Septal aperture of the humerus: Aetiology and frequency rates in two European populations

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Abstract

Analysis of the septal aperture was conducted on two documented European populations. Collections from the National Museum of Natural History Lisbon, Portugal and University of Athens, Greece were used for the study. Both collections are modern and documented for sex and age. The Portuguese sample comprises 297 individuals (149 males and 148 females) between the ages of 18 and 88. A septal aperture was observed in 50 individuals resulting in a frequency of 16.83%. The Greek sample comprises 117 individuals (68 males and 49 females) between the ages of 20 and 65. Twenty-five septal apertures were observed, giving a frequency of 21.37%. Both populations had high frequencies which exceeded those observed in European countries in previous studies. Sex analysis shows that both samples confirm that septal apertures are more common in females. The Portuguese sample also supports that septal apertures are more common in the left humerus, however the Greek sample had a higher frequency of bilateral cases. Measurements of the Portuguese sample were taken to determine whether robusticity correlates with presence of septal apertures. These measurements concluded that there was no difference in robusticity with presence or absence of a septal aperture, challenging previous studies.

Keywords: human anatomy, human variation, suprathrochlear foramen, humerus, septal aperture

Introduction

Human skeletal variation presents itself in many forms and it is sometimes difficult to differentiate from pathological conditions. Recognising these morphological polymorphisms is important in order to accurately construct the biological profile. Some variations convey information regarding the individual, whereas others are less significant (Brinton, 1894). One variance that has been studied since the 19th century is the septal aperture found on the distal humerus. Septal apertures have been described as early as 1825 and are found in species other than *Homo sapie*ns such as gorillas, wild hogs, hedgehogs and prong-horned antelopes (Meckel, 1825; Lamb, 1890).

The septal aperture is a foramen that develops at the distal end of the humerus. Possible other names to describe the septal aperture are the supratrochlear foramen and olecranon perforation; however, throughout this work it will only be referred to as the septal aperture (SA). Past research has concluded that this foramen forms post-fusion of the distal end of the humerus rather than during development (Mays, 2008). It has been suggested that if the septal aperture was caused by a failure in development, it would be associated with the epiphyseal line. However, the septal aperture is found superior to the fusion line in the olecranon fossa (Lamb, 1890). The fusion of the distal epiphysis occurs between the ages of 11-15 for females and 12-17 for males (Scheuer and Black, 2004). Therefore, if it is associated with development, no cases under that age would be observed. Cases of septal apertures in children as young as five have been recorded, further supporting that they are not related to fusion of the epiphysis (Hrdlička, 1932). Juvenile cases appear to be an anomaly and most of the septal apertures develop in early adulthood. It has also been reported that the septal aperture is found in a higher frequency in ancient rather than modern populations (Hirsh, 1927). Past research has also shown that the frequency of the septal aperture does differ from one population to another, posing the question of whether there is a genetic component to the development of the foramen (e.g., Glanville, 1967; Singhal and Rao, 2007; Mays, 2008; Papaloukas *et al.,* 2011).

Since the early 20th century, studies have been conducted on various populations resulting in the determination of frequencies on the global distribution. The highest frequencies of septal apertures recorded to date have been found by studies conducted on Native Americans, Africans and Australians. The frequencies are as high as 58% for Native Americans from Arkansas (Hirsh, 1927), 57.2% in Libyans (Macalister, 1990) and 46.5% in Australians

(Hrdlička, 1932). Asian populations tend to have mid to high frequencies, ranging from 11% in Koreans (Akabori, 1934) to 34.3% in Indians (Nayak *et al.,* 2009). The lowest frequencies recorded are those from European populations. Italians are reported to have a frequency of 9.4% (Hrdlička, 1932), Germans 8.8% (Hrdlička, 1932), Polish 7.5% (Myszka, 2015), English 6.9% (Mays, 2008), Dutch 6.1% (Glanville, 1967) and the lowest frequency is presented by a previous study on the Greeks with 0.304% (Papaloucas *et al.,* 2011). These studies show that there are some global trends and some geographical areas tend to consistently have higher frequencies than others.

Even though it is rather common, not much is known about the septal aperture. Some theories proposed early on were beliefs such as individuals that possess a septal aperture die earlier than those without; these ideas have only been suggested but not supported (Trotter, 1934). However, there are trends that have been recognised: firstly, the septal aperture appears more in females than males (Schultz, 1937). Secondly, the septal aperture is more frequently found in the left humerus over the right humerus up to a rate of almost double (Lamb, 1890). On the other hand, two previous studies have found frequencies that do not match the reported trends. A study conducted on a Polish sample recorded a higher number of septal apertures in males than in females and a study conducted on an Indian sample recorded a higher number of septal apertures in the right humerus than the left (Nayak *et al,.* 2009; Myszka, 2015). Another study found a higher frequency in bilateral septal apertures compared to left side only (Koyun *et al,.* 2011). Despite these studies, most research on the topic suggests that the septal aperture is more common in females and on the left humerus. This observation of a higher occurrence in the left humerus of females has influenced many theories of why the septal aperture forms.

Two of the most popular are the “mechanical theory” and the “robusticity theory” (Lamb, 1890; Hrdlička, 1932). The mechanical theory proposes that the septal aperture is created by the atrophy of the olecranon fossa due to a repetitive motion conducted by the individual. It is proposed that affected individuals possess a large proximal end of the ulna and habitually engage in a strong hyperextension of the elbow joint (Kubicka *et al.,* 2015). The size of the olecranon and coronoid processes of the ulna influence the amount of pressure placed on the olecranon fossa. It has been suggested that the septal aperture develops from anterior to posterior, implicating that the coronoid process is the primary cause for the degradation of the septum (Mays, 2008). However, this is just a theory as cases have been observed where the anterior of the olecranon fossa shows signs of cribriform formation while the posterior does not (Hrdlička, 1932). Hyperextension of the olecranon is a hypothesis which proposes that

over-extending the natural movement of the olecranon ulnar joint eventually causes a septal aperture to form (Hirsh, 1927). This hyperextension can be due to a loose joint caused by increased elasticity of the collagen fibre. Loose joints are more common in females and this may explain the higher frequency of the septal aperture in females (Papaloucas *et al.,* 2011).

The robusticity theory suggests that a more gracile humerus is more likely to acquire a septal aperture than a robust humerus (Hirsh, 1927; Benfer and McKern, 1966; Papaloucas *et al,.* 2011). Gracility of the left humerus of females is deemed as the most pronounced because the left is habitually the non-dominant side. Therefore, the most gracile of the humeri will be found in the non-dominant arm of the less robust sex (Mathew *et al.,* 2016). This gracility is proposed to cause the atrophy of the septum, which in turn results in the formation of the septal aperture (Hirsh, 1927). These two theories have been investigated in various studies and to date, no theory has been widely accepted. For example, Benfer and McKern (1966) concluded that there is a significant association between the diameter of the midshaft of the humerus and the presence of septal aperture. In other words, the more gracile the humerus, the higher the probability that a septal aperture would be present, a finding that is in support of the robusticity theory. However, data collected from Mays (2008), indicates that there is no evidence that humeri with a septal aperture are less robust than those without. In the study completed by Kubicka *et al.,* (2015), it was determined that there was partial shape difference in ulnae between those with and without an aperture, thus supporting the mechanical theory. This was also concluded in Mays (2008); however, it is emphasized that these results should be taken with caution and need to be further supported with additional research.

The septal aperture is a trait that is detectable in living individuals through the use of medical imaging techniques and is generally an asymptomatic trait. However, it does increase the susceptibility of fractures in low-energy trauma (Sahajpal and Pichora, 2006). Furthermore, it increases stress to the bone, which may modify the fracture pattern of the distal humerus. Therefore, if surgical correction is necessary this may alter the surgical plan (Sahajpal and Pichora, 2006; Paraskevas *et al.,* 2010). Knowledge on the frequency and causation of the septal aperture will improve the ability to modify the surgical approach for patients who possess this trait.

This study will examine two well-documented skeletal collections from Portugal and Greece to establish the frequency of septal apertures. This will determine whether these populations follow the frequency patterns observed in other countries. The inclusion of data

from two different populations will aid our understanding of the expression of the septal aperture. The study will also examine the size of the septal aperture and the robusticity of the humeri and ulnae in order to evaluate the mechanical and robusticity theories.

Materials and methods

To obtain data for the Portuguese population, the collection curated at the National Museum of Natural History in Lisbon, Portugal was used. This collection was selected as it contains over 1600 skeletons from the late 19th and the 20th centuries and the individuals represent a variety of ages and socioeconomic statuses (Cardoso, 2006). In addition to the extensive variation within the collection, it is both well-documented for sex and age and well-preserved, as the skeletons in this collection came from three cemeteries around the city of Lisbon (Cardoso, 2006).

A random sample of 307 skeletons (152 males, 155 females) from the Lisbon Collection was used for this study. Juveniles were eliminated from the sample as previous research has indicated that the septal aperture does not form during development, but rather once epiphyseal fusion has completed (Mays, 2008). Skeletons in which both distal ends of the humeri were missing due to taphonomic or preservation issues were eliminated from the study. Skeletons with pathologies were not excluded unless the pathology inhibited the ability to determine whether a septal aperture was present or not. Ten skeletons were excluded from the original sample, leaving a total of 297 skeletons that were observed by the first author.

Data on the Greek population was collected by the second author from the Athens Collection, housed at the University of Athens. The sample for this study comprises 117 adult individuals (68 males, 49 females) with an age range of 20-65. As with the Portuguese collection, the Greek collection was created using remains from cemeteries and is well documented as information on all individuals is derived from death certificates (Eliopoulos *et al.,* 2007). The Greek data were collected in the past and only presence/absence of the septal aperture had been recorded at the time.

The frequency of the septal aperture was established by scoring each humerus as either possessing an aperture or not. The septal aperture was scored as present only after the possibility of the aperture being caused by post-mortem damage was eliminated. This was determined by a careful examination of the walls of the aperture. A septal aperture has smooth edges whereas post mortem damage has jagged and rough edges. Even though it was apparent that some of the humeri possessed a rather translucent olecranon fossa, only the humeri that had a complete perforation of the olecranon fossa were noted. For the Portuguese sample, in the instances where a septal aperture was observed, the inferior-superior and

