Cranfield UNIVERSITY

Forensic Modular Masters

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The prevalence of Wormian bones in relation with Ancestry:

A comparison between Caucasian and Mongoloid populations in the light of Artificial Cranial Deformation and Pathological conditions.

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ABSTRACT

The allocation of non-metric traits to specific ancestry groups has been a common practice in Forensic Anthropology and Physical Anthropology since 1905 (Parker 1905). However many of these non-metric traits have a complicated aetiology that has not been explored fully. Such is the case for Wormian bones, often used as an aid for ancestry allocation in biological profiles and commonly accepted as indicative of populations with Mongoloid ancestry (see Dolinak *et al.* 2005). The study of Wormian bones in relation to artificial cranial deformation (ACD) and the identification of Wormian bones in many disorders such as osteogenesis imperfecta (OI) and craniosynostosis suggest that there is more to understand about this non-metric trait than what has been made evident through population prevalence studies.

This project aimed to explore the link between Wormian bones, ACD and a number of pathologies in three collections: Sierra Norte-Ecuador archaeological collection (41 individuals), Haslar-UK historical collection (44 individuals) and SHARP-UK archaeological collection (120 individuals); from two ancestry groups, Mongoloid and Caucasian. Through the recording of craniometrical measurements and observations on Wormian bones, ACD and presence of certain pathologies, a series of databases were made and then interrogated by statistical tests such as the Spearman correlation coefficient calculation, the Kendall's tau coefficient calculation and the Kruskal-Wallis non-parametric test, as well as by creating graphical representations on frequency and percentage of prevalence of Wormian bones within different variables.

The results show no relation between Wormian bones and ACD, a possible link between Wormian bones and nutritional/developmental disorders and some genetic/hereditary pathologies. The relation between Wormian bones and ancestry however, when considered separate from the other two variables, remained unclear.

It is possible to conclude therefore that Wormian bones cannot be used as ancestry related non-metric traits, especially not for the purpose of identification between Native American and European archaeological-historical populations, as there are multiple other variables - two of which are ACD (as a cultural practice) and pathological disorders - that can contribute to the occurrence of Wormian bones in an individual. Further research is needed to explore the nature of the relationship between nutritional/developmental disorders and Wormian bones as well as the implications of high indices of genetic disorders in a population when considering the prevalence of Wormian bones.

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GLOSSARY

1. ***ACD*** **=** Artificial Cranial Deformation.
2. ***Cranial Base Length*** **=** Cranial measurement that accounts for the distance between basion (ba) and nasion (n) landmarks of the human skull.
3. ***Fontanel*** **=** Soft spots or cartilage zones between sutures that exist on the human skull until the 12 months after birth.
4. ***Maximum Cranial Breadth*****=** Cranial measurement that accounts for the distance between euryon (eu) and euryon (eu) landmarks of the human skull.
5. ***Maximum Cranial Height*** **=** Cranial measurement that accounts for the distance between basion (ba) and bregma (b) landmarks of the human skull.
6. ***Maximum Cranial Length*** **=** Cranial measurement that accounts for the distance between glabella (g) and ophistocranion (op) landmarks of the human skull.
7. ***OI*** = Osteogenesis Imperfecta or Brittle Bone Disease
8. ***Ossicles*** = Wormian bones
9. ***Ossification centre*** = location or site where bone tissue start to form, as a result of osteoblasts action and that will lead to the formation of a specific bone structure.
10. ***Pedigree research*** **=** Genetic research for traceability of genetic conditions /hereditary conditions.
11. ***PG*** = Pathology of genetic origin.
12. ***PN*** = Pathology of nutritional deficiency origin.
13. ***SHARP*** = Sedgeford Historical and Archaeological Research Project
14. ***SNWB*** = Super Numerary Wormian Bones; term used to describe the presence of more than 10 Wormian bones in a skull.
15. ***Suture*** **=** The line formed when two bones connect or join, especially used for the skull.
16. ***Wormian bone site*** = place or location in the human skull where a Wormian bone is present.

INTRODUCTION

The main issue surrounding Wormian bones is that they have been repeatedly referred to, and included as, part of the ancestry specific non-metrical traits of the skeleton. Examples of this can be found in Forensic Anthropology and Physical Anthropology websites (redwoods education 2011), learning tools (flashcard machine 2011) and textbooks (Dolinak *et al.* (2005)); consistently suggesting to practitioners the use of Wormian bones for ancestry identification in skeletonized human remains .

This study aims to build on existing research on the effects of artificial cranial deformation (ACD) on cranial sutures and the occurrence of Wormian bones (García-Hernández and Murphy-Echeverría (2009); El Najjar and Dawnson (1977)), the incidence of Wormian bones in relation to pathological conditions (Cohen (2005), Oostra *et al.* (2005), Semler *et al.* (2010)), and in relation to ancestry, (Brothwell (1981), Hanihara and Ishida (2001), Sánchez-Lara *et al.* (2007)).

Literature on the subject of Wormian bones is scarce, exploring only artificial cranial deformation, pathology or ancestry in its turn.

The proposed aetiology of Wormian bones is related to the separation of existing ossification centres of the skull or the addition of new ossification centres; both cases related to stress during the developmental or growth processes of the cranium (Parker (1905), Zambare (2001), Sánchez-Lara *et al.* (2007)). However the types of stress that influence Wormian bone formation or the direct influence of stress in the presence of Wormian bones is still unknown.

This project argues that, given the conflicting results regarding the relation of Wormian bones and ancestry, and the lack of comparative literature regarding Wormian bone presence between ancestry and pathology and artificial cranial deformation, there is a need to eliminate their use as ancestry specific traits in Forensic Anthropology practice.

To support this argument three archaeological/historical collections from two different ancestry backgrounds, (European (Caucasian) and South American

(Mongoloid), were examined to determine the prevalence of Wormian bones, taking into account the relation between Wormian bone presence and ACD presence as well as pathology presence.

Conclusions were then attained by completion of the following objectives:

General Objectives:

- Establish a base line of prevalence of Wormian bones in a Caucasian population, through comparison of a control and a pathological population (SHARP and Haslar)

- Establish a relative percentage of prevalence of Wormian bones in a Mongoloid population, by comparison between deformed and non-deformed skulls in the Sierra Norte collection.

- Compare the prevalence of Wormian bones in both ancestry groups.

Specific Objectives:

- Determine if there is a difference between the expected prevalence of Wormian bones in relation to ancestry according to the literature, and the prevalence of Wormian bones recorded for each population.

- Establish the effect of stress (by pathological conditions or ACD) on the incidence of Wormian bones in a population.

Hypotheses

The examination of the results obtained was done following the guidelines proposed by the working hypotheses:

1) The prevalence of Wormian bones in Caucasian populations is higher than that described by the literature on the subject.
2) The effects of pathology/ACD on the incidence of Wormian bones are high enough to supersede ancestry predisposition.
3) ACD does not have a bigger effect on incidence on Wormian bones than pathology.
4) Cranial measurements that show cranial vault shape have a direct relation with Wormian bone presence.

In consequence the Null Hypotheses tested were:

1) *The distribution of Wormian bones is the same across the categories of Ancestry.*
2) *The distribution of Wormian bones is the same across the categories of Pathologies.*
3) *The distribution of Wormian bones is the same across the categories of Artificial Cranial Deformation.*
4) *The distribution of Wormian bones is the same across the categories of cranial vault measurements.*

Chapter 1- Aetiology of Wormian bones

<u>What are Wormian bones?</u>

The term Wormian Bones is applied to all sutural bones, supernumerary bones and ossicles in the cranium. They have been documented on most mammals and in hominids, so they are not exclusive to modern human skulls.

Wormian bones are found in both sexes in similar percentages as well as in both sides of the skull, being predominantly symmetrical (Hanihara and Ishida 2001: 10). They can have different irregular shapes (round, oval, oblong, triangular, quadrilateral and polygonal have all been reported) and can vary from under 1mm in diameter to 5x9cm or 1-2 inches in diameter. Wormian bones articulate with the surrounding bones by sutures with indentations more complex on the outer surface of the skull than on the inner aspect. (Parker 1905:12; Sanchez Lara *et al*. 2007:1)

Although they are most commonly found in the posterior sutures (lamboidal and occipito-mastoid sutures), they can occur in any cranial suture and fontanels. They can develop either from independent ossification centres or by their separation from primary centres (Chambellan 1882 in Parker 1905, Sanchez Lara *et al*. 2007).

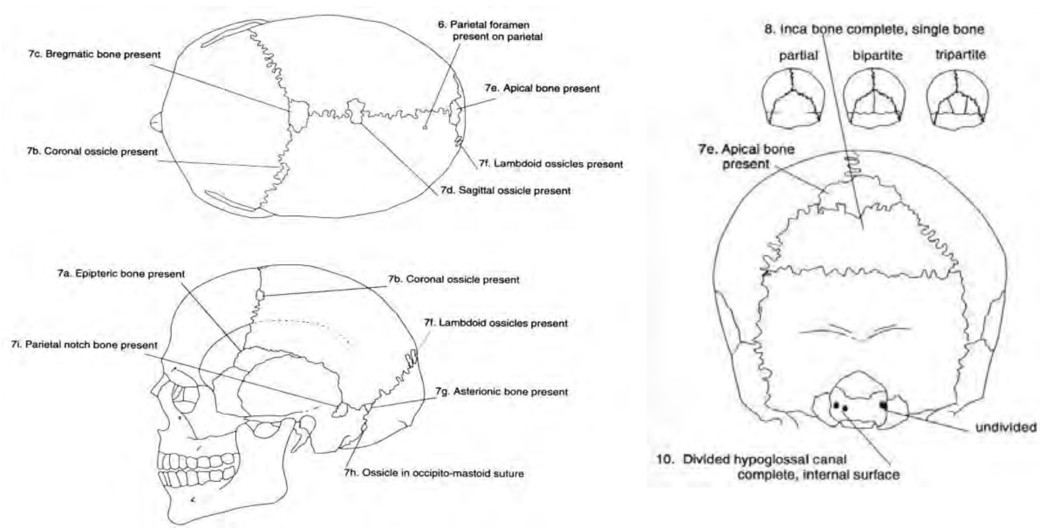

Figure 1. Wormian bones diagram. Taken from Buikstra and Ubelaker (1994:88-89)

According to the site where Wormian bones are formed they receive a different name that is, in most cases, derivative from the suture or sutures they are in contact with or with the centre of ossification or fontanel where they originate.

Figure 2. Wormian bones. a) Epipteric bone; b) Lambdoidal ossicles; c) Occipito-mastoid ossicles; d) Apical bone; e) Lambdoidal ossicles. Photos taken by the author.

Some scientists make a distinction between supernumerary ossicles resulting from the separation of primary centres from that resultant from separate ossification centres, calling the first "true Wormian bones"; however, this distinction is very hard to make when observing Wormian bones without the use of a CT scanner or similar equipment (Oostra *et al*. 2005:14). In our case all ossicles found in the sutures will be grouped under the same category of Wormian bones.

There is also a big distinction made between wormian ossicles and the Inca bone or “Os Incae”. This last one is believed to be the division – non-fusion- of two primary ossification centres of the occipital bone rather than a product of independent ossification centres (Antón *et al*. 1992; Srivasta 1977; Burrows *et al*. 1997: 2).

The first official accounts of these ossicles where made by Ola s Worm 1588-1654). The Danish anatomist described them in a letter to his colleague Thomas Bartholin, who after reading it termed them *ossa wormiana*, in his honour (Parker 1905: 6).

Similarly, the Inca bone or interparietal bone was first described by Tschudi (1844) from Peruvian skulls, presumably from archaeological collections. First believed to be an exclusive Native American trait it was quickly given its memorable name (Ossenberg 1969; Hanihara and Ishida 2000:1; Wu *et al*. 2010:1).

There are several claims for earlier mentions of wormian bones, for example a German scientist Gonther D’Adernach 1487-1577) is said to have made a detail description of them in his memories. A Belgian doctor by the last name Vesale (1514-1564) gave an account of skull ossicles in relation to cerebral affections such as epilepsy. (Parker 1905:7)

<u>When do they appear?</u>

At the moment of birth the human skull is composed by forty five separate elements including areas of dense tissue between the growing bone plates, called “soft spots” or fontanels which are membranes composed of cartilage. As growth and ossification occurs, gradually these fontanels become bone and the area of contact between each other takes the form of sutures (Jeanty 2000:6; White 2005: 84)

There are five main sutures in the human skull: two squamous (one on each side of the skull), one coronal, one lambdoid and one sagittal suture.

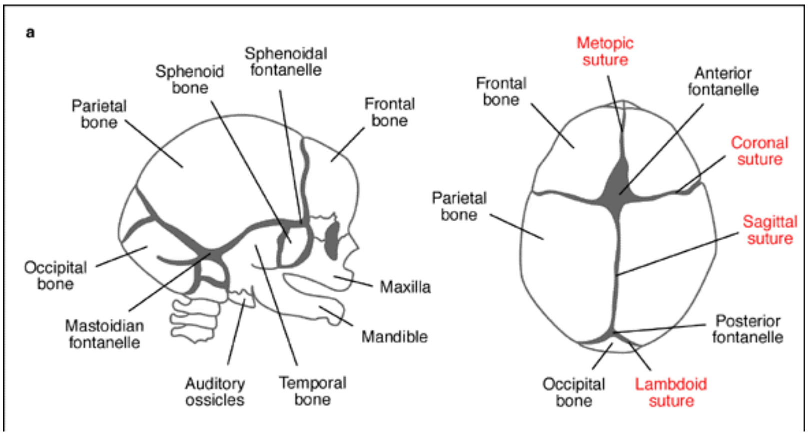

Figure 3. Diagram of Skull Sutures. Taken from ADAM 2011, http://www.nlm.nih.gov/medlineplus/ency/imagepages/1127.htm).

These will close from eight weeks up to eighteen months. The metopic suture that marks the connecting point of the two ossification centres of the frontal bone is not commonly present after the first 18 months of life and therefore is not mentioned as one of the primary sutures (Oostra *et al*. 2005:2).

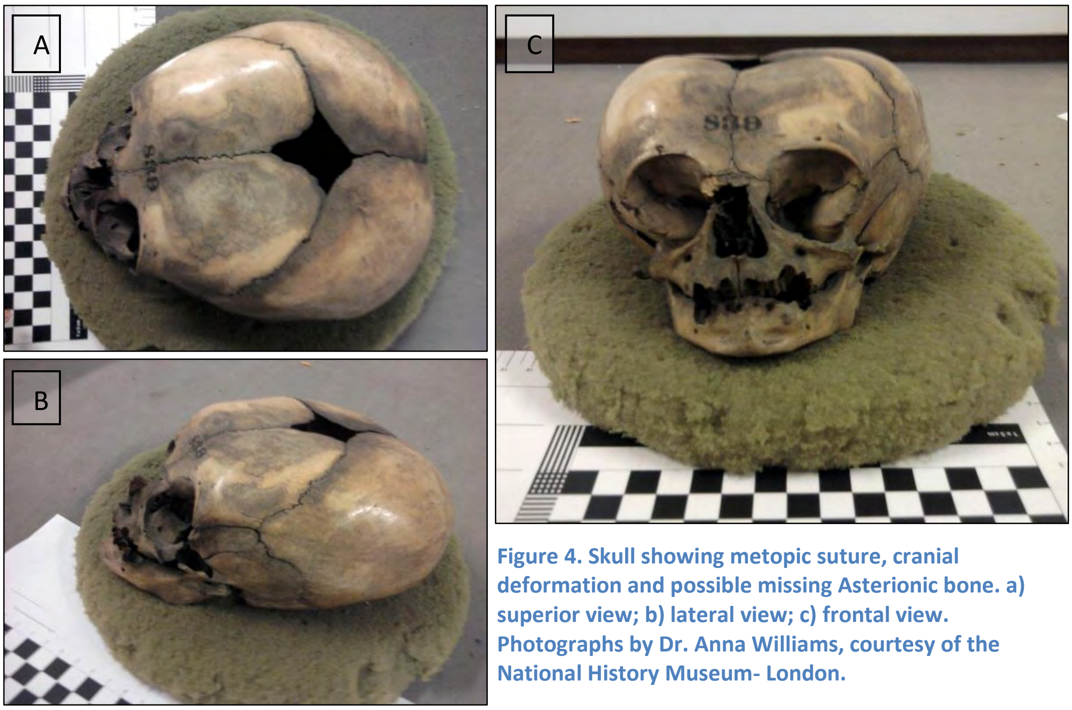

Figure 4. Skull showing metopic suture, cranial deformation and possible missing Asterionic bone. a) superior view; b) lateral view; c) frontal view. Photographs by Dr. Anna Williams, courtesy of the National History Museum- London.

Wormian bones share the same formation process as suture lines as they can only form while suture growth has not finished. The lack of fusion between two or more ossification centres is one of the reasons why supernumerary sutures and interparietal bones form, (Srivastava 1992; Hanihara and Ishida 2001; Oostra *et al*. 2005:2).

In some cases Wormian bones will appear at the same time as the normal ossification centres; in others, as with some ossification centres, they will appear as necessity for them arises (Parker 1905: 20). At any rate, growth rithm for Wormian bones is similar to that of larger bones, by growth from the ossification center outwards (Parker 1905:20).

Why do they appear?

As explained in the previous section, it is the non-fusion of primary ossification centres and the formation of independent ossification centres that leads to the formation of Wormian bones. The reasons for this resulting non-fusion however are multiple,. Wormian bones are seen in literature as supplementary ossification points that appear when normal growth from the centres of ossification seems insufficient (Parker 1905: 20; Zambare 2001:1).

Wormian bones have been reported in both normal and pathological crania. Their aetiology is still unclear; nevertheless it has been related to genetics, in terms of population, as well as external forces, such as stress conditions (Burrows *et al*. 2007: 2; White 1996:3). The arguments for both will be exposed in separate sections.

Genetic origin of Wormian bones

Several authors have explored the possibility that the formation and incidence of Wormian bones are primarily related to genes (Berry and Berry 1967 and Finkel 1976 in O'Laughlin 2004:1).

The first study of Wormian bone incidence according to population was published in 1883 by Victor Chambellan. His results are seen in the table 1 underneath, and are taken from the examination of 485 normal human skulls from different races and sexes. (Chambellan 1883 in Parker 1905: 11)

Table 1. Location, Size and Number of Wormian bones in 100 adult human skulls. Taken from Chambellan (1883,) in Parker (1905:11).

Lambdoid suture, right	19.49 (+1),	19.77 (1),	33.58 (2),	27.88 (3),	9.17 (4),	0.42 (5).	Total 110.31	Total both sides—215.81
Lambdoid suture, left	17.16 (+1),	16.98 (1),	30.66 (2),	33.96 (3),	6.41 (4),	0.33 (5).	Total 105.50	
Coronal suture, right	50.33 (+1),	24.02 (1),	0.34 (2),	0.59 (3),	......	......	Total 75.28	Total both sides—126.22
Coronal suture, left	47.24 (+1),	1.85 (1),	1.15 (2),	0.70 (3),	......	......	Total 50.94	
Mastoparietal, right	4.52 (+1),	12.30 (1),	3.28 (2),	1.95 (3),	0.34 (4),	......	Total 22.39	Total both sides— 45.18
Mastoparietal, left	4.35 (+1),	10.22 (1),	6.18 (2),	2.04 (3),	......	......	Total 22.79	
Asterion, right	0.08 (+1),	1.74 (1),	6.48 (2),	10.80 (3),	1.50 (4),	......	Total 20.69	Total both sides— 35.48
Asterion, left	0.08 (+1),	1.35 (1),	5.18 (2),	5.67 (3),	2.51 (4),	......	Total 14.79	
Pterion, right	......	2.63 (1),	2.68 (2),	8.84 (3),	2.29 (4),	......	Total 16.44	Total both sides— 28.00
Pterion, left	......	0.19 (1),	6.54 (2),	3.06 (3),	1.77 (4),	......	Total 11.56	
Squamoparietal suture, right	2.24 (+1),	4.09 (1),	4.86 (2),	2.22 (3),	0.48 (4),	......	Total 13.89	Total both sides— 27.19
Squamoparietal suture, left	2.64 (+1),	5.05 (1),	4.50 (2),	0.86 (3),	0.16 (4),	......	Total 13.30	
Sagittal suture	7.82 (+1),	7.85 (1),	2.18 (2),	4.04 (3),	0,85 (4),	0.29 (5),	Total 23.03	
Masto-occipital suture, right	1.21 (+1),	1.86 (1),	2.56 (2),	3.04 (3),	......	......	Total 8.70	Total both sides— 19.83
Masto-occipital suture, left	0.16 (+1),	3.50 (1),	1.70 (2),	5.44 (3),	0.22 (4),	0.11 (5),	Total 11.13	
Orbit, right	0.40 (+1),	6.42 (1),	2.32 (2),	0.59 (3),	......	......	Total 9.73	Total both sides— 11.29
Orbit, left	0.18 (+1),	1.20 (1),	0.18 (2),	......	......	......	Total 1.56	
Metopic suture	3.52 (+1),	......	......	......	......	......	Total 3.52	
Sphenofrontal suture, right	0.18 (+1),	0.18 (1),	......	0.18 (3),	......	......	Total 0.54	Total both sides— 1.08
Sphenofrontal suture, left	0.18 (+1),	......	......	0.36 (3),	......	......	Total 0.54	
Bregma	......	0.18 (1),	......	0.27 (3),	......	......	Total 0.45	
Obelion	0.08 (+1),	......	......	0.08 (3),	......	......	Total 0.16	
TOTAL	161.89 (+1),	121.38 (1),	114.46 (2),	112.57 (3),	25.79 (4),	1.15 (5).	......537.24	

During his pedigree research Torgerson found that Wormian bones were hereditary traits with 50% penetrance and expression, which means that even when it would be hereditary the trait will not necessarily be expressed in half of the cases. (Torgerson 1954)

Much later, in 1963, Brothwell presented a table with the incidence of Wormian bones (recorded exclusively from the lambdoid suture), as is seen underneath (Brothwell 1981: 93-94).

Table 2. Percentage of frequencies of ten discontinous morphological traits in fourteen populations. Taken from Brothwell (1981:11)

	Percentage									
	with tori mandi-bularis	*with torus palat-inus*	*with tori auditivi*	*with a metopic suture*	*showing fronto-temporal articu-lation*	*display-ing wormian bones*	*of pteria with epipteric bones*	*of sides with parietal notch bones*	*showing orbital osteo-porosis*	*of sides with multiple mental foramina*
1. Eskimo	39.81†	31.39†	0.20‡	0.28*	1.92*	25.00*	4.85*	14.62*	2.02*	2.22
2. Chinese	9.43*	3.59*	0.28*	8.17*	3.69*	80.32	11.28*	31.88	13.38*	11.43
3. Australian	6.25*	18.84†	14.47*	0.63*	23.85*	72.58	7.59*	12.86	5.26*	11.25
4. Melanesian	0.00†	0.00†	6.10*	2.02‡	15.07†	64.15	10.91†	19.29	1.65‡	9.71‡
5. Polynesian	4.05‡	24.42†	25.74‡	1.33†	2.29†	29.92*	9.09†	3.45	6.49‡	12.50‡
6. African Negro	14.15*	0.00‡	1.71‡	1.23†	13.55*	45.05*	11.58*	22.78	32.07*	8.01‡
7. N. American Indian	13.34†	8.05†	12.76‡	1.45†	0.49	28.18*	2.28†	11.82	11.51*	3.65‡
8. Ancient Egyptian	2.41‡	1.33	1.98‡	3.87†	1.55*	55.56*	10.08*	16.05	7.47‡	4.59*
9. Lachish	25.00	3.08	1.98	8.81‡	1.87‡	63.41	20.78	21.69	12.16	6.85
10. Anglo-Saxon	27.27	9.20*	0.00	8.30*	1.03	55.56	11.29	8.59	27.64	11.18
11. Iron Age Romano-British	37.23	9.71	1.82	9.91	2.73	71.03	19.89	36.04	35.00	9.18
12. Peruvian	1.79†	19.31†	14.49†	2.56†	1.48*	51.85*	2.68*	20.45	8.09‡	10.00
13. German	0.00‡	4.87‡	5.00	8.37†	1.61†	75.00	18.29	12.5	6.47†	8.62
14. London (17th C.)	19.61	10.78*	5.63	9.09*	2.88*	36.02*	13.10*	8.08*	15.38	9.46

§ Certain published data have been omitted owing to lack of information as to the exact number of sides examined.
* = Data by the author and from the literature
† = Means calculated from various published sources
‡ = Already published data by one author
No mark = Original data by the author

A more recent study on the subject is presented by Hanihara and Ishida in 2001. Their finds have been grouped according to geographic location and site of Wormian bone and summarized in the following table (Hanihara and Ishida 2001: 9).

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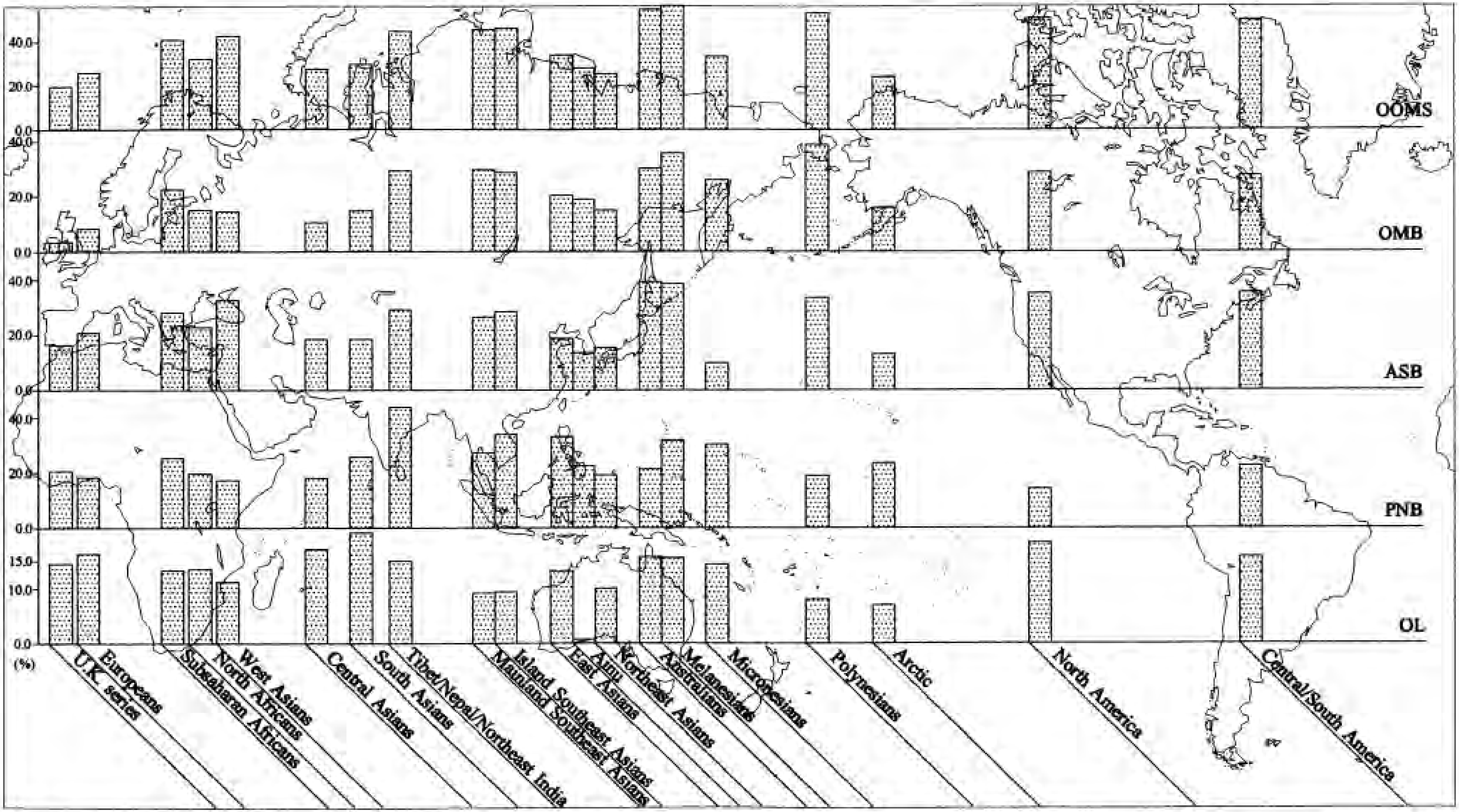
Table 3. Percentage of frequencies of Wormian bones according to site, by location in a world map. Taken from Hanihara and Ishida (2001: 9)



From the graph we can gather that the lowest frequencies for all the ossicles appear in East/northern Asian groups as well as in Artic populations. Western Europe & Subsaharan Africa presented high frequencies of Wormian bones, as well as Australians, Mealnesians and the Americas (Hanihara and Ishida 2001: 1).

Not included in the table is the Inca bone variation between population groups. According to Hanihara and Ishida (2001) it is an uncommon trait in Northeast Asia and western Eurasia, however it has a high frequency, over 20% of the total population, in the Americas and Sub-Saharan Africa (Hanihara and Ishida 2000:8). This information is important because it has been reported that crania that present and Inca bone more often than not will also have Wormian bones as can be found in Hanihara and Ishida (2000:8) though specific numbers are not mentioned (Hanihara and Ishida 2000:8;Del Papa and Perez 2007: 1)

<u>Stress Related origin of Wormian bones</u>

A second point of view regarding the aetiology of Wormian bones has to do with environmental stressors that will affect the normal growth of the skull. Artificial Cranial Deformation or experimentally created craniosynostosis are an example of such environmental stressors Dorsey 1897 in O'Laughlin 2004:1; Hanihara and Ishida 2001: 2).

In fact, it has been implied that sutural variation is related to mechanical stress during the early stages of development. This type of stress is classed under the category of "ontogenic stress" Konisberg *et al*. 1993 in Hanihara and Ishida 2001:2; Burrows *et al*. 2007: 1)

Anaemia related disorders, Vitamin deficiency disorders (like rickets) and genetic diseases that alter the overall cranial vault shape (Down syndrome, *osteogenesis imperfecta*, craniosynostosis) are examples of pathologies that present "ontogenic stress" or that directly affect the normal rate of growth of bone. These stress inducing factors will be described in some detail in the next two chapters.

Chapter 2.- Artificial Cranial Deformation

<u>What is Artificial Cranial Deformation and how has it been studied?</u>

Artificial Cranial Deformation (ACD) is a cultural practice that was, especially until the start of the 1900's, geographically extensive. Its occurrence was also temporarily widespread, from early archaeological groups to ethnographic recollections ACD has been largely documented (Dorsey 1895; Hrdlicka 1905; McGibbon 1912; Boaz 1913; Dingwall 1932; Imbelloni 1924-25; Brothwell 1963; Munizaga 1973; Gerszten 1993 among others).

Around the world, accounts of this practice have been commonly published in early ethnographic registers. For the Americas for example, the earliest account regarding ACD belongs to a church edict in 1585 condemning the practice, and later taken by the Government of the Indies in 1752 (*McGibbon W* 1912.)

A great number of styles of intentional cranial modification has been registered for the Andes, in several collections of osteological remains around the world that have been analyzed since the c19th (as seen in Dembo and Ibelloni, 1938; Drusini *et al*. 1983; Falkenburger, 1938; Morton 1839).

By the XIX century, the only work dedicated to record methods of ACD was that of the Italian Girolamo Cardono in 1557. Three centuries later in 1862 a French researcher J.J. Virey published his notes regarding ACD in infants, according to cases he had stumbled upon.

In 1862, Canadian Sir Daniel Wilson published his short memories, where he acknowledges the division between intentional and non-intentional cranial deformation. The following year R Knox published an article where he concluded that several Neanderthal skulls showed signs of ACD (Trinkaus 1982 in O'laughlin 2004)

By 1869, L. Lunier, another French researcher, had made an important contribution to the subject by including the definition for four types of cranial deformation: plastic, pathological, posthumous and artificial in the *Nouveau Dictionnaire de Médecine et de Chirurgie*.

After several failed efforts to come up with new classifications such as geographical distribution, for cranial deformation from France and other European countries, Rudolf Virchow – known as the father of modern pathology- wrote in 1892 a series about craniometrical measurements in several deformed skulls.

The first comprehensive article regarding ACD however was not published until 1919, when Ales Hrdlicka from the Smithsonian Institution included an in-depth discussion on the known types of cranial deformation in his article “Anthropometry” in The American Journal of Physical Anthropology, and even attempted a morphological comparison between them. (Gerstzen 1995)

It is worth mentioning that those studies on the subject, previous to Hrdlicka’s contribution, had been mainly oriented towards the classification of cranial deformation from by the end product (Gosse 1855, 1862; Broca 1878, 1879; Topinard 1879), whereas Hrdlicka focused on the different techniques, instruments and processes that led to the resulting deformation.

In a sense physical anthropologists focusing on ACD had, until the beginning of the century, dedicated their efforts to mirror those descriptions made by archaeologists in their encounters with ACD. That means recounting their finds, trying to catalog them according to definite types or mapping their geographical distribution. There are very few investigations that explore the function, morphology or their relation to skeletal growth ACD (Oetteking 1924, 1930).

In the twentieth century there were three important contributions to the study of ACD. First the researched carried by the Argentinian José Imbelloni (Imbelloni 1924-25) who, during the second and third decades of the 1900s, wrote several articles that detailed the practice of ACD in South America.

Eric John Dingwall’s book *Artificial Cranial Deformation: A contribution to the Study of Ethnic Mutilations,* published in 1931, which is cited even today as one of the most comprehensive compilations on the subject that has ever been written.

Finally, a North American, T. Dale Stewart, successor of Hrdlicka at the Smithsonian Institution thoroughly studied the ACD practice in the Americas and developed a wide discussion regarding the effectiveness of using rigid classifications for the existing types of cranial deformations (Stewart 1943)

From the second half of the century onwards, most studies have been concerned with the effects of ACD on craniofacial growth and development (as seen in Corruccini 1976; Antón 1989; Kohn *et al*. 1993; Konigsberg *et al*. 1993) rather than in the overall effects of ACD on the skull.

The reasons for practicing ACD are varied and culture specific (Dingwall 1931; Topinard 1978). Many studies have been conducted with available ethnographic data, as well with archaeological knowledge on the subject (see Ordoñez 2009), since they do not present particular interest to our work however, they will not be mentioned further.

<u>How is ACD achieved?</u>

In order to understand the ACD practice in detail it is necessary to understand the biological procedure it implies. There are two conditions ACD depends on: the age of the individual and the deforming devices utilized.

These devices can present a constant or alternating pressure to the head and can be either rigid (like boards) or flexible (like bandages, head bands, hats or pads). The main consequence of the application of the devices is the alteration of the direction and magnitude of the cranial shape (Manríquez *et al*. 2005:14)

During infancy, the cranial bones are soft and can therefore be molded according to cultural practices. This deliberate molding of the skull through various procedures has been seen in skulls recovered from all over the world (Ortner and Putschar 1985; Ubelaker 1989; White and Folkens 1991).

It is because of the existence of fontanels, and the possibility of modeling them through the application of continuous force, that ACD is achievable. Therefore, a useful definition of ACD is: the change of the natural form of the skull by submitting it, in newborns and during the first years of life, to continuous pressure provided by a device either on some parts or the totality of the skull (Santiana 1958)

As it has been mentioned before, there are various types of ACD. These types are cataloged in relation to the overall changes suffered by three main skull bones: frontal, parietals and occipital.

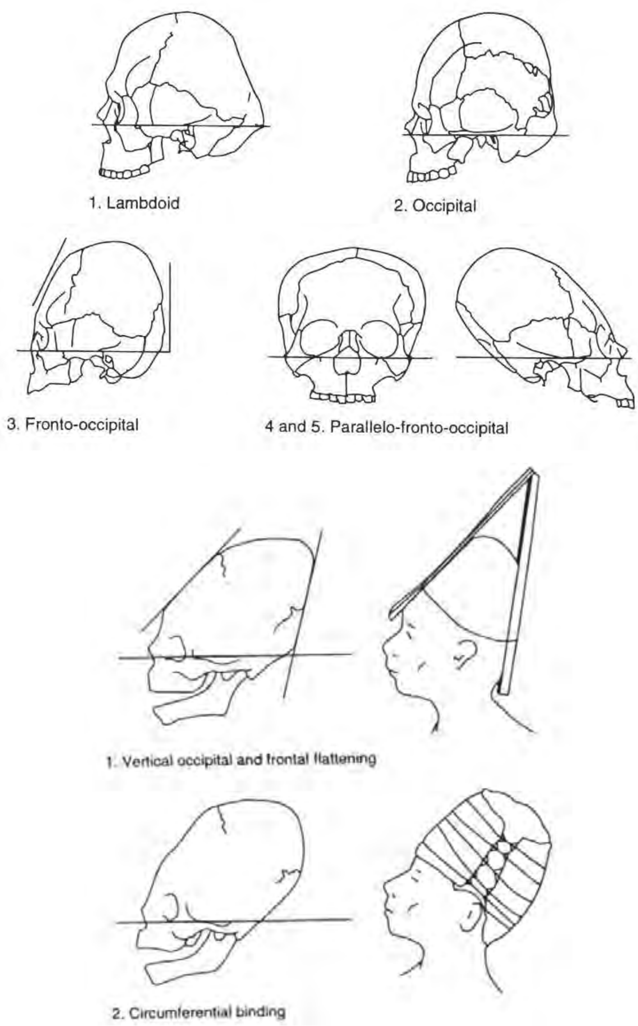


Figure 5. Types of ACD and deformation devices. Taken form Ubelaker and Buikstra (1994: 161-162).

The frontal bone is commonly deformed in association with the posterior flattening of the skull centered on the occipital (around lambda). Typically the squamous portion of the frontal bone becomes depressed, sometimes preserving the shape of those pads that accompany the deforming device. There are very few cases when a deformation of the frontal (narrowing of both sides of the frontal) has been achieved; that deformation has been termed a "bi-frontal-occipital deformation" (Stewart 1943). Circumferential binding around the skull can create different shapes according to the orientation and extension of the bandage. If the ties go from the base of the neck to the frontal will result in an elongated skull – or "loaf shape". Binds located in a posterior area can encourage late growth and posterior expansion (Buikstra and Ubelaker 1994:162)

Posterior flattening can be centered on lambda – the term "lamboidal deformation" is used in those cases". If the pressure is relocated in a vertical way over the occipital (perpendicular to the transverse plane of the occipital), it is termed an "occipital deformation". If there is an association between frontal and occipital flattening, then the type of deformation is called a "fronto-occipital deformation" as mentioned in Dembo and Imbelloni 1938; Stewart 1941; Ubelaker 1989). This fronto-occipital deformation can be either erect or oblique; the difference relies on the position of the pressure in relation to the occipital. In the oblique variation the pressure is located under the occipital, flattening ophistocranion; it is normally accompanied by a laterally expanded skull. (Dembo and Imbelloni 1938).

