METHODOLOGICAL COMPARISON OF THE MACROSCOPIC VERSUS RADIOGRAPHIC ASSESSMENT OF CRANIAL POROSITIES WITHIN THE TEXAS STATE UNIVERSITY DONATED SKELETAL COLLECTION

by

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LIST OF ABBREVIATIONS

Abbreviation	Description
CO	Cribra Orbitalia
DPT	Diploic Thickening
HE	“Hair-on-end” Pattern
ORT	Orbital Roof Thickening
OTT	Outer Table Thinning
PH	Porotic Hyperostosis

I. INTRODUCTION

Porotic Hyperostosis and Cribra Orbitalia

The presence of skeletal stress indicators has been documented throughout various prehistoric and historic archaeological contexts as a way to understand the life history of a population and gauge their overall health and nutritional status (Walker *et al.* 2009). By studying these bone alterations, researchers can address questions related to biological and environmental contexts such as disease, activity patterns, cultural factors, or social variables (Mays 2012), social organization (Piperata *et al.* 2014), and living conditions linked to population density, nutritional stress, and sanitation (Kent 1986, Eisenberg 1991). Two of the skeletal lesions most frequently observed and analyzed within archaeological skeletal remains are porotic hyperostosis and cribra orbitalia, and they are used as indicators of health and nutrition (Walker *et al.* 2009, Mays 2012).

The term "cribra orbitalia" was first described by Welcker in 1888 (Williams 1929, Mensforth *et al.* 1978, Salvadei *et al.* 2001, Rothschild *et al.* 2005), while "porotic hyperostosis" was coined by Angel in 1966 (Larsen and Sering 2000, Ortner 2003). These terms describe the presence of marrow hyperplasia and pitting on the cranial vault and eye orbits (Angel 1978; Stuart-Macadam 1985, 1989; Hill & Armelagos 1990; Salvadei *et al.* 2001; Rothschild *et al.* 2005). Today, porotic hyperostosis (PH) is almost exclusively used to describe the presence of porosities and diploic thickening in the cranial vault, while cribra orbital (CO) is used to describe porosities on the superior surface of the eye orbits, and both are used as markers of anemia. These porosities are commonly used in bioarchaeology to investigate the decline of human health that is thought to result from the adoption and transition to agriculture (Cohen and Armelagos

1984, Kent 1986). They are the most frequently categorized skeletal lesions because of their relative abundance and usefulness in health assessment (Mays 2012). However, the presence of these skeletal stress indicators and their relationship to health within contemporary skeletal collections has not been readily examined. Therefore, this research will aim to assess the relationship between these porosities and health on a documented skeletal collection with self-reported health.

The etiology of PH and CO are attributed to a variety of biocultural factors including diets deficient in iron, the malabsorption of nutrients, chronic blood loss, parasitic infection, general nutritional deficiencies, and/or anemia (Kent 1986, Stuart-Macadam 1992, Holland and O'Brien 1997, Walker *et al.* 2009).

Iron-deficiency anemia is the most common form of anemia (Roberts and Manchester 2005) presently affecting half of the 2 billion people afflicted with anemia worldwide (World Health Organization 2014, 2016). Since the 1950s anemia has been linked to PH because of the similarity in cranial vault changes to those observed in children afflicted with iron-deficiency anemia (Walker *et al.* 2009, Mays 2012). Additionally, PH has been associated with iron-deficiency anemia because of the co-occurrence of marrow hypertrophy within the cranial vault (Mays 2012), which is a response to the formation of red blood cells within the bone marrow (Roberts and Manchester 2005), and the reabsorption of the outer table, similarly observed in radiographs of clinical anemic patients (Stuart-Macadam 1982, 1987a; Mays 2012). These diagnostic clinical radiographs have been compared by Stuart-Macadam (1982) to an archaeological population that presents macroscopic cranial porosities in the form of PH and CO, and her research suggests the appearance of PH and CO corresponds with the presence of seven radiographic traits indicative of anemia (Stuart-Macadam 1987a). Since the original linkage to clinical research, PH has become nearly synonymous with iron-deficiency anemia in antiquity (Moseley 1965, Mays 2012) and has become readily adopted by paleopathologists as the primary explanation for both CO and PH (Mays 2012).

CO was believed to be one of the earliest expressions of anemia (Carlson *et al.* 1974, Lallo *et al.* 1977), and is more commonly found in children than adults (Nathan and Haas 1966), leading some to consider and use this lesion as an indicator of childhood anemia (Stuart-Macadam 1985). Additionally, some researchers believe that PH is a more severe form of childhood anemia (Kent 1986; Stuart-Macadam 1985, 1992) and is typically accompanied by CO (Stuart-Macadam 1989). However, it has been noted not all individuals who display PH exhibit CO (Walker *et al.* 2009), so there is a suggestion that these two pathologies may represent varying stages of anemia (Carlson *et al.* 1974, Lallo *et al.* 1977, Larsen and Sering 2000).

Etiology is uncertain, however until recently, iron-deficiency anemia has been thought to be the primary causal factor responsible for PH and CO (Sheldon 1936, Eng 1958, Britton *et al.* 1960, Shahidi and Diamond 1960, Burko *et al.* 1961, Jelliffe and Blackman 1962, Powell *et al.* 1965, Aksoy *et al.* 1966, Lanzkowsky 1968, Agarwal *et al.* 1970, Moseley 1974, Eisenberg 1991, Walker *et al.* 2009). However, as outlined in Walker *et al.* 2009, other researchers have hypothesized that iron-deficiency may actually be an adaptive response to parasitic infection (Hengen 1971, Stuart-Macadam 1992), although this parasite model has not been widely accepted (Holland and O'Brien 1997). Alternatively, some researchers challenge the notion that the marrow hypertrophy attributed to iron-deficiency anemia does not result from a diet deficient in iron, but may be a result of the marrow hypertrophy's consumption of iron causing the individual to become deficient in that nutrient (Rothschild 2012). Others argue that the porosities observed on the cranium may actually be from differing etiologies, attributing the presence of PH to an acquired megaloblastic vitamin B12 deficiency in addition to synergistic factors (Walker *et al.* 2009), a niacin (B3 vitamin) deficiency resulting in pellagra (Paine and Brenton 2006), or their presence is a result of scurvy and/or rickets (vitamin C and D deficiency, respectively) (Robert and Manchester 2005). However, the two most widely debated etiologies revolve around the vitamin B12 deficiency (megaloblastic anemia) and iron-deficiency anemia (hemolytic anemia) (see Walker *et al.* 2009). Ultimately, the presence of non-specific cranial porosities may indicate a metabolic deficiency (i.e., iron-deficiency anemia) or a non-specific infection present (Ortner 2012).

Potentially as a result of this uncertainty in causation and etiology regarding PH and CO, some researchers have chosen not to use the specific terms PH or CO in the absence of a clinical diagnosis, and instead use descriptive terms such as, "ectocranial porosities" (Mann and Hunt 2005), or "cranial pitting" (Goodman and Martin 2002, Paine *et al*. 2009) to describe porosities of uncertain causation in the eye orbits and on the cranial vault.

Since there is a lack of a diagnostic agreement in the current literature, the author will use the terminology "orbital porosities" and "ectocranial porosities" in this research to refer to defects that may be reflective of CO and PH, with the understanding that these defects as they appear in dry bone are not definitively diagnosed in the modern clinical/medical sense. The term “cranial porosities” will be used to combine both orbital and ectocranial porosities for easy description within this research. However, the presence of orbital and ectocranial porosities may represent different causations and thus their results will be reported separately. While the exact causal factors of these two skeletal lesions are still debated, researches do agree upon their connection to past human life histories and their utility in the interpretation and study of past health (Goodman and Martin 2002) in relation to diet, nutrition, and disease.

Research Questions

Due to the predominant use and utility of these two cranial porosities within bioarchaeological contexts to signify health status, the author wanted to observe the frequency of these pathologies and their association to health within a modern documented skeletal sample to ascertain the relationship between the presence of cranial porosities and the expected health of an individual. As these pathologies are commonly used in bioarchaeology, dry bone diagnostic criteria (outlined in Buikstra and Ubelaker (1995)) for use in archaeological materials will be preformed on a documented skeletal collection to enhance our understanding of these pathologies on a contemporary skeletal population and to assess the pathological degree of expression (or severity) in modern populations as compared to those of individuals from the past. However, the expectation of cranial porosities indicative of anemia within a modern documented skeletal collection is thought to be low as current individuals have access to general health care and nutritional resources.

By utilizing the documented age, sex, ancestry, and socio-economic status within a modern skeletal collection, this research will enhance our understanding of the association between cranial porosities and health. Further supporting or diminishing the use of orbital and ectocranial porosities within the health dialogue. In turn, improving our understanding of CO and PH and refining terminology or diagnostic criteria specific to these pathologies.

The identification of orbital and ectocranial porosities can be performed both macroscopically and radiographically, however the assessment of PH and CO in skeletal material can be difficult if porosities do not present as classical lesions. Therefore, to definitively assess the presence of PH and CO, it is suggested that both macroscopic and radiographic assessments should be performed (Ortner 2003). Macroscopic observations have typically been used to assess the presence of these cranial porosities (Mays 2012), while radiographic assessments have attempted to explore the presence of these cranial porosities in relationship to anemia in archaeological populations (Stuart-Macadam 1982, 1987a). However, it has not been specified which of these approaches, macroscopic assessment or radiographic analysis, is the most accurate method to assess cranial porosities, and only two researchers, Stuart-Macadam (1982) and Bauder (2009), have performed a methodological comparison using both radiographic and macroscopic methods in the examination of cranial porosities.

Stuart-Macadam (1982) sought to test the hypothesis that PH was related to anemia through the comparison of radiographs performed on the Poundbury Camp archaeological skeletal collection from a Romano-British cemetery to that of radiographed clinical anemic patients. Using seven radiographic indicators, Stuart-

Macadam (1987a:519) found that the radiographic pattern of bone changes, within the Poundbury Camp skeletal collection who displayed PH, resembled those of radiographed clinical anemic patients with associated marrow expansion, further linking PH and clinical anemia together. The seven indicators Stuart-Macadam utilized include 1) ”hair-on-end” pattern of trabeculation, which is where “the bony trabeculae assume a position in which they radiate out in a perpendicular arrangement to the bony tables” (Stuart-Macadam 1987a:512) typically at a 90 degree angle (Stuart-Macadam 1987b), 2) outer table thinning, which is an increased pressure on the diploë causing “…a thinning or disappearance of the adjacent compact bone” (Stuart-Macadam 1987a:512), 3) texture changes, which are “…a course , granular, or stippled pattern with an increase in radiolucency” observed in the skull vault (Stuart-Macadam 198a:513), 4) dipolic thickening, which is “an increase in skull vault thickness…” (Stuart-Macadam 1987a:513), 5) orbital roof thickening, which is “...clearly evident in lateral radiographs…[where] the roof of the orbit is often greatly thickened…” (Stuart-Macadam 1987a:513), 6) orbital rim changes, which are the “…thinning, flattening, loss of definition and in some cases obscuring of the normal rim outline,” which are observed in the posterior-anterior view (Stuart-Macadam 1987a:513), and 7) frontal sinus development, which is “…a reduced or, in some cases total lack of sinus development” (Stuart-Macadam 1987a:514).

Bauder (2009) performed a differential diagnosis of PH on a prehistoric skeletal population for the study of subadult survivorship in addition to a comparison of three methods in the examination of lesions to assess overall performance. Bauder (2009) found that the diagnostic accuracy was not statistically increased with the use of radiography, and that macroscopic observations were better when active lesions were present.

However, no test of the radiographic versus macroscopic approach has been conducted using a documented skeletal sample to understand if the appearance of these cranial porosities in contemporary populations compares to those from the past, and which method is the most accurate to detect these porosities. Therefore, this thesis will aim to test the Stuart-Macadam (1987a) radiological method for assessing the presence of cranial porosities suggestive of PH and CO, versus using the visual macroscopic analysis alone in a modern documented skeletal collection. This assessment will be performed using individuals from the Texas State University Donated Skeletal Collection (n=50) in conjunction with their documented age, sex, ancestry, and socio-economic status.

Because the literature speculates the presence of cranial porosities may relate to the age, sex, ancestry, or socio-economic status of an individual, this research will further test the relationship between the presence of these pathologies against a collection with known demographics and self-reported health unlike similar studies, which utilized archaeological populations with estimated demographics.

Utilizing the comparison between cranial porosities and socio-economic status may potentially further support or reject the use of these pathologies as an indicator of socio-economic status of an individual within modern populations and/or challenge the use of these skeletal lesions when assessing the presumed status of individuals within archaeological populations. Thus, the author aims to provide further evidence to either promote the linkage or discourage the association between skeletal stress indicators and the expected observation of status in antiquity and/or socio-economic status in contemporary individuals.

Furthermore, this research will compare the frequency of the radiographic indicators observed within clinical anemic patients (Stuart-Macadam 1987a) to the frequency observed within a documented skeletal collection to assess if these radiographic indicators are confined solely to clinical anemic patients. Four of the seven radiographic indicators (outer table thinning, diploic thickening, “hair-on-end” pattern, and orbital roof thickening) outlined by Stuart-Macadam (1987a) were chosen based on the frequency observed within clinical anemic patients, their ease of identification within radiographs, their association to anemia, and the location on the cranium potentially relating to the presence of macroscopic porosities.

Overall, the purpose of the study is to further explore which of the analyses is the most accurate method for the examination and measurement of cranial porosities, to assess which radiographic features perform the best at capturing the presence of these cranial porosities, and to assess if the presence of cranial porosities is reflective of age, sex, ancestry, or socio-economic status. This research aims to address the following points:

1. To evaluate which method, macroscopic or radiographic, is preferred in the identification of cranial porosities.
2. To assess the frequency of cranial porosities within the Texas State University Donated Skeletal Collection in relation to known age, sex, ancestry, and self-identified socio-economic status.

3. To evaluate the overall performance of four radiographic indicators (outer table thinning, diploic thickening, “hair-on-end” pattern, and orbital roof thickening) outlined in Stuart-Macadam (1987a) when utilized in a sample of self-reported health.
4. To observe whether the presence of macroscopic cranial porosities or radiographic indicators predict sex, age, or socio-economic status.

My hypothesis is that radiographs will better identify the presence of cranial porosities not apparent macroscopically, and that they may further indicate degree or severity (e.g., mild to moderate), due to the potential to observe expansion of the diploë. The expected frequency of the radiographic traits is believed to fall below the frequencies observed in clinical anemic patients (Stuart-Macadam 1987a). While the expected frequencies of cranial porosities as observed by age, sex, ancestry, or socio-economic status is that women and those in lower socio-economic status levels are thought to exhibit more cranial porosities. Younger individuals are believed to exhibit more orbital porosities (Stuart-Macadam 1985), while middle-aged individuals are expected to show more ectocranial porosities (Mann and Hunt 2005). For differences within ancestry groups, the presence of cranial porosities is expected to relate to their self-reported socio-economic status group. While childhood socio-economic status level is believed to suggest the presence or absence of orbital porosities.

In answering the questions listed above, the author aims to validate the use of radiographic traits when related to macroscopically observed cranial porosities, to assess the frequency of orbital and cranial porosities within a modern documented skeletal collection, and to establish a baseline profile for the presence of cranial porosities within a contemporary skeletal collection.

II. MATERIALS AND METHODS

Materials

This research examined modern crania (n=50) from the Texas State University Donated Skeletal Collection for the macroscopic and radiographic assessment of cranial porosities. X-rays were taken by the author using a portable MinXray® machine located at the Forensic Anthropology Center's Osteological Research and Processing Lab to capture radiographic images of each crania in two anatomical positions (anterior-posterior and lateral) in order to assess the presence and/or degree of orbital and ectocranial porosities suggestive of porotic hyperostotis (PH) and cribra orbitalia (CO).

Skeletal Collection Sample

The Texas State University Donated Skeletal Collection is comprised of modern individuals who have generously gifted their body to the Forensic Anthropology Center at Texas State for the advancement of scientific research, continuing education, and training within biological anthropology and forensic sciences (www.txstate.edu/anthropology/facts/donations/Body.html). Through their donation, our understanding of decomposition processes, skeletal biology, and knowledge of osteological health indicators is made possible. In addition to their body donation, documentation of their age at death, occupation, and self-reported childhood/adult socio-economic status is available for the majority of individuals within the collection to enhance health related research studies. Thus, childhood and adult socio-economic statuses have been included, when available, for individuals utilized within this study in order to test the expected and observed frequency of cranial porosities and radiographic indicators against self-reported socio-economic status.

Childhood socio-economic status was included in order to assess whether there was a significant correlation between orbital porosities and socio-economic status during childhood, as orbital porosities (or CO) are thought to be indicative of childhood anemia (Stuart-Macadam 1985). Additionally, adult socio-economic status was utilized to assess the correlation between the presence of ectocranial porosities and their expected socio-economic status. In the Texas State University Donated Skeletal Collection socio-economic status is self-reported, and there are six categories provided for donors to select from for childhood socio-economic status and adult socio-economic status levels: unknown, lower, lower-middle, middle, upper-middle, and upper class.