transverse diameters of the foramen were measured. The measurements for the foramen were taken according to the study conducted by Nayak *et al.* (2009). Measurements were also taken in order to determine the robusticity of all the Portuguese humeri and ulnae. This may help establish whether robusticity is a contributing factor in the development of the septal aperture. The measurements taken on the humerus were the vertical diameter of the head, the maximum and minimum midshaft diameter, the epicondylar width and the minimum width of the trochlea (Brothwell, 1981; Bass, 1987; Buikstra and Ubelaker, 1994). On the ulna, the coronoid process length and the olecranon process length were measured (Glanville, 1967; Mays, 2008). The ulnar measurements were taken to determine whether the ulnar projections, both coronoid and olecranon, could influence the development of the septal aperture, as the mechanical theory suggests. The projection was calculated by dividing either the coronoid or olecranon process by the width of the trochlea; the result describes the amount of projection for each ulna (Mays, 2008). These measurements, in millimetres, were taken on all humeri and ulnae available for the study. The cases without a septal aperture were used as a control group for comparative purposes. The authors took all measurements using a Digimatic Sliding Caliper by Mitutoyo®.

Statistical analysis was conducted to compare the means of the aperture size. The robusticity of the humeri with and without the presence of the septal aperture was also statistically compared. Normality tests (Shapiro-Wilk) were conducted on all measurements and in cases where the data were not normally distributed, Mann-Whitney U tests were completed. When data were normally distributed, independent T-tests were performed to determine whether the differences were statistically significant, with $P < 0.05$ (SPSS, IMB Corp, 2015).

Results

In the Portuguese sample, it was found that 50 skeletons out of 297 possessed at least one septal aperture. This gives an overall population frequency of 16.83%. Of the 148 females studied, 30 (20.27%) had a septal aperture, corresponding to 10.10% of the total population, whereas out of 149 males, 20 (13.42%) had a septal aperture, corresponding to 6.73% of the total population (Table 1). Table 2 presents the distribution of septal apertures in the Portuguese sample by sex and side. Of these apertures, nine cases in females and six cases in males were bilateral, 34% of the total number of apertures. The remaining 66% of the septal apertures were unilateral. The majority of the unilateral apertures were found in the left humerus; however, 11 cases were observed in the right humerus, two in males and nine in females. Females and males both exhibited 12 unilateral cases of septal apertures in the left humerus. It was determined using a McNemar test for paired data that there is a statistical difference between apertures present on the right side and those on the left (Table 3).

It is possible to evaluate the age distribution of the septal aperture as this collection has documented ages for each skeleton. Table 4 shows a breakdown of the number of septal apertures by age for Portuguese males and females. The youngest skeleton in the sample was an 18-year-old male; this individual is also the youngest to possess a septal aperture. The oldest individual with a septal aperture is an 86-year-old female.

From the total Greek sample of 117 individuals, 25 individuals possessed at least one septal aperture (Table 5). This results in a total frequency of 21.56%. Of the 68 males, nine septal apertures were found (13.24%) which corresponds to 7.69% of the total population. For females 16 of the 49 (32.65%) of the sample possessed a septal aperture which corresponds to 13.68% of the total population (Table 6). In this population, a high frequency of bilateral septal apertures was observed. Ten cases out of the 25 (40%) are bilateral, with eight of those from female individuals. Males had a higher frequency of left side occurrence when compared to bilateral and right side only. Females however, had the highest frequency of bilateral cases followed by right side only apertures.

The age is distributed fairly evenly among males, with the exception of the age category of 20-29 which has the highest frequency of four (Table 7). For females, ages 40-49 have the highest frequency with six cases, followed by ages 20-29 that have five.

For the Portuguese collection, the size of each septal aperture was calculated by two measurements, the inferior- superior diameter and the transverse diameter (Table 8). For males, the mean was 3.78 mm for the inferior-superior diameter in the left humerus and 3.27 mm in the right humerus. The transverse diameter mean was 5.13 mm and 3.97 mm in the left and right humeri respectively. Both measurements for males did not differ in a statistically significant manner between the right and left humeri. For females, the mean inferior-superior measurement in the left humerus was 3.57 mm while the mean in the right humerus was 3.94 mm. The mean transverse diameter for the left humerus was 4.84 mm and 5.47 mm for the right. As with the male measurements, the difference between the means of the female measurements was not statistically significant (Table 9). There was also no significant difference between males and females when comparing both inferior-superior measurements and transverse measurements for both left and right humeri.

The remaining measurements were taken for determining the robusticity of the humerus. The results of the measurements appear in Table 10 for males and Table 11 for females. As seen in the tables, the mean values in each of the measurements between those with a septal aperture and those without were similar in both males and females. Differences were minimal and were not proven to be statistically significant with the exception of the maximum midshaft diameter of the left humerus in males. The ulnar measurements provided similar results. Even though some differences in averages were observed, after the completion of the independent T-tests ~~analysis~~, it was determined that the differences were not statistically significant (Table 12).

Discussion

The overall frequencies of 16.83%, calculated from the Lisbon collection and 21.36% from the Athens collection are considerably higher than the frequencies calculated for other European countries. Previous to this study, the highest reported frequency in Europe was 9.4% for Italians followed by 8.8% for Germans (Hrdlička, 1932). The high frequencies obtained in the present study were unanticipated, as values closer to countries geographically proximal were expected for both Portugal and Greece (Table 13).

The high frequency in the Portuguese collection may be explained by the history of Portugal and its ties to other geographical regions. The proximity of Portugal to Africa and its colonization of various African countries (Gallagher, 1983) may influence the frequency of the Portuguese population. Africa has been identified as possessing some of the highest frequencies of septal apertures reported to be as high as 57.2% whereas the lowest African frequency is 7.9% in Egyptians (Hirsh, 1927; Glanville, 1967; Öztürk *et al,.* 2000; Ndou *et al,.* 2013). However, it should be noted that the genetic influence of the African colonies to the Portuguese population is largely unknown and difficult to quantify. In addition, some studies have suggested that there may be a genetic component to the septal aperture formation; however, there are no conclusive results of their validity (Granville, 1967; Mays, 2008).

The results from the Greek data are vastly different from a previous study. Papaloucas *et al*., (2011) reported a frequency of 0.302%. Alongside this small overall frequency, the results of that study found that no males possessed a septal aperture indicating that out of the 656 pairs of humeri studied only two females had an aperture (Papaloucas *et al.,* 2011). In contrast, the data for this study had a significantly higher frequency of septal apertures at 21.36%, which includes both sexes (Table 5). It is uncertain as to why there is such a vast difference between the two studies. However, based on the frequency obtained for other European and neighbouring countries such as Portugal (16.83%), Italy (9.4%) and Turkey (8.6%) a frequency of 0.304% is peculiar and a higher frequency would be expected.

Two tendencies have been recognized in past studies on the septal aperture. The usual patterns are for females to have a higher frequency compared to males and for the left humerus to have a higher frequency than the right humerus (Schultz, 1937; Lamb, 1890). In both the Portuguese and the Greek data females presented a higher frequency of septal apertures than males. The Portuguese followed the higher left humerus tendency; however, this was not observed in the Greeks.

For the Portuguese, frequencies of 20.27% in females and 13.42% in males were identified, while for the Greeks they were 32.65% for females and 13.24% for males (Tables 2 and 6). It is significant to note that only a fraction of past studies have used collections with known sex and age. It is possible however, to make comparisons to these studies. As reported earlier, the frequency of the septal aperture in males is lower than in females. In some cases, studies have even failed to find a single male with a septal aperture; this includes the 2011 study conducted in Greece and the Tukumo Neolithic people (Akabori, 1934; Papaloucas *et al.,* 2011). In contrast to these findings, in a study conducted in Poland, males were determined to have a higher number of humeri with a septal aperture than females; their frequency was 8.5% while females had a frequency of 6.4% (Myszka, 2015). A frequency ranging from 7% to 8% is common for males according to several studies, for example 7.9% in Chinese males, 7.1% in Turkish males and 7.3% in Japanese (Tokyo) males (Akabori, 1934; Ming-Tzu, 1935; Koyun *et al.,* 2011). Both collections in the present study have higher average male frequencies when compared to these studies.

The second known tendency of the septal aperture is the higher frequency in the left over the right humerus. From the total number of septal apertures observed in the Portuguese collection, 34% were bilateral cases and 66% were unilateral (Table 1). The 66% unilateral is further broken down as 46% left and 20% right humerus. This shows that the highest frequency of septal apertures is found in the left humerus. The septal apertures found in males were 30% bilateral, 60% left and 10% right out of all males with apertures. Of all females with septal apertures in the Portuguese collection, 30% had bilateral, 40% left and 30% right sides (Table 2). The numbers from the Portuguese study support the notion that septal apertures are more frequent on the left side and also show that bilateral apertures are common within this population. The frequency of bilateral apertures in females is equal to the frequency of right humerus unilateral apertures found. In males, the bilateral aperture is far more frequent than the right side. On the other hand, the side breakdown of the Greek data does not support the left humerus norm. The cases of septal apertures are 40% bilateral and 60% unilateral (Table

5). However, in contrast to the Portuguese, from the 60% unilateral, 36% are left humerus and 24% are right humerus (Figure 1 shows an example of a right humerus with SA). This indicates that bilateral cases were the most prevalent over both left humerus and right humerus cases in the Greek sample. This is more apparent when examining the cases according to sex. The frequency out of all males with septal apertures stood at 22% for bilateral cases, 66.67% for left side and 11.11% for right. In comparison, of all females with apertures 50% had bilateral, 18.75% left side only and 31.25% right side only (Table 6). Females not only possessed a higher frequency of bilateral cases but they also possessed a higher frequency of right humerus septal apertures. In males there was a higher frequency of left side apertures; however, they still displayed a high frequency of bilateral.

Previous studies show that the frequency of bilateral apertures is population dependant. Bilateral cases were found to be more dominant in one other study. This study was conducted in Turkey and resulted in the following frequencies: of the septal apertures found in males 46.2% were bilateral, 38.5% left humerus and 15.4% right humerus. Females had 62.9% bilateral, 22.9% left humerus and 14.3% right humerus apertures (Koyun *et al.,* 2011). The results from Turkey found higher bilateral cases in both males and females while in the present study the results from the Greek sample showed higher bilateral cases only in females.

Measurements of the septal aperture size in the Portuguese population had a wide variation. It ranged from a small pinpoint to an aperture that extended to the length of the olecranon fossa (Figure 2). The size of the septal apertures recorded in Portugal do not differ in a statistically significant manner between the left and right humerus in both sexes (Table 9). There was also no statistically significant difference between males and females in regard to the size of the septal aperture.