These two types of cranial deformation will be focused on: fronto-occipital and circumferential. The first one having two variations erect and oblique.

Figure 6. Skulls from Sierra Norte Collection with ACD. Photos by the author, courtesy of the Jacinto Jijon y Caamaño Museum.

In more detail, fronto occipital deformation exhibits anterior and posterior compression of the frontal and occipital bones; this leads to a shortening of the parietal chord and a lengthening of the occipital chord. In extreme cases the parietals are extended laterally (Blom 2005:6). The most common devices used to achieve this kind of deformation are pads or boards joined by thin straps. According to the positioning of these straps, their flexibility and the angle in which the pressure is applied there are a variety of small differences in the resulting cranial shape, overall.

Figure 7. Skulls from the National History Museum- London, presenting ACD. Photos by Dr. Anna Williams, Courtesy of the NHM-London.

Circumferential (or annular) deformation creates an elongated cranial vault, produced by the pressure applied all around the skull with textile bands that encircle the frontal, temporals, parietals and occipital. (Blom 2005:6)

<u>What is the relation between ACD and Wormian bones?</u>

As it has been detailed before, Wormian bones are non-metric traits noticed by anthropologists, medical examiners, physical anthropologists and osteology experts (human and animal alike).

Precisely because their Aetiology is so related to the developmental years of the skull, the possible link between practices that alter the overall cranial shape during those years and the appearance of Wormian bones has been explored.

This interest has been pursued extensively (Van Arsdale and Clark 2010; Dorsey 1897, Ossenberg 1969; Pucciarelli 1974; El-Najjar and Dawson 1977; Antón *et al*. 1992; White 1996, O'laughlin 2004; Del Papa and Pérez 2007 among others). What is known about this relation however is still not clearly understood, and opposing views have been expressed in the matter.

In general, the two opposing views are very straight forward, either ACD has an effect on the incidence of Wormian bones or it doesn't. Both points of view have been supported by multiple other publications on the subject complicating the matter.

Some of the first studies conducted on the subject date back to the 1970s. The main advocates for a positive relationship between Wormian bones and ACD are Ossenberg (1969) and Gottlieb (1978). On the other corner stand the findings of El-Najjar and Dawson (1977). From that point on, up to this year, a number of studies have been conducted to reinforce or disprove both sides.

An example of such work can be found in Table #4, by (Van Arsdale and Clark 2010:2). However, as has clearly summarized, the studies conducted are far from standardized and perhaps that contributes to the differences in results.

Nevertheless, the most relevant publications since the 1970's are seen in the next table:

Table 4. Relevant studies on Wormian bones and ACD since 1970's. Taken from Van Arsdale and Clark (2010:2)

Study	Geographic region	Deformation type	Results
Antón *et al.* (1992)	Peru (multiple sites, all pre-date European contact)	Fronto-occipital, circumferential	(1) No difference in frequency (presence) of occurrence between deformed and undeformed crania (2) Compared to undeformed crania, F-O deformed crania had a significantly greater number of wormians along the coronal and lambdoidal sutures (3) Compared to circumferentially deformed crania, undeformed crania showed a significantly greater number of wormians along the coronal and lambdoidal sutures
White (1996)	Belize (single site)	Fronto-occipital	Analysis limited to lambdoidal suture, frequency of occurrence only; found deformed crania were significantly more likely to have wormian bones
O'Loughlin (2004)	North & South America (multiple sites)	Fronto-occipital, circumferential and occipital-only	Did not consider frequency of occurrence, but when comparing mean number of ossicles, found a greater number of posteriorly placed wormian bones among the deformed sample
Wilczak & Ousley (2009)	North America (single site)	Occipital-only	No significant difference in presence *or* number of ossicles between deformed and undeformed crania

Negative Relationship:

Besides El Najjar and Dawson in 1977 and their examination of the lamboid suture in ACD skulls from the American Southwest, the most convincing article written from this point of view is that by Ousley and Wilczak in 2009. While analyzing exclusively the effects of tabular ACD on the occipital they found that there was no evidence of a positive relation between the appearance of Wormian ossicles and this type of ACD (Ousley and Wilczak 2009:8).

It is not clear if both types of tabular ACD were represented in the sample, only that the effects of the ACD where visible in lamboidal area and the occipital. Also, only skulls from New Mexico were used, without taking into consideration the recorded percentages of Wormian bones in non-deformed crania.

However, they do present a table for percentages of ossicles in various cranial points to support their opinion.

Table 5. Prevalence of crania with ossicles at craniometric points. Taken from Wilczak and Ousley (2009: 8)

	Undeformed		Deformed	
	n	Percentage	*n*	Percentage
Bregma	64	3.1	45	0.0
Apical	49	44.9	41	29.3
Inca	61	1.6	46	2.2
R. Asterion	57	35.1	40	17.5
L. Asterion	52	34.6	40	27.5

[a] No significant differences at $P \leq 0.05$ for undeformed vs. deformed; *n*, sample size.

Positive relationship:

The counter argument has been argued more after it was first presented by Ossenberg (1970) and Gottlieb (1978).

White (1996), analyzed a sample of Mayan occipitally deformed crania, and found the formation of Wormian bones to be highly dependent on ACD. She added that, in her entire sample, only 12% of deformed crania did not present Wormian bones. However, she also added that it is possible that the style of ACD can provoke a different response in the skull and therefore a different expression of Wormian bones, very linked to the type of pressure applied and its strength. (White 1996: 10).

In 2004 a very interesting study was conducted by O'Laughlin with a large number of skulls from several American collections (from North, Central and South America). In it she examined the effects the three types of ACD in relation with Wormian bones and concluded that there was a strong relationship between them (O'Laughlin 2004:5). Furthermore, after a review of the sites where ossicles appeared she concluded that tabular ACD (fronto-occipital as well as lamboidal) would have the biggest probability of also presenting Wormian bones in the lamboidal suture O'Laughlin 2004:7). This brings up the suggestion that the posteriorly placed sutures of the skull might be the most affected by ACD compared to sites in the anterior aspect of the skull; the effect over Wormian bones in other sites of the skull was also reported: apical bones presented a positive relationship with ACD, while coronal ossicles were more often present in non-deformed skulls O'Laughlin 2004:7).

Del Papa and Perez (2007) conducted a similar study taking into account skulls from various populations across the Americas that presented several types of ACD. They established that, following O'laughlin's proposition, all types of ACD have an influence on the frequency of Wormian bones. This is because of the effects of retarding suture ossification and its stimulation of accidental ossification centres in the fontanels (Del Papa and Perez 2007:7). Also in accordance with O'Laughlin, for these authors, the most likely area of the skull where Wormian bones appear after ACD is the lamboidal suture, all other sites for Wormian bones seem less affected (Del Papa and Perez 2007:8).

In 2010 the latest study on the subject was conducted by Van Arsdale and Clark. Again the results seem to agree with the statement that fronto-occipital ACD has a significant effect on the number of Wormian bones and suture ossicles present on all sites. (Van Arsdale and Clark 2010: 4). However, in contrast with previous studies, the findings of Van Arsdale and Clark suggest that the area most affected by ACD, when compared bystatistical methods to non-deformed crania, was the coronal suture and asterion (Van Arsdale and Clark 2010: 5)

Meeting Halfway:

It is generally accepted that all types of ACD have an effect on the expression of nonmetric traits in some of the analyzed samples, but not all (Del Papa and Perez 2007:10). Taking into account how different the collections where these studies have been conducted are, and the examined impact areas of ACD reported, there is very little that can be said for certain (Wilczak and Ousley 2009:11).

It has also been agreed that the more marked the ACD is, the greater its effects on the overall incidence of nonmetric traits, such as Wormian bones. As Del Papa and Perez put it:

"[...] the presence of nonmetric traits is independent from deformation, while its frequency does covary with it."(Del Papa and Perez 2007: 9)

Nevertheless there is some consistency across the works regarding on the effect of ACD on the lambdoid suture, accepting that some variation in the incidence of Wormian bones can be visible. In that case there is a tendency to report higher numbers of Wormian bones in said suture with fronto-occipital deformation, lower numbers with circumferential deformation and no significant change with occipito-lambdoid deformation, all in comparison with non-deformed skulls. (Wilczak and Ousley 2009:10).

This leads to the agreement that any relationship between Wormian bones, extra suture bones and ACD depends on two factors: how the data collected is classified and the types of ACD observed (Van Arsdale and Clark 2010: 6).

The most important conclusion presented in all of the cited and review studies however is that there is still much to be said in relation to the question of whether environmental influences or genetic predisposition play a bigger role in Wormian bone formation (see O'Laughlin 2004; Van Arsdale and Clark 2010 for examples). It has even been suggested by Vans Arsdale and Clark that crania already disposed to present Wormian bones will, in the event of ACD, have a higher number of ossicles, whilst other skulls less prone to ossicles will simply not have them (Van Arsdale and Clark 2010: 7).

Chapter 3- Pathology and Wormian Bones

Developmental stress, visible in the skull can be produced by disease as much as by external or environmental pressures. There are a number of pathologies that cause Wormian Bones as a consequence of the strains put to the normal ossification process (see Wolpowitz and Matisonn 1974).

In this chapter only those diseases that can be found and identified in archaeological populations by examination of the skeletal remains have been taken into account. Vitamin deficiency related diseases were also noted, regarding their impact on cranial development at the early stages of growth and their relation with Wormian Bones.

The term "Significant number of Wormian bones" SNWB) has been used in medical and anthropological literature to identify those skulls that present 10 or more Wormian bones (Cremin *et al*. 1982 in Semler *et al*. 2009:2; Sanchez-Lara *et al.* 2007). SNWB have been found in relation to hypothyroidism, osteogenesis imperfecta, cleidocranial dysplasia, as well as craniosynostoses (Sanchez-Lara *et al*. 2007).

<u>Craniosynostosis:</u>

Craniosynostosis is a congenital defect that involves an abnormal closure of the sutures of the skull. As a "present at birth" defect the suture closure starts in the womb but it may continue into later periods of the infant's life.

The cause of craniosynostosis is unknown. The London Dysmorphology Database presented a list of 169 monogenic[1] syndromes that can present craniosynostosis. The most popularly associated genetic disorders with craniosynostosis are Crouzon, Apert, Carpenter, Chotzen, and Pfeiffer syndromes. These disorders are often accompanied by seizures, diminished intellectual capacity, and blindness (Cohen 2000 in Oostra *et al*. 2005: 8).

[1] A monogenic syndrome is a genetic disorder controlled by a single pair of genes that follows a Mendelian hereditary pattern.

However, the majority of reported cases of craniosynostosis take place in families with no history of the defect. This is called Secondary Craniosynostosis which refers to conditions that will cause the defect because of suture tissue abnormalities. Metabolic disorders such as hyperthyroidism, metabolic storage diseases, anaemic disorders, and rickets are counted as related to secondary craniosynostosis (Burrows *et al*. 1997:3; Cohen 2000 in Oostra *et al*. 2005: 8).

Craniosynostosis can be either syndromic (part of a number of defects present in an individual) or non-syndromic (isolated condition). The first can be caused by one of four genetic mutations: FGFR1, FGFR2 and FGFR3 and TWIST related to cell growth and therefore bone growth/ formation; the second may be caused by external pressures such as the baby adopting an unusual position in the womb.

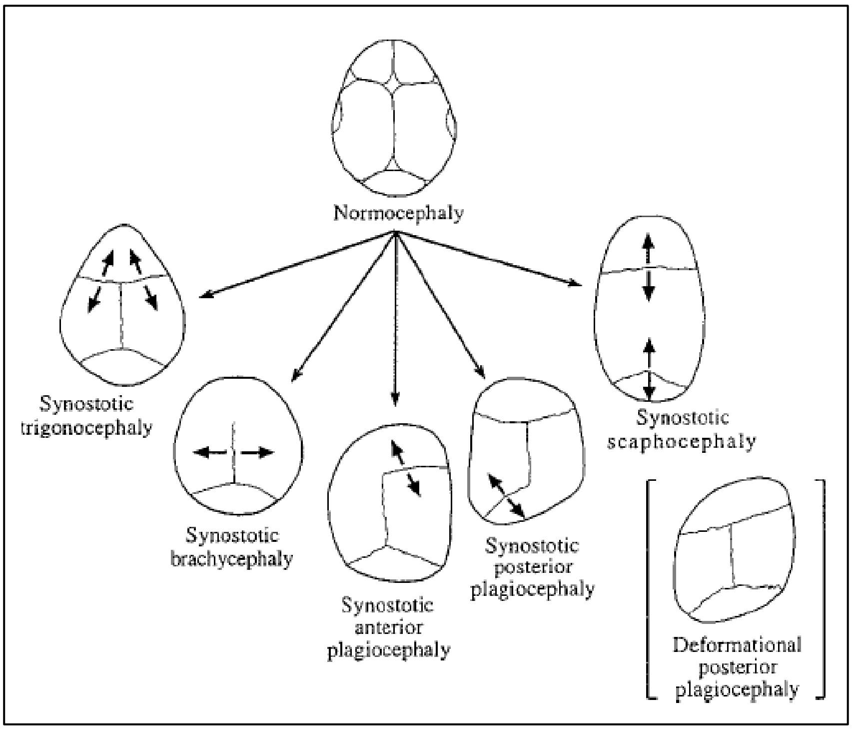


Figure 8.Craniosynostosis types and suture changes. As presented by Cohen and Maclean (2000) in Oostra *et al.* 2005:8)

Though craniosynostosis is not an extremely rare condition it is not common. According to Cohen its frequency is about 3-5 per 10,000 people, seen more in male infants than in female infants. (Cohen 2000 in Oostra *et al*. 2005:8).

It can occur in one or more of the sutures of the skull (Cohen 1986, 1993 in Burrows *et al*. 1997:3) Depending in which of the sutures are involved, the order in which they fuse (synostose) and the time at which the do, the skull will then adopt a distinctive shape. The earlier it occurs, the more dramatic its effects on the later cranial growth (Cohen 2005:4).

Figure 9. Skull showing craniosynostosis. a) lateral view; b) inferior view; c) posterior view; d) superior view. Photos taken by the author, Haslar collection, individual HAS08- B106.

Since craniosynostosis involves abnormal variations of sutural growth, it necessarily entails variation in sutural patterns, which in turn leads to Wormian bone formation. Lambdoidal ossicles are the most noticed Wormian bones in craniosynostosis, the earlier study conducted by Tubbs *et al*. in 2003 (Tubbs *et al*. 2003 in Wu *et al*. 2010: 7). But depending on the synostosed sutures other sites might be favoured for their formation. Regarding the interparietal bone for example, Wu *et al*. 2010 note that its presence increases in relation with coronal and metopic synostosis, but not sagittal synostosis (Wu *et al*. 2010: 7).

Osteogenesis Imperfecta (Brittle Bone Disease)

Osteogenesis Imperfecta (OI) is a genetic disorder where the bone structure has an unusual deficiency of collagen, either because the existing collagen is of poor quality, or because there is not enough of the protein to support the mineral structure of bone (Rauch and Glorieux 2004 in Semler *et al*. 2009:1). As a result bones become very weak and fragile, are susceptible to fractures and difficult to heal (prone to mal-union ad repeated fractures in the same place).

There are different degrees of manifestation of OI, ranging from lethal to nearly asymptomatic (Semler *et al*. 2009:1).

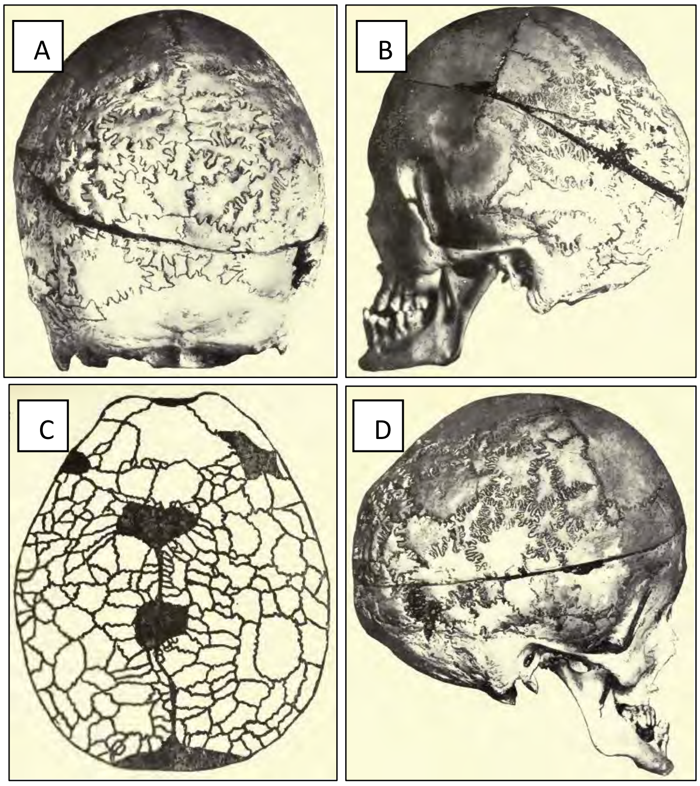


Figure 10. Skull presenting O.I and Wormian bones. Taken from Parker (1905) a) posterior view (page 61); b) lateral view (page 57); c) skull drawing of individual with osteogenesis imperfecta (page 43); d) lateral view (page 59).

The majority of OI cases are related to the mutation of genes COL1A1 or COL1A2, which are responsible for collage formation, and they have been defined clinically from Type I to IV. The first Type presents little to no deformities and normal stature; Type II OI is lethal in perinatal period; Type III OI is very severe and leads to extreme short stature (Rauch and Glorieux 2004 in Semler 2009:1). Type IV of OI has been expanded to include up to a Type VI of the disorder, ranging from mild collagen deficiency to "temporary OI", a form of the disorder very little known and under current study (Miller 2003)

Figure 11. Skull presenting possible O.I. Showing multiple Wormian bones or SNWB. Photos taken by the author, courtesy of S.H.A.R.P project, individual S0212. a) lateral view; b) superior view; c) posterior view.

The frequency of OI has not been calculated, but in its more complicated Types (I, II and III) it is very rare. Types IV to VI as well as Temporary OI are more common but rarely diagnosed (as presented in the Osteogenesis Imperfecta Foundation webpage (2011).

The presence of a SNWB in OI is a well-documented fact. A more relevant study of their presence in OI has been conducted through the examination of radiographic material from the disease by Semler *et al.* in 2009, where it was recorded that SNWB were present in all Types of OI and, furthermore, that 58% of cases of OI Types I to IV had SNWB (Semler *et al.* 2009:1). According to Semler, the more severe the manifestation of OI the higher the number of Wormian bones. These finds agree with those presented by Kovero *et al.* in 2006 where SNWB were recorded in 63% of adult OI patients (Kovero *et al.* 2006 in Semler *et al.* 2009:5).

Nutritional- Vitamin deficiency disorders:

There are three closely related nutritional deficiency disorders that have been reported in archaeology, ethnography and history: rickets (Ortner and Mays 1998), scurvy (Ortner and Ericksen 1997) and iron deficiency anaemia (Von Endst and Ortner 1982, Stuart Macadam 1987, 1989). Given their shared malnutrition aetiology, two or even three of these diseases may be present in the same group of people or even in one patient at the same time (Ortner *et al*. 1999:2).

Rickets

In the category of vitamin deficiency disorders the most common is probably Rickets (Kumaravel 2003). Caused by insufficiency of vitamin D, calcium, or phosphate, this disorder will cause bone to weaken and soften. It primarily affects the process of cartilage transformation into bone (endochondral ossification), and causes the body to fail to mineralise the newly created bone tissue (osteoid) that allows bone to grow and transform (Wharton and Bishop 2003:1)

Rickets can be a consequence of disorders of the gut, pancreas, liver, kidney or metabolism but it is most commonly associated with nutrient deficiency (Wharton and Bishop 2003:1). It has three subtypes: hypophosphatemia rickets; Vitamin-D-resistant rickets, renal osteodystrophy or kidney rickets; and the more well-known nutritional rickets or osteomalacia caused by dietary deficiency of vitamin D, calcium, or phosphate.

Out of these three types of the disorder, only kidney rickets has been recognized as hereditary and therefore classed as a genetic disorder, though it may also appear as a consequence of other renal diseases.

As in any developmental disorder, the expression of rickets is closely associated with growth, body composition and biological changes (hormone production for example). In fact it can only occur before the fusing of the epiphyses (Wharton and Bishop 2003:1).

Severe cases of Rickets will lead to skeletal deformities such as an asymmetrical skull, bowed legs, pelvic deformities, rib malformations, bumps in the ribcage known as a “rachitic rosary” (this description can be found in NHS webpage

2011). Also a protruding sternum or “pigeon chest” are common, as are spine deformities like scoliosis and kyphosis.

The severity of the disease is determined by the age of onset, the degree of the vitamin D deficiency, the time of year when the problem began (as vitamin D absorption is highly determined by sun exposure) and any treatment that has been given to the patient (Ortner and Mays 1998:7)

As with most nutritional disorders, OI can be corrected by replacing vitamin D and lost minerals in the body, however if it is not corrected while child growth is still going, the deformities and short stature characteristic of the disease will be permanent. When corrected some skeletal deformities will disappear in time or improve.

Rickets is a well-known condition, included in some pre-modern medical texts and documents. It was a very common disorder in the 1640s across England; it has also been documented extensively for other historical populations around the world (Kumaravel 2003). However, it is hardly mentioned in paleopathology texts and there is little evidence of its presence in archaeological populations (Ortner and Mays 1998:1).

Scurvy

Resulting from the deficiency of Vitamin C, which is essential for synthesizing collagen, scurvy is present in infants as a symptom of malnutrition and thus not uncommon in developing nations. Scurvy has also been called Barlow’s disease, Moeller’s disease and Cheadle’s disease (Carpenter 1988)

There are many enzymes related to the production and absorption of collagen in the body. When one of these enzymes fails then a defective chain of production of collagen will result. As a consequence the body will be slower to heal wounds, and bone formation and healing will be severely impaired. A secondary effect is the formation of weak capillaries; this will result in abnormal bleeding (Carpenter 1988)

Very common in sailors given their reduced diet, scurvy played an important role during the 15th century when European powers where embarking in long distance journeys for land discovery, and again during the 20th century through World War I, (Holst and Frölich 1907)

Scurvy has also been reported in archaeological samples (Maat 1982, Carli-Thiele 1996 in Ortner *et al.* 1999:8). Although it is believed it has been underrepresented in the archaeological record, an examination of archaeological collections from North America in the Smithsonian Institution led Ortner *et al.* (2001). to establish that the prevalence of scurvy in sub-adult populations ranges from 0% in the Plains to 38% in Florida. The reasons noted for this variation are linked to seasonal variation of food, cultural patterns of storage and the importance of corn as a stable crop to the diet (Ortner *et al*. 2001: 1)

<u>Iron deficiency anaemia, Porotic Hyperostosis and Cribra Orbitalia</u>

Porotic Hyperostosis (P.H) and Cribra Orbitalia (C.O.) are pathological lesions commonly reported in skeletal collections from archaeological and historical sites. Although they have been linked with iron deficiency anemia since the 1950s, and therefore related to other conditions conducive to iron deficiency such as intestinal parasites and iron malabsortion disorders, there has been a lot of recent debate on their aetiology (Walker *et al*. 2009:1).

This first link to anaemia was established from evidence of the lesions of P.H and C.O in archaeological collections where anaemia was endemic. However, Walker *et al*. 2009 argued that anaemia does not produce the bone marrow hypertrophy that will lead to the pathological lesions related to P.H and C.O, but will instead create the opposite effect on bone (Walker *et al*. 2009: 11).

<u>Cribra Orbitalia.-</u>

The condition is described as osteoporotic lesions inside the orbits, causing erosion and destruction of cortical bone. Caused by a hypertrophy and hypoplasia of the spongy tissue, the affected area will resemble a “bee hive”, with expansion of the cortical bone as well. The erosion in the orbits can be easily identified from postmortem erosion and other pathological conditions because of this (see figure below from Walker *et al*. 2009:2).

Figure 12. Cribra Orbitalia. Taken from Walker *et al*. (2009:2)

The presence of Cribra Orbitalia is indicative of a chronic health problem, though not necessarily anaemia (Warpler *et al*. 2004:6). As can be seen in the graph below by Warpler *et al.* (2004:3), there are several pathologies that have been reported to present C.O lesions.

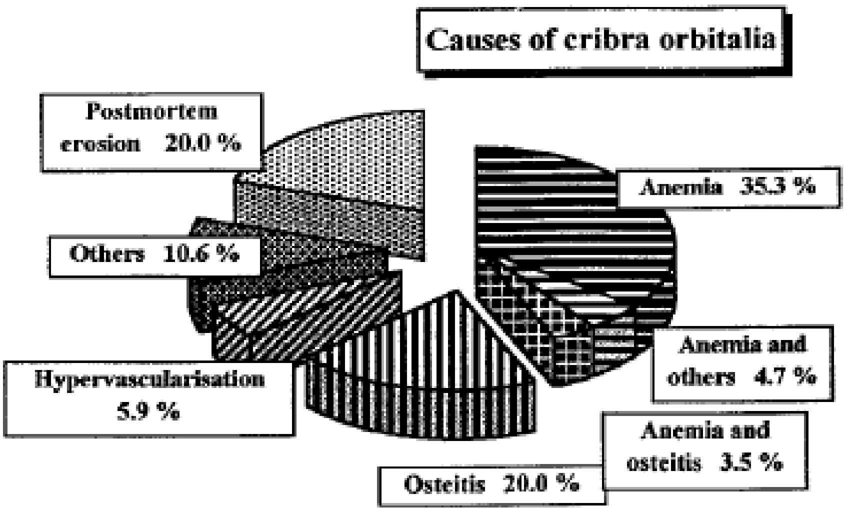


Figure 13. Graph of causesfor Cribra orbitalia. Taken from Warpler *et al*. (2004:3)

Porotic hyperostosis.-

Described as porous and pitting lesions in the external surface of the cranial vault, porotic hyperostosis is caused, like Cribra Orbitalia, by hypertrophy and hypoplasia of the diploe in response to pathological processes (Walker *et al*. 2009).

It affects the anterior portion of the supraorbital plate and the external surfaces of the frontal, parietal and occipital bones (Angel 1966 in Winter 1978). Other bones as the sphenoid, temporal, zigomatics and maxillae are less affected.

Porotic hyperostosis like lesions can be caused by chronic scalp infections, scurvy, hookworm infestations and malaria for example (Ortner 2003; El- Najjar 1975: 1). However its aetiology is linked mostly with nutritional deficiency disorders as iron deficiency anaemia (Walker *et al*. 2009:1).

In its most severe cases it produces not only pitting and porous lesions but foramen like lesions and extreme thickening of the spongy tissue of the skull and loss of the cortical bone, as can be seen in the figure below taken from Walker (Walker *et al*. 2009:2).

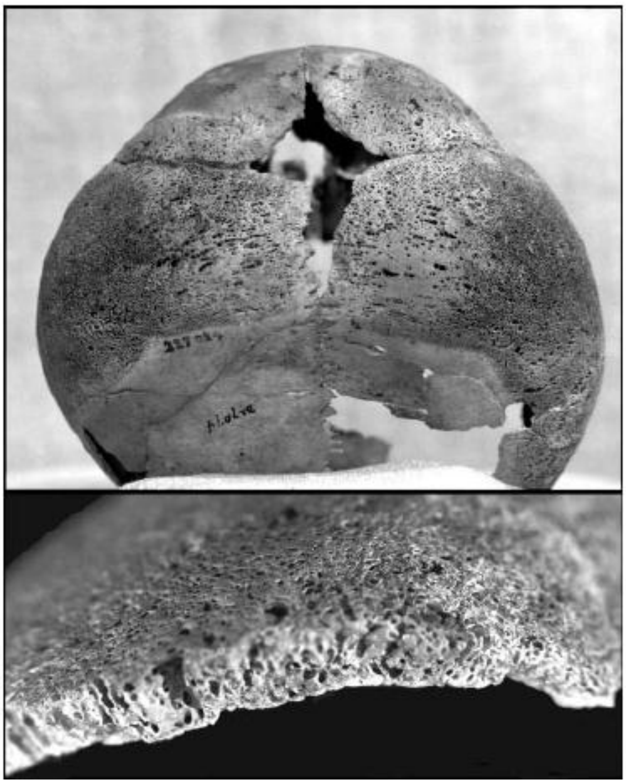


Figure 14. Porotic Hyperostosis. Taken from Walker et al. (2009:2)

All the previously presented pathologies have been found in the collections examined for the purpose of this dissertation. Their relationship with the presence of Wormian bones in those skulls will be explored in the following chapters.

It is important to note however that many of these diseases, although manifested signs in the skull, have been diagnosed in relation to the rest of the body as well as from the skull and are therefore represented in varying degrees of manifestation.

Chapter 4. – Study Populations

As it has been mentioned before, there are three collections that have been analyzed for this dissertation. Each one represents a different ancestry and cultural background. This chapter focuses on the raw data extracted from each of the samples. These data, once it was organized, was the first step towards further statistical analysis to answer the questions posed during the introduction.

A brief background on the origin and composition of the sample is given as to provide the reader with an idea on the reasons, besides availability, for choosing each one of these collections.

<u>Ecuadorian "Sierra Norte" collection</u>

The Ecuadorian "Sierra Norte" collection is part of the Human Remains collection at the Jacinto Jijón y Caamaño Museum located in the campus of the Pontifical Catholic University of Quito (PUCE).

The private collection of Mr Jacinto Jijón y Caamaño (1890- 1950), an Ecuadorian aristocrat, patron of arts and archaeology enthusiast, was converted into a museum after been donated to the PUCE in the 1960s. It holds hundreds of pieces of art, thousands of anthropological and archaeological artefacts and an important osteological collection including funerary bundles and disarticulated remains.

Most of the archaeological artefacts and human remains present in this museum where excavated by Jijón y Caamaño himself during his lifetime, and described in some detail in his books –*Antropología Prehispánica del Ecuador" (*Prehispanic Anthropology of Ecuador), –*Contribución al conocimiento de los Indígenas de Imbabura en la Republica del Ecuador"* (Contribution to the Knowledge of Imbabura Indigenous people from the Ecuadorian Republic) and –*El Ecuador interandino y occidental antes de la conquista castellana"*.

As part of a new inventory of the collection from September 2005 to February 2007 a description and primary analysis of the human remains collection was conducted[2]. Coupled with osteometric measurements and photographic evidence the remains were divided into an Ecuadorian and a Peruvian Human Remains Collections, each with a specific database (physical and later digital).

The Ecuadorian Collection holds 142 skulls kept by Jijón y Caamaño from his multiple excavations around Ecuador. These skulls are part of the general inventory of the museum (2004) and where given a context, according to region province and archaeological site, if possible during the latest inventory in 2005-2007.

With this information it was possible to determine the composition of the collection, in terms of populations represented. Out of the 142 skulls that form the collection 74 had a good enough trail of documents that allowed locating them in a specific archaeological site. Of these 74 skulls, 42 belong to the area known as "Sierra Norte" or Northern Highlands of Ecuador, a well delimited area both archaeologically and geographically.

The sites excavated by Jijón y Caamaño in the Sierra Norte area of Ecuador have all been associated with one specific period in Ecuadorian Archaeology the termed "Integration Period" from 8000-1500 a.C. This period has been cataloged and described extensively for the area both ethno historically and archaeologically (Bray 1992 and 2005, Landazuri 1995, Balanzategui 2007). The archeological sites excavated by Jijón y Caamaño have been traced to two ethnical groups in the area: the Caranquis and the Pastos. A more detailed description of the ethnical and archaeological associations of the collection can be found in Ordoñez (2009).

The Sierra Norte Collection at the Jacinto Jijón y Caamaño Museum is special precisely because of its accurate context and its remarkable state of preservation. For the purposes of this project it also presented a unique opportunity to examine the presence of Artificial Cranial Deformation (ACD) in a specific population at a specific point in time.

The Sierra Norte collection is also a well distributed collection in terms of population age and sex that makes it useful as comparison material. It also has a very low number of possibly genetic disorders and a low incidence of nutritional related

[2] Conducted by the author with help from Miss Ana Maria Guerron and Mr. Mateo Caicedo. More details can be found in Ordonez (2009).

diseases (though within the ranges expected for an American archaeological population).

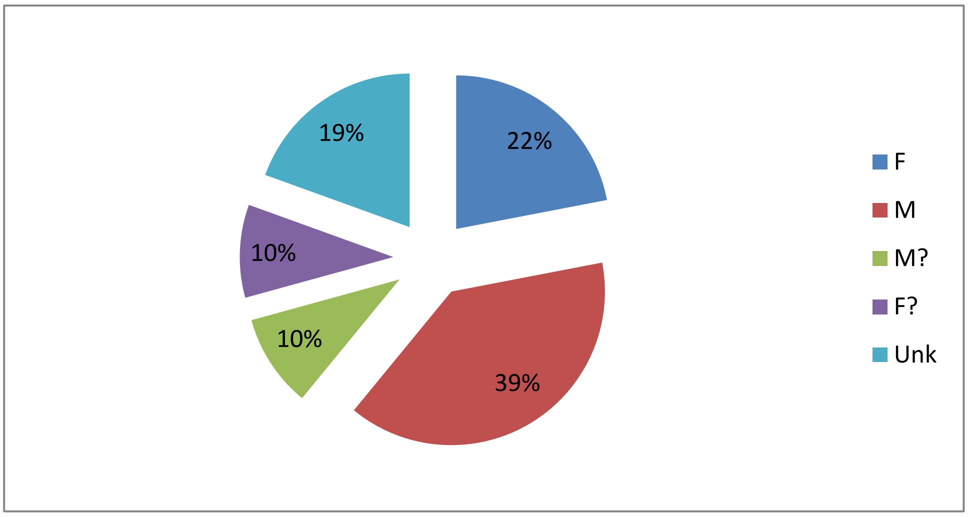


Figure 15. Sex distribution of Sierra Norte collection, in percentage.

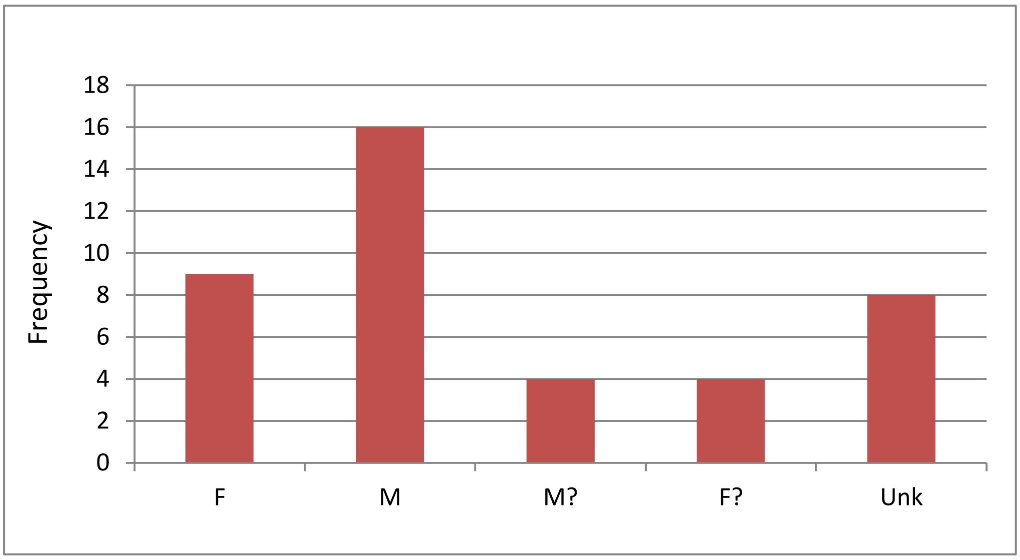


Figure 16. Sex distribution of Sierra Norte collection, in frequencies.

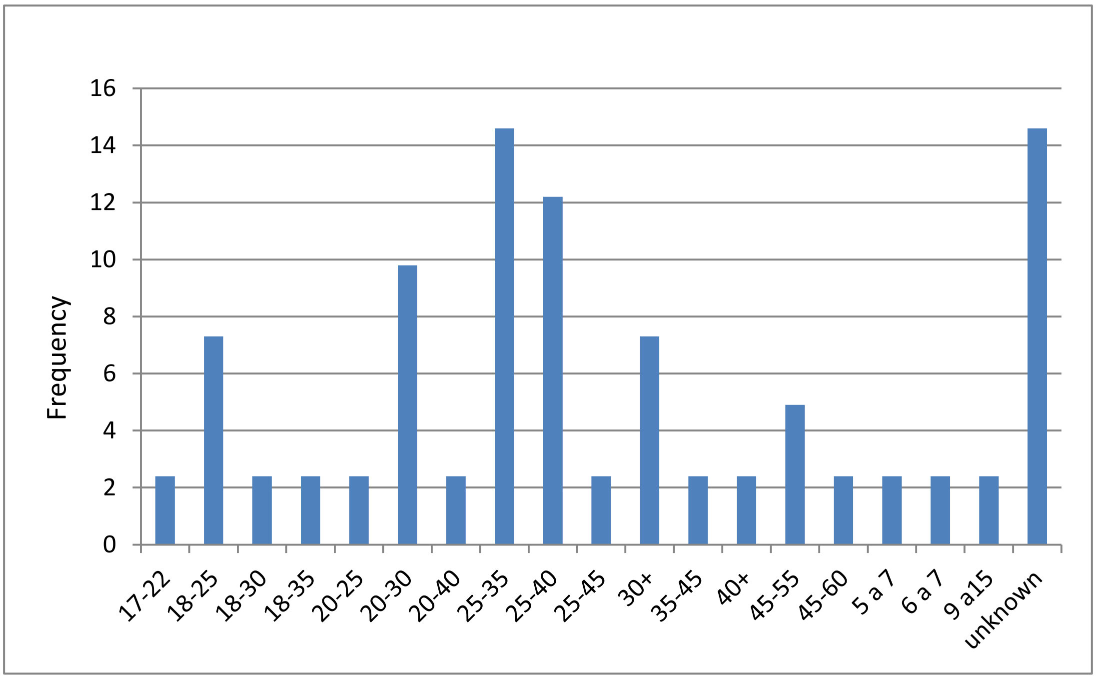


Figure 17. Age distribution of Sierra Norte collection, in frequencies.

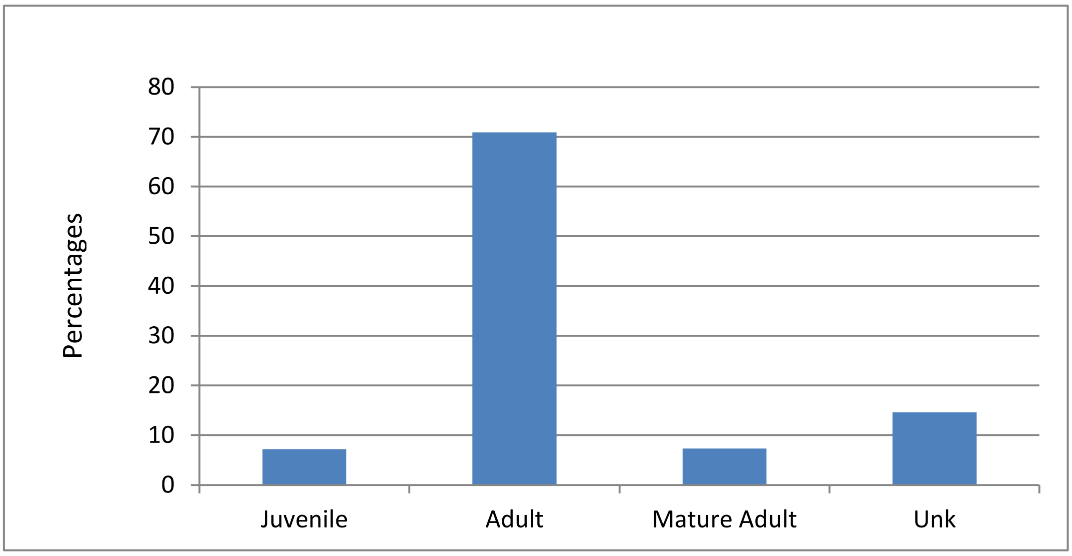


Figure 18. Age distribution of Sierra Norte collection, in percentages.

Table 6. Artificial Cranial Deformation. Descriptive statistics.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	19	46,3	46,3	46,3
	yes	22	53,7	53,7	100,0
	Total	41	100,0	100,0	

Table 7. Wormian bone/ Inca bone. Descriptive statistics.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	17	41,5	41,5	41,5
	yes	24	58,5	58,5	100,0
	Total	41	100,0	100,0	

<u>Haslar Collection</u>

Briefly hosted at the Human Remains Laboratories of Cranfield University-Shrivenham, the Haslar Collection is formed by the human remains excavated by a team of archaeologists from 2007 until 2010 at the Royal Hospital Haslar in Gosport.

The Hampshire based Hospital ceased to function in 2010 and as part of the Land Quality Assessment conducted by the Ministry of Defence (MOD) the onsite burial grounds had to excavated.

Directed by the Centre for Archaeological and Forensic Analysis (CAFA) the project with its consecutive field seasons focused on a historical background research and human remains examination.

The Royal Hospital Haslar opened in 1753 and from that point on those people who died under the care of the Hospital where buried in the south-west area of the hospital building in a large un-consecrated burial ground (Tait 1906, Lloyd and Coultner 1963). This continued until 1826 when a review of burial practice took place.

There are a number of well documented reports on the use of the site; however given its continuous use and onsite reforms, including the removal of burial markers between the nineteenth and twentieth centuries, the precise number of burials and their origins was unknown.

The majority of patients at Haslar where seamen and marines from the Royal Navy therefore, it was assumed that most of the remains that would be uncovered came from a seafaring background. Some of the dead form the sinking of HMS Royal George of Spitthead (1782) and those wounded from battles such as Trafalgar (1805) were also buried in the site (Shortland *et al*. 2008)

In total the sample held until May 2011 at Cranfield University contained the remains of 47 individuals, not all complete. Of this 47 the great majority were sailors or marines as expected. They represent a group of people from different populations in England, Scotland and Wales as well as some foreigners, from diverse socio-economic backgrounds and occupations joint together by their service at sea with the Royal Navy. After the craniometrics and physical examination of the remains however only 44 individuals could be taken into consideration for this study. Some had been renamed in the second inventory process; other simply did not have a skull that could be examined.

This collection is very interesting since it presents a section of a particular population, though mostly male, that has set of very specific diseases and diet linked to their occupation. It is known for example that most of the sailors that made the Royal Navy were part of the working class, (Boston *et al*. 2008), this is made evident by the large amount of nutritional pathologies identified in the remains and is a fact of great importance for our study case as we can have a population with well-known pathologies for comparison.

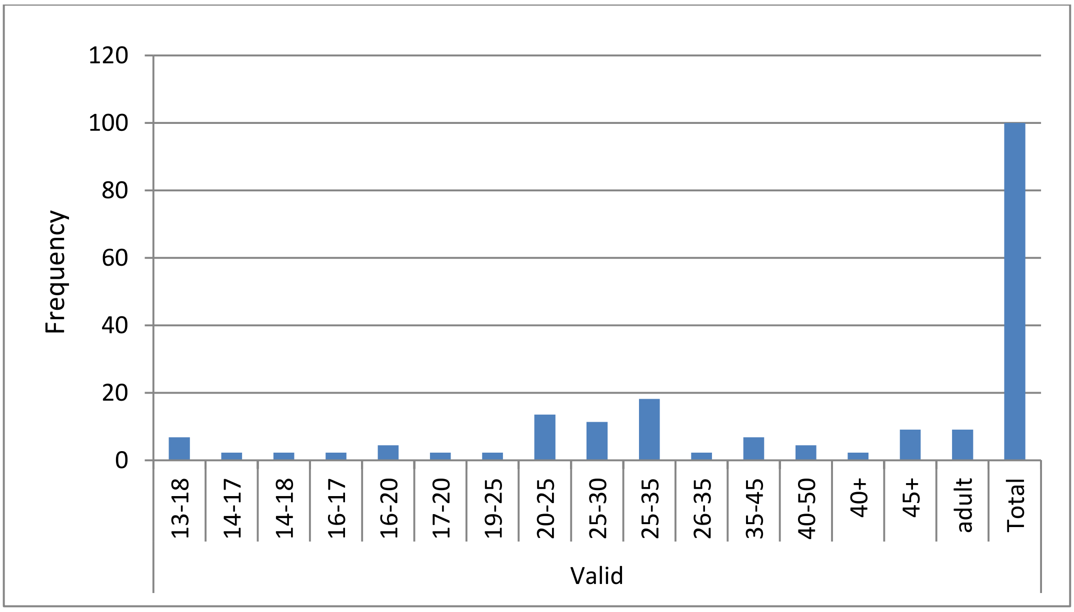


Figure 19. Age distribution of Haslar collection, in frequencies.

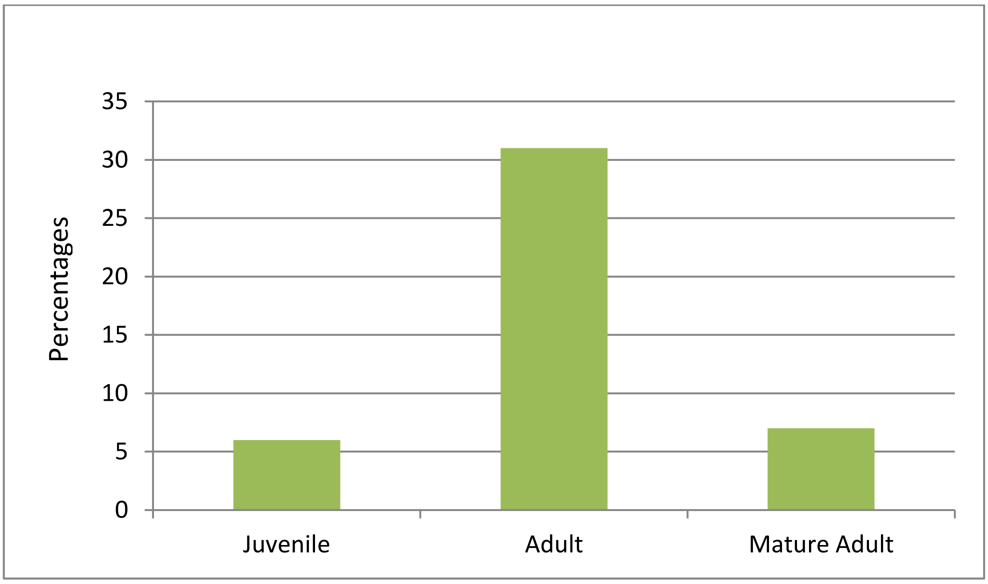


Figure 20. Age distribution for Haslar collection, in percentages.

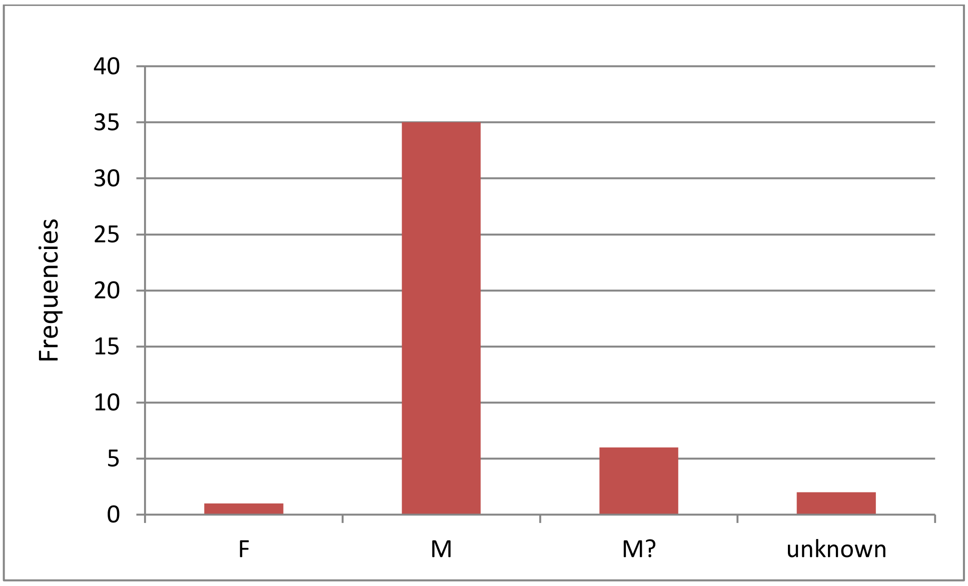


Figure 21. Sex distribution for Haslar collection, in frequencies.

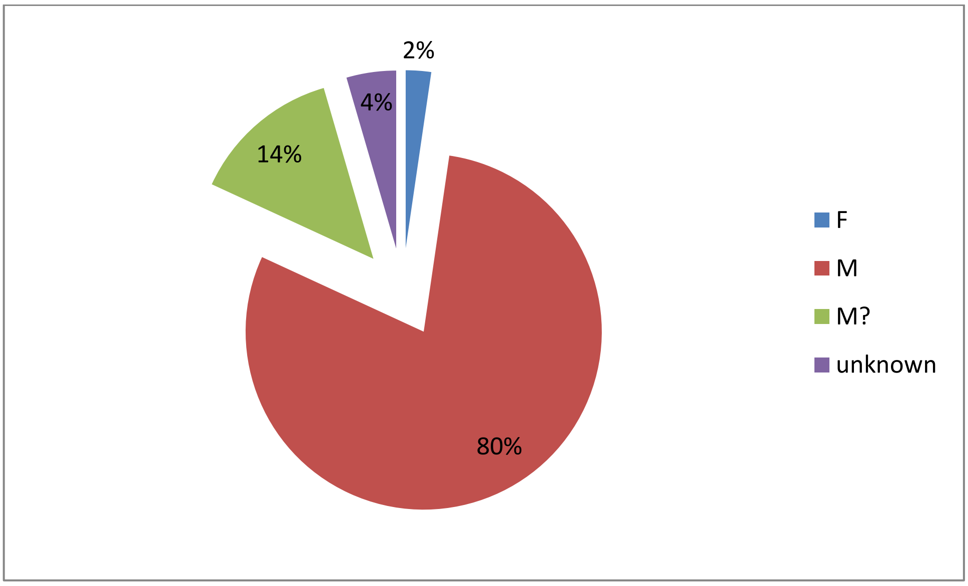


Figure 22. Sex distribution for Haslar collection, in percentages.

Table 8. Wormian bone/ Inca bone. Descriptive statistics.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	8	18,2	18,2	18,2
	unobservable	16	36,4	36,4	54,5
	yes	20	45,5	45,5	100,0
	Total	44	100,0	100,0	

SHARP Collection

The Sedgeford Historical and Archaeological Research project has been running since 1996 as a multidisciplinary research project in the area of Sedgeford, north-west of Norfolk.

The project is run by a team of directors, supervisors and committee members in an effort to have a project run by what has been termed "democratic archaeology". The joint effort of survey, open area excavation and historical research is focused on understanding the range of human settlement and land use in the sites.

The excavation and interpretation of the remains in the area called Boneyard was the main focus of the excavations conducted from 1996 to 2007.

The human remains recovered form that area belongs to an Anglo-Saxon cemetery dated for c.750-c.950 AD. In total 297 burials have been excavated in the seasons that the project has focused in the Boneyard:

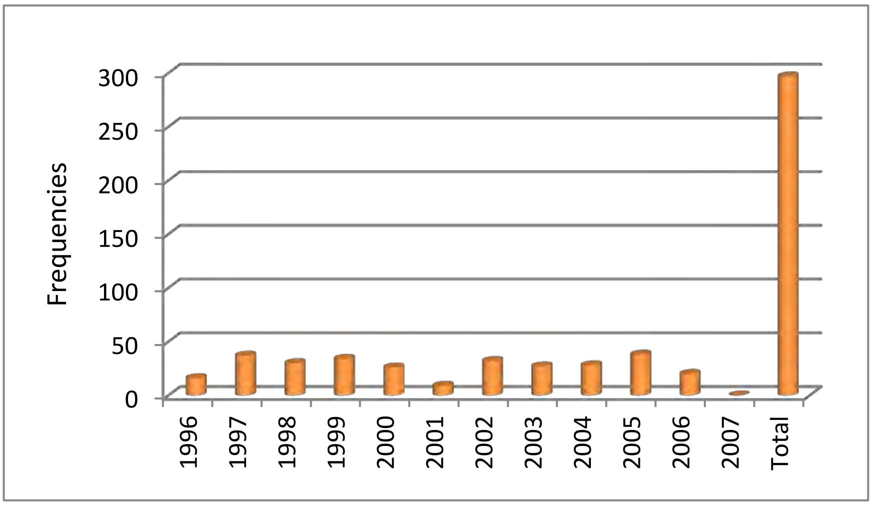


Figure 23. Burials excavated by SHARP according to year. As described in the project website (http://ccgi.sedgeford.plus.com/blog/?page_id=935)

Working with the existing "Catalogue of Burials as at 04 April 2011" and the Human Remains Digital Database, made available by the SHARP team it was possible to narrow down the total of 297 burials to an initial inventory of 198 individuals that had a skull.

Of those 198 a new inventory was made ranking the state of preservation of the skulls from bad, very fragmented, fragmented to good. Of those all the skulls classed into the bad and very fragmented ranks where then removed from the sample, this considered (as well as some recording errors and omissions from the original databases), the total of skulls to be used in this project was of 120.

The burials belong to three areas within the previously mentioned Boneyard, and this original area distribution was kept to be taken into account when selecting data for statistical purposes.

The total numbers of individuals in each one of the three groups and the areas they correspond with are detailed next:

- Group 1 = Boneyard (areas 1 & 4), total of 79 individuals.
- Group 2 = Reed Dam (area 2 and northern extent area 4), total of 35 individuals.
- Group 3 = Boneyard new trench, total of 7 individuals.

The advantages of having a collection with such a great amount of data available is obvious, it not only provides a very well distributed population in terms of age and sex ranges, but it also allows for a good representation of pathologies.

This been said however it is important to note that for an archaeological population the SHARP individuals have are, overall, a healthy cohort, with no dominant genetic diseases visible and no extreme malnutrition.

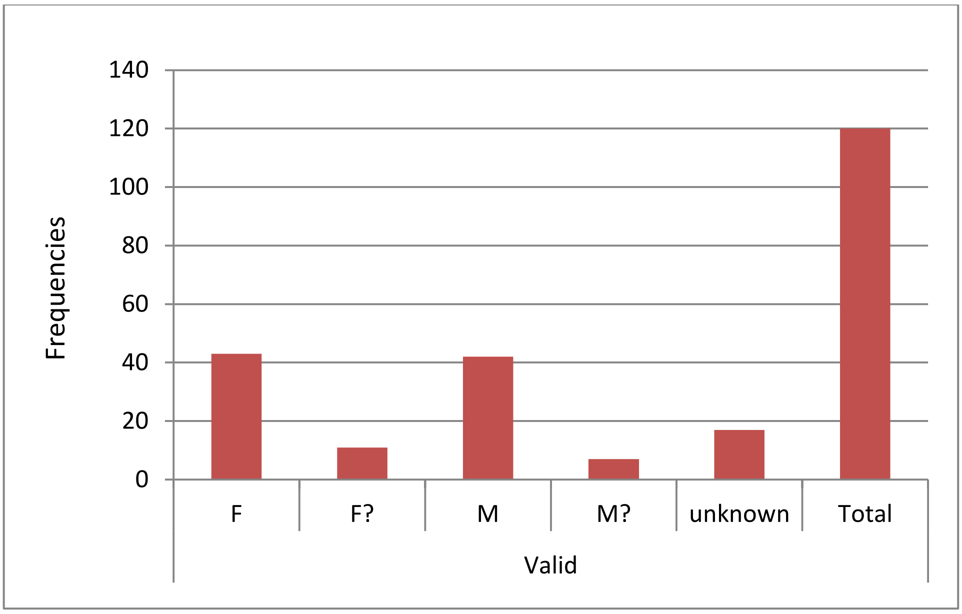


Figure 24. Sex distribution for SHARP collection, in frequencies.

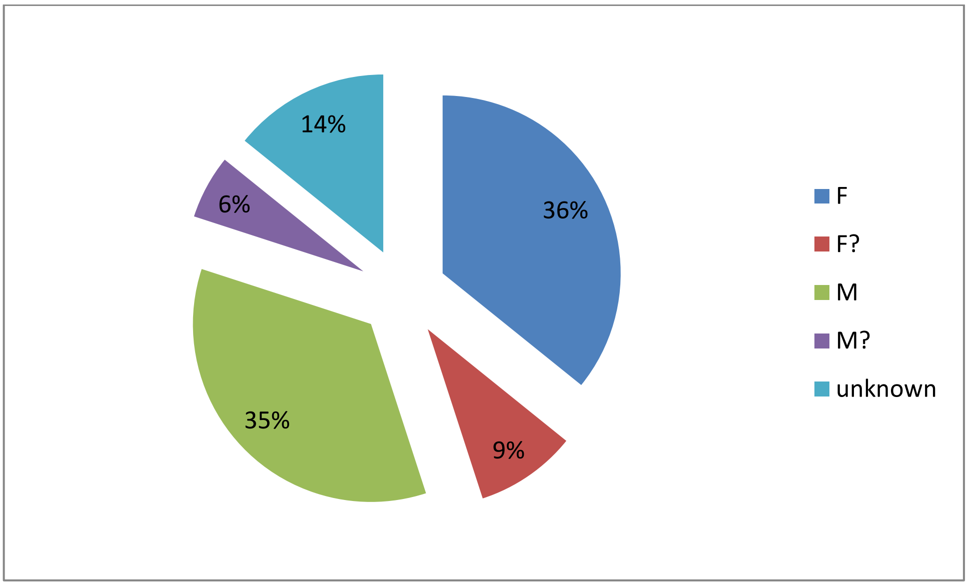


Figure 25. Sex distribution for SHARP collection, in percentages.