For this research, the author chose a sample size of 50 crania. The majority of the Texas State University Donated Skeletal Collection (N=190) is made up of individuals of European ancestry. Therefore, all available adult American Black (n=6) and American Hispanic (n=8) donors in the collection were utilized for this study. The remainder of the sample is comprised of American White individuals (n=36) to total the 50 crania needed for this research.

Recorded age at death was used to organize individuals into decade categories ranging from 18 to 101 years of age (Table 2.1). Note that the age category 18-20 is not a full decade, however the author needed to represent the youngest adult donor at 18 years of age, and that the age category 101-110 only includes a single individual aged 101. Within the American White sample, a random number generator was used to choose 36 individuals (18 female and 18 male), choosing two within each age decade wherever possible. Overall, 28 males and 22 females were used for this research (Table 2.1).

Table 2.1. Age Categories

Age	n=50
18-20	2
21-30	4
31-40	3
41-50	5
51-60	5
61-70	11
71-80	7
81-90	8
91-100	4
101-110	1

Methods

Macroscopic and Radiographic Analysis

The crania were scored separately for the presence or absence of orbital and ectocranial porosities using macroscopic scoring guidelines outlined in *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker 1994), and using radiographic scoring guidelines outlined in Stuart-Macadam (1987a). For additional photographic examples of macroscopic orbital/ectocranial porosities and radiographic indicators within the Texas State University Donated Skeletal Collection, see Appendix A and B.

Macroscopic Analysis – Ectocranial and Orbital Porosity (PH/CO) Appearance and Scoring

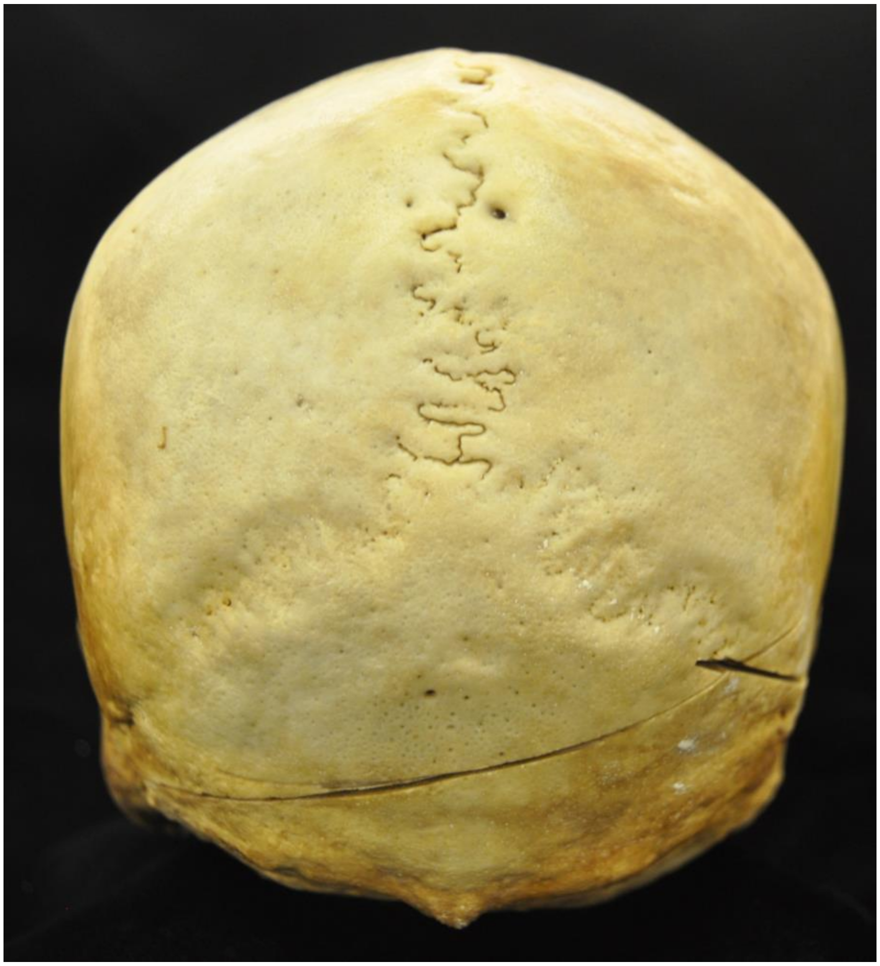


Figure 2.1 Example of slight ectocranial porosities in the Texas State University Donated Skeletal Collection

For the purpose of this research, ectocranial porosities are defined as tiny porosities or pits on the cranial vault with no increased thickening of bone, giving the appearance of an "orange-peel" texture (Mann and Hunt 2005), typically seen along the parietals, occipital, and frontal bone near bregma (Stuart-Macadam 1987b) (Figure 2.1). Hrdlicka (1914) described the pathological process of PH beginning on the frontal squama, subsequently spreading to the posterior portion of the parietal, and then onto the occipital. Although, it most commonly manifests along the frontal, parietal, and occipital bones, it does not extend past the temporal or nuchal muscle lines (El-Najjar *et al.* 1975). On dry bone, PH is characterized by increased vault thickness and small (0.5mm) to large (2.0mm) sporadic holes upon the diploë (Mann and Hunt 2005), ending adjacent to the frontal, sagittal, or lambdoidal sutures, creating a band of little to no porotic activity due to the avoidance of the suture (Moseley 1965). The variation and severity of this pathology may fluctuate throughout skeletal collections. For a depiction of severe PH, please refer to Mann and Hunt (2005:21).

Cribra orbitalia (CO) maintains a similar morphological signature as PH, appearing as large pinpoint defects located bilaterally within the superior surface of the eye orbit (Mann and Hunt 2005) (Figure 2.2), which itself exhibits increased superior orbital bone thickness (visible radiographically). In some adults, only small pits or remnants of porosities remain (Mann and Hunt 2005) as a result of bone remodeling and healing. Some researchers consider CO to be a response to childhood anemia and any vault lesions are likely indicative of a more severe form of anemia (Stuart-Macadam 1989).

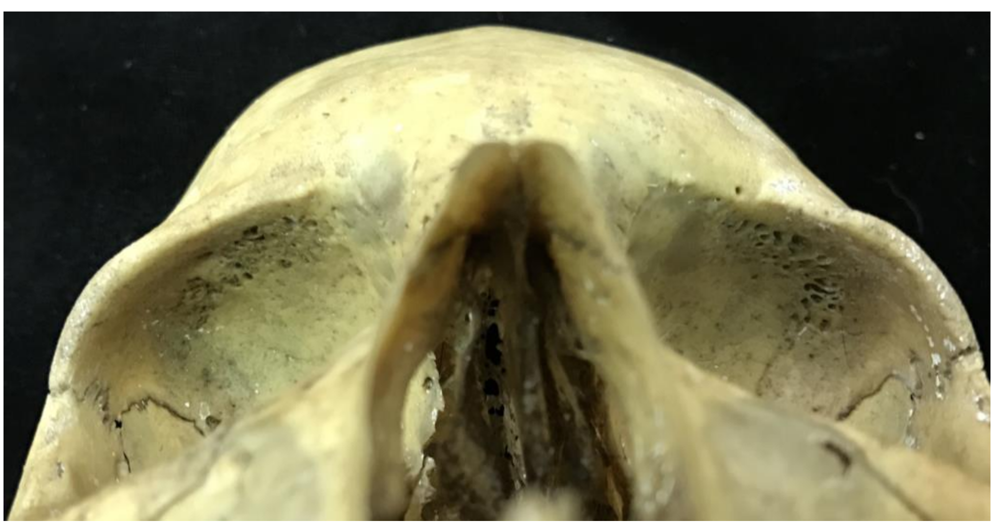


Figure 2.2 Example of moderate orbital porosities in the Texas State University Donated Skeletal collection

Because mild or moderate cases of CO/PH are not as easy to discern, and the paleopathological literature tends to document only clear or extreme cases, only crania that present classical lesions displaying marrow expansion, and coalescing foramina (Buikstra and Ubelaker 1994) with a band of no porotic activity (Moseley 1965) around the cranial vault sutures, will be scored as presenting PH. Ambiguous crania with cranial vault pitting but no marrow expansion and no banding will not be classified as displaying the metabolic reactions potentially indicative of PH. Orbital porosities will be scored as present if they present bilateral foramina (Stuart-Macadam 1985).

Ectocranial porosities were also scored as absent and present (Table 2.2). When present, ectocranial porosities were then further assessed for degree and were given a score of 0 to 5. If a score of 1 (barely discernible (pinpoints)) through 4 (coalescing foramina with increased thickness) was documented, this would indicate the macroscopic appearance of PH (as defined by Buikstra and Ubelaker 1994), and subsequently would be assessed as positive for the presence of PH. If porosities were present but did not meet the criteria for scores 1-4, a score of 5 was given to indicate non-specific porosities were present. This score of 5 was created and designated by the author to indicate porosities were not consistent with PH terminology. To score for orbital porosities, a score of 0 for absent and 1 for present were recorded (Table 2.2).

Table 2.2 Macroscopic Data Collection[1]

Orbital Porosities	Ectocranial Porosities		Porotic Hyperostosis (PH)
Presence/ Absence	Presence/ Absence	Degree	Presence/ Absence
0. Absent 1. Present	0. Absent 1. Present	0. Unobservable 1. Barely discernible 2. Porosity only 3. Porosity with coalescence of foramina 4. Coalescing foramina with increased thickness 5. Non-specific porosities	0. Absent 1. Present

[1]Adapted from Buikstra and Ubelaker (1994)

Radiographic Analysis – Ectocranial and Orbital Porosity (PH/CO) Appearance and Scoring

In addition to the macroscopic assessment, the presence or absence of four non-metric radiographic traits (discussed below) of PH and CO as outlined by Stuart-Macadam (1987a) was collected in two anatomical radiographic views: anterior-posterior and lateral. The presence of these radiographic traits establishes if the individual is scored as positive for lesions suggestive of PH/CO, as well as degree of severity.

To measure diploic changes and/or severity of cranial lesions radiographically, distinct cranial changes as outlined in Stuart-Macadam (1987a, 1987b) were assessed. These radiographic observations include a "hair-on-end" pattern, diploic thickening and outer table thinning of the cranial vault (Figure 2.3), and granular texture changes of the bone (Stuart-Macadam 1987a), all of which can be observed laterally. The radiographic appearance of CO is observed through features such as orbital rim changes, orbital roof thickening (Figure 2.4), and underdevelopment of the frontal sinuses (Stuart-Macadam 1987a). The four radiographic features utilized in this research (outer table thinning, diploic thickening, “hair-on-end” pattern, and orbital roof thickening) were chosen because they are easily recognizable and the most frequently discussed and radiographed traits pertaining to anemia.

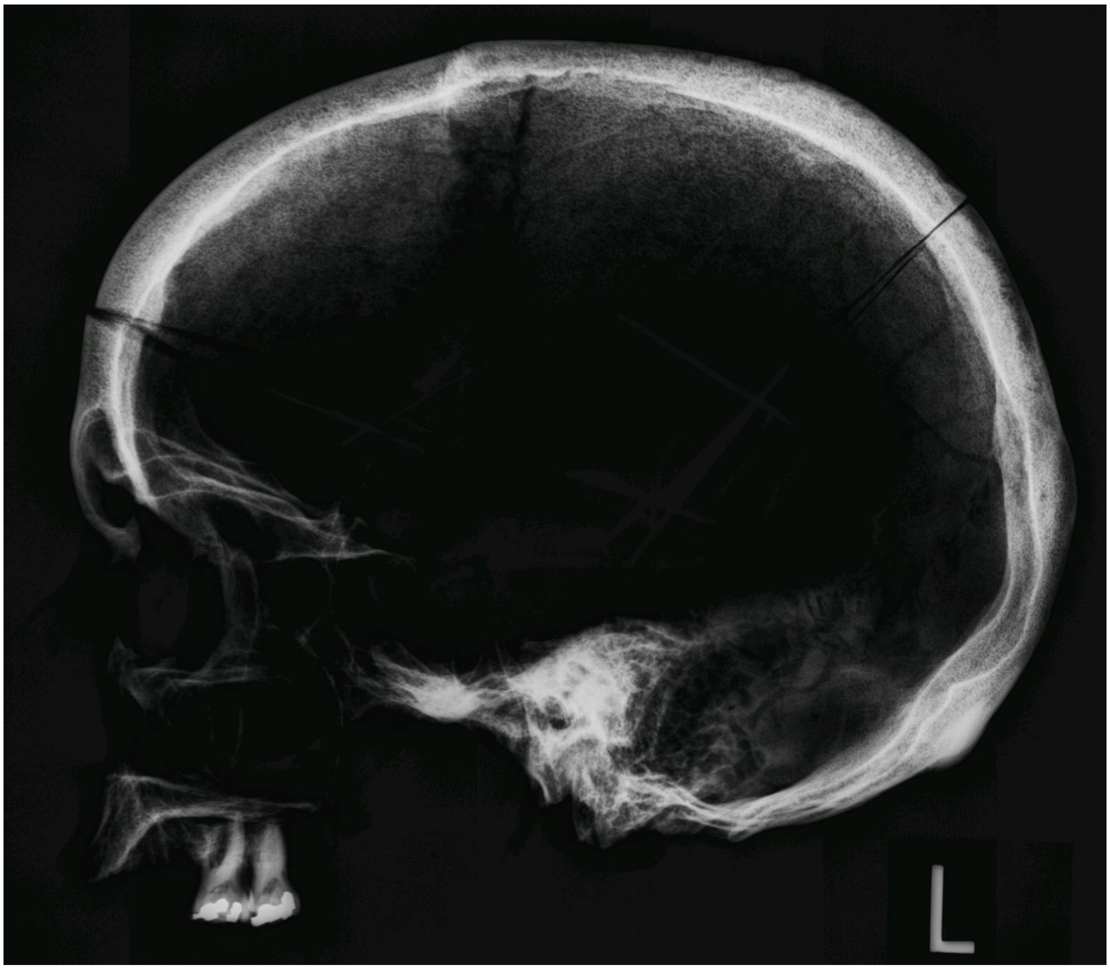


Figure 2.3 Example of the radiographic appearance of diploic thickening in the cranial vault and outer table thinning on the posterior aspect of the cranium in the Texas State University Donated Skeletal Collection

The “hair-on-end” pattern is described as a ray-like arrangement or radiating lines within the cross-section of the diploë, laid down by bony trabeculae and accompanied by the destruction of the outer table (Williams 1929; Stuart-Macadam 1987a,1987b; Ortner 2003). For a depiction of the “hair-on-end” pattern, please refer to Sebes and Diggs (1979:375). This “hair-on-end” pattern is not a common expression in anemia; only

5-10% of individuals exhibit this trait (Stuart-Macadam 1982, 1987a). However, if present, this trait likely indicates severe anemia. More common than the severe "hair-on-end" pattern, outer table thinning may occur within 20-90% of clinical radiographs and is identified when the outer compact layer of bone thins or disappears (Stuart-Macadam 1982, 1987a) (Figure 2.3). This is a result of marrow hypertrophy and the stress of the expanding diploë upon the outer table of the cranial vault (Stuart-Macadam 1987a,1987b). The expansion of diploë is caused by a hypertrophic event due to abnormal red blood cell production, which creates the response to enlarge the marrow between the inner and outer cranial vault in order to accommodate the increased hemapoietic activity (Stuart-Macadam 1987b, Mays 2012). This expansion within the cranial vault can be observed radiographically in 22% of clinical anemic patients (Stuart-Macadam 1987a) (Figure 2.3). The diploic space is thought to be 2.3 times thicker than the presented compact bone (Reynolds 1962, Sebes and Diggs 1979, Stuart-Macadam 1987a). However, the ratio between compact bone and diploic space varies in every individual due to biological factors (Stuart-Macadam 1987a). Traditionally, the macroscopic appearance of diploic thickness in addition to cranial porosities is essential to identify PH. Lastly, to assess and distinguish the presence of CO, abnormal orbital roof thickening of 3mm must be present along the horizontal plate of the frontal bone (Stuart-Macadam 1987b) as observed in lateral radiographs (Figure 2.4).

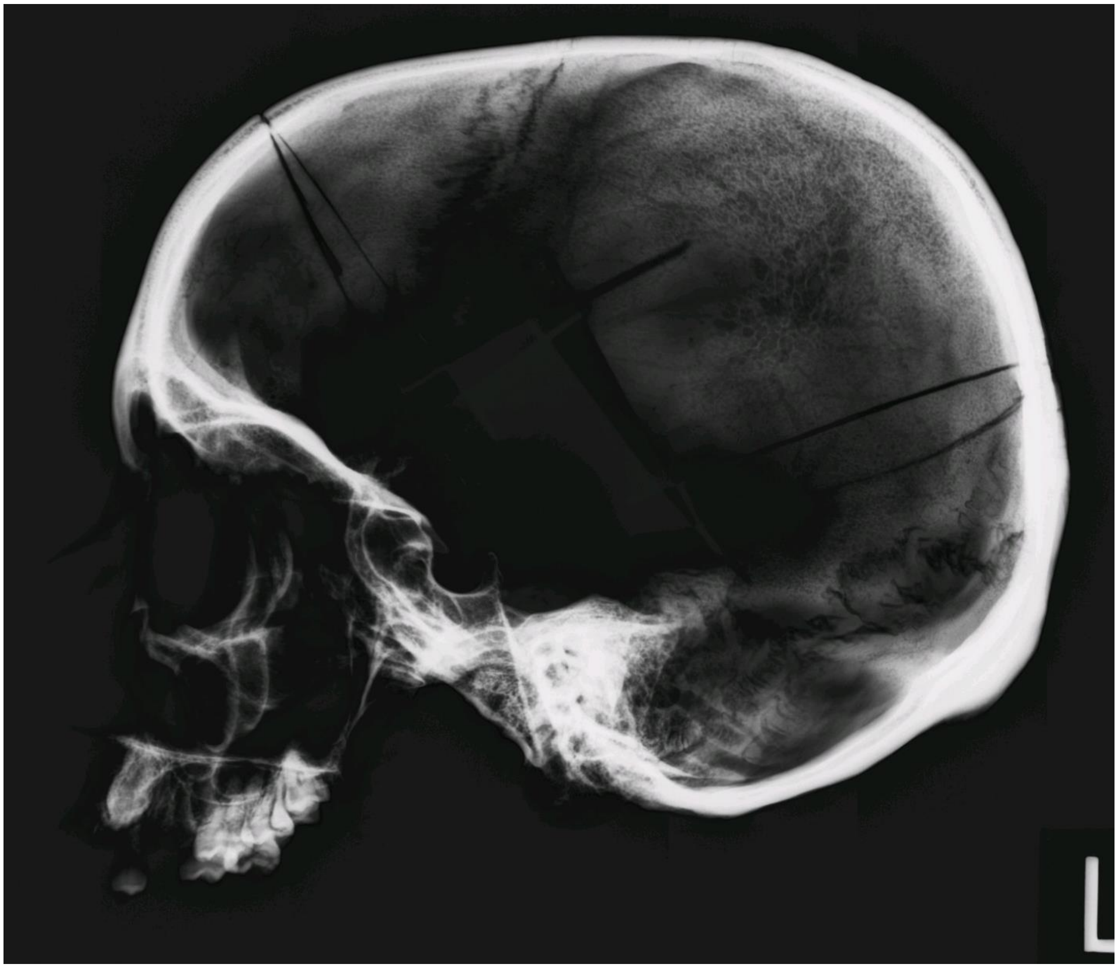


Figure 2.4 Example of the radiographic appearance of orbital roof thickening in the Texas State University Donated Skeletal Collection

Using the MinXray® machine, the crania were placed on the X-ray board at a distance of 30 inches from the collimare tube in the Frankfurt horizontal, first in an anterior-posterior position, followed by the left lateral view. The exposure rate used on the crania was set at 3.6 mAs and the kVp exposure varied from 46-54 kVps, depending on the anatomical view and density of the cranium. Milliampere seconds, or mAs, measures the exposure time of the electrical current, while kVp, or kilovolt peak, measures the energy of the electrical current (Ortner 2003) and typically the density of the radiograph produced. The mAs output controls the quality of the radiograph.

Statistical Analysis

The macroscopic and radiographic data were scored a total of three times, averaged, and entered into SPSS as binary data, 0 for absent and 1 for present. Macroscopic data was scored solely for the presence/absence of orbital/ectocranial porosities and PH; and radiographic data was scored for the presence/absence of outer table thinning, diploic thickening, “hair-on-end” pattern, and orbital roof thickening.

Age was condensed into decades (Table 2.1) and sex was converted into binary data – 0 for male and 1 for female for the analysis of macroscopic and radiographic methods as well as any intra and intergroup differences (e.g., between age groups, sex, ancestry, and socio-economic status). The following contingency tables were used to compare the macroscopic and radiographic frequencies: 1) orbital and ectocranial porosities by age, sex, ancestry, and socio-economic status, as well as the presence of PH if observed and 2) the four radiographic trait indicators (outer table thinning, diploic thickening, “hair-on-end” pattern, and orbital roof thickening) by age, sex, ancestry, and socio-economic status. This will be done in order to establish a baseline profile for the presence of radiographic indicators and/or orbital/ectocranial porosities within a sample of a modern documented skeletal collection and to assess how the rates of modern cranial porosities compare to archaeological populations in terms of degree and frequency.

Additionally, a chi-square was performed separately on the radiographic and macroscopic data to determine the expected versus observed frequencies between both methods within the sample and between sex, age groups, ancestry, and socio-economic status. A Pearson Chi-Square was used to examine the significance of the traits against age, ancestry, and socio-economic status to evaluate whether the likelihood of these observations occurred by chance. While a Fisher's exact test was used to examine the significance of the traits against sex.

The statistical analyses were performed in order to observe if the age, sex, ancestry, or socio-economic status of an individual will predict the presence of either macroscopic or radiographic indicators occurring within one of these groups at a statistically significant level. In addition to assessing whether the presence of the radiographic indicators and/or orbital/ectocranial porosities within age, sex, and ancestry is significant in order to evaluate how frequently they are observed within a documented skeletal collection with self-reported health.

III. RESULTS

Crania from the Texas State University Donated Skeletal Collection (n=50) were examined macroscopically and radiographically for the presence/absence of orbital and ectocranial porosities suggestive of porotic hyperostosis (PH) and cribra orbitalia (CO). Additionally, the following abbreviations will be used for the radiographic terms within this research: outer table thinning (OTT), diploic thickening (DPT), "hair-on-end" pattern (HE), and orbital roof thickening (ORT).

Macroscopic and Radiographic Results

Macroscopic results indicate 78% (39/50) of individuals exhibit ectocranial porosities, 16% (8/50) display orbital porosities, and 2% (1/50) exhibit porosities of a degree to be indicative of PH (Table 3.1).

Radiographically, using Stuart-Macadam's criteria, 48% (24/50) of individuals displayed outer table thinning (OTT), 24% (12/50) diploic thickening (DPT), 22% (11/50) orbital roof thickening (ORT), and no individuals displayed the "hair-on-end" pattern (HE) (Table 3.2).

Overall, no macroscopic results were statistically significant for age, sex, ancestry, or socio-economic status at $\alpha=.05$. However, when a Pearson's chi-square was performed for radiographic results within age, sex, ancestry, and socio-economic status, ORT ($p=.054$) within age was statistically significant ($\alpha=.05$) (Table 3.2). Additionally, when a Fisher's Exact was conducted for radiographic traits against sex, OTT ($p=0.12$) was statistically significant ($\alpha=.05$) (Table 3.2).

Table 3.1 Macroscopic results by age, sex, and ancestry.

		Orbital Porosities	%	Ectocranial Porosities	%	PH	%
AGE	18-20	1/2	50	2/2	100	0/2	0
	21-30	1/4	25	4/4	100	0/2	0
	31-40	1/3	33	3/3	100	0/3	0
	41-50	0/5	0	4/5	80	0/5	0
	51-60	0/5	0	4/5	80	1/5	20
	61-70	1/11	9	8/11	73	0/11	0
	71-80	1/7	14	6/7	86	0/7	0
	81-90	1/8	13	5/8	63	0/8	0
	91-100	2/4	50	3/4	75	0/4	0
	101+	0/1	0	0/1	0	0/1	0
	Pearson's p-value	.471		.568		.420	
SEX	Male	5/28	18	23/28	82	0/28	0
	Female	3/22	14	16/22	73	1/22	5
	Fisher's p-value	.498		.323		.440	
ANCESTRY	American Black	2/6	33	5/6	50	0/6	0
	American Hispanic	1/8	13	6/8	75	0/8	0
	American White	5/36	14	30/36	83	1/36	3
	Pearson's p-value	.465		.185		.820	
	Total	8/50	16	39/50	78	1/50	2

Table 3.2 Radiographic results by age, sex, and ancestry.

		Outer table thinning (OTT)	**%**	**Diploic thickening (DPT)**	**%**	**"Hair-on-end" (HE)**	**%**	**Orbital roof thickening (ORT)**	**%**
AGE	18-20	2/2	100	1/2	50	0/2	0	2/2	100
	21-30	3/4	75	0/4	0	0/4	0	1/4	25
	31-40	0/3	0	1/3	33	0/3	0	1/3	33
	41-50	2/5	40	1/5	20	0/5	0	1/5	20
	51-60	3/5	60	3/5	60	0/5	0	3/5	60
	61-70	6/11	55	3/11	27	0/11	0	0/11	0
	71-80	1/7	14	0/7	0	0/7	0	2/7	29
	81-90	5/8	63	2/8	25	0/8	0	1/8	13
	91-100	1/4	25	0/4	0	0/4	0	0/4	0
	101+	1/1	100	1/1	100	0/1	0	0/1	0
	Pearson's p-value	.186		.189		-		***.054***	
SEX	Male	9/28	32	6/28	21	0/28	0	7/28	25
	Female	15/22	68	6/22	27	0/22	0	4/22	18
	Fisher's p-value	***.012***		.439		-		.411	
ANCESTRY	American Black	2/6	33	2/6	33	0/6	0	2/6	33
	American Hispanic	4/8	50	0/8	0	0/8	0	1/8	13
	American White	18/36	50	10/36	28	0/36	0	8/36	22
	Pearson's p-value	.745		.213		-		.647	
	Total	24/50	48	12/50	24	0/50	0	11/50	22

Age

Age was broken into decade categories to capture ages ranging from 18 years of age to 101 years of age. The frequencies for orbital/ectocranial porosities, PH, and radiographic traits by decade can be seen in Table 3.1 - 3.2 and Figure 3.1 - 3.2. When a Pearson's chi-square was performed within age for macroscopic and radiographic observations, only ORT at p=.054 was statistically significant (Table 3.1 and 3.2).

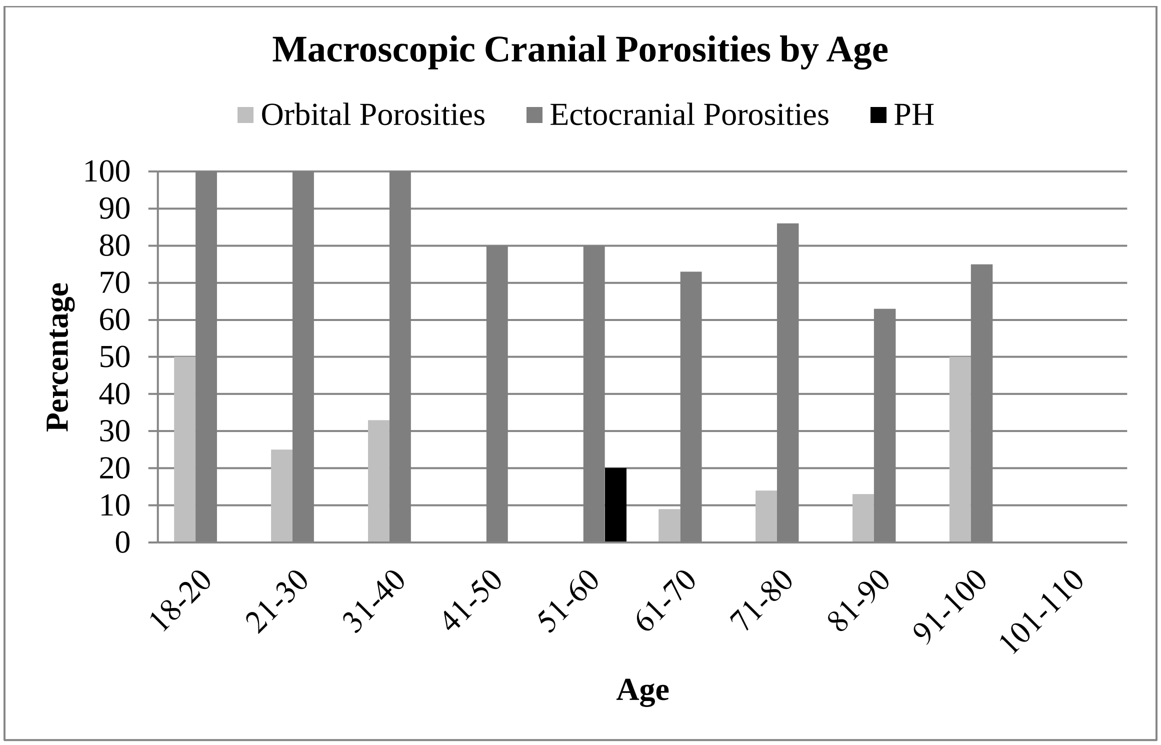


Figure 3.1 Frequency of macroscopic cranial porosities by age

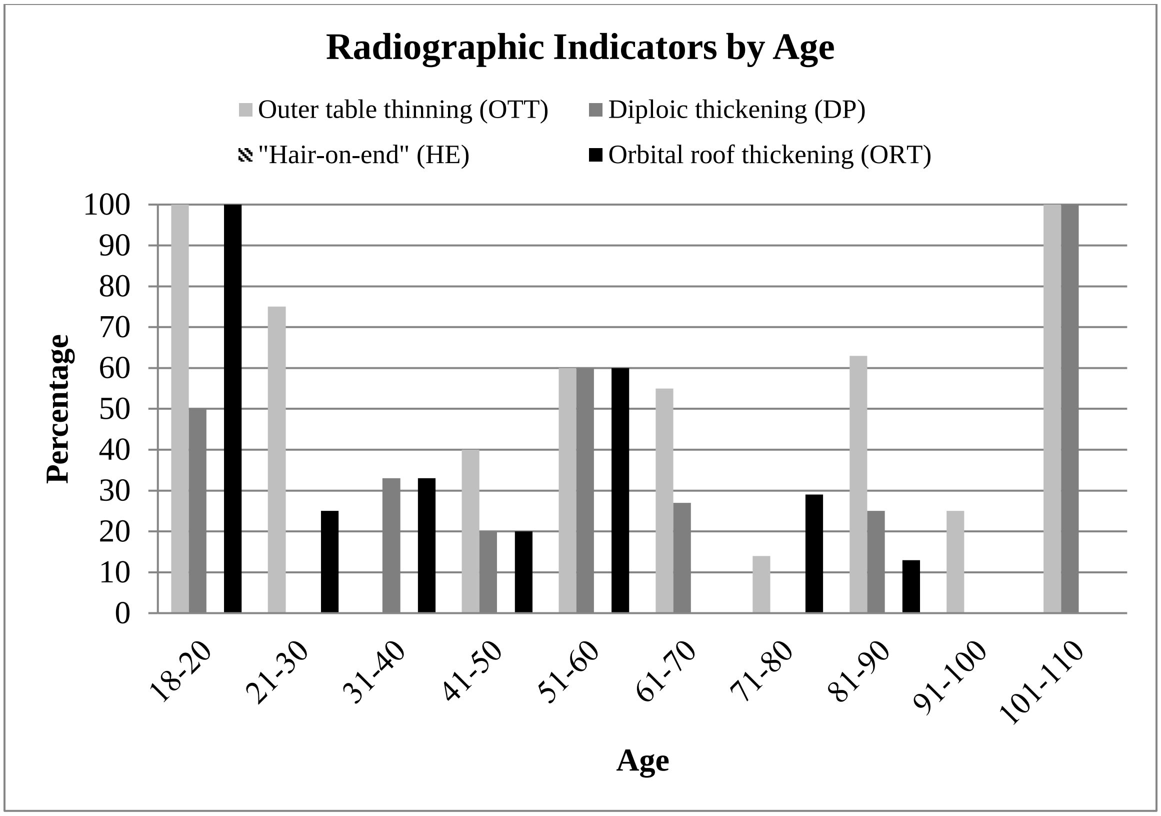


Figure 3.2 Frequency of radiographic indicators by age

Sex

When all crania were separated by sex, 18% (5/28) of males displayed orbital porosities while 82% displayed ectocranial porosities, and 0% (0/28) exhibited PH. Females exhibited orbital porosities at 14% (3/22) and ectocranial porosities at 73% (16/22), indicating a slightly lower frequency than males, although not statistically significant. Only one case of PH was present and it was observed in a female (5%, 1/22) (Table 3.1 and Figure 3.3).

Radiographically, when a Fisher's exact test was performed, only outer table thinning (OTT) was significant at p=.012 (Table 3.2 and Figure 3.3). Neither sex displayed the "hair-on-end" pattern (HE). For males, 32% (9/28) displayed OTT, 21% (6/28) diploic thickening (DPT), and 25% (7/28) orbital roof thickening (ORT). Females displayed OTT and DPT at a slightly higher percentage, with 68% (15/22) and 27% (6/22), respectively. ORT was observed at a lower rate than males at 18% (4/22).

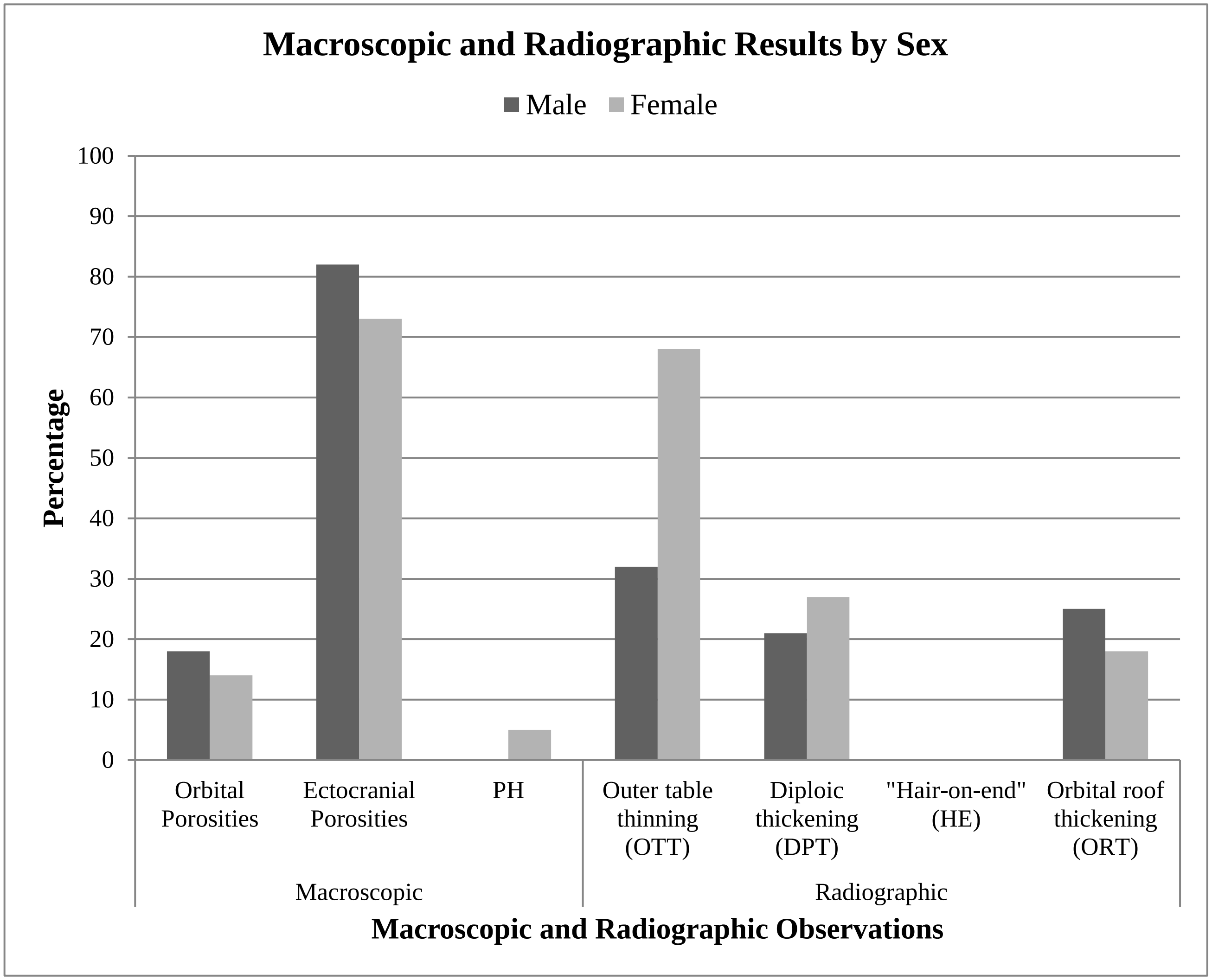


Figure 3.3 Macroscopic and radiographic frequency results by sex

Ancestry

Individuals were separated based on self-reported ancestry into American Black, American Hispanic, and American White ancestry groups (Table 3.1 - 3.2 and Figure 3.4). No ancestry group displayed the "hair-on-end" pattern (HE).

American Black individuals displayed orbital porosities at 33% (2/6), ectocranial porosities at 50% (3/6), and PH was not present. Outer table thinning (OTT), diploic thickening (DPT), and orbital roof thickening (ORT) were all observed at a frequency of 33% (2/6).

American Hispanic individuals displayed orbital porosities at 13% (1/8), ectocranial porosities at 75% (6/8), and PH was not present (0/8). OTT was noted at 50% (4/8), DPT at 0% (0/8), and ORT at 13% (1/8).

Individuals classified as American White displayed orbital porosities at 14% (5/36), ectocranial porosities at 83% (30/36), and PH at 3% (1/36). OTT was observed at rate of 50% (18/36), DPT at 28% (10/36), and ORT at 22% (11/50).

Radiographically, OTT was most frequent in American Hispanic (4/8) and American White (18/36) individuals at 50%, while DPT, ORT, and orbital porosities were present most often in American Black individuals who displayed the highest frequency (33%, 2/6). American White individuals displayed the highest frequency of macroscopic ectocranial porosities at 83% (30/36), followed by American Hispanic at 75% (6/8), and American Black at 50% (5/6). The above results for ectocranial porosities corresponds with the single case of PH observed within the American White ancestry group, since the most ectocranial porosities were located within this ancestry group; however, this was not statistically significant.

When a Pearson's chi-square was conducted for ancestry within macroscopic and radiographic frequencies, no traits were statistically significant.

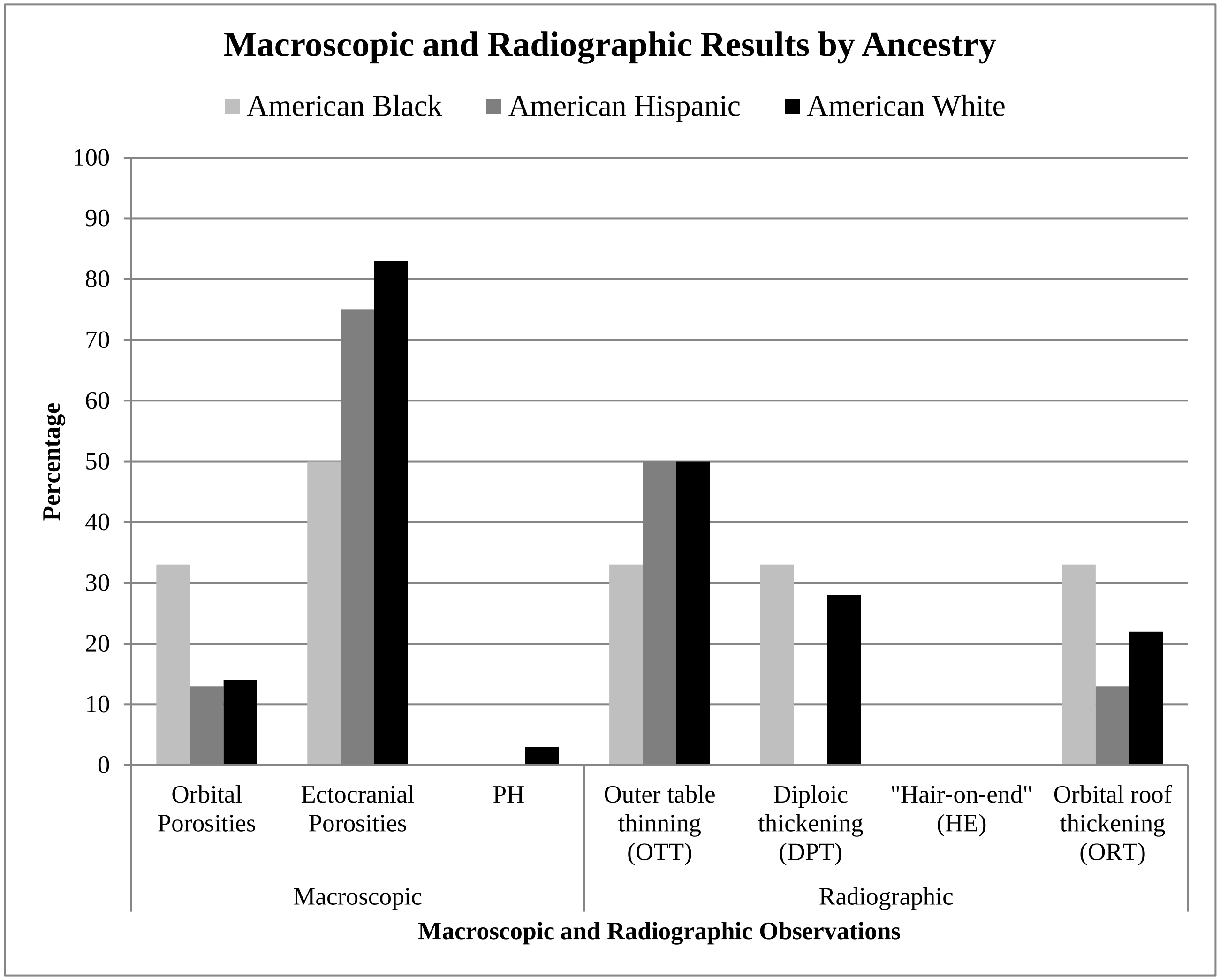


Figure 3.4 Macroscopic and radiographic results by ancestry

Socio-Economic Status

Within the Texas State University Donated Skeletal Collection, socio-economic status is self-reported. One of six fields can be marked for the optional documentation of both childhood and adult socio-economic status levels. These fields include: unknown, lower, lower-middle, middle, upper-middle, and upper class. The following macroscopic and radiographic data has been separated by childhood and adult socio-economic status and organized within those categories (Figure 3.5 - 3.8 and Table 3.3 - 3.4). Note, there were no individuals who classified themselves as upper socio-economic status during childhood. Additionally, neither macroscopic nor radiographic results for child and adulthood socio-economic status were statistically significant at $\alpha=.05$.

Socio-Economic Status - Childhood

For the macroscopic analysis, no individuals displayed cranial porosities in the unknown and lower-middle socio-economic status levels (Figure 3.5 and Table 3.3). However, lower (23%, 3/13), middle (24%, 4/17), and upper-middle (17%, 1/6) all displayed orbital porosities. All socio-economic status groups presented ectocranial porosities: unknown at 100% (3/3), lower at 69% (9/13), lower-middle at 82% (9/11), middle at 83% (14/17), and upper-middle at 67% (4/6). The single individual who presented PH classified as upper-middle socio-economic status in childhood (17%, 1/6) and as middle socio-economic status in adulthood (6%, 1/16).

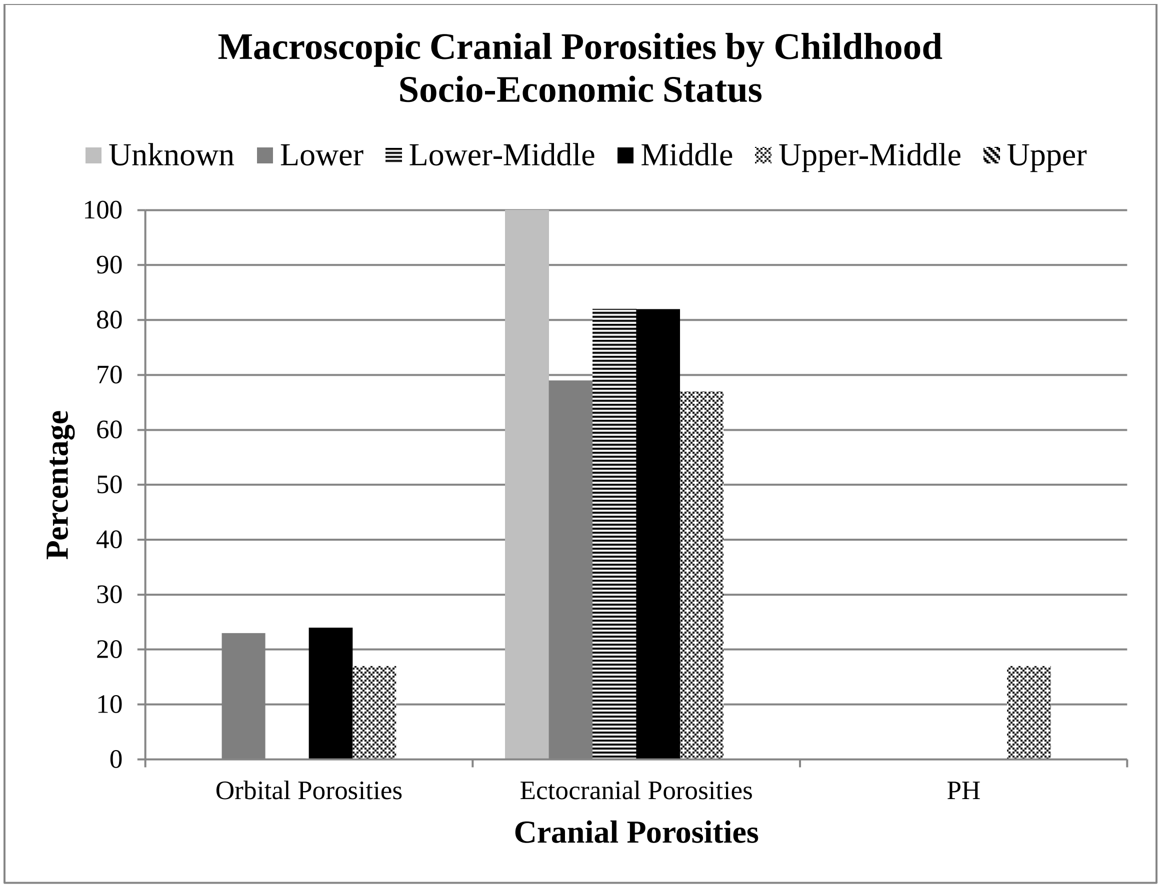


Figure 3.5 Frequency of macroscopic cranial porosities by childhood socio-economic status

Within the radiographic assessment, no individuals displayed the "hair-on-end" pattern (HE) (Figure 3.6 and Table 3.4). Outer table thinning (OTT) was present in the unknown socio-economic status level at 33% (1/3), in lower at 31% (4/13), in lower-middle at 46% (5/11), in middle at 59% (10/17), and in upper-middle at 67% (4/60). Diploic thickening (DTT) was seen within the unknown socio-economic status level at 33% (1/3), in lower at 8% (1/13), in lower-middle at 36% (4/11), in middle at 24% (4/17), and in upper-middle at 33% (2/6). Lastly, orbital roof thickening (ORT) was observed in the unknown socio-economic status level at 0% (0/3), in lower at 15% (2/13), in lower-middle at 27% (3/11), in middle at 35% (3/16), and 0% within upper-middle (0/6) (Figure 3.6).

When a Pearson's chi-square was performed for socio-economic status, neither macroscopic nor radiographic p-values were statistically significant.

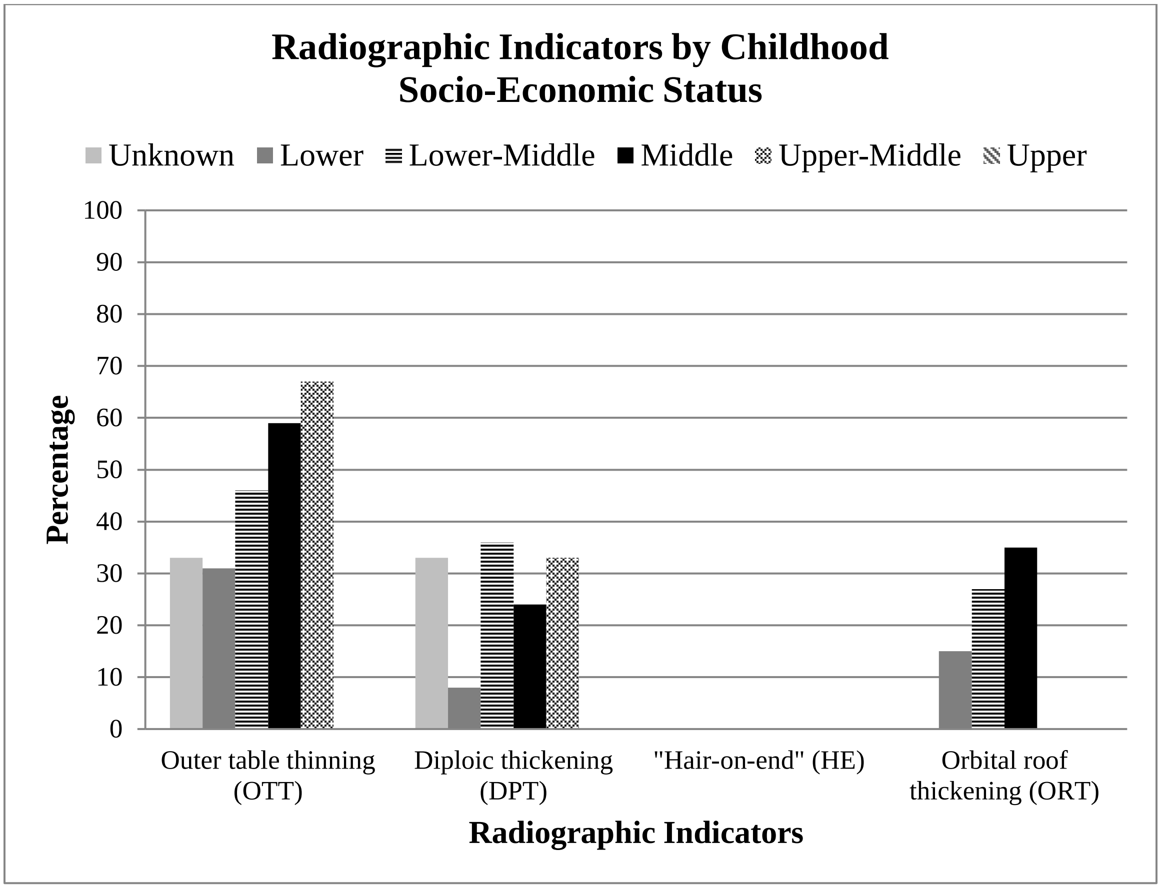


Figure 3.6 Frequency of radiographic indicators by childhood socio-economic status

Socio-Economic Status - Adulthood

When adult socio-economic status was assessed for macroscopic lesions, 18% (2/11) of unknown, 10% (1/10) of lower-middle, 25% (4/16) of middle, and 20% (1/5) of upper-middle exhibited orbital porosities, while neither lower (0/7) or upper (0/1) socio-economic status individuals presented orbital porosities (Figure 3.7 and Table 3.3).

Ectocranial porosities were present at 73% (8/11) in unknown, 71% (5/7) in lower, 80% (8/10) in lower-middle, 88% (14/16) in middle, 60% (3/5) in upper-middle, and 100% (1/1) in upper socio-economic status levels. One individual who reported as middle socio-economic status presented PH (6% or 1/16).

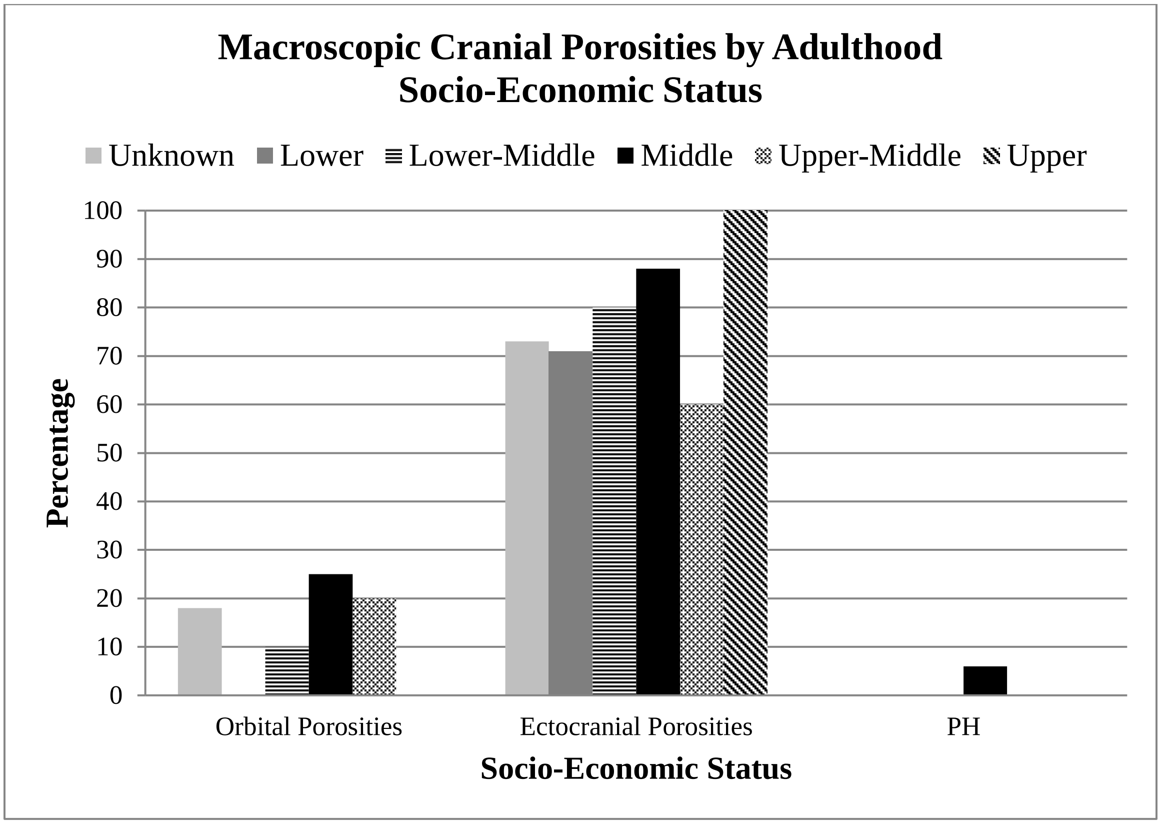


Figure 3.7 Frequency of macroscopic cranial porosities by adulthood socio-economic status

Radiographically, OTT was observed at 46% (5/11) in unknown, 57% (4/7) in lower, 50% (5/10) in lower-middle, 44% (7/16) in middle, 60% (3/5) in upper-middle, and 0% (0/1) in upper socio-economic status individuals (Figure 3.8 and Table 3.4). DPT was present at 27% (3/11) in unknown, 14% (1/7) in lower, 40% (4/10) in lower-middle, 19% (3/16) in middle, 20% (1/5) in upper-middle, and 0% (0/1) in upper socio-economic status categories. Lastly, ORT was seen in 18% (2/11) of unknown, 29% (2/7) of lower, 10% (1/10) of lower-middle, 25% (4/16) of middle, 20% (1/5) in upper-middle, and 100% (1/1) of upper individuals.

When a Pearson's chi-square was performed on individuals within socio-economic status for the macroscopic and radiographic analyses, neither assessment was statistically significant.

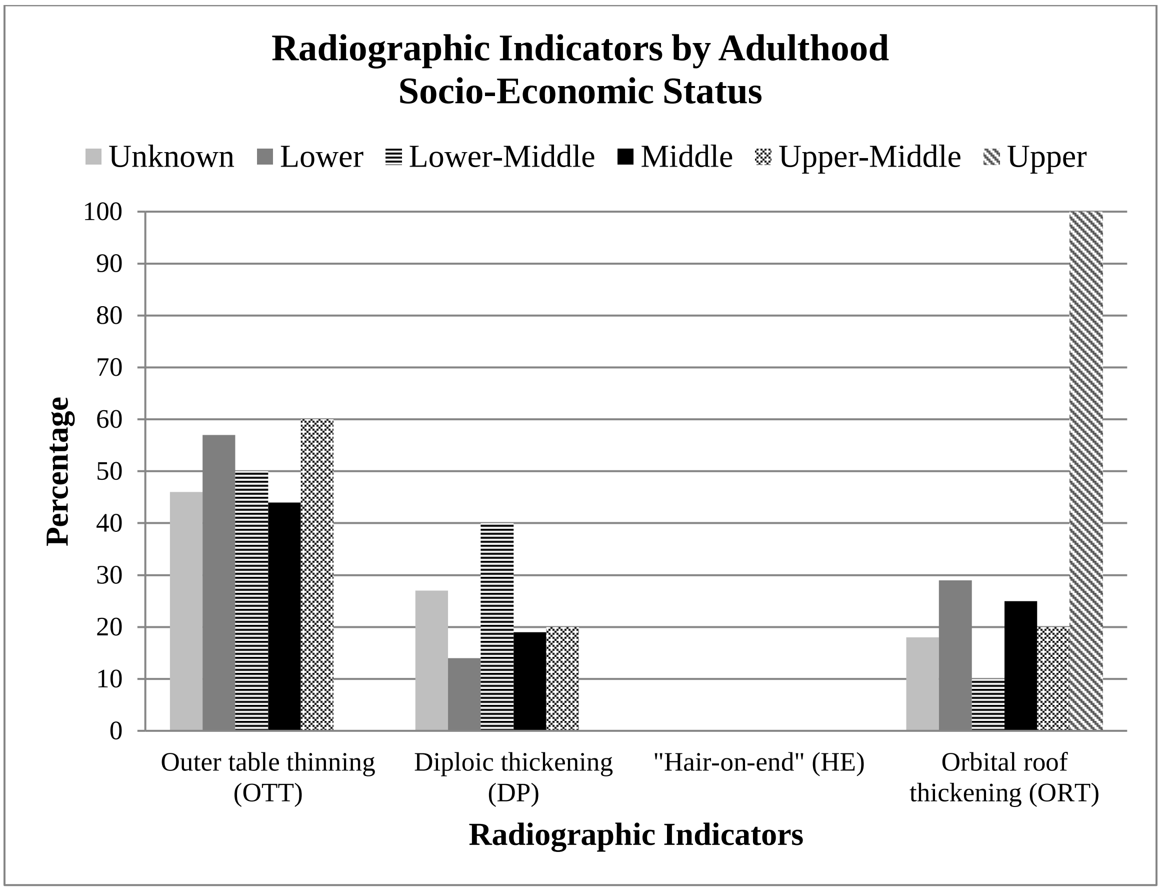


Figure 3.8 Frequency of radiographic indicators by adulthood socio-economic status

Table. 3.3 Macroscopic results by socio-economic status

		Orbital Porosities	%	Ectocranial Porosities	%	PH	%
SOCIO-ECONOMIC STATUS	**Unknown**						
	Child	0/3	-	3/3	100	0/3	-
	Adult	2/11	18	8/11	73	0/11	-
	Lower						
	Child	3/13	23	9/13	69	0/13	-
	Adult	0/7	-	5/7	71	0/7	-
	Lower-Middle						
	Child	0/11	-	9/11	82	0/11	-
	Adult	1/10	10	8/10	80	0/10	-
	Middle						
	Child	4/17	24	14/17	82	0/17	-
	Adult	4/16	25	14/16	88	1/16	6
	Upper-Middle						
	Child	1/6	17	4/6	67	1/6	17
	Adult	1/5	20	3/5	60	0/5	-
	Upper						
	Child	0/0	-	0/0	-	0/0	-
	Adult	0/1	-	1/1	100	0/1	-
	Pearson's p-value						
	Child	.424		.707		.112	
	Adult	.722		.785		.825	

Table 3.4 Radiographic results by socio-economic status

		Outer table thinning (OTT)	%	Diploic thickening (DPT)	%	"Hair-on-end" (HE)	%	Orbital roof thickening (ORT)	%
SOCIO-ECONOMIC STATUS	**Unknown**								
	Child	1/3	33	1/3	33	0/3	-	0/3	-
	Adult	5/11	46	3/11	27	0/11	-	2/11	18
	Lower								
	Child	4/13	31	1/13	8	0/13	-	2/13	15
	Adult	4/7	57	1/7	14	0/7	-	2/7	29
	Lower-Middle								
	Child	5/11	46	4/11	36	0/11	-	3/11	27
	Adult	5/10	50	4/10	40	0/10	-	1/10	10
	Middle								
	Child	10/17	59	4/17	24	0/17	-	6/17	35
	Adult	7/16	44	3/16	19	0/16	-	4/16	25
	Upper-Middle								
	Child	4/6	67	2/6	33	0/6	-	0/6	-
	Adult	3/5	60	1/5	20	0/5	-	1/5	20
	Upper								
	Child	0/0	-	0/0	-	0/0	-	0/0	-
	Adult	0/1	-	0/1	-	0/1	-	1/1	100
	Pearson's p-value								
	Child	.483		.517		-		.309	
	Adult	.900		.787		-		.447	

IV. DISCUSSION

Cranial and orbital porosities, in the form of porotic hyperostosis (PH) and cribra orbitalia (CO) are frequently identified and discussed in bioarchaeological contexts linked to the transition of agriculture in association with increasing sedentism, change in subsistence, and/or increasing parasitic infection loads (Stuart-Macadam 1992, Roberts and Manchester 2005, Bonogofsky 2011). To understand the past lifeways and overall health of a population, bioarchaeological researchers utilize a biocultural approach to understand the broad causations of ill health through the use of nutritional stress indicators, which are heavily influenced by lifestyle. Seldom are these cranial porosities discussed in relationship to modern individuals, likely due to the availability of adequate nutritional resources, access to general healthcare, or the fact that the lowest socio-economic status level today is not equal to the lowest status level during the transition to agriculture.

Thus, the middle to high prevalence of cranial porosities (16% for orbital and 78% for ectocranial porosities) seen within the Texas State University Donated Skeletal Collection was unexpected and not as severe as those seen within antiquity, given that the rates of these porosities typically observed among archaeological populations are likely due to lack of access to modern foods/supplements. The potential for these markers to be over diagnosed and overrepresented in bioarchaeological research could be attributed to the severity of porosities typically observed in the past.

The frequency of these lesions seen within this modern skeletal collection is noteworthy (although not statistically significant), since the presence of these porosities has been used in the past to indicate a skeletal sample inflicted with various non-specific infections, stressors, or nutritional deficiencies, chief among them iron-deficiency anemia. In this study, no case of cranial porosities was classified as severe, only mild to moderate cranial pitting was present, and only one case of PH was identified macroscopically. The presence of these cranial porosities throughout the modern sample indicates the presence of these markers may be related to or influenced by factors beyond diet such as socio-economic status, age, intrinsic health, or sex differences.

The radiographic appearance of these cranial porosities can enhance the understanding of the changes occurring at the macroscopic level. Solely establishing the presence of cranial porosities macroscopically within a sample may only graze the surface of what information could be obtained. Through the use of radiographs, analyzing the degree or severity of these porosities may garner more fine-grained results.

Some researchers believe the radiographic traits outlined in Stuart-Macadam (1987a, 1987b) are an indication of severe anemia and are utilized as such (Roberts and Manchester 2005, and Piperata *et al*. 2014). Severe or obvious anemia was not found in this modern skeletal sample, although ectocranial porosities were the predominant pathology recorded, the “hair-on-end” (HE) pattern (the sole radiographic indicator of severe anemia) was not present, and is rarely documented (Reynolds 1962). The other three radiographic traits (outer table thinning (OTT), diploic thickening (DPT), and orbital roof thickening (ORT)) observed in this research do not suggest severe anemia because of their frequency in clinical anemic patients (Reynolds 1962). Contrastingly, these radiographic traits indicate that the degree of activity occurring within the diploë is not apparent macroscopically. As the outer table gives way to trabecular changes that are occurring in the diploë, cranial remodeling activity is appearing between the outer and inner tables which could indicate the presence of metabolic stress or PH. Furthermore, mild to moderate forms of PH may be present in the 24% of individuals who displayed DPT in conjunction with ectocranial porosities, falling above the range noted by Stuart-Macadam (1987a) at 22%.

These potential cases of mild or moderate PH may not have had enough marrow hypertrophy present to be observed macroscopically, and thus could only be assessed radiographically. Active orbital porosities were present in 72% of individuals who displayed ORT, confirming the relationship between radiographic indicator and orbital lesion, although not statistically significant. OTT was present in 48% of individuals, falling within the 20-90% range of clinical anemic patients who similarly displayed these traits (Stuart-Macadam 1987a). Therefore, positive findings of the radiographic indicators (with the exception of HE) does not necessarily suggest the presence of severe anemia, but it may indicate that anemia is currently present, or was once present.

Macroscopically, while males exhibited cranial porosities more frequently than females in this research, one female did display the only case of PH within the skeletal sample. These findings are dissimilar to previous research findings, where women have been noted to exhibit higher frequencies of cranial porosities (Stuart-Macadam 1985). However, the small sample size used in this study must be kept in mind, and this finding could be an anomaly. A study conducted on living populations found women were four times more likely to be anemic than males, with their risk increased during pregnancy and breast-feeding (Piperata *et al*. 2014). Although females are more likely to exhibit these specific stress markers, the high occurrence of cranial porosities macroscopically within this male sample may indicate other causal factors such as non-specific infection and/or chronic disease at higher rates, or the presence of these porosities may correlate with the age or the socio-economic status of the sample. In addition to orbital porosities being more prevalent in males, the radiographic appearance of ORT was also shown to appear more frequently in males, corresponding with macroscopic observations.

While females did not display cranial porosities as frequently as males, they did exhibit more radiographic cranial vault remodeling as indicated by the appearance of OTT and DPT. Because the appearance of these two traits are more frequent among females, it might also be assumed that they would display more ectocranial porosities. However, this research did not support this assumption. It is unclear why females exhibited OTT at higher rates than males at a statistically significant rate (p=.012), because males displayed more macroscopic lesions. Throughout the paleopathological literature, females are believed to be more susceptible than men due to differences in nutritional absorption as a result of biological processes (i.e., menstruation, pregnancy, and lactation (Piperata *et al.* 2014)), chronic infections, or disease (Blom *et al.* 2005, Walker *et al.* 2009). The statistically significant presence of OTT between sex in this sample may be a remnant of these processes from early life or childhood. As the women aged, there was more time for the cranial vault to remodel macroscopically and heal any ectocranial porosities that were once present. Therefore, radiographically, OTT may be a remnant of healed ectocranial porosities, indicating the individual potentially experienced a stressful life event or chronic condition that led to the formation of these defects. Similarly, clinical studies have reported that bone alterations observed in the skull, spine, and pelvis can remain and may not regress with age, unlike changes in the extremities (Caffey 1951, Sebes and Diggs 1979, Stuart-Macadam 1985). This discovery suggests that the presence of these radiographic traits may show that both active and healed lesions may have been present at some point in an individual's lifetime.

For differences within ancestry groups, it was speculated that the majority of cranial porosities might be more prominent in one ancestral group over another (Mann and Hunt 2005), possibly as an effect of socio-economic status. American White individuals displayed ectocranial porosities and OTT most frequently (Table 3.1 and Figure 3.4) while American Black individuals displayed orbital porosities, DPT, and ORT more so than any other group (Table 3.1 - 3.2 and Figure 3.4). The high presence of orbital porosities, as well as two radiographic traits, within the American Black group may directly relate to socio-economic status because the majority of individuals in this group reported being members of low and/or middle socio-economic status groups in adult or childhood. The American Black results could also likely be skewed by the small sample size within this research, as only six individuals were present for analysis. The American White results may relate to the larger sample size for this ancestry group (n=36), or the overall socio-economic status of the American White sample, since the majority of individuals self-reported as middle socio-economic status for both child and adulthood.

Lastly, American Hispanics displayed the second highest frequency for ectocranial porosities and the least amount of orbital porosities; however, this is not statistically significant. The causation of cranial porosities within American Hispanics is difficult to assess and understand because the sample size was also small (n=6). All American Hispanic donors were above the age of 61 at time of death, and half of the donors (3/6) did not list their adult socio-economic status, and of those who listed a childhood socio-economic status, none were above middle socio-economic status. It is not understood whether the results in this research are related to their self-reported socio-economic status group, age at death, or other factors such as cultural differences in diet and nutrition.

When socio-economic status was taken into account for both macroscopic and radiographic observations (Figure 3.5 - 3.8 and Table 3.3 - 3.4), the middle class socio-economic status group most often presented the highest frequency for macroscopic observations in both childhood and adulthood periods. For radiographic observations, there was a relationship between socio-economic status and life history stage (adult or child) for each radiographic trait. In both adult and childhood, OTT was most prevalent in the upper-middle socio-economic status category. Similar to DPT, lower-middle socio-economic status was most frequent in both child and adulthood. However, ORT did not present the same pattern. In childhood, the middle socio-economic status group presented ORT the most, while in adulthood it was the lower socio-economic status category. Overall, this demonstrates that radiographic indicators may not be a good assessment of socio-economic status.

Since the majority of macroscopic observations fell within the middle socio-economic status group, and radiographic observations spanned all three middle socio-economic status categories (lower-middle, middle, and upper-middle), this analysis demonstrates how potentially unreliable socio-economic status is in predicting the overall health of a group, and that the causes for these porosities are likely multifactorial and not attributable to single causes such as diet. Research on anemia status in living peoples in conjunction with socio-economic status found similar results in which anemia was a poor predictor of economic status (Piperata *et al*. 2014). Additionally, the range between lower-middle to upper-middle socio-economic status varies extensively depending on family unit and their social or cultural circumstances. The fact that the majority of these individuals fell within one of the three self-reported middle socio-economic status groups may indicate, just as in biological variation, there is more variation within groups than between them, and it may be due to a variable that is unknown, such as diet, cultural factors, or individual frailty (Piperata *et al*. 2014). Additionally, consideration must be given to the possibility that self-reported socio-economic status may not have been an accurate reflection of true socio-economic status, since it is a subjective category that asks individuals to choose from fluid categories versus absolute income levels.

Relating the above socio-economic status information into archaeological contexts, when utilizing status in archaeological populations it is important to understand the context of the population when making inferences based on the presence of pathologies (Goodman and Martin 2002) in relation to presumed status, as the pathology could be occurring due to differing ecological or cultural circumstances. One would think the presence and severity of pathologies would correspond with the level of social ranking, however, this was not the case as Paine *et al*. (2007) discovered that individuals observed in high-ranking status positions were not protected from common health problems occurring in antiquity. This example, in addition to the information previously presented on socio-economic status, supports the notion that modern socio-economic status or status ranking among past peoples may not correctly report the level of perceived health in individuals.

Multiple researchers have speculated orbital porosities (e.g. CO) may be a less severe precursor of PH, and are an indicator of childhood anemia observed within juveniles (Stuart-Macadam 1985), while ectocranial porosities were commonly found in middle-aged individuals (Mann and Hunt 2005). As the majority of the modern sample used in this research was of older age (61-101 years of age), a future test of this observation between middle-age (possibly 41-60 years old) individuals and ectocranial porosities should be conducted.

Since age at death has been documented for the Texas State University Donated Skeletal Collection, the author also wanted to examine which age category exhibited the majority of ectocranial porosities. When individuals were separated into age decades for this research, the high frequency of ectocranial porosities throughout all age categories became apparent, indicating that ectocranial porosities are not confined to only middle-aged individuals (Table 3.1 and Figure 3.1). In fact, individuals aged 18-40 displayed ectocranial porosities at a rate of 100%, while the rest of the sample did not reach below 63%, excluding the 101-110 age category with only one individual. This research highlights that ectocranial porosities are not necessarily confined to older age categories.

Of the 50 individuals in this study who were analyzed for cranial porosities, 39 (78%) displayed ectocranial porosities, eight (16%) displayed orbital porosities, five (10%) displayed both orbital and ectocranial porosities, and the single case of PH (2%) did not exhibit orbital porosities. ORT is statistically significant within age and is observed at 100% in those between 18-20 years of age. Additionally, there was a high frequency of OTT (at 100%) in the younger (18-20) (2/2) and older age groups (101-110) (1/1). This combined sample size of three may be too small to report observations, however, the presence of OTT in the older individual may be consistent with old age as this individual did not exhibit ectocranial porosities.

The high occurrence of ectocranial porosities and the low frequency of orbital porosities in this sample, in addition to the significance of ORT by age, may support the original idea that CO is more commonly found among younger individuals. However, the notion that PH may be a more severe form of CO is not supported in this research, as the single individual who displayed PH did not exhibit orbital porosities.

The presence of ectocranial porosities in this research, aside from being a potential PH precursor, may also be attributed to a host of other factors that may not be related to diet. These include metabolic disturbances such as the low intake or poor absorption of micronutrients, menstruation, pregnancy, and/or lactation (Piperata *et al.* 2014:218) in women. Additionally, cancers, infectious diseases, toxin exposure (Walker *et al*. 2009, Piperata *et al.* 2014), parasitic infection (Stuart-Macadam 1992), or environmental contexts (Piperata *et al.* 2014) may correspond to the presence of these cranial porosities. It is even possible that the manifestation of these ectocranial porosities may be attributed to human variation as a result of individual frailty (Piperata *et al.* 2014) and genetic dispositions (Mensforth *et al.* 1978) such as thalassemia or sickle cell anemia (Roberts and Manchester 2005), which most probably does not occur within this collection due to geographic location. Additionally, as 78% of individuals exhibited ectocranial porosities, the presence of these porosities could just be another form of human variation that commonly occurs in “normal” crania (Mann and Hunt 2005:20).

However, the presence of these cranial porosities within the Texas State University Donated Skeletal Collection may be strongly related to metabolic deficiencies while a smaller subset of the sample may exhibit mild or moderate forms of anemia, as nearly 2 billion people are afflicted with some form of anemia around the world, half of which is caused by iron-deficiency anemia (World Health Organization 2014, 2016). It is worth mentioning, that within the Texas State University Donated Skeletal collection, individuals did not report if they suffered from anemia in their past medical history. Therefore, there is no definitive medical/clinical diagnosis of anemia within any individuals utilized in this study. Thus, these cranial porosities are most likely attributed to nutritional deficiencies, metabolic disturbances, or non-specific infections.

The profile established within this contemporary skeletal collection is a moderate profile given that 78% and 16% of individuals displayed ectocranial and orbital porosities, respectively, no HE pattern was present, and only one case of PH was identified; dissimilar to archaeological individuals who display prominent porosities and marrow expansion at higher frequencies. Additionally, the degree of macroscopic cranial porosities in this sample was not as extreme in severity as bioarchaeological examples most probably due to sanitation and environmental differences. It is interesting to note the parallel between the high prevalence of iron-deficiency anemia seen within modern populations and the severity of PH in antiquity. Therefore, this observation can allow researchers to extrapolate the effect this nutritional stress indicator has/had on past peoples and their life history (Goodman and Martin 2002).

It must be of note that within bioarchaeology the presence of skeletal stress indicators may not necessarily indicate an unhealthy individual, but one that has successfully adapted to their stressful environmental and are relatively healthy. Conversely, the lack of skeletal lesion responses may in fact be representative of an unhealthy individual who was unable to acclimate to their environment and died before the stress indicators could occur. However, it is unclear how this osteological paradox (Wood *et al.* 1992) fits into contemporary populations because individuals now live relatively long lives, socio-economic status is not a good predictor of health, and the lowest form of modern access to general health care and nutritional resources is sufficient compared to archaeological populations during the transition to agriculture.

Macroscopic versus Radiographic Assessment

In this research, both macroscopic and radiographic analyses were performed to evaluate the most accurate method of assessing the presence of cranial porosities. Macroscopic observations are typically the primary method when observing and identifying pathologies as it is quick, inexpensive, and fairly effective, and requires no additional technology or operator skills. However, with the use of x-ray machinery and radiographs, researchers can go a step further and obtain a glimpse of the changes occurring within the cranium to assess the degree or severity of these pathological alterations. The limitations of using the radiographic method include the availability and accessibility of x-ray machinery, the time investment related to performing and analyzing radiographs, and possible location-based restrictions if a skeletal collection cannot be transported elsewhere or the researcher is in a remote location. However, if x-ray machinery is available, utilizing both forms of methodology will enhance the researcher's ability to diagnose or conceptualize what is occurring within the bones.

Macroscopic observations were found to be more efficient and diagnostically effective than radiographic techniques in the analysis of active cranial lesions, and were quicker than taking and analyzing radiographs. However, the use of radiographs allowed the researcher to assess the severity or degree of porosities based upon various radiographic traits outlined in Stuart-Macadam (1987a). Using radiographic methods as the sole form of diagnosis is not recommended, since it was found that macroscopic evaluations allowed the researcher to recognize and record cranial porosities more accurately than when using radiographs. However, utilizing both methods is advised in order to fully assess the presence, severity, and frequency of cranial porosities. Using both methods also allows the researcher to better recognize patterns and implications occurring within the sample (i.e. severe anemia when “hair-on-end” (HE) pattern is present) and to prevent the underestimating of frequencies when only using one method.

While macroscopic observations may be the preferred choice over radiographs, they each have their difficulties and challenges when it comes to assessing cranial porosities. Issues the author discovered during analysis predominantly surround the radiographic method. X-ray settings were difficult to establish with the portable MinXray® machine, but once the correct ranges for both mA and kVp were effectively assessed, taking multiple x-rays at a time in anterior-posterior and lateral positions was relatively quick. Having little to no prior exposure taking or interpreting radiographs, the author found that the initial analysis was difficult to assess when looking for the appearance of the four radiographic traits simply based on the Stuart-Macadam (1987a) guidelines alone. However, as with most things, after observing many radiographs over extended periods of time, identifying the radiographic indicators became much easier.

Outer table thinning (OTT) and diploic thickening (DPT) became easier to identify with experience, or when either trait was prominent. Orbital roof thickening

(ORT) was more difficult to observe and it was harder to recreate similar measurement criteria used by Stuart-Macadam (1987a), but prominent cases of ORT were very apparent. After analyzing many radiographs, the researcher noticed most of Stuart-Macadam's radiographic traits could be interpreted in multiple ways, and creating better definitions and photographs to document each trait would be beneficial for future use.

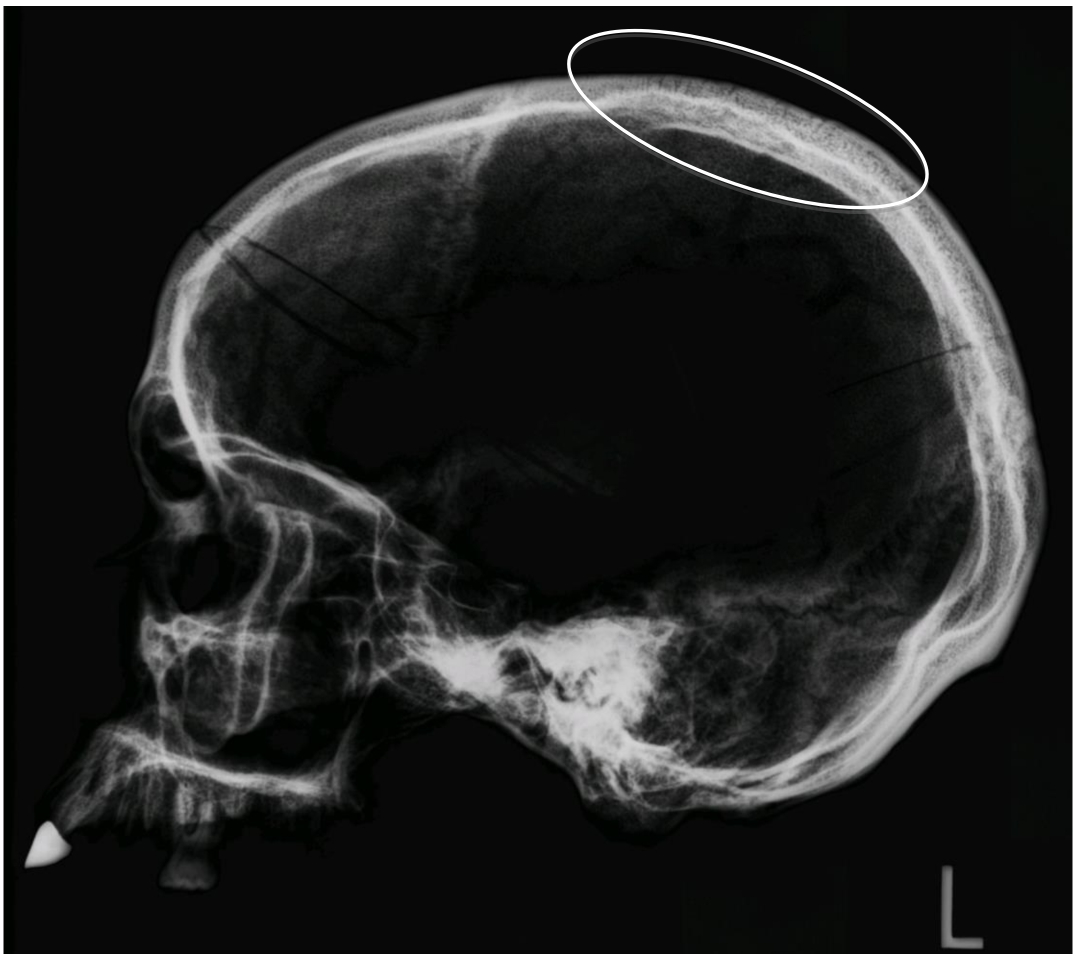


Figure 4.1 Example of the serrated appearance of the sagittal suture in lateral radiographs within the Texas State University Donated Skeletal Collection

For instance, the HE pattern is a very distinct trait that does not manifest often. This radiographic trait can easily be misdiagnosed as present, when in fact, the serrated appearance within the midparietal area observable in lateral radiographs is actually the sagittal suture (Reynolds 1962) (Figure 4.1). Because of this misinterpretation, the author cautions researchers to observe whether the striations are confined to the midparietal region and to observer whether they only extend to the outer table, which is characteristic of the sagittal suture as viewed radiographically. If these vertical striations go beyond the outer table and extend throughout the cranial vault, the HE pattern is most likely present within the individual.

Stuart-Macadam (1987a) noted a granular texture change of the frontal or parietal bones of the cranial vault that has also been identified by other researchers (Reynolds 1962, Simon 1965). This trait can occur within 25-50% of patients radiographed with documented anemia, and is thought to be the earliest manifestation of marrow expansion (Reynolds 1962, Stuart-Macadam 1987a). Before beginning this research, it was thought that this trait would be difficult to assess, and subsequently up to the interpretation of the researcher. Therefore, the author chose not to utilize this trait. After analyzing many radiographs, the author did notice the occasional presence of this trait, and this suggests additional analysis of this feature for future investigation.

Of the seven traits originally compiled by Stuart-Macadam (1987a), the ones chosen for this research were all observed at varying levels, with the exception of HE pattern. Overall, in conjunction with macroscopic analysis of cranial porosities, the author would recommend the use of the four radiographic traits utilized in this thesis (OTT, DPT, HE, and ORT) and suggests the inclusion of these radiographic traits in future studies.

Terminology and Description

Throughout this research, the author found that the lack of standardized descriptions and definitions were an impediment, and lead to misdiagnoses or miscategorizations. Without solid definitions and associated photographic examples, these pathologies can be interpreted in many ways, and the learning curve can be steep and is contingent on the experience of the researcher. For lesser-experienced researchers, understanding the etiology, description, and manifestations of these lesions is essential for diagnosis using both macroscopic and radiographic methods.

Ortner (2003) discusses the importance of terminology and understanding descriptive distinctions between bone changes. For instance, PH was originally a term used by Angel in 1966 to describe “any porous enlargement of bone tissue” (Ortner 2003:55) but has since become associated almost exclusively with the term iron-deficiency anemia. While early paleopathologists were initially careful in the identification of PH by confirming the presence of marrow hypertrophy, over time a divergence occurred between the paleopathological and clinical literature; with paleopathologists emphasizing the porotic aspect, and clinicians still emphasizing hyperostosis (Mays 2012:292). The ubiquity of these porosities in antiquity may be related to the separation of this terminology and the overemphasis of the term porotic, in addition to the easy assessment of these porosities on dry crania (Mays 2012). Thus, PH has since taken on the specific pathological definition of anemic alterations occurring within the cranium, predominantly on the cranial vault and/or superior eye orbits. However, for anemic reactions, both bone formation and destruction must take place, and understanding whether abnormal osteoblast or osteoclast activity has occurred is also important in understanding the pathology (Ortner 2003).

The author agrees with these caveats regarding manifestation, definition, and etiology made by Ortner (2003) and Mays (2012), and proposes that paleopathological researchers should take care to stress that PH is not necessarily associated exclusively with anemia, unless marrow hypertrophy is also present. Unless marrow hypertrophy can be observed macroscopically, radiographic assessments must also be performed to confirm the presence of bone formation in addition to bone destruction, which is typical of anemic reactions. If not present, the term PH should retain its original definition as a porous enlargement of bone, or else the general term “ectocranial porosity” or “cranial pitting” should be utilized to infer non-specific defects not necessarily indicative of anemia.

Additionally, when searching for comparative examples of PH or CO to use during the course of this research, the author found that sufficient photographic evidence exists for crania exhibiting extreme or severe porosities, but this was not the case for mild or moderate forms of PH or CO. The display of extreme PH and CO cases referenced throughout the paleopathological literature makes understanding what mild or moderate forms of PH and CO may present as very difficult for inexperienced observers, potentially promoting the underrepresentation of these diagnoses (Jacobi and Danforth 2002). Because extreme cases are documented at higher rates, researchers are likely losing valuable data if crania do not display the classical PH and CO lesions typically referenced in bioarchaeological publications. In turn, this lack of standardization makes the comparison of pathological frequencies across populations difficult (Jacobi and Danforth 2002).

As previously noted, the modern appearance of cranial porosities has seldom been examined. When modern crania do present cranial porosities, they may be more likely to display mild or moderate forms of PH and CO because of widespread access to healthcare and nutritional resources. Thus, the author suggests the future photographic documentation of mild or moderate forms of PH and CO, verified macroscopically and radiographically, should be disseminated to provide a more comprehensive diagnostic tool for reference.

V. CONCLUSION

The purpose of the study was to explore which of the two assessments, macroscopic or radiographic, was the more accurate method for the examination and measurement of cranial porosities within a modern documented skeletal sample. The hypothesis was that radiographs would better identify the presence of ectocranial porosities not apparent macroscopically, potentially indicating mild to moderate porotic hyperostosis (PH) through the presence/absence of radiographic indicators observed within the cranial vault. The author concludes that while radiographs do better assess the degree of porosities and presence of cranial remodeling, the macroscopic analysis better evaluates the presence of the cranial porosities themselves. In future studies, the use of both macroscopic and radiographic assessments is recommended. However, if time does not permit for both methods, utilizing only the macroscopic assessment for the analysis of cranial porosities would best suffice in terms of quickly evaluating the presence of cranial porosities.

This research assessed the frequency of cranial porosities present within the Texas State University Donated Skeletal Collection (n=50) in conjunction with their age, sex, ancestry, and socio-economic status. It was found that orbital roof thickening (ORT) is statistically significant in those aged 18-20, while women present outer table thinning (OTT) at a statistically more significant rate than men. Males exhibit the highest frequency of cranial porosities overall, and within ancestry categories, American Whites present more ectocranial porosities and American Blacks exhibit more orbital porosities. Socio-economic status was a poor predictor of the presence of both radiographic indicators and macroscopic observations, since a range of variation occurred even within socio-economic status groups. For age, orbital porosities were observed most frequently in the extreme ends – those aged 18-20 and 91-100. In the literature, ectocranial porosities were speculated to commonly occur in the majority of middle-age individuals (Mann and Hunt 2005), however, this research demonstrates that ectocranial porosities did not appear to be age specific as they are present within all age categories (with the exception of the one person in the 101-110 category), and the presence of these porosities does not correlate with age but most probably with the health or other intrinsic variables of the individual or their environment.

The use of the four radiographic traits in this study aimed to validate the use of these traits when compared to macroscopically observed cranial porosities. The following radiographic traits were identified to correspond best with macroscopic observations: 1) Outer table thinning (OTT) corresponds to ectocranial porosities, 2) Diploic thickening (DPT) corresponds to marrow hypertrophy indicating PH, 3) "Hair-on-end" (HE) pattern corresponds to severe PH, and 4) Orbital roof thickening (ORT) corresponds to orbital porosities. The HE pattern was not observed in this research indicating no severe anemia was present. Active orbital porosities were present in 72% of individuals who displayed ORT, confirming the correlation between radiographic indicator and orbital lesion. Mild to moderate PH was also established within the skeletal collection due to the appearance of DPT and OTT via radiographs, in conjunction with macroscopic ectocranial porosities.

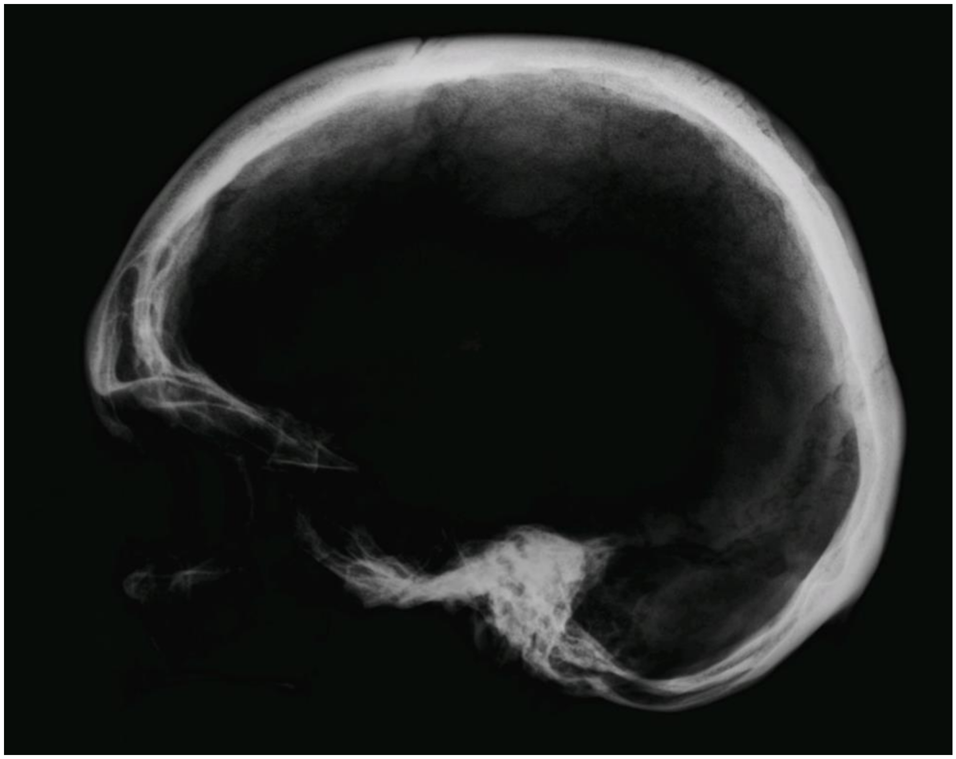
The data presented here confirm the utility of using both radiographic and macroscopic methods to identify mild to moderate forms of PH within a modern skeletal sample. This research demonstrates the usefulness of cranial porosities to potentially assess underlying health differences of a modern population, even when the accessibility of resources and to general health care are assumed to be similar. Overall, this methodological comparison can be utilized in both a bioarchaeological and forensic context in order to further comprehend and enhance the understanding and definitions of ectocranial/orbital porosities potentially indicative of PH/CO.

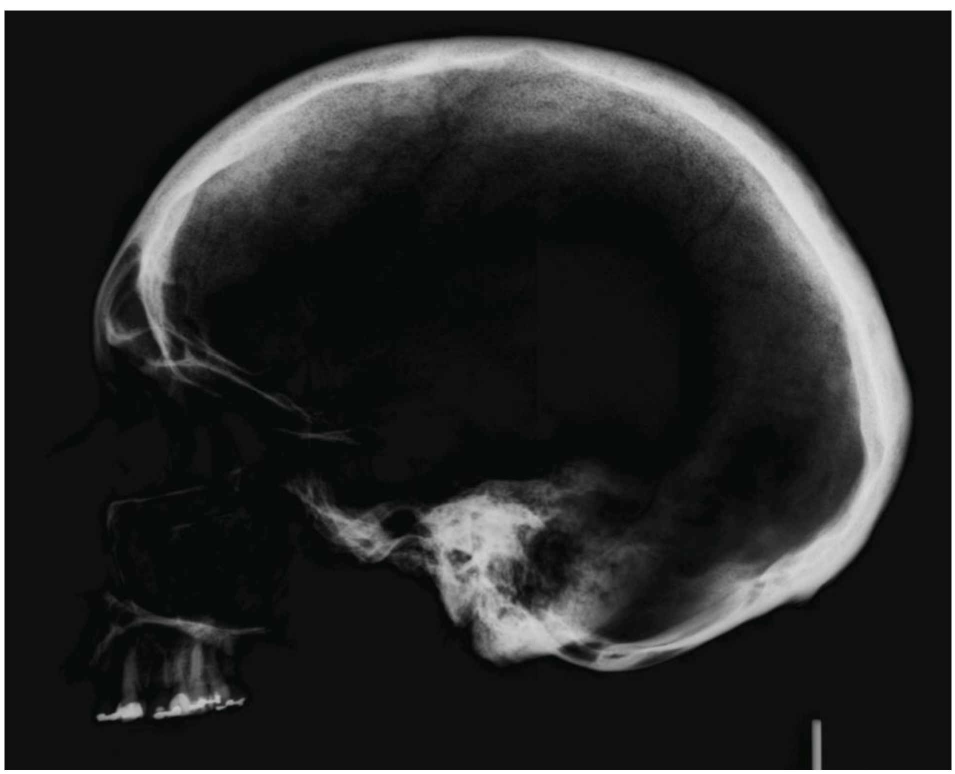
Suggestions for future studies include utilizing stable isotopes in conjunction with the appearance of cranial porosities to produce information on the subsistence regime of the individual and provide a linkage between diet and pathology. Moreover, future investigations can test the relationship between metabolic diseases and the presence/absence of cranial porosities in a modern documented skeletal sample, to further explore the relationship between porosities and health. Additionally, efforts can be undertaken to create better definitions, photographic documentation, and radiographic examples for the traits outlined in Stuart-Macadam (1987a) to minimalize misinterpretation by researchers.

APPENDIX SECTION

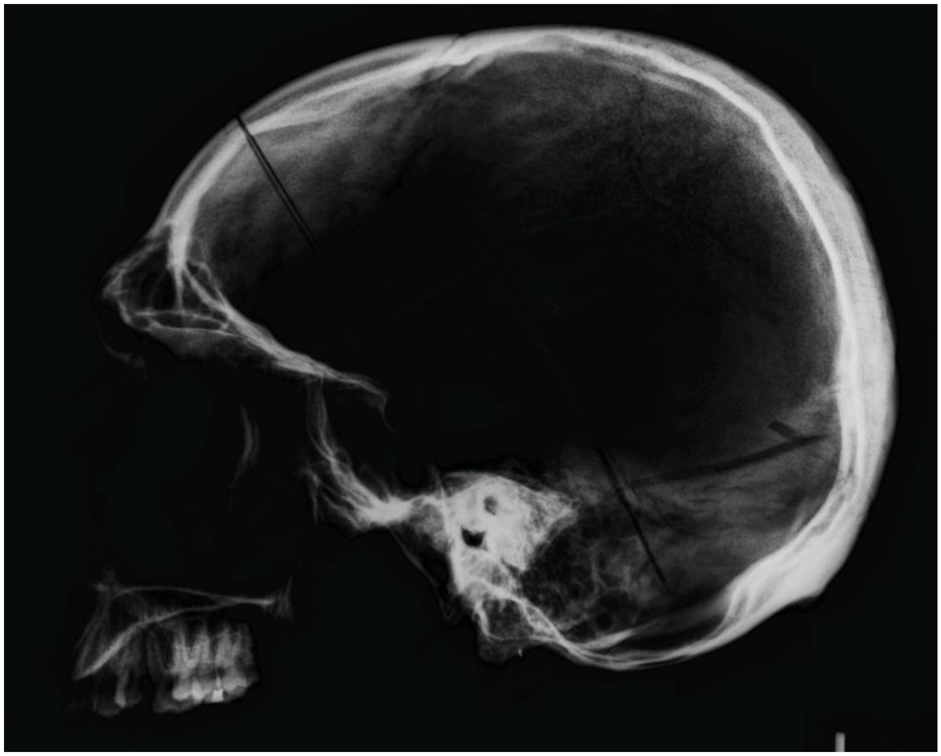
APPENDIX A

Outer table thinning (OTT)



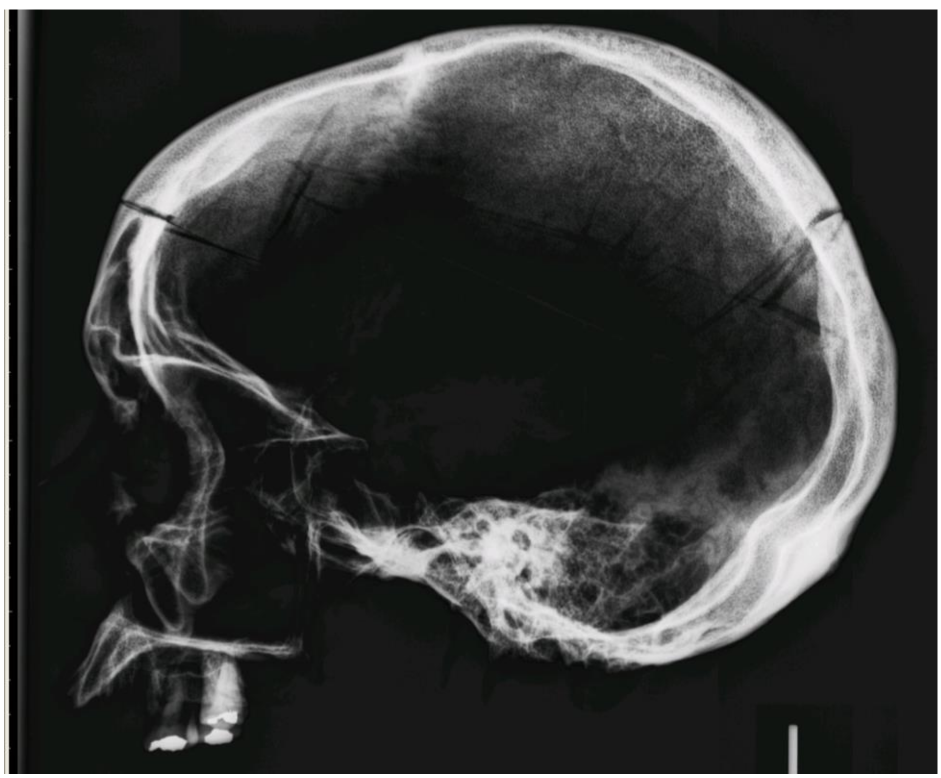


Outer table thinning (OTT), continued

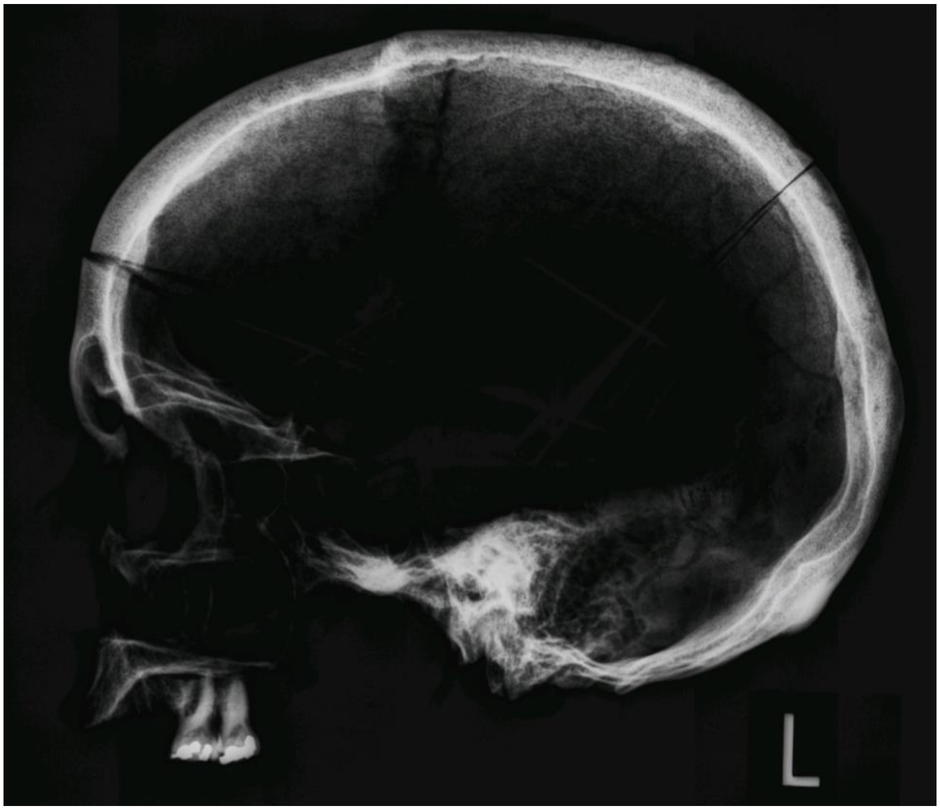


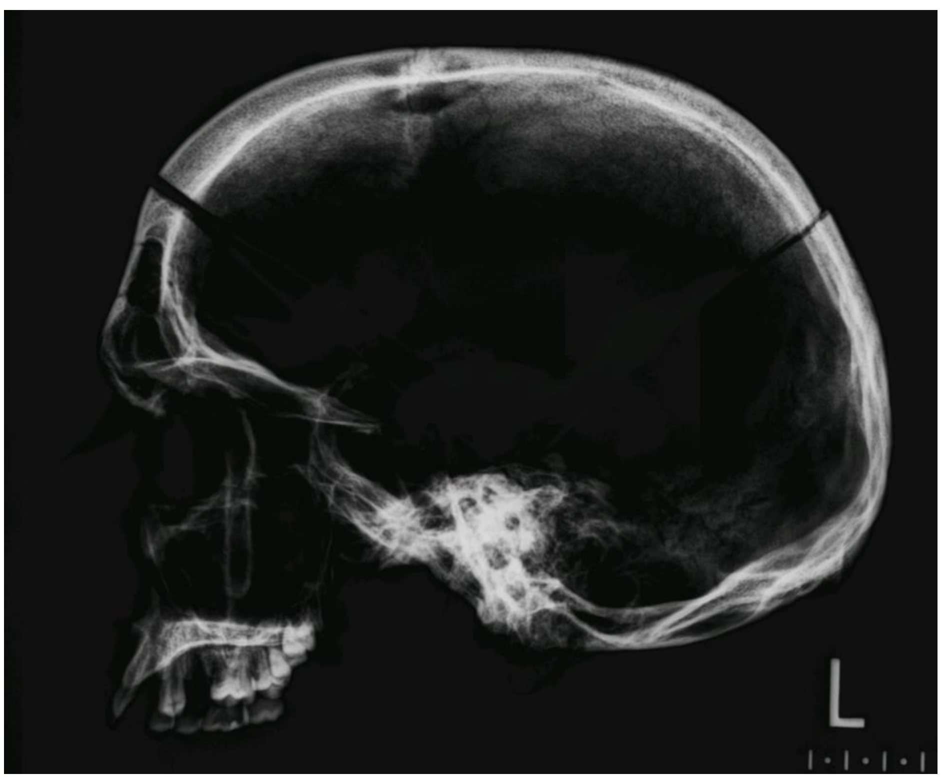
Outer table thinning (OTT), continued

Diploic Thickening

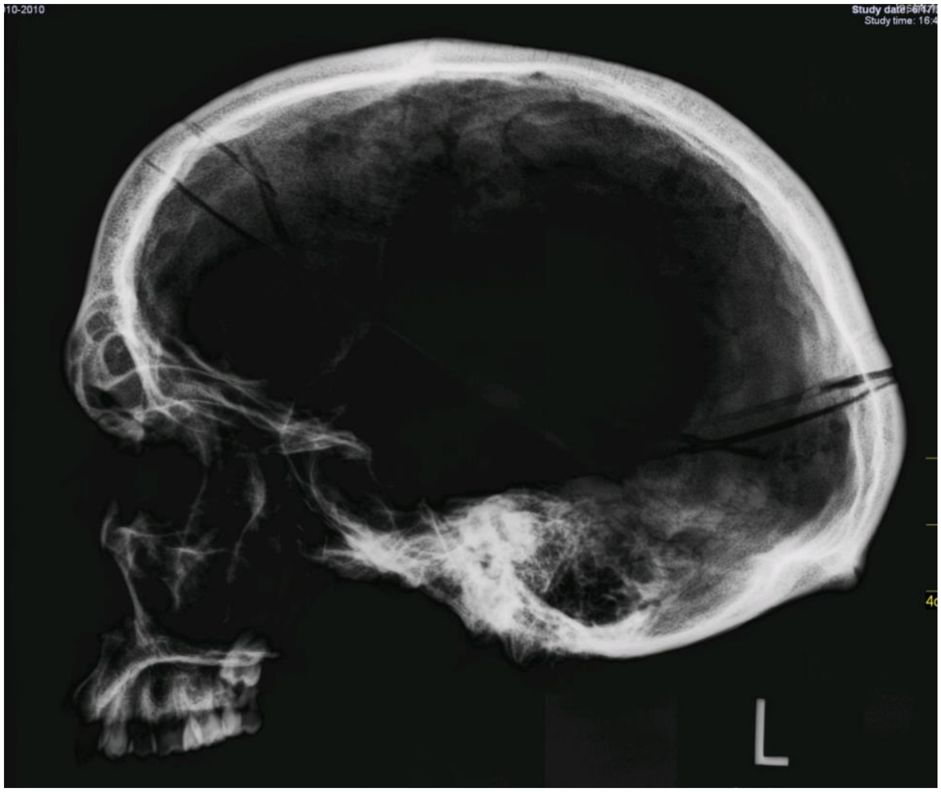


Diploic Thickening (DPT), continued

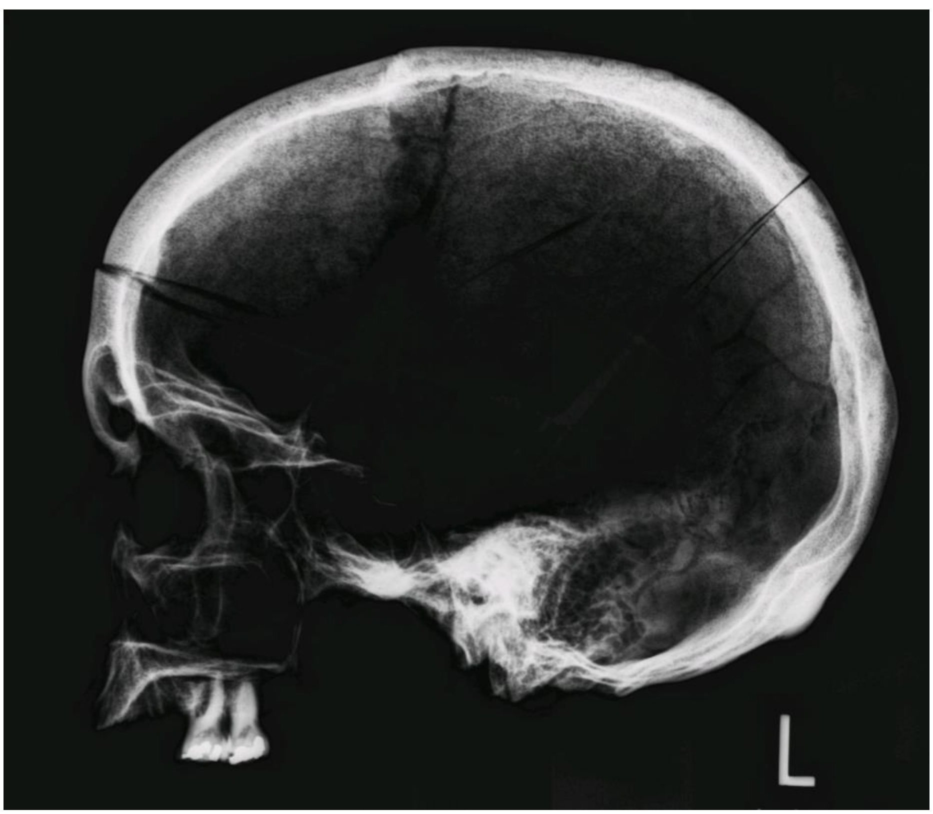




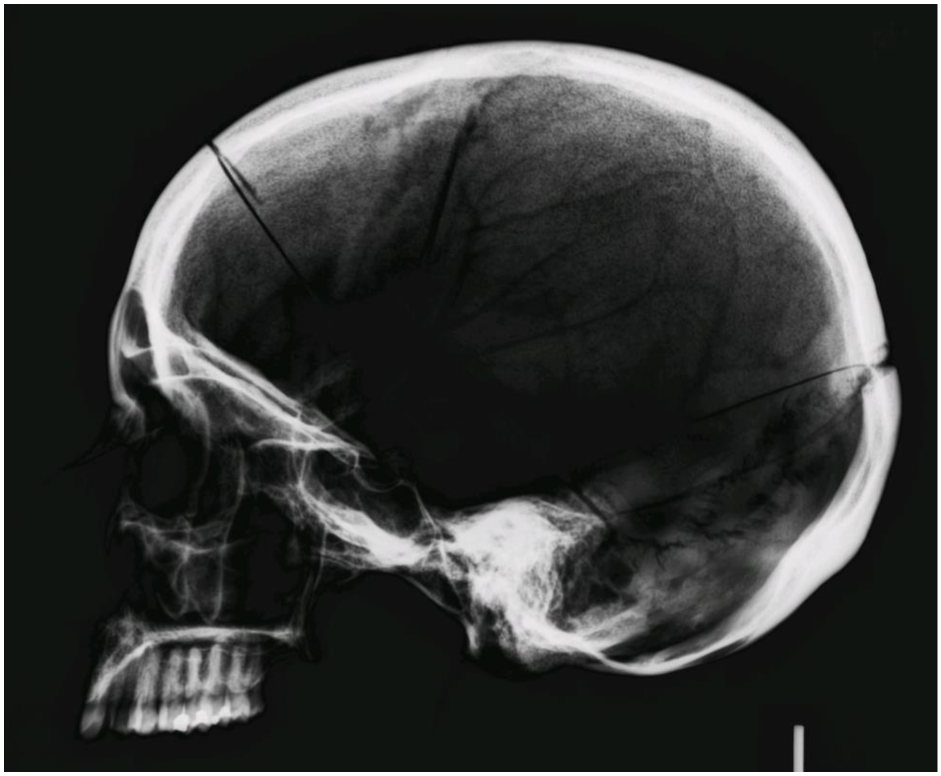
Diploic Thickening (DPT), continued

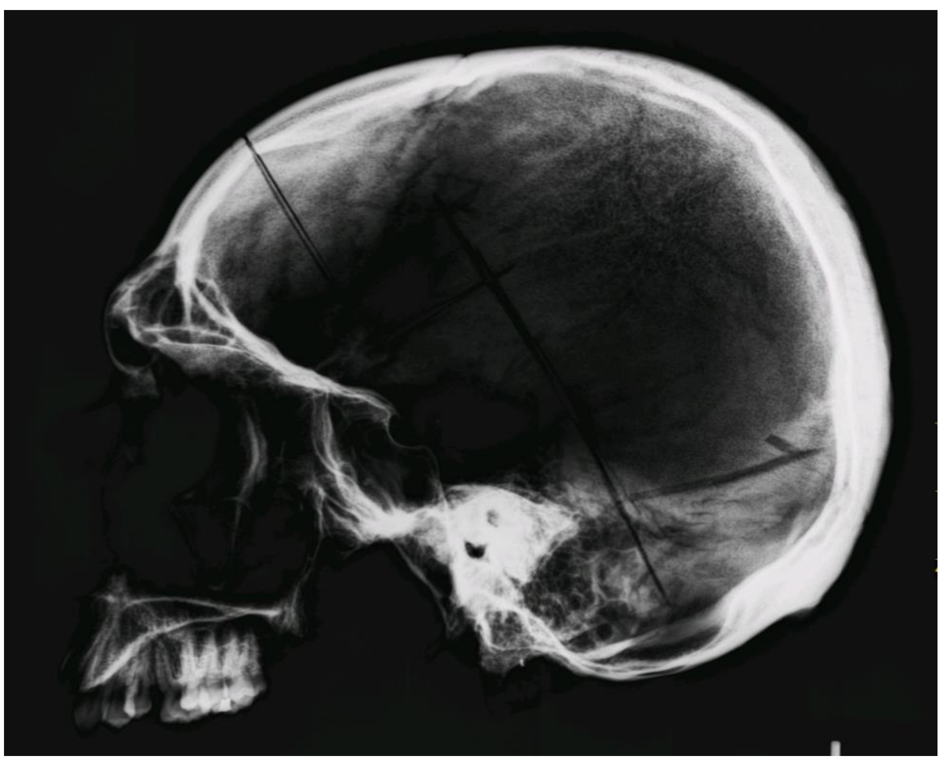


Orbital roof thickening (ORT)

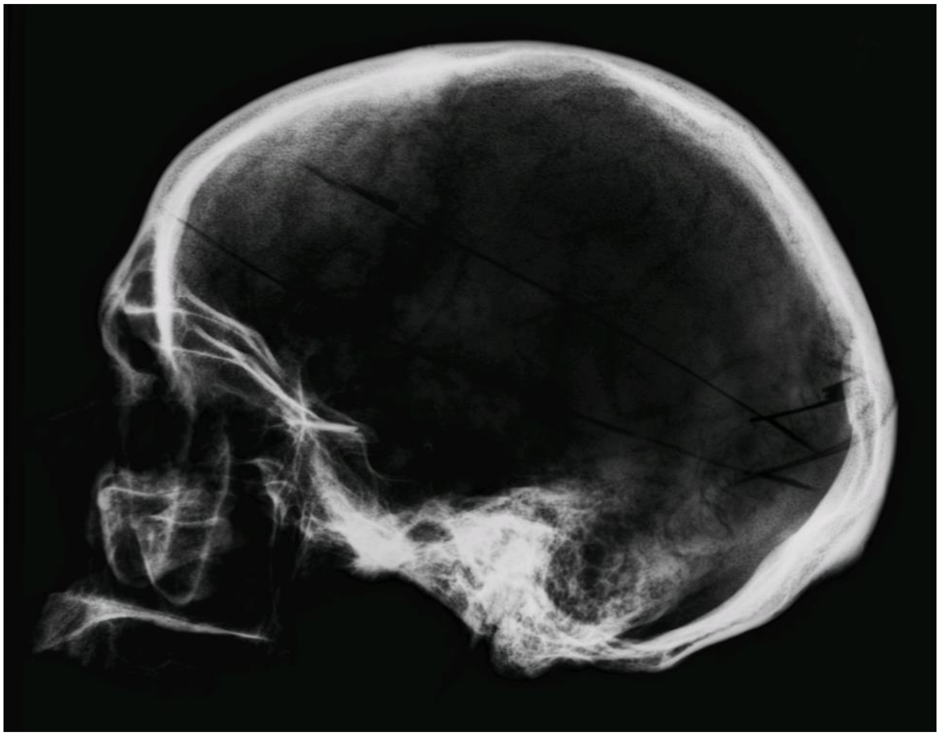


Orbital roof thickening (ORT), