuals with mature acetabulae, and without any observable pathology which could affect the pubis, auricular surface or acetabulum, were chosen. In particular, we excluded specimens with evidence of cancer, tuberculosis, spondyloarthropathies or rheumatoid arthritis. A total of 31 males and 31 females, ranging between 16 and 80 years of age, were selected. Table 1 shows the age and sex distribution of the chosen individuals. As differences between the right and left pubis [35], the right and left auricular surface [6,36] and the right and left acetabulum [37] are negligible, only the left innominate was scored. If the left innominate was damaged, pathologic or taphonomically altered, the right innominate was used.

The second metacarpal from each individual was used for evaluating bone loss. Only perfectly intact bones, showing no postdepositional erosion, were selected for the study. In skeletons where both left and right metacarpals were available for the study, left and right were chosen at random, following the method of Mays [38,39].

For each innominate, the three variables of the pubic symphysis proposed by Schmitt [3], the five variables of the auricular surface proposed by Buckberry and Chamberlain [6] and the seven variables of the acetabulum proposed by Rissech et al. [7] were evaluated. In these three methods, each variable of each method is broken into different stages describing the different morphological conditions of the region evaluated for the method.

The three variables of the pubis defined by Schmitt [3] are the following: 1) posterior demi-face (VPA) which evaluates the presence of ridge and furrows in the posterior demi-face of the pubic symphysis; 2) anterior demi-face (VPB) which analyses the presence of the ventral rampant in the anterior demi-face of the pubic symphysis; and 3) posterior labrum (VPC) which analyses the presence of labrum in the posterior area of the pubic symphysis.

The five variables of Buckberry and Chamberlain [6] are the following: 1) transverse organization (VI1), which refers to the horizontally-orientated billows and striae that run from the medial to the lateral margins of the auricular surface; 2) surface texture (VI2), which evaluates the presence of granularity defined by Lovejoy et al [40]; 3) microporosity (VI3), which evaluates the presence of this type of porosity; 4) macroporosity (VI4), which evaluates the presence of holes greater than 1 mm; and 5) apical changes (VI5), which evaluates the growth of osteophytes in the apex of the auricular surface.

The seven variables of Rissech et al [6] are the following: 1) acetabular groove (VA1) which evaluates the presence of a groove below the acetabular rim; 2) rim shape (VA2) which evaluates the form of the rim; 3) rim porosity (VA3) which evaluates the presence of microporosity on the rim; 4) apex activity (VA4) which evaluates osteophytic growth in the posterior horn of the lunate surface; 5) activity on the outer edge of the rim fossa (VA5) which evaluates the presence of osteophyte formation on the outer edge of the fossa; 6) activity of the acetabular fossa (VA6) which evaluates bone or porosity production on the fossa; and 7) porosities of the acetabular fossa (VA7) which evaluates the distribution and type of porosities on the fossa.

The original variables of these three methods had already demonstrated good levels of repeatability in different studies [3,6, 7,10, 37,41,42]. Taking into account this scoring consistence and the fact that the analysis was undertaken by the same person (A.C.), the measurement error in the scores was considered negligible.

To evaluate bone loss, we used metacarpal radiogrametry which gives a measure of cortical bone through the calculation of cortical index (CI; Mays [38,39]). In osteoporosis, loss of cortical and trabecular bone occurs. In adults 80% of bone is cortical, which indicates that cortical bone is a good reference for bone loss in past populations [38,39,43].

The turnover rate of trabecular bone is commonly thought to be much faster than in cortical bone. These differences are significant in indicating that trabecular bone is likely to present changes resulting from metabolic bone disease earlier than cortical bone [43]. However, overall the most bone lost with age is cortical [43,44]. The surface-to-volume ratio of bone loss indicates that while the relative rate of bone loss is slower in cortical bone, the absolute amount lost with age is greater as trabecular bone surfaces decrease with age following removal of the structural elements [44]. Most age-related bone loss largely occurs at the endosteal surface next to the marrow [45]. Therefore,

techniques that specifically measure cortical bone loss, particularly taking into account loss at the endosteal surface, are reflective of overall bone loss [43,44]. In addition, results in 2nd metacarpal radiogrammetry correlates well with bone loss in skeletal sites that are primarily composed of trabecular bone [43], such as the fourth lumbar vertebra (a site of compression fractures) and the iliac crest (the location for clinical biopsies). In fact, metacarpal radiogrammetry is a useful technique in archaeological human bone studies. This technique has demonstrated its utility for identifying age-related cortical bone loss and osteoporosis risk in past populations [43] and has been helping to identify differential patterns of bone loss with age and between the sexes [39,43,44,45,46]. In fact, metacarpal radiogrammetry was devised as a way of monitoring osteoporosis in a clinical context more than 40 years ago [47] and, despite the advent of newer methods, it is a technique that remains important [48,49,50,51]. In addition, metacarpal radiogrammetry has several advantages in archaeological studies, as for example, it is a non-destructive method and taphonomic alterations which may affect cortical bone thickness are generally obvious on the bone, and such specimens can then be excluded from study. Contrarily, although densitometric techniques have been used to study osteoporosis in ancient skeletons [52,53,54,55], bones with affected density by diagenetic factors are difficult to be determined in archaeological collections [38,39]. For all of these reasons, and because the second metacarpal is the skeletal element most used in archaeological studies based on radiogrametry [9], we decided to use the radiogramety of this skeletal element to evaluate bone loss in the present study.

Antero-posterior digital radiographs were made of one second metacarpal for each adult skeleton using a Xograph DRagon mobile x-ray unit. We calculated the cortical index of the second metacarpal proposed by Barnett and Nordin [47]. Measurements of the total bone width (T) and medullary width (M) were taken from radiographs at the midshaft of the bone. The software used for the measurement was eFilm 3.1. Cortical index (CI) was calculated as percentage between the cortical thickness (T - M) in relation to the total bone width [cortical index (CI) = 100 x (T - M)/ T].

To explore possible sexual differences in both cortical width and cortical index taking into account the entire sample (31 males and 31 females), we applied a Student-T test.

Kruskall-Wallis test was performed to assess the possible relationship between the cortical index and the three age methods' stages in each sex series. The degree of this relation was assessed numerically by Spearman's correlation coefficient. The Spearman's correlation coefficient or Spearman's rho is a non-parametric test of statistical dependence between two variables. It is used when one or both of the variables consist of ranks, like the stages of the variables of the three methods which we are analysing.

Spearman's correlation coefficient assesses how well the relationship between two variables can be described using a monotonic function. A perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other. We performed Kruskall-Wallis test in men and women separately, because of possible sex differences in bone loss tax between both sexes [56,57].

All the statistics were calculated with SPSS 15.0.

RESULTS

Student's T test applied taken into account the entire sample (31 males and 31 females) indicates significant sexual differences of the cortical width, with male values higher than those obtained for females (mean=0.44, SD=0.070 in males; mean=0.35, SD=0.086 in females; p=0.000*). However, when the same test was applied to the cortical index, results indicate no sexual differences (50.27±6.67 in males; 45.88±10.92 in females; p=0.086).

Table 2 shows the values obtained for the cortical index taking into account each stage of each variable of the three analysed methods.

Figures 2 to 7 graphically and numerically show the degree of the relationship between each variable's stages and cortical index in males (Figures 2 to 4) and females (Figures 5 to 7). These results indicate low degree of relationship between variables and cortical index. Most correlation coefficients are negatives and their absolute values are between 0.001 and 0.44, suggesting low influence of bone loss on the analysed variables. The Kruskal-Wallis test (Table 3 and 4) indicates that in general there are no significant differences between the cortical index in the different stages of the variables of the pubis, auricular surface or acetabulum in men (Table 3) and women (Table 4), with the exception of Buckberry and Chamberlain's variables VI3 and VI4 of the auricular surface in the feminine series.

Although Buckberry and Chamberlain's variables VI3 and VI4 evaluate the microporosity and macroporosity respectively and showed a statistically significant relationship with cortical index, the degree of correlation is negative and low enough (-0.306; -0.226) to indicate low influence of bone loss for these two variables (Figures 3 and 6). However, a larger and more detailed study is necessary to confirm these interpretations.

DISCUSSION

This study has evaluated the relationship between the three age indicators of the innominate and bone loss in both sexes by using three methods based on Bayesian inference (Schmitt, Buckberry-

Chamberlain and Rissech methods) on a British sample. As was expected, cortical width mean was higher in males than in females because of the known greater male robusticity. In cortical index sexual differences were not observed because in this measure the effect of allometry was eliminated. It is for this reason that cortical index is used to evaluate bone loss.

In general terms, our findings indicate little influence of bone loss in the three ageing methods, suggesting that the ageing changes observed in these three adult age markers (pubic symphysis, auricular surface and acetabulum) are not related to bone loss. However, previously to affirm this, a larger and more detailed study based on a documented collection is necessary.

It seems that the most affected variables for bone loss are VI3 and VI4 in females. These two variables evaluate micro and macroporosity on the auricular surface (Buckberry-Chamberlain method), but this influence seems to be extremely low, especially in VI3, in which the "p" value is very close to the limit of statistical significance and the obtained correlation coefficients are less than 0.01. Schmitt's method for the pubis does not have any variable related to micro and macroporosities. She avoided these types of definitions, focusing mostly on the presence or absence of ridge and furrows (VPA); ventral rampart (VPB) and labrum (VPC). However, the Rissech method has variables for which porosities are important elements in their definition, as for example VA3 and VA7 which evaluate the porosity of the acetabular rim and acetabular fossa respectively, and they did not show significant differences for the cortical index in either males or females in this study. This fact seems to suggest that the age-related changes observed in VA3 and VA7 are not related to bone loss and may be caused by other physiological changes related to age. Our results are in accordance with the observations of Rissech et al. [9], who observed a low influence of bone loss on the variables of the acetabulum [18] and the auricular surface [3] in a male sample from the Coimbra collection (Portugal). In this case, minimally significant differences were observed exclusively in VA3 (porosity on the acetabular rim). However, as we said previously, it would be necessary a larger and more detailed study to affirm anything.

The significant differences in VI3 and VI4 in the female series from our study could be related to the well-known female tendency towards bone loss [57]. However, the significant difference in VA3 in men from the Coimbra collection observed by Rissech et al. [9] contradicts this possible explanation. There are no other similar studies with which the current analysis can be compared and additional work with a larger and documented sample is needed to clarify the processes underlying these results.

Recently, the necessity of analysing the influence of different factors in adult age markers have been highlighted [10,13,56,58,59] and the interest in these confounding factors in the ageing process has increased. Although different studies on the influence of occupation and physical activity [10,42,60],

sex [13], body size [61,62,63], substance abuse [64,65,66] and parturition [67] on different joint ageing processes have been published. There are few studies which focus on the influence of different pathologies on the three age markers of the innominate either through direct observation of skeletal remains [9,10] or as a literature review [9,11]. The first attempt to carry out this type of research took place in 2004 and it was mostly a literature review study [9]. In 2012, Mays [10] analysed the influence of DISH and occupation on the Rissech method. He found that there was no relationship between acetabular age and the occurrence of DISH, but that those in non-manual professions showed greater acetabular scores for age than those in manual trades. In 2015, Mays developed a literature review study on effect of bone production, vitamin D status, energy balance, reproductive factors, biomechanical factors and genetic factors on adult age markers [11]. He pointed out that age-related changes predominantly involve bone formation. These observations of Mays [11] are in accordance with San-Millán et al. [12] who evaluated the shape variability of the acetabulum and acetabular fossa in relation to sex and age and also found that age-related changes were mostly related to bone formation. According to these last authors, the acetabular fossa can be described as a clover-leaf shape with three lobes: anterior, superior and posterior, which is, in turn, in accordance with Rissech et al. [68]. With ageing, the outer edge of the acetabular fossa has a tendency to gradually lose its clover-leaf morphology, becoming more rounded and increasing its shape variability [13]. This pattern of bone remodelling due to ageing is defined by: (i) the narrowing of the acetabular notch; (ii) the modification of the acetabular rim profile; and (iii) the reduction of the acetabular fossa. These ageing changes are mostly related to bone production around the entire border of the lunate surface. However, the degree of bone formation with ageing seems, in general terms, to be variable between populations, depending on where the population lies on the bone-former/bone loser continuum [11,12,56]. Perhaps, as Mays [11] has suggested, these differences in bone production can be related to vitamin D intake (and potentially in other conditions that result in inadequately mineralized bone). In fact, Hengen [69] observed a relation between the prevalence of porosities as cribra orbitalia and the latitude in which the population is living.

Campanacho [63] analysed the influence of body mass, stature and joint surface area on the variables of the three age markers of the innominate. Her results indicated that smaller individuals tend to age more slowly than bigger individuals. According to this, Mays [10] described a slower rate of ageing in female acetabulum in relation to male, which could be explained by male and female size differences. However, the ageing process is not as simple as it sounds, at least acetabular ageing process. San-Millán et al [37] analysed separately every acetabular trait between males and females. According to San-Millán et al. [37], both sexes follow the same acetabular ageing pattern; however the ageing rate is different between sexes, being statistically significant in mainly middle-aged stages. Following San-Millán et al [37], female ageing rate is slower than male ageing rate in the entire analysed period of

ages in VA1, VA4 and VA5. The four remaining acetabular variables (VA2, VA3, VA6, and VA7) exhibited this pattern (slower rate in females) only from middle-aged stages (from stage 3 in variables 2 and 3 and from stage 2 in variables 6 and 7). However, the opposite pattern was observed before 40 years of age in these four variables as males showed a slower aging rate than females for these specific characteristics. In addition to this Campanacho [63] and Rissech [56] found different patterns of ageing between population samples. All of these observations indicate the complexity of the ageing process and for this reason we do not believe that the results of the present study be due to body size influences on the pelvic joints. In addition, in our study the variability in size is reduced, because we analysed a specific population (Coventry) from a specific period (18th century), and the most different individuals in size (males and females) were separated during the analysis.

It is obvious that there is a paucity of studies on the different factors that can influence age changes and age markers. It is thus critical to develop more research on the impact of inherent tendency towards bone loss and bone formation and their influence in adult age markers in a larger and documented sample

CONCLUSION

The acetabulum has been the adult age marker most analysed in terms of the influence of factors other than ageing on the features used to estimate age. There is currently a lack of in-depth studies analysing the influence of different factors (e.g. pathologies, occupation, bone loss, latitude and climate) on other age markers. It is absolutely essential to develop a good biological knowledge of factors affecting age markers in order to develop accurate ageing methods.

This is the first study to analyse the influence of bone loss in the ageing changes undergone by the variables of the three adult age indicators of the innominate. Our results suggested that there is no clear overall relationship between most variables and bone loss. However, previously to affirm this, a larger and more detailed study based on a documented collection is necessary.

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Figure 1. Occurrence of different pathologies in the three articulations of the innominate according to Rissech et al. (2004a). The order in which pathologies are quoted in each articulation reflects the frequency of occurrence for this articulation. Prevalence is indicated by percentage for each condition. No percentage is indicated when we know that the joint is affected by the condition, however we did not find the specific percentage of prevalence.

Figure 2. Box plot showing the relationship between each stage of each of Schmitt's pubic variables (horizontal axis) with cortical index (vertical axis) in males. The central line indicates the mean, the box represents the standard error, and the whiskers correspond to the standard deviation. Spearman correlation coefficients for VPA, VPB and VPC are 0.221, 0.203, and 0.037 respectively.

Figure 3. Box plot showing the relationship between each stage of each of Buckberry and Chamberlain's auricular surface variables (horizontal axis) and cortical index (vertical axis) in males. The central line indicates the mean, the box represents the standard error, and the whiskers correspond to the standard deviation. Spearman correlation coefficients for VI1, VI2, VI3, VI4 and VI5 are -0.312, -0.042, 0.118, 0.048 and -0.340 respectively.

Figure 4. Box plot showing the relationship between each stage of each of Rissech's acetabular variables (horizontal axis) and cortical index (vertical axis) in males. The central line indicates the mean, the box represents the standard error, and the whiskers correspond to the standard deviation. Spearman correlation coefficients for VA1, VA2, VA3, VA4, VA5, VA6 and VA7 are -0.073, -0.001, -0.201, -0.207, -0.281, 0.091 and 0.091 respectively.

Figure 5: Box plot showing the relationship between each stage of each of Schmitt's pubic variables (horizontal axis) and cortical index (vertical axis) in females. The central line indicates the mean, the box represents the standard error, and the whiskers correspond to the standard deviation. Spearman correlation coefficients for VPA, VPB and VPC are -0.329, -0.231, and -0.354 respectively.

Figure 6. Box plot showing the relationship between each stage of each of Buckberry and Chamberlain's auricular surface variables (horitzontal axis) and cortical index (vertical axis) in females. The central line indicates the mean, the box represents the standard error, and the whiskers

correspond to the standard deviation. Spearman correlation coefficients for VI1, VI2, VI3, VI4 and VI5 are 0.013, -0.346, 0.023, -0.409 and 0.041 respectively.