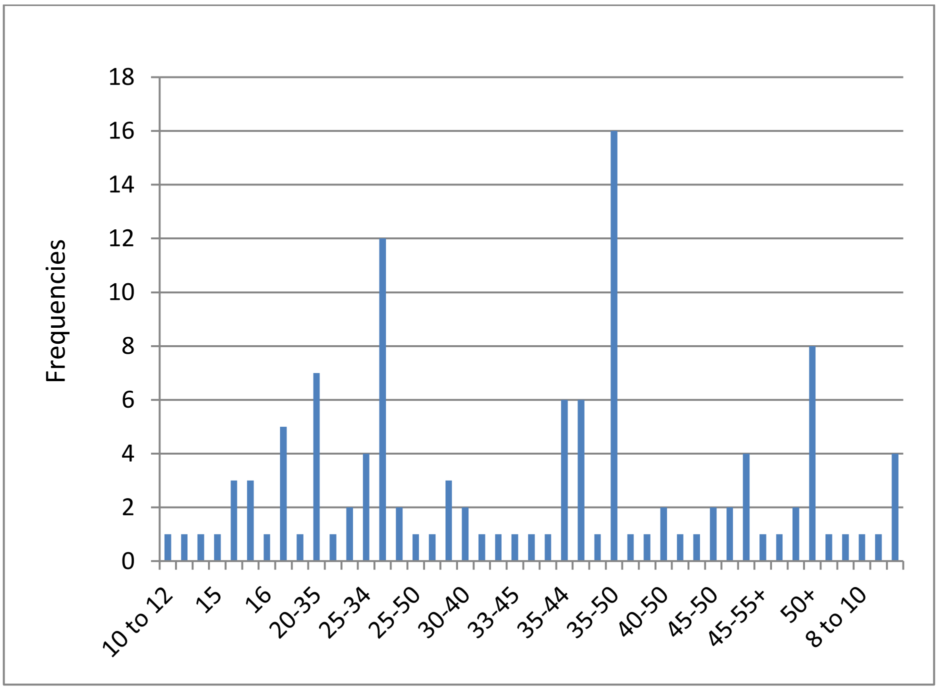


Figure 26. Age distribution for SHARP collection, in frequencies.

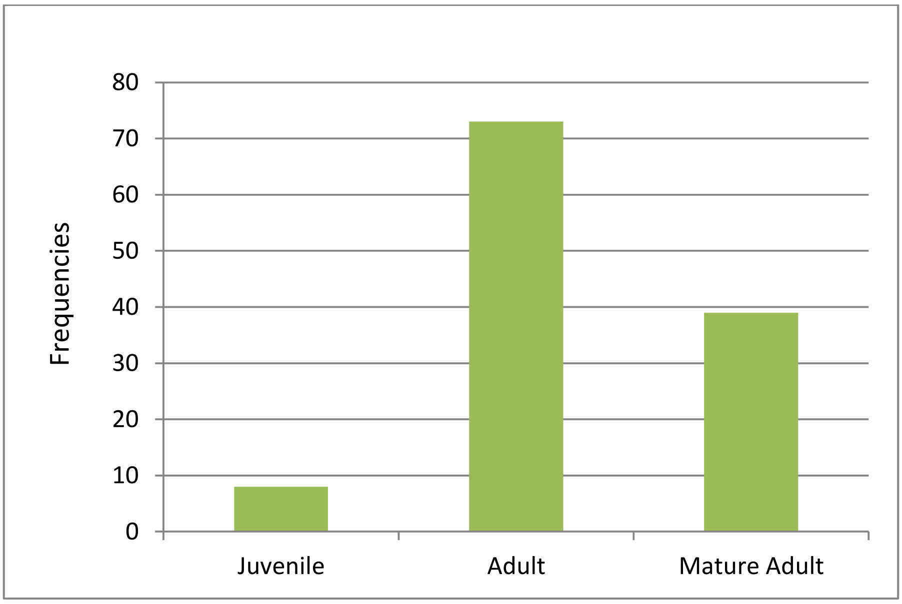


Figure 27. Age distribution for SHARP collection, in percentages.

Table 9. Wormian bone/ Inca bone. Descriptive statistics.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	N	62	51,7	51,7	51,7
	Y	58	48,3	48,3	100,0
	Total	120	100,0	100,0	

Chapter 5.- Materials and Methods

Materials:

The tools used for all craniometrics measurements were:

- Spreading calliper: "Draper Expert", D61/PRO, 150mm, outside spring calliper with quick release feature (fabricated in 2001). Stock Nº 64746. Size 118x287mm, depth 18mm, weight 120g.
- Spreading calliper: "Yankee Calliper", 79A, 12. EDP 50372.
- Sliding calliper: "Moore & Wright", polycarbonate calliper. Range 0-6'' / 0-150mm. 4 way measurement. Resolution 0.0005''/0.01mm. 110-15DPC). Accuracy ±0.0008''/0.20mm. Repeatability 0.001''/0.01mm. Measuring system: capacitive. Display: LCD (10.0m high).
- Camera details:

Canon EOS 450D (DS126181 DC 8.1v)
Nº 2280570052
Canon battery charger LC-E5E
USB/Camera cable for digital download

- WH Smith 30cm left handed ruler.
- Scale: TETRA SOC 01277- 626100
- Scale: The Human Bone Manual photo target (White 2001)

Statistical software:

- Microsoft office Excel 2010
- IBM SPSS Statistics 19

Methods and techniques

The three collections used in the study were selected because they:

- Come from a known context, site or project.

- Are associated with a specific time period, historical or archaeological.

In particular:

- One of them represents a specific population with known pathology incidence within the normal/expected ranges for the time period and area they come from).
- One collection represents a specific population with known high pathology incidences.
- One collection represents a specific population with known pathology incidences within the normal/expected ranges, and a reported presence of ACD.

The selected options were: Haslar collection, S.H.A.R.P collection and JJC Museum Sierra Norte collection. Details on each collection and the obtained data are exposed in the chapter titled “Sample Populations”.

For the case of the JJC Museum Sierra Norte collection all data was retrieved from a previously existing database, composed between 2005 and 2007 and used by the author in Ordoñez 2009. The database 20 columns can be seen in table 12.

The tools and techniques used to collect this data are reported in Ordoñez 2009. For this research study further data was included in the original database for Wormian bones/ Inca bone presence. This was done by cross-referencing the Sierra Norte collection with the general Human Remains database that belongs to the Museum JJC-PUCE (Ordoñez 2009).

For the HASLAR and S.H.A.R.P collections a recording form was created[3]. This recording form has 4 sub-divisions:

Part 1: 24 cranial measurements were recorded, as presented by Buikstra and Ubelaker (1994). The measurement is taken three times and then averaged. The values are recorded in the four column space.

Part 2: Recording of cranial suture complexity, including 10 different sutural bones and their possible positions/site. This is done by simple observation, recording

[3] The original forms are included as parts of the annex section.

number and site of the Wormian bones but not their size, unless noted on the observations at the end of the form.

Part 3: A descriptive recording chart for porotic hyperostosis that includes degree, location and activity of the disease, as well as a key to understand the form, (also taken from the recommendations for pathology recording available in Buikstra and Ubelaker (1994).

Part 4: A space for further observations and photography numbers.

In the case of the Haslar collection all individuals with skulls were measured and registered. The data collected in the physical forms was then transformed into a digital database containing the following fields:

Table 10. Variables recorded in paper forms and digital databases for the three human remains collections used.

	COLLECTION		
VARIABLE	HASLAR	SHARP	Sierra Norte
Code	x	x	x
Origin	x	x	x
Jijón Number			x
Type of Item			x
Province			x
County			x
Borough			x
Registered by			x
Original Site			x
State of Preservation	x	x	x
Sex	x	x	x
Age	x	x	x
Dental Development	x	x	x
Maximum Cranial Length	x	x	x
Maximum Cranial Breadth	x	x	x
Byzigomatic Diameter	x	x	x
Basio-Bregma Height	x	x	x
Cranial Base length	x	x	x
Cranial Deformation			x
Type of ACD			x
Basio Prosthion Length	x	x	
Maxillo-Alveolar Breadth	x	x	
Maxillo-Alveolar Length	x	x	
Biauricular Breadth	x	x	
Upper Facial Breadth	x	x	
Minimum Frontal Breadth	x	x	

Upper Facial Breadth	x	x	
Nasal Height	x	x	
Nasal Breadth	x	x	
Orbital Breadth	x	x	
Orbital Height	x	x	
Biorbital Breadth	x	x	
Interorbital Breadth	x	x	
Frontal Chord	x	x	
Parietal Chord	x	x	
Occipital Chord	x	x	
Foramen Magnum length	x	x	
Foramen Magnum Breadth	x	x	
Mastoid Length	x	x	
Wormian Bones/Inca Bone	x	x	x
Nº of Wormian Bones	x	x	
Observations	x	x	x
Pathology	x	x	x
Photographs	x	x	x

In the case of the S.H.A.R.P collection 24 individuals (20% of the total population of the collection) were selected to be measured and photographed. Since the S.H.A.R.P digital database contains the details for the 120 individuals and given the time constraints for the dissertation it was decided that a significant sample was to be measured to be certain that the recording was equivalent and could be used without increasing the error significantly.

Of these 24 skulls 12 presented Wormian bones (according to the database) and 12 do not. The skulls were selected by stratified sampling from the three groups of human remains (separated in the SHARP inventory according to location within the sites), as follows:

Group 1: 12 skulls (6 with Wormian Bones, 6 without)

Group 2: 8 skulls (4 with Wormian bones, 4 without)

Group 3: 4 skulls (2 with Wormian bones, 2 without)

The data collected was introduced into a digital database that has the same columns and distribution as those detailed for the Haslar collection and can be seen in table 6 and in the annex section.

Another database was created for the total of 120 skulls of the SHARP collection. This includes the following variables:

1) Code
2) Sex
3) Age
4) State of preservation
5) Wormian bones/ Inca bone
6) Wormian bone site
7) Observations
8) Pathology

The same database was separated into a specific sheet for each group as to show variability between site areas and can be seen as part of the annex section.

With the data in order the next step was to interpret the relationships between the variables. For that purpose three types of tests were conducted:

- Simple percentage and presence-absence graphs.
- Correlation coefficient calculations between ancestry, pathology and Wormian bones.
- Kruskal-Wallis non-parametric data test to see differences between the independent groups (pathology, ACD and ancestry) in relation with Wormian bones.

The tests were selected according to the data distribution.

In the case of correlations two correlation coefficient calculations were used. Spearman's coefficient and Kendall's tau coefficient, both standard for non-parametric data.

The Kruskal-Wallis test was selected as a variant of the Mann-Whitney *U* test to deal with more than two variables that need to be examined for hypothesis resolution. These tests are equivalent to *t*-test and ANOVA tests, respectively, for parametric data.

The first statistical test conducted on the data was the calculation of correlation coefficients. In order to conduct the test in SPSS, the nominal variables had to be changed into numeric values.

The change was conducted as follows:

ACD: yes (1); no (2)

Pathology: PG (1); PN (2); PG+PN (3); None (4)

Ancestry: SHARP (1); Haslar (2); Sierra Norte (3)

Wormian bones: yes (1); no (2); unobservable (3)

Once this was done two correlation coefficients were calculated, Kendall's tau and Spearman's, and their results shown in the results section.

Error Calculation

Various craniometrics measurements were taken to see if their results would be informative in our analysis, however only four were used find out if there is a visible relation between cranial shape and Wormian bone presence. For further work however other measurements might be important and in that interest they have been kept.

In order to establish the intra-observer error and be able to ascertain through it that the measurements and observations made by the author were correct (in terms of repeatability) a descriptive statistics table was created in SPSS using the Haslar collection data. Those fields unavailable were not taken into account by the program for the statistics.

As a rule, any Standard Deviation lower than 1 is considered adequate for anthropometric measurements. There are three out of the 24 measurements that do not fulfill that condition: Cranial Length, Basion to Prosthion Length and Orbital Breadth.

The case of the Cranial Length can be explained because of the craniosynostosis cranium that was included in the calculations; this skull raised the mean and therefore the Standard Deviation calculation. When this case is removed from the table altogether the deviation goes back to under 1.

The graphic representation of those standard deviations can be seen after the table in figure 28.

Table 11. Measurement Descriptive statistics.

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Cranial Lenght	15	5	18	22	18,99	1,209	1,461
Cranial Breath	12	3	12	15	13,53	,868	,754
Bizigomatic breath	0						
Cranial Height	13	3	13	15	13,90	,792	,627
Cranial Base Lenght	11	3	9	12	10,27	,695	,483
(ba-pr)	7	3	7	10	9,22	1,099	1,207
(ecm-ecm)	10	1	6	7	6,18	,371	,138
(pr-alv)	11	2	4	6	5,10	,537	,289
(au-au)	10	3	10	13	11,67	,794	,631
(n-pr)	10	2	6	8	6,84	,537	,288
(ft-ft)	12	2	10	11	10,48	,494	,244
(fmt-fmt)	13	2	9	11	9,88	,555	,308
(n-ns)	9	1	4	6	5,06	,379	,144
(al-al)	8	0	2	3	2,30	,146	,021
(d-ec)	11	4	3	8	4,05	1,185	1,404
Orbital height	12	1	3	4	3,55	,208	,043
(ec-ec)	5	1	9	10	9,65	,595	,354
(d-d)	10	2	2	4	2,61	,519	,270
Frontal Chord	16	3	10	13	11,41	,693	,481
Parietal Chord	22	4	10	14	11,83	,893	,797
Occipital Chord	22	3	9	11	9,86	,555	,308
(ba-o)	15	1	3	4	3,71	,258	,066
foramen magnum breadht	14	1	2	3	3,04	,229	,052
mastoid lenght	24	3	2	5	3,75	,724	,524
Valid N (listwise)	0						

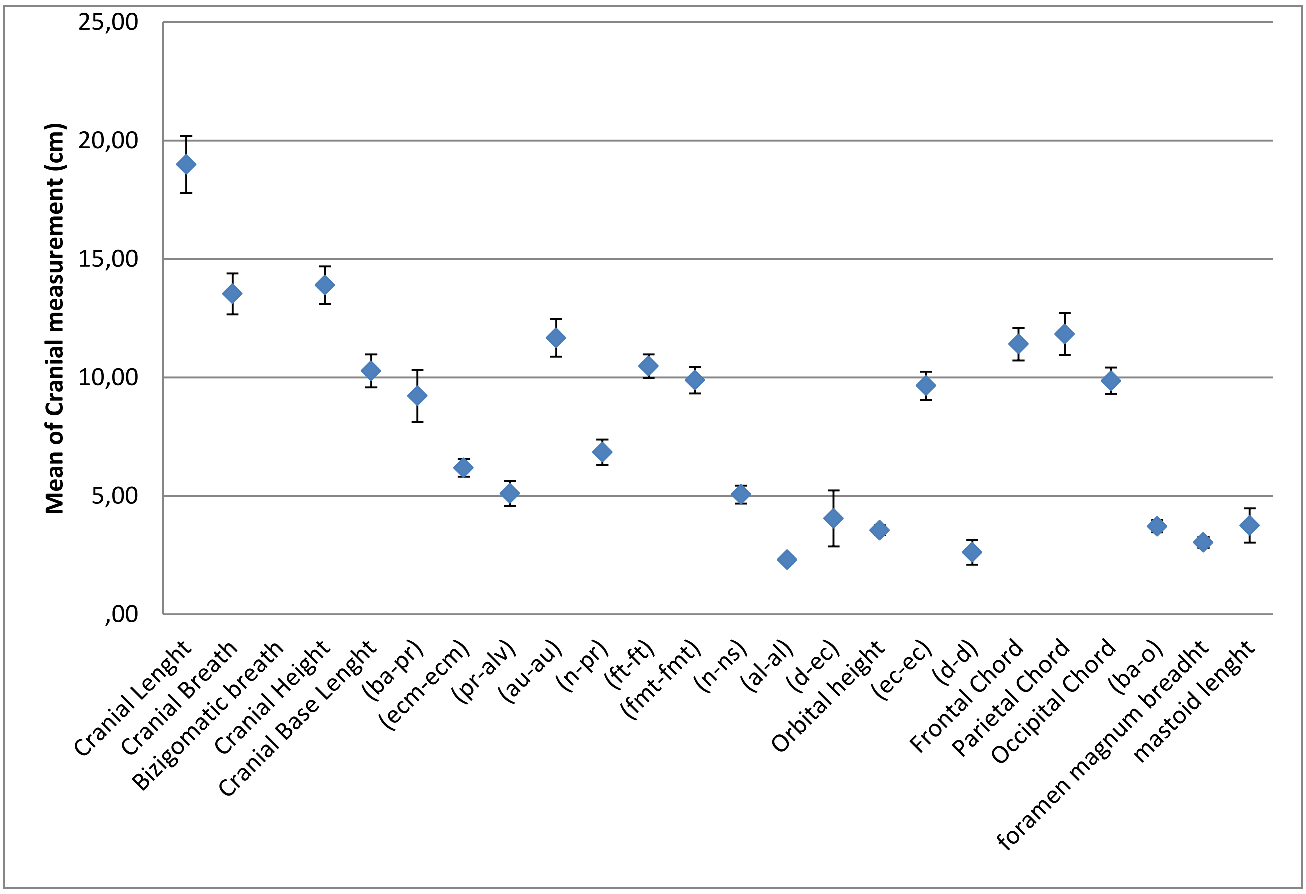


Figure 28. Graphical representation of measurements and error in Haslar collection. Bars represent Standard Deviation for each measurement.

Chapter 6. - RESULTS

The following results have been organized according to the questions posed by the hypothesis and the use of data analysis to answer them. Graphs and tables have been added and explained in each section but for further information on the tests conducted and the individual data included in each graph the Annex section must be consulted.

Ancestry

The first graph presents the percentage of Wormian bones in each ancestry group. Including the total Wormian bone presence in Artificial Cranial Deformation (ACD) and pathological skulls.

As can be seen in figure 29, for Haslar the percentage of Wormian bones is of 46%, for SHARP 48% and for Sierra Norte 58%.

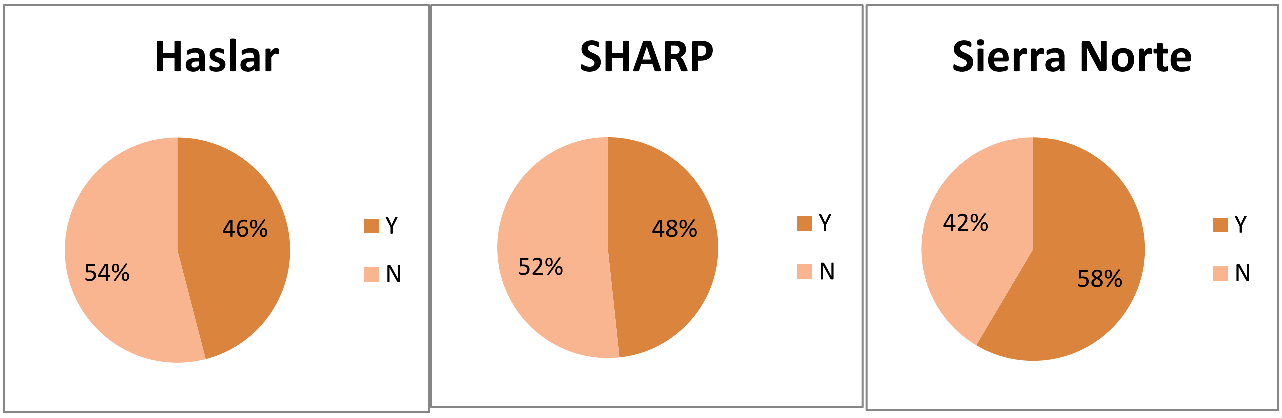


Figure 29. percentage of Wormian bones according to ancestry.

Figure 30 shows these same percentages as bars in the same graph for further comparison.

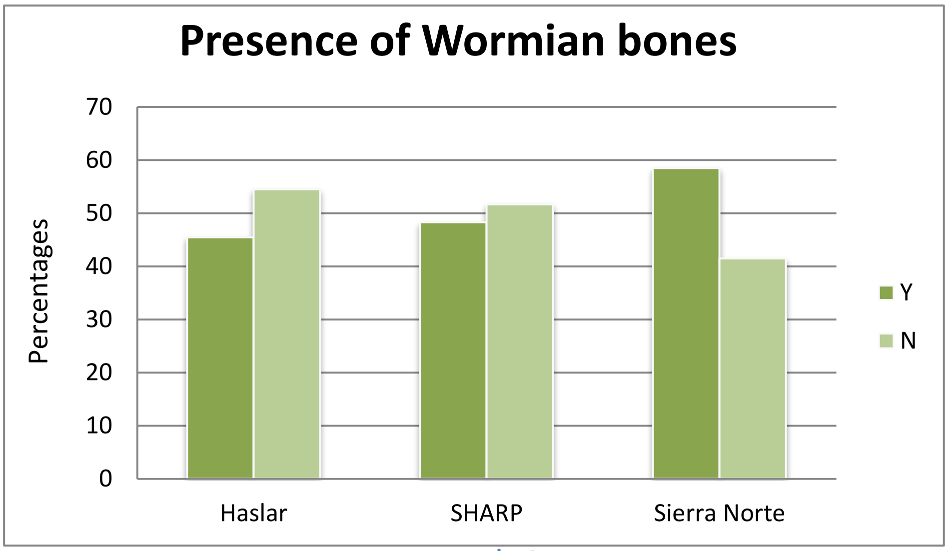


chart.

The graph presented in figure 31 excludes all those skulls that present ACD and pathologies as to limit the effect they may have on the overall percentages.

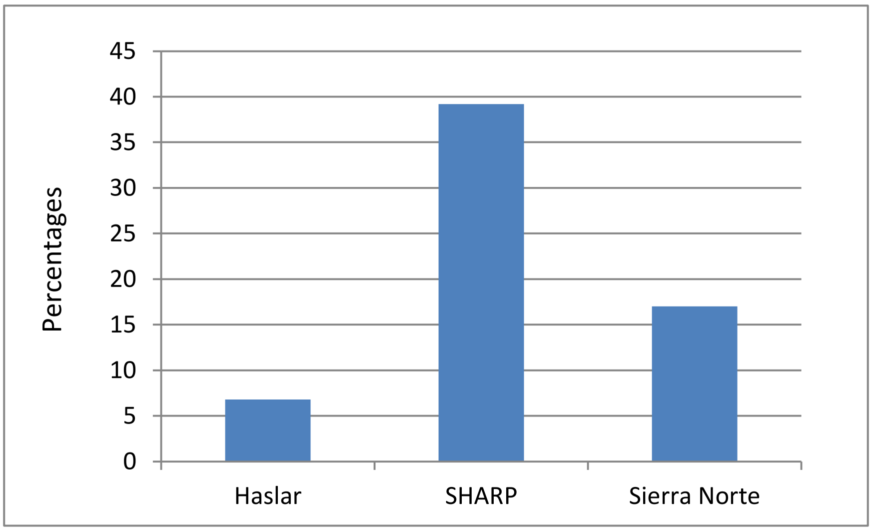


Figure 31. Presence of Wormian bones according to Ancestry in "normal" skulls. In percentages.

In percentage terms figure 31 shows that the presence of Wormian bones in skulls with no pathologies or ACD is: in Haslar 6%, in SHARP 39% and in Sierra Norte 17%. To further interrogate the relation between Wormian bone incidence and ancestry group two correlation coefficients were calculated as seen in tables 12 and 13.

Tables 12-13.Kendall's Tau Correlation Coefficient ands Spearman's Correlation Coefficient calculation between Ancestry and Wormian bones Descriptive statistics.

Kendall's Tau Correlation Coefficient		
	Wormian Bones	Ancestry
Wormian Bones	1	-0,200
Ancestry	-0,200	1
Significance in a 1 tail test		.001
Number of co-related cases		205

Spearman's Correlation Coefficient		
	Wormian Bones	Ancestry
Wormian Bones	1	-0,220
Ancestry	-0,220	1
Significance in a 1 tail test		.001
Number of co-related cases		205

The tables show there is an inversely proportional correlation between the two variables. The correlation is significant at the 0.01 level; in both cases the coefficient is higher than that.

When tested by Kruskal-Wallis, with the null hypothesis: ―*The distribution of Wormian bones is the same across categories of Ancestry",* the results showed that the hypothesis should be rejected but the significance level of the relation is not high enough to propose the nature of such relationship.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Wormian is the same across categories of Ancestry.	Independent-Samples Kruskal-Wallis Test	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 32. Results for Kruskal-Wallis test between Wormian bones and Ancestry group.

Pathology

The first graph (figure 33) shows the presence of pathologies on the collections. In order to make a further difference regarding types of pathological conditions the data was divided into those skulls that present Genetic Pathologies (PG), Nutritional Pathologies (PN), skulls with both pathologies (PG+ PN) and skull with no pathologies.

This reflects the selection that was made initially regarding the overall health of the collections, where Haslar was singled out as the least healthy of the three while SHARP and Sierra Norte have very similar pathology presences.

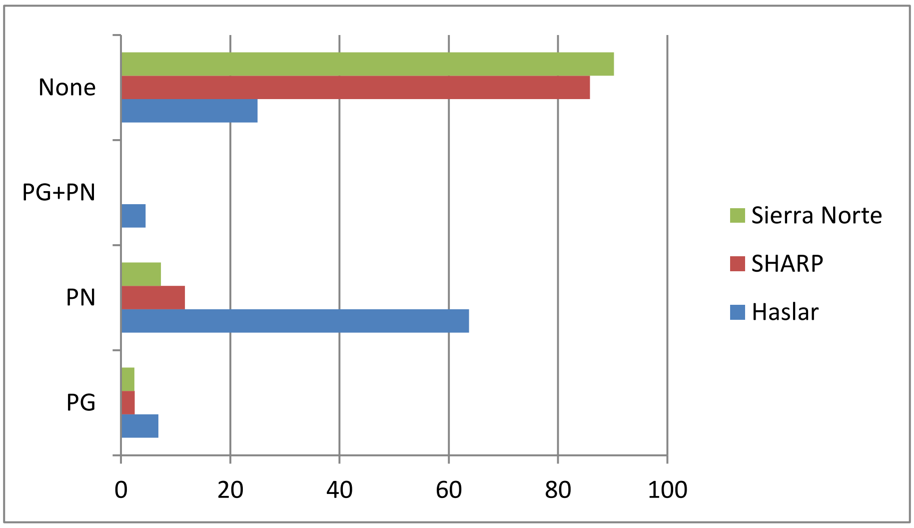


Figure 33. Pathology percentages according to Ancestry.

The percentage of skulls with Wormian bones and certain pathologies follows the normal distribution of pathologies as shown in the previous graph.

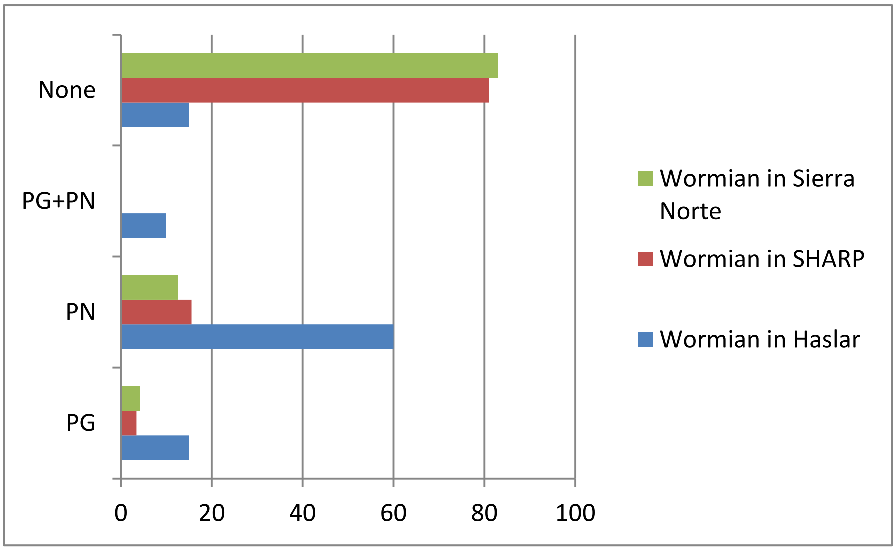


Figure 34. Pathology percentage in skulls with Wormian bones according to Ancestry.

To further interrogate the relation between Wormian bone incidence and ancestry group two correlation coefficients were calculated as seen in tables 14 and 15.

Tables 14-15.Kendall's Tau Correlation Coefficient and Spearman's Correlation Coefficient calculation between Ancestry and Wormian bones Descriptive statistics.

Kendall's Tau Correlation Coefficient		
	Wormian Bones	Pathology
Wormian Bones	1	0,269
Pathology	0,269	1
Significance in a 1 tail test		.000
Numer of related cases		205

Spearman's Correlation Coefficient		
	Wormian Bones	Pathology
Wormian Bones	1	0,283
Pathology	0,283	1
Significance in a 1 tail test		.000
Numer of related cases		205

The tables show there is a directly proportional correlation between the two variables. The correlation is significant at the 0.01 level; in both cases the coefficient is higher than that.

When tested by Kruskal-Wallis, with the null hypothesis: ―*The distribution of Wormian bones is the same across categories of Pathology", *the results showed that the hypothesis should be rejected, but the significance level of the relation is not high enough to propose the nature of such relationship.

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Wormian is the same across categories of Pathology.	Independent-Samples Kruskal-Wallis Test	,001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 35. Results for Kruskall-Wallis test between Wormian bones and Pathologies.

The correlations between the three previously detailed variables can be seen in a graphical representation underneath.

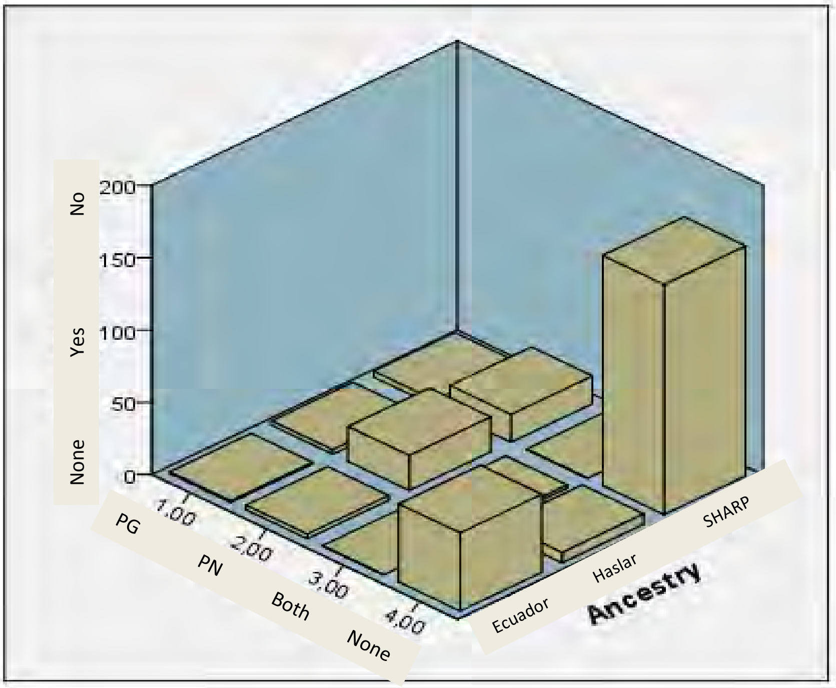


Figure 36. Graphical representation of correlations.

In this graphical representation the relation between the three variables is visible. Taking as an example the highest column in the graph it shows that, for SHARP, the majority of skulls with "none" pathologies have "no" wormian bones.

Artificial Cranial Deformation

Figure 37 shows the percentage of skulls that have Wormian bones in the Sierra Norte collection, divided into those with ACD and those without it. In simple percentages the ACD skulls have a much higher incidence of Wormian bones than those without it.

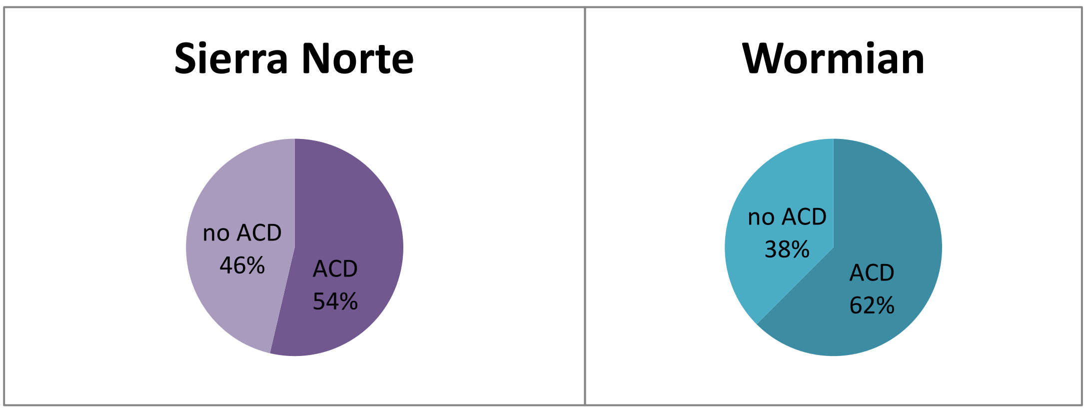


Figure 37. Percentages of skulls with ACD (left) and percentages of Skulls with Wormian bones and ACD (right).

The percentage change between the total population percentages of presence of Wormian bones in comparison with the same percentage in skulls with ACD is of around 8%.

When tested by Kruskal-Wallis, with the null hypothesis: ―*The distribution of Wormian bones is the same across categories of Artificial Cranial Deformation",* the results showed that the hypothesis should be accepted. The significance level of the relation is of 0,439.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Wormian is the same across categories of ACD.	Independent-Samples Kruskal-Wallis Test	,439	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 38. REsults for Kruskall-Wallis test between Wormian bones and Aritificial Cranial Deformation.

Measurement Analysis

From the total of 24 cranial measurements recorded on the paper and digital forms, four (4) were selected given their relation with overall cranial structure and suture lines to determine if there is a visible connection between cranial shape and Wormian bones.

The measurements analyzed were: maximum cranial length, maximum cranial breadth, maximum cranial height and cranial base lenght. The total of skulls that presented at least one of those measurements was of 65. The normal distributions of the measurement values can be seen in figure 39.

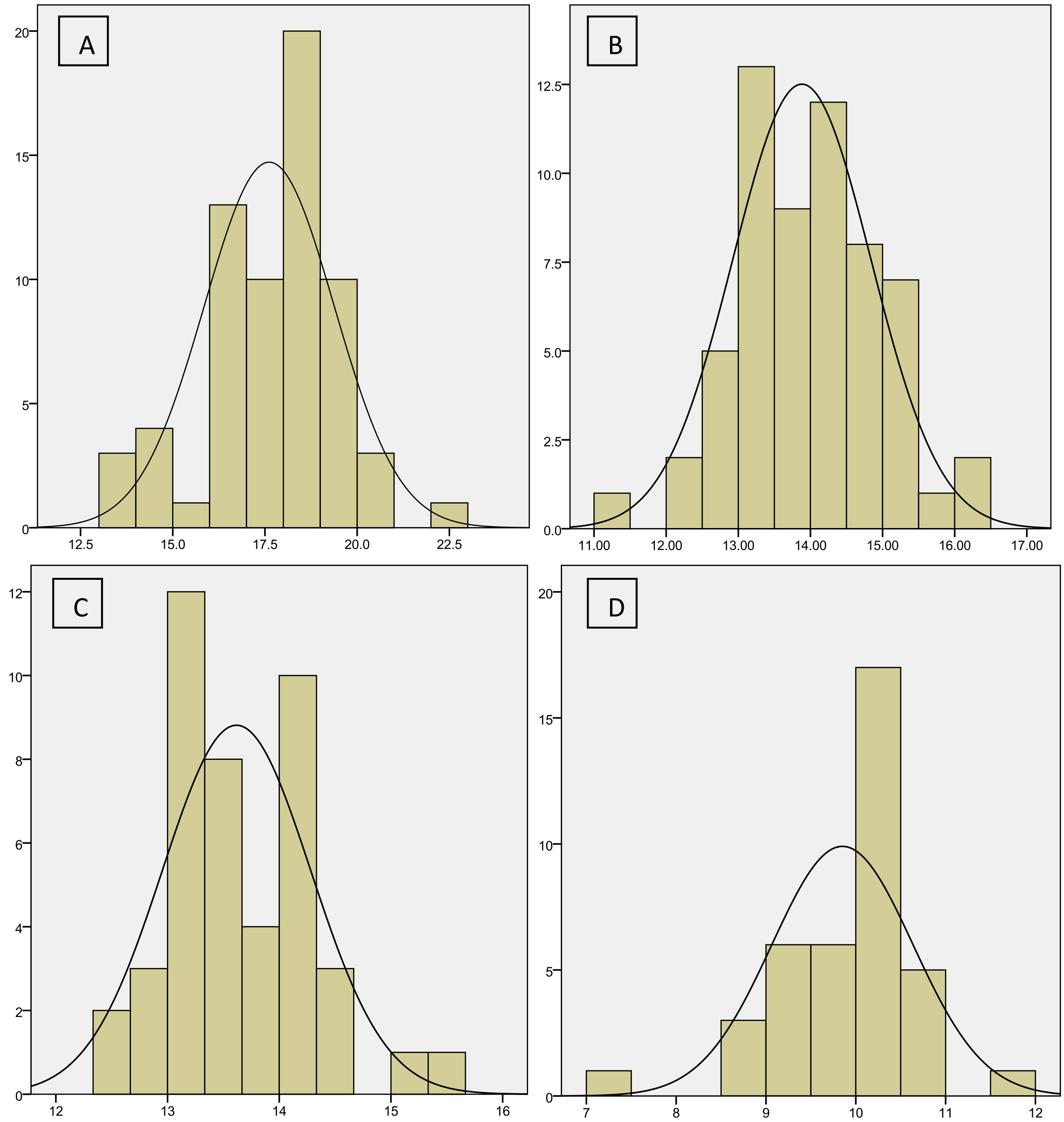


Figure 39. Normal distribution of measurement values from 65 skulls. a) Maximum Cranial Lenght; b) Maximum Cranial Breadth; c) Maximum Cranial Height; d) Cranial Base Lenght

The details for mean and standard deviation of each measurement are as follows:

Table 16. Measurement descriptive statistics.

Measurement	Mean	Standard Deviation
Maximum Cranial Length	17,62	1,761
Maximum Cranial Breadth	13,88	0,957
Maximum Cranial Height	13,62	0,664
Cranial Base Length	9,85	0,785

The relation between measurement and presence/absence of Wormian bones, as presented by boxplot graphs, can be seen in the following pages. The use of boxplot graphs illustrates the mean of each measurement as well as their distribution in two plots, one for skulls with Wormian bones, the other for skulls without them.

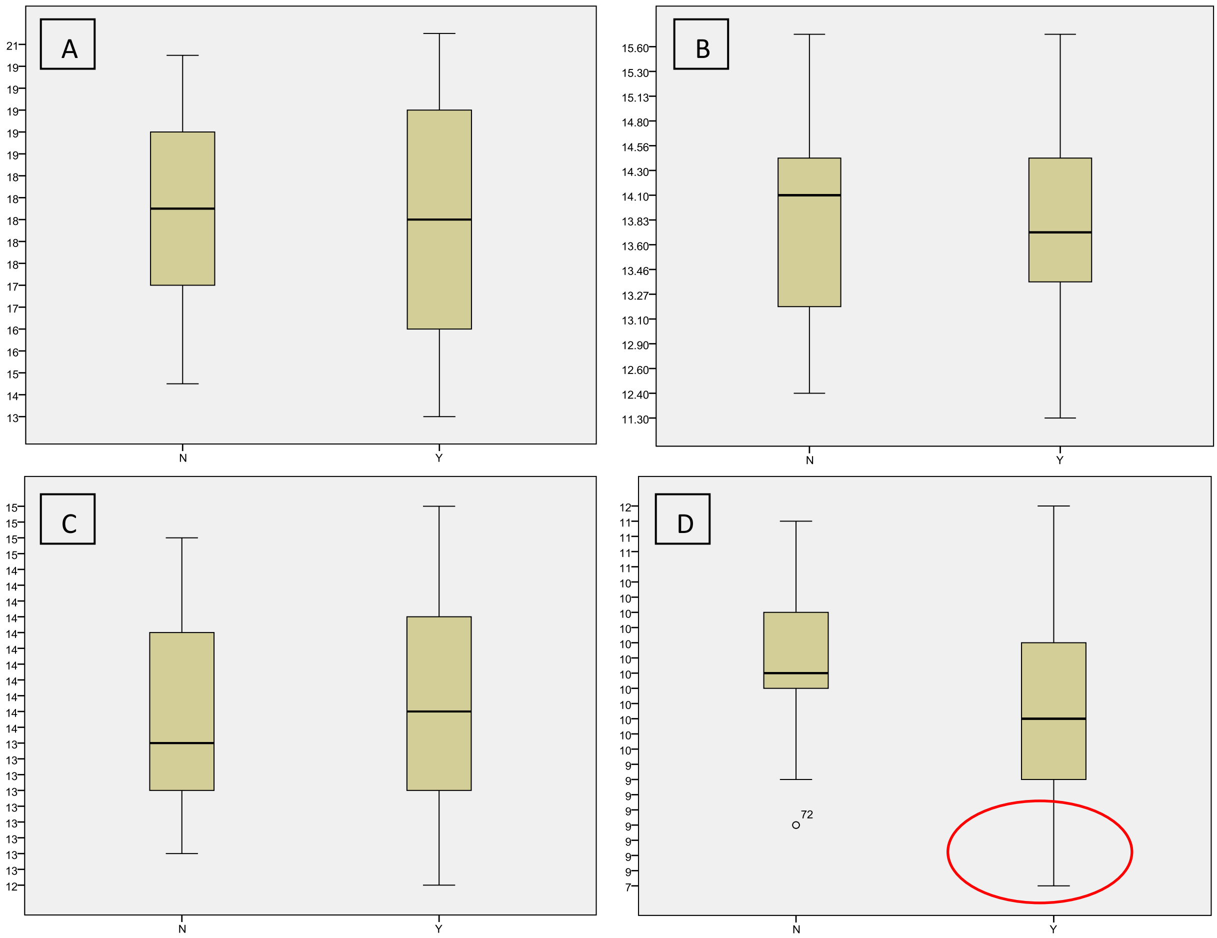


Figure 40. Boxplot graphs of measurements in relation with presence/absence of Wormian bones. a) Maximum Cranial Length; b) Maximum Cranial Breadth; c) Maximum Cranial Height; d) Cranial Base Length, red circle shows difference in measurements.

The implications from the result shown in the four sections presented in this chapter will be further discussed in the next chapter in relation with the literature available on the subject and other similar research.

Chapter 7.- Discussion

While reviewing the results for this project it is noticeable that the percentage prevalence of Wormian bones in all the populations used, does not agree with those reported in the literature. As it stands however, the literature in the subject is in itself contradictory.

For example; in the case of the data presented by Brothwell (1981), the reported percentages for an Anglo-Saxon population is of 55,56%, for a population from London (17^{th} century) 36,02% and for a Peruvian population 51,85%. The percentages reported by Hanihara and Ishida (2001) are very different; for the UK and Europe in general 20% and for Central and South America between 15-40% according to the site of Wormian bones.

Compared to our findings: for the Haslar (UK) population we concluded 45,5%, for SHARP (Anglo-Saxon) 48,3% and for Sierra Norte (South America) 58,5%, it would seem that the percentage prevalence presented by Brothwell are the closest. However in table 2, (Brothwell 1981), it is specified that only those ossicles in the lamboidal suture have been taken into account. The reasons behind the decision to ignore other Wormian bone sites is not clearly explained by Brothwell, but it is reasonable to assume that if other sites had been included then those percentages would have changed.

In respect to the percentages reported by Hanihara and Ishida (2001), the difference could be explained because of the use of modern populations as part of their study. The high indices of pathological conditions and ACD in our studied sample would then create the gap that is reported between the percentages.

When those skulls presenting ACD and pathological conditions were taken out of the sample to calculate new percentages (Haslar 6,8%, SHARP 39,2% and Sierra Norte 17%), the difference with Hanihara and Ishida's findings became even greater. This could indicate that the samples used by Hanihara and Ishida did contain skulls with pathological conditions but they have been compensated by the percentages in modern populations.

We have suggested that the inclusion of pathological conditions when considering Wormian bones will affect the percentage prevalence of Wormian bones in a population. As reported in the results section there is a correspondence between the graphs that represent prevalence of pathological conditions in the entire population and the presence of skulls that presented both Wormian bones and pathologies. In percentage terms the relation is even more evident:

Table 17. Pathology prevalence by Ancestry. Percentage descriptive statistics.

	PG	PN	PG+PN	None
Haslar	6,8	63,7	4,5	25
SHARP	2,5	11,66667	0	85,83333
Sierra Norte	2,439024	7,317073	0	90,2439

	PG	PN	PG+PN	None
Wormian in Haslar	15	60	10	15
Wormian in SHARP	3,4	15,5	0	81
Wormian in Sierra Norte	4,2	12,5	0	83

It is a problem, therefore, that studies on the prevalence of Wormian bones do not indicate the health of the individuals in their samples, making it harder to compare with our finds whilst also hindering the understanding of the relation between pathological conditions and Wormian bones.

The same considerations can be made regarding ACD. Unless a study addresses the problem of ACD and the prevalence of Wormian bones specifically, there is no consideration for the use or exclusion of skulls with ACD when referring to the incidence of Wormian bones in a population.

As it has been presented in the results with the correlation table, there is a significant relation between the incidence of Wormian bones and the presence of pathological conditions in a population. The results shown in the correlation tables are similar to those observed with the simple statistical graphs in the results section.

The relation between Wormian bones and ancestry is recorded with a negative sign to indicate an inversely proportional relationship. This agrees with the initial graph where Wormian bones are in percentile, similar in Haslar and SHARP and higher in Sierra Norte.

Wormian bones and pathology show a directly proportional relationship, with both values increasing at the same time. This indicates that as “No” becomes more common in the Wormian bone column; in the pathology column “None” also becomes more common.

The last relationship is that between Ancestry and Pathology. Again we find an inversely proportional relationship. This reflects the conclusions gathered from the graph in the previous section where SHARP (1) has the least number of pathologies (None) (4).

However, the nature of this relation cannot be explained with this study. Firstly because of the small number of genetic pathologies present in the collections, but more importantly because of the discussion on the aetiology of Wormian bones. If and when that subject has been explored, with conclusions obtained regarding what physical strains give way to the creation of Wormian bones in the different sutures; then the selection of pathologies that involve similar strains for further research on will be easier and more site specific.

There are a number of steps that can be taken in upcoming studies to try and understand that relation. The pathology variables need to be analysed separately for one, as to establish if genetic pathologies have a different relation to Wormian bones than nutritional based pathologies. Secondly, the sample populations for the study should be increased as to include an equally high number of healthy individuals and pathological individuals.

Taking this into account; the problem of using archaeological data for pathology assessment is that there are higher indices of nutritional pathologies; as well as taphonomical changes that can be misinterpreted as such. It would be interesting to apply the findings of this project on a modern population collection as to identify what pathologies would need to be considered, taking careful note on those differences that separate modern pathologies from those reported in the archaeological data.

In that case, another point that should be taken into account is a population’s predisposition for genetic disorders. Using a population where genetic disorders that have a high incidence rate, in particular those that could present SNWB, can change the results obtained and skew interpretations. In the present study genetic data was not available as the collections were archaeological populations where little or no DNA studies have been conducted. For future studies it could be considered, especially in modern populations where such indices are known by local authorities.

Regarding ACD in the Sierra Norte population, they initially revealed a strong correlation with Wormian bone presence, but that was rejected by the Kruskal Wallis test. Equivalent to the ANOVA test for parametric data, this test allows calculating the significance level of the relationship between two variables. When the level is over .05 the relationship is valid.

The first two results tables again reinforce what the correlation tables and graphs showed before. Ancestry and pathology don't have a significance level higher than .05 when related with Wormian bones, however the rejection of the null hypothesis indicates that there is a relation to be considered.

The third result table corroborates what percentages and previous graphs have suggested regarding ACD. The significance level is high at .439 and that indicates that the null hypothesis is accepted and there is no apparent relation between the two variables.

This indicates that the external forces applied for ACD do not have a direct effect over the formation of extra ossicles in the skull. This is found to be in disagreement with most of the literature on the subject (O`Laughlin 2004; Del Papa and Perez 2007) except for (El Najjar and Dawson 1977) however it is necessary to consider that:

- The literature is focused on single populations and not in comparison between populations of different ancestry backgrounds with ACD. That is the case of the studies by (O`Laughlin 2004; Del Papa and Perez 2007; García-Hernandez and Murphy-Echeverría 2009). In consequence, those conclusions cannot be universally applied; they are valid exclusively for the populations used and as such very limited.
- It is not safe to presume that all other populations with ACD and a different background than that of the Sierra Norte collection will in fact

show a strong correlation between Wormian bone prevalence and Wormian bones. Further research needs to be conducted in collections from other ancestry groups that present ACD.

Finally, the measurement analysis indicated that those four cranial measurements that give an overall idea of cranial shape do not show a significant relation with the presence or absence of Wormian bones in a skull. This is independent from ancestry group.

It was expected that ACD or deformative pathologies would show up as outliers in the boxplot graphs, that is not the case for the most obviously affected measurement as Maximum Cranial Length and Breadth. There is however a marked difference in Cranial Base Length between those skulls with and without Wormian bones, as can be seen in figure 35, those skulls that present Wormian bones exhibit smaller measurements. This is something that should be explored in further research with a bigger sample.

Project Limitations:

As in any project there were several limitations encountered while conducting this study. The most important of those are discussed in this segment.

1) We could not get access to collections that, for comparison purposes, presented: ACD in a European or African population; a healthy historical English collection. It was therefore difficult to make more specific tests and derive detailed conclusions on the relation of Wormian bones with ACD and with pathologies. The availability of such collections is not in question, however given the time constraints this MSc dissertation has, and the lack of response from the contacted collection curators it was not possible to include them in the project.

2) Given the lack of similarities in terms of age and sex distribution between the three collections, it was decided that such variables would not be taken into account in the present study. It is noted however that, especially age specific studies on the subject could give interesting results and shed more light on Wormian bone aetiology.

3) Another problem was using the data collected by multiple observers on the SHARP collection. Even when measures were taken as to try and reduce the effect that multiple observers might have in the consistency of the collected data (by means of the twenty skulls measured and registered personally as a sample of the 120 as described in the methodology chapter), it still leaves room for a margin of error that could be prevented by first hand collection of the data in future investigations. Even when in this particular case it is not presenting a recognisable skew on the results it should be limited in the future.

4) The data collection for the Sierra Norte population conducted in 2008, while focusing on the practice of ACD and the description of nutritional pathologies, is limited in regards to genetic pathology recognition. The inventories conducted for both Haslar and SHARP have an emphasis on pathology recognition and registration; in the case of SHARP being in continuous actualization as research with the remains is conducted by the group of archaeologists and anthropologists that have access to the collection. The fact that some genetic pathologies might have been overlooked or misdiagnosed in the Sierra Norte collection is something that should be taken into account when considering the overall results for the relation between pathologies and Wormian bones. It is not a big problem for the current study that comprises a first appraisal of the relation between pathology and Wormian bones, but must be taken into account for more detailed studies.

Recommendations

The subject of the relation of Wormian bone prevalence with ancestry has been, in the authors opinion, explored in enough studies. However other aspects regarding Wormian bones have been overlooked. Starting with their still confusing aetiology to the relation their prevalence has with genetic diseases as presented by SNWB and nutritional pathologies as suggested in this project. In that respect, if more studies on Wormian bones should be conducted they must consider the population where they are studied in terms of pathology incidence as well.

It should also be encouraged that several comparison collections from different ancestries are used, as to try and find more universal conclusions regarding Wormian bone prevalence and star distancing research from population specific results.

As it has been stated elsewhere, the most important conclusion from the work conducted is that Wormian bones should not be considered as confinable ancestry related non-metric traits. they should especially not be used as tools for ancestry assessing in archaeological or historical populations as many other factors have been proven to be involved in the prevalence of Wormian bones in the human skull.

It is strongly recommended that Anthropology professionals abandon the notion of Wormian bones as ancestry markers and rather include them as non-metrical traits that could in the future aid in pathology diagnosis.

CONCLUSION

This research project aimed to make evident that, given the conflicting results regarding the relation of Wormian bones and ancestry, and the lack of comparative literature regarding Wormian bone presence between ancestry and pathology and artificial cranial deformation, there is a need to eliminate their use as ancestry specific traits in Forensic Anthropology practice.

This aim was attained by the successful completion of the majority of the general and specific objectives this project set out to accomplish:

- A relative percentage of prevalence of Wormian bones in a Mongoloid population, by comparison between non-deformed and ACD skulls in a population. It was concluded that, in our population, this percentage was between 58% and 62%
- I was possible to establish a base line of prevalence of Wormian bones in a Caucasian population given the similarities presented by Haslar and SHARP, in Wormian bone prevalence percentages: 46% for Haslar and 48% for SHARP.
- The comparison of Wormian bone prevalence percentages between populations allowed to propose that there is a link between Ancestry and Wormian bone presence, but since it is affected by other variables such as pathology and ACD they cannot be regarded as population specific traits.
- It was also possible to determine that there is marked difference between the expected prevalence of Wormian bones in relation to ancestry found in our study when compared to the literature. This is attributed mainly to population specific variation and highlights the need for broader studies that include the pathology variable.
- Though the nature of the relationship of pathological conditions with Wormian bones was not made clear by this project, it was noted that there is a relationship between the variables and it needs to be further explored.

The four hypotheses proposed for this study were either confirmed or rejected as follows:

> **ACCEPTED:** The prevalence of Wormian bones in Caucasian populations is higher than that described by the literature on the subject.
> **ACCEPTED:** ACD does not have a bigger effect on incidence on Wormian bones than pathology when occurring in two different ancestry groups.
>
> **REJECTED:** Cranial measurements that show cranial vault shape have a direct relation with Wormian bone presence.

Hypothesis four however was more difficult to answer: —*The effects of pathology/ACD on the incidence of Wormian bones are high enough to supersede ancestry predisposition."*.

It is accepted that pathology and ACD have a strong relation with Wormian bone prevalence, however if this relation is stronger than that present between ancestry and Wormian bone prevalence could not be establish with this project and requires further research.

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Annex 1.- original recording forms

FORENSIC ANTHROPOLOGY AND ARCHAEOLOGY MSC PROGRAM
Maria Patricia Ordonez – Dissertation Project 2010
RECORDING FORMS

Cranfield UNIVERSITY

Recording Form for Cranial Measurements

Code:
Sex:
Age:

	Measurement	Value			
		First	Second	Third	Average
	Maximum Cranial Length (g-op)				
	Maximum Cranial Breadth (eu-eu)				
	Byzigomatic Diameter (zy-zy)				
Cranial shape	Basion- Bregma Height (ba-b)				
	Cranial Base Length (ba-n)				
	Basio Prosthion Length (ba-pr)				
	Maxilio- Alveolar Breadth (ecm-ecm)				
	Maxilio-Alveoriar Length (pr-alv)				
	Biauricular Breadth (au-au)				
	Upper Facial Height (n-pr)				
	Minimum Frontal Breadht (ft-ft)				
	Upper Facial Breadth (fmt-fmt)				
	Nasal Height (n-ns)				
	Nasal Breadth (al-al)				
	Orbital Breadth (d-ec)				
	Orbital Height				
Facial Shape	Biorbital Breadth (ec-ec)				
	Interorbital Breath (d-d)				
	Frontal Chord (n-b)				
Cranial shape	Parietal Chord (b-l)				
	Occipital Chord (l-o)				
	Foramen Magnum Length (ba-o)				
	Foramen Magnum Breadth				
Other	Mastoid Length				

Adapted from Buikstra, Jane E. and Douglas Ubelaker, "Standards for data collection from human skeletal remains", Arkansas Archeological Survey Research Series No. 44 (1994)

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SUTURAL COMPLEXITY

	Absent	Present				Unobservable
Sutural Bones						
			Middle	Left	Right	
Epipteric Bone						
Coronal Ossicle						
Bregmatic Bone						
Sagittal Ossicle						
Apical Bone						
Lambdoid Ossicle						
Asterionic Bone						
Ossicle in Occipito-Mastoid suture						
Parietal Notch Bones						

	Absent	Complete, Single Bone	Bipartite	Tripartite	Partial	Unobservable
Inca Bone						

POROTIC HYPEROTOSIS

	1	2	3	4
Degree				

	A	B	C	A & B	B & C
Location					

	At time of death	Healed	Mixed reaction
Activity			

Key

1 = Barely Discernible

2 = Porosity Only

3 = Porosity with coalescence of foramina, no thickening

4 = Coalescing foramina with increased thickening

A = orbits

B = Adjacent to sutures

C = Near bosses or within squamous portion of occipital

Adapted from Buikstra, Jane E. and Douglas Ubelaker, "Standards for data collection from human skeletal remains", Arkansas Archeological Survey Research Series No. 44 (1994)

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Cranfield UNIVERSITY

Observations

Photographs

Camera:

Number of projections: *1 2 3 4 5 6 7 8*

Type of projection: *anterior lateral posterior superior inferior details*

Photo Log:

from *to*

Adapted from Buikstra, Jane E. and Douglas Ubelaker, "Standards for data collection from human skeletal remains". Arkansas Archeological Survey Research Series No. 44 (1994)

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Annex 2.- Databases

All the databases utilized for this thesis have been included in the attached compact disc (CD) given the size of the files and the photographs.

The folders in the disc are organized as follows.

- Haslar.- contains the original database with the data for the 44 skulls measured and analyzed of the Haslar collection. It also includes all the photographs taken of each skull in an individual folder.

- SHARP.- contains the original database with the data for the 2' skulls measured and analyzed of the SHARP collection. It also includes all the photographs taken of each skull in an individual folder and all other databases constructed with the information made available by SHARP.

- Sierra Norte.- contains the original database with the data for the 41 skulls measured and analyzed of the Sierra Norte collection.