Age is a component that not all previous studies have had the capacity to discuss in detail, as it was not always documented. This study however, has the opportunity to perform such an analysis on both populations. The sample was restricted to adults with the youngest individual from the Portuguese collection being 18 years old and 20 years from the Greek. Septal apertures are generally associated with adults rather than juveniles and are known to be extremely rare in foetuses or infants. However, cases of juveniles have been recorded as young as five years old (Hrdlička, 1932; Akabori, 1934). In the present study, the age group 50-59 had the highest frequency of septal apertures for both males and females in the Portuguese sample, while in Greeks it was 20-29 for males and 40-49 for females (Tables 4 and 7). A clear

pattern is not apparent in any other age categories in the two populations. Another reason for this is the fact that when the two populations are broken down by age and sex, the sample size for each category is small. Therefore, no reliable conclusions can be drawn on the relationship between age and the presence of the septal aperture.

One of the proposed causes of the septal aperture in past literature has been the mechanical theory. The mechanical theory suggests that the aperture is formed by the pressure placed on the fossa by the extension or flexion of the ulna (Lamb, 1890; Granville, 1967; Mays, 2008; Kubicka *et al.,* 2015). The two elements at play in this theory are the degree of ulnar projection as it is expressed by the size of the processes and the repetitive motion at the joint which may be related to occupation. In order to evaluate the mechanical theory, measurements of the ulna were taken and the occupations of the individuals in the Portuguese collection were examined. The ulnar projections produced non-significant statistical differences between ulnae associated with a septal aperture compared to those without (Table 12). This is the case for both the olecranon and coronoid projections. As this produced non-significant results, it can be concluded that the size of the proximal ulna does not impact the cause of development for a septal aperture. It was observed however, that when articulated, the olecranon process of the ulna did insert into the septal aperture in many cases. As this was determined on dry bone, it cannot be known for certain whether this was the case when soft tissue was present.

Occupation information is known for most individuals in the Portugal collection. The most frequent occupations for males are sales and service workers which comprise 30% of the male individuals, followed by craftsmen at 23%. For females, 85% of the individuals in the collection are reported to have been housewives, while the rest are maids, teachers and students (Cardoso, 2006). Information on occupation was not available for each individual in the sample used in this study; however, there is a high probability that they fall within the previously mentioned occupation categories. None of these occupations however appear to be directly involved in the creation of a septal aperture. A further examination into what repetitive movements these occupations entail may help determine whether this is a factor for the high frequency of septal apertures within this collection. The mechanical theory may help explain why septal apertures are less common in modern humans in contrast to prehistoric populations. Examples are the Veddes population (58%) and Saladoans (53.9%) (Hirsh, 1927). It may also explain why septal apertures are less common in males. This is proposed to be due to activities which were more common in prehistoric times, such as grain grinding, which involve a

repetitive motion of the elbow joint and were more frequently undertaken by females (Hirsh, 1927).

Another leading hypothesis for the formation of the septal aperture is the degree of robusticity of the humerus. The theory suggests that the more gracile the humerus, the more susceptible it is to develop a perforation of the olecranon fossa (Hrdlička, 1932). It has been demonstrated that there is a strong negative correlation between aperture development and robusticity (Larsen, 2015). This theory is based on the common occurrence of the septal aperture in the female left humerus. Early research has tested whether this could be a leading factor in the causation of the aperture. It has been stated that the development of a septal aperture is obstructed in more robust humeri or in overall more robust individuals (Trotter, 1934). To further support the robusticity theory, a study was conducted using measurements of the midshaft of the humerus. The study conducted by Benfer and McKern (1966) did not measure the features directly related to the formation of the septal aperture but only took measurements pertaining to the size of the midshaft. They concluded that there was a correlation between the presence of a septal aperture and the decreasing size of the midshaft diameter. This has led to the supposition that robusticity does play a role in the development of the septal aperture.

Based on the measurements taken in the present study, including the minimum midshaft diameter, we found that there was no statistically significant difference between humeri with and without a septal aperture in males or females (Tables 10 and 11). This conflicts with the robusticity theory, as our results are similar to those conducted on an English Medieval collection, where Mays (2008) concluded that there was no difference in gracility between the humeri with or without an aperture. In the Portuguese data there was a slight variation in the average values of measurements between those with septal apertures and those without, however they were found not to be statistically different.

As previously noted, the frequency of both the Portuguese and Greek populations is higher than expected when compared to other European countries. The analysis presented above showed that the robusticity of the humerus has no correlation with the development of the septal aperture. Other possible causes must be explored to explain why an aperture develops. As each population has a different frequency, a genetic explanation may be concluded (Singhal and Rao, 2007). Previous studies have suggested that the presence of the septal aperture can be used as an ancestry identifier (Mathew *et al.,* 2016). However, many

different elements are involved in establishing that the development of a septal aperture is an ancestral characteristic. Additional research into the genetic component of the humerus is needed to further support this theory.

Pathologies such as osteoporosis or joint disease which cause the bone to weaken making it easier to penetrate the olecranon fossa, have been suggested as the cause of development for the septal aperture (Papaloucas *et al,.* 2011). Only one case of joint disease in an individual with a septal aperture was observed in the Portuguese collection. The septal aperture on this individual is not affected by the osteophytic growth on the distal end of the humerus. If osteoporosis is a causative factor, septal apertures would not be observed in younger individuals, which is not the case as the Portuguese and Greek data demonstrate. No other cases within the sample had any obvious signs of other pathologies that could cause the development of an aperture. Therefore, this theory requires more evidence before it can be concluded that pathological conditions contribute to the development of the septal aperture.

Other influences such as nutrition may explain the variance of the septum thickness (Glanville, 1967). In addition to calcium, many other nutrients such as protein, magnesium, vitamins A, C, D and K are needed to establish a normal metabolism in bone (Ilich and Kerstetter, 2000). If nutrition and diet play a role in the development of the septum thickness, this may explain the geographical variance. It would be of interest to explore the Mediterranean diet of Portugal and Greece in order to evaluate whether the common dietary elements can explain the higher frequency of septal apertures in comparison to other European countries.

Conclusion

The present study on two well-documented collections was able to supply additional information to the previous research conducted on the septal aperture. It adds to our knowledge on geographical distribution and compares the observed frequencies to those of other European populations. It was found that the Greek collection has a much higher frequency than previously recorded for Greeks. It was also observed that both samples exceeded other European frequencies. An important finding is that the robusticity of the humeri did not differ significantly between those with and without a septal aperture, contradicting the robusticity theory. In addition, measurements on the ulna conclude that the size of the proximal end of the ulna is not significantly different between those with and those without a septal aperture. This

suggests that if the mechanical theory is proven to be true, the size of the ulna does not have any impact on the atrophy of the fossa.

Even though it was possible to challenge the robusticity theory with the present findings, it was not possible to pinpoint an exact cause for the septal aperture. Future research will be necessary to determine the most probable cause. For example, genetic and/or microscopic analysis may aid the investigation. Research on soft tissue could evaluate the hyperflexion or hyperextension of the olecranon joint and determine how it influences the development of an aperture. Further research on other populations will be important to conduct as more knowledge on the distribution pattern will be useful not only for anthropologists but for other health professionals.

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References

Akabori, E. (1934) Septal apertures in the humerus in Japanese, Ainu and Koreans, *American Journal of Physical Anthropology*, 18(3), 395-400.

Akpinar, F., Aydinlioglu, A., Tosun, N., Dogan, A., Tuncay, I. and Ünal, Ö. (2003) A morphometric study on the humerus for intramedullary fixation, *The Tohoku Journal of Experimental Medicine*, 199(1), 35-42.

Bass, W. (1987) *Human osteology. A laboratory and field manual*, USA: Missouri Archaeological Society'.

Benfer, R. A. and McKern, T. W. (1966) The correlation of bone robusticity with the perforation of the coronoid-olecranon septum in the humerus of man, *American Journal of Physical Anthropology*, 24(2), 247-252.

Brinton, D. G. (1894) Variations in the human skeleton and their causes, *American Anthropologist*, 7(4), 377-388.

Brothwell, D. R. (1981) *Digging up bones: the excavation, treatment, and study of human skeletal remains*, New York: Cornell University Press.

Buikstra, J. E. and Ubelaker, D. H. (1994) *Standards for data collection from human skeletal remains: proceedings of a seminar at the Field Museum of Natural History*, Arkansas Archeological Survey Research Series no. 44. Fayetteville: Arkansas Archeological Society

Cardoso, H. F. (2006) Brief communication: the collection of identified human skeletons housed at the Bocage Museum (National Museum of Natural History), Lisbon, Portugal, *American Journal of Physical Anthropology*, 129(2), 173-176.

Eliopoulos, C., Lagia, A. and Manolis, S., (2007). A modern, documented human skeletal collection from Greece. *HOMO-Journal of Comparative Human Biology*, *58*(3), 221-228.

Erdogmus, S., Guler, M., Eroglu, S. and Duran, N. (2014) The importance of the supratrochlear foramen of the humerus in humans: an anatomical study, *Medical science monitor: International Medical Journal of Experimental and Clinical Research*, 20, 2643-2650.

Gallagher, T. (1983) *Portugal: A twentieth-century interpretation*, Manchester: Manchester University Press.

Glanville, E. V. (1967) Perforation of the coronoid-olecranon septum humero-ulnar relationships in Netherlands and African populations, *American Journal of Physical Anthropology*, 26(1), 85-92.

Hirsh, I. S. (1927) The supratrochlear foramen: clinical and anthropological considerations, *The American Journal of Surgery*, 2(5), 500-505.

Hrdlička, A. (1932) The humerus: septal apertures, *Anthropologie,* 10, 31-96 .

IBM Corp. (2015) SPSS statistics for Windows. Version 23.0. Armonk (NY): IBM.

Ilich, J. Z. and Kerstetter, J. E. (2000) Nutrition in bone health revisited: a story beyond calcium, *Journal of the American College of Nutrition*, 19(6), 715-737.

Ingman, A. and Waters, D. (1994) Locked intramedullary nailing of humeral shaft fractures. Implant design, surgical technique, and clinical results, *Bone & Joint Journal*, 76(1), 23-29.

Kate, B.R. and Dubey, P.N. (1970) A note on the septal apertures in the humerus of Central Indians. *Eastern Anthropologist* 33, 105–10.

Koyun, N., Aydinlioglu, A. and Gumrukcuoglu, F. N. (2011) Aperture in coronoid-olecranon septum: A radiological evaluation, *Indian Journal of Orthopaedics*, 45(5), 392-396.

Krishnamurthy, A., Yelicharla, A.R., Takkalapalli, A., Munishamappa, V., Bovinndala, B. and Chandramohan, M., (2011) Supratrochlear foramen of humerus: a morphometric study. *Int J Biol Med Res*, *2*(3), 829-31.

Kubicka, A.M., Myszka, A. and Piontek, J., (2015) Geometric morphometrics: does the appearance of the septal aperture depend on the shape of ulnar processes?. *The Anatomical Record*, 298(12), 2030-2038.

Lamb, D. S. (1890) The olecranon perforation, *American Anthropologist*, 3(2), 159-174.

Larsen, C.S., (2015) Bioarchaeology: interpreting behavior from the human skeleton. *Cambridge University Press,* 69.

Macalister, A. (1990). Anatomical notes and quaries. Series II. 1. Perforate humeri in ancient Egyptian skeletons, *Journal of Anatomy and Physiology*, 35, 121-122.

Mathew, A. J., Gopidas, G. S. and Sukumaran, T. T. (2016) A Study of the Supratrochlear Foramen of the Humerus: Anatomical and Clinical Perspective, *Journal of Clinical and Diagnostic Research,* 10(2), AC05-AC08.

Mays, S. (2008) Septal aperture of the humerus in a mediaeval human skeletal population, *American Journal of Physical Anthropology*, 136(4), 432-440.

Meckel, J. H. (1825) 'Cited by Kate, BR. and Dubey, PN. (1970) Note on septal apertures in humerus of central indians', *Eastern Anthropologist*, 23(1), 105-110.

Ming-Tzu, P. A. (1935) Septal apertures in the humerus in the Chinese, *American Journal of Physical Anthropology*, 20(2), 165-170.

Myszka, A. (2015) Septal aperture etiology: still more questions than answers, *Folia Morphologica*, 74(2), 219-224.

Nayak, S. R., Das, S., Krishnamurthy, A., Prabhu, L. V. and Potu, B. K. (2009) Supratrochlear foramen of the humerus: An anatomico-radiological study with clinical implications, *Upsala Journal of Medical Sciences*, 114(2), 90-94.

Ndou, R., Smith, P., Gemell, R. and Mohatla, O. (2013) The supratrochlear foramen of the humerus in a South African dry bone sample, *Clinical Anatomy*, 26(7), 870-874.

Öztürk, A., Kutlu, C., Bayraktar, B., Ari, Z. and Sahinoglu, K., (2000). The supratrochlear foramen in the humerus: anatomical study. *Istanbul Tip Fak Mecmuasi*, *63*, 72-76.

Papaloucas, C., Papaloucas, M. and Stergioulas, A. (2011) Rare cases of humerus septal apertures in Greeks, *Trends in Medical Research*, 6(3), 178-83.

Paraskevas, G. K., Papaziogas, B., Tzaveas, A., Giaglis, G., Kitsoulis, P. and Natsis, K. (2010) The supratrochlear foramen of the humerus and its relation to the medullary canal: a potential surgical application, *Medical Science Monitor*, 16(4), BR119-BR123.

Sahajpal, D. T. and Pichora, D. (2006) Septal aperture: an anatomic variant predisposing to bilateral low-energy fractures of the distal humerus, *Canadian Journal of Surgery*, 49(5), 363.

Scheuer, L. and Black, S. (2004) *The juvenile skeleton*, Academic Press.

Schultz, A. H. (1937) Proportions, variability and asymmetries of the long bones of the limbs and the clavicles in man and apes, *Human Biology*, 9(3), 281-328.

Singhal, S. and Rao, V. (2007) Supratrochlear foramen of the humerus, *Anatomical Science International*, 82(2), 105-107.

Trotter, M. (1934) Septal apertures in the humerus of American whites and negroes, *American Journal of Physical Anthropology*, 19(2), 213-227.

Tables

Table 1. Distribution of septal apertures in the Portuguese collection

	Present	Absent	Missing humeri	Total	Frequency (%)
Males	20	124	5	149	13.42
Females	30	113	6	148	20.27
Total	50	237	11	297	16.83

Table 2. Distribution of septal apertures by sex and side in the Portuguese collection

	Bilateral	Left side	Right side	No Aperture	Total
Males	6	12	2	124	144
Females	9	12	9	113	143
Total	15	24	11	237	287

Table 3. NcNemar Test results

	Right	
Left	Absent	Present
Absent	237	11
Present	24	15

p-value = 0.043

Table 4. Distribution of septal apertures in the Portuguese collection by age and sex

Age Groups	Males		Females		Total	
	N	SA	N	SA	N	SA
10-19	1	1	0	0	1	1
20-29	6	1	7	2	13	3
30-39	12	2	7	1	19	3
40-49	26	3	4	1	30	4
50-59	35	5	23	8	58	13
60-69	21	1	23	6	44	7
70-79	26	4	48	8	74	12
80-79	22	3	36	4	58	7
Total	149	20	148	30	297	50

Table 5. Distribution of septal apertures in the Greek collection

	Present	Absent	Total	Frequency (%)
Males	9	59	68	13.24
Females	16	33	49	32.65
Total	25	92	117	21.56

Table 6. Distribution of septal apertures by sex and side in the Greek collection

	Bilateral	Left side	Right side	No aperture	Total
Males	2	6	1	59	68
Females	8	3	5	33	49
Total	10	9	6	92	117

Table 7. Distribution of septal apertures in Greeks by age and sex

Age Groups	Males		Females		Total	
	N	SA	N	SA	N	SA
20-29	14	4	6	5	20	9
30-39	9	1	8	2	17	3
40-49	16	1	15	6	31	7
50-59	15	1	14	2	29	3
60-69	14	2	6	1	20	3
Total	68	9	49	16	117	25

Table 8. Measurements of the septal aperture in Portuguese males and females

	Males						Females					
	Left			Right			Left			Right		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Inf-Sup	18	3.78	1.2	8	3.27	1.46	21	3.57	1.49	18	3.94	1.30
Trans	18	5.13	2.1	8	3.97	2.14	21	4.84	2.53	18	5.47	2.36

Inf-Sup: Inferior-Superior diameter, Trans: transverse diameter

Table 9. Statistical difference of septal aperture measurements between Portuguese males and females

	Left		Right	
	Trans	Inf-Sup	Trans	Inf-Sup
P-value	0.700	0.637	0.637	0.248

Trans: transverse diameter, Inf-Sup: Inferior-Superior diameter

Table 10. Humeral and ulnar projection measurements for Portuguese males. Statistical significance of the comparison between the measurements of elements with and without a septal aperture

	SA Present			SA Absent			p-value
	N	Mean	SD	N	Mean	SD	
Left Humerus							
Head diameter	18	43.59	1.45	129	44.47	2.43	0.137[1]
Max. midshaft diam.	18	21.20	1.68	129	22.34	1.98	0.02[1]
Min. midshaft diam.	18	17.58	1.64	129	18.55	1.84	0.076[2]
Epicondylar width	17	59.00	3.75	120	58.74	4.4	0.813[1]
Right Humerus							
Head diameter	8	45.29	1.77	139	45.00	2.38	0.742[1]
Max. midshaft diam.	8	22.02	1.92	141	23.30	3.20	0.159[2]
Min. midshaft diam.	8	17.65	2.93	141	18.75	1.72	0.094[1]
Epicondylar width	7	60.00	4.78	134	59.19	4.44	0.642[1]
Left Ulna							
Relative olecranon projection	17	0.77	0.10	119	0.76	0.12	
Relative coronoid projection	17	0.66	0.06	121	0.64	0.09	
Right Ulna							
Relative olecranon projection	8	0.73	0.11	133	0.75	0.11	
Relative coronoid projection	8	0.65	0.09	134	0.66	0.08	

[1] T-test (data normally distributed)

[2] Mann-Whitney test (data not normally distributed)

Table 11. Humeral and ulnar projection measurements for Portuguese females. Statistical significance of the comparison between the measurements of elements with and without a septal aperture

	SA Present			SA Absent			p-value
	N	Mean	SD	N	Mean	SD	
Left Humerus							
Head diameter	21	39.66	2.14	124	39.54	2.20	0.832[2]
Max. midshaft diam.	21	19.47	1.74	126	19.90	1.71	0.310[2]
Min. midshaft diam.	21	15.38	1.28	126	15.91	1.54	0.164[2]
Epicondylar width	21	51.00	6.66	118	50.99	4.61	0.453[2]
Right Humerus							
Head diameter	18	39.01	1.76	128	39.78	2.34	0.185[2]
Max. midshaft diam.	18	19.80	1.56	130	20.46	1.65	0.114[1]
Min. midshaft diam.	18	15.91	1.58	130	16.55	3.38	0.273[2]
Epicondylar width	18	50.87	3.97	122	51.78	4.65	0.429[1]
Left Ulna							
Relative olecranon projection	21	0.79	0.12	109	0.76	0.12	
Relative coronoid projection	21	0.67	0.07	109	0.65	0.07	
Right Ulna							
Relative olecranon projection	17	0.75	0.10	109	0.74	0.10	
Relative coronoid projection	17	0.68	0.09	117	0.67	0.08	

[1] T-test (data normally distributed)

[2] Mann-Whitney test (data not normally distributed)

Table 12. Statistical difference of ulnar measurements with and without a septal aperture

	Coronoid		Olecranon	
	Left	Right	Left	Right
P-value	0.069	0.456	0.314	0.965

Table 13. Frequencies by population from previous studies

Population	Frequency	Reference
White American	4.2%	Hirsh, 1927
Native American Arkansas	58%	Hirsh, 1927
Americans	6.9%	Benfer and McKern, 1966
Eskimos	19.8%	Krishnamurthy *et al.* 2011
Mexicans	38.7%	Krishnamurthy *et al.* 2011
Indians (All Over)	34.3%	Nayak, 2009
Central Indians	32%	Kate & Dubey, 1970
South Indians	28%	Singhal and Rao, 2007
North Indians	27.4%	Singh and Singh, 1972
Eastern Indians	27.4%	Chatterjee, 1968
Japanese	18.1%	Akabori, 1934
Koreans	11%	Akabori, 1934
Chinese	17.5%	Ming-Tzu, 1935
Turkish	8.6%	Koyun *et al.,* 2011
Egyptians	7.9%	Ozturk *et al.* 2000
Libyans	57.2%	Macalister, 1990
African	21.7%	Hirsh, 1927
South Africans	32.5%	Ndou *et al.* 2013
Italians	9.4%	Hrdlička, 1932
German	8.8%	Hrdlička, 1932
Poland	7.5%	Myszka, 2015
Dutch	6.1%	Glanville, 1967
English	6.9%	Mays, 2008
Greek	0.304%	Papaloucas *et al.,* 2011
Australian	46.5%	Hrdlička, 1932