Figure 7. Box plot showing the relationship between each stage of each of Rissech's acetabular variables (horizontal axis) and cortical index (vertical axis) in females. The central line indicates the mean, the box represents the standard error, and the whiskers correspond to the standard deviation. Spearman correlation coefficients for VA1, VA2, VA3, VA4, VA5, VA6 and VA7 are -0.038, -0.090, -0.306, -0.226, -0.440, -0.168 and -0.329 respectively

Age in years	Males	Females	Total
16-20	4	1	4
22-30	2	5	7
31-40	2	4	6
41-50	5	3	8
51-60	9	7	16
61-70	3	5	8
71-80	1	1	2
Adult undetermined	5	5	9
Total	31	31	62

Table 1. Sex and age distribution of the chosen individuals from Coventry collection

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Pubic symphysis

Males

VPA	**n**	**Cortical index**	**VPB**	**n**	**Cortical index**	**VPC**	**n**	**Cortical index**
1	7	52.1	1	6	50.0	1	6	48.6
2	3	45.2	2	2	52,7	2	36	50.3
3	32	49.1	3	29	48.9	-	-	-
Total	42	49.3	Total	37	49.3	Total	21	49.3

Auricular surface

Males

VI1	n	Cortical index	VI2	n	Cortical index	VI3	n	Cortical index	VI4	n	Cortical index	VI5	n	Cortical index
1	8	48.2	1	12	50.0	1	3	50.0	1	24	50.6	1	15	46.2
2	10	47.4	2	4	45.5	2	15	47.0	2	22	47.5	2	24	51.9
3	4	63.5	3	7	51.8	3	41	48.6	3	13	45.3	3	20	45.4
4	12	46.4	4	27	45.7	-	-	-	-	-	-	-	-	-
5	25	48.2	5	9	51.6	-	-	-	-	-	-	-	-	-
Total	59	48.3	Total	59	48.3	Total	59	48.3	Total	59	48.3	Total	59	48.3

Acetabulum

Males

VA1	**n**	**Cortical width**	**VA2**	**n**	**Cortical width**	**VA3**	**n**	**Cortical width**	**VA4**	**n**	**Cortical width**	**VA5**	**n**	**Cortical width**	**VA6**	**n**	**Cortical width**	**VA7**	**n**	**Cortical Index**
0	1	50.0	0	4	50.0	0	8	53.3	0	7	53.3	0	2	50.0	0	1	50.0	0	-	-
1	53	48.7	1	6	52.5	1	3	50.0	1	21	50.3	1	7	50.0	1	0	-	1	6	51.7
2	6	48.1	2	8	48.5	2	15	47.6	2	17	44.8	2	6	53.6	2	10	47.9	2	5	39.2
3	2	37.5	3	24	46.4	3	25	48.1	3	8	46.6	3	15	44.5	3	25	48.8	3	27	50.0
-	-	-	4	15	49.1	4	5	43.7	4	3	50.0	4	25	49.2	4	19	49.1	4	14	50.9
-	-	-	5	2	62.5	5	4	44.0	-	-	-	5	1	37.5	5	2	37.5	5	4	39.3
-	-	-	6	1	37.5	-	-	-	-	-	-							6	1	37.5
Total	62	48.3	Total	60	48.3	Total	25	48.1	Total	56	48.3	Total	56	48.1	Total	57	48.6	Total	57	48.6

Table 2: Mean cortical index in relation to the stages of each variable of the three analysed methods.

Pubic symphysis	p	Auricular surface	p	Acetabulum	p
				VA1	0.0997
				VA2	0.521
		VI1	0.753	VA3	0.908
		VI2	0.671	VA4	0.075
VPA	0.229	VI3	0.995	VA5	0.997
VPB	0.247	VI4	0.436	VA6	0.207
VPC	0.594	VI5	0.078	VA7	0.819

Table 3. Results in male series when Kruskal-Wallis test is applied between the cortical index and the stages of each age variable in the three age markers.

Pubic symphysis	p	Auricular surface	p	Acetabulum	p
				VA1	0.333
				VA2	0.234
		VI1	0.388	VA3	0.258
		VI2	0.055	VA4	0.247
VPA	0.423	VI3	0.046*	VA5	0.373
VPB	0.399	VI4	0.033*	VA6	0.405
VPC	0.558	VI5	0.268	VA7	0.069

Table 4. Results in female series when Kruskal-Wallis test is applied between the cortical index and the stages of each age variable in the three age markers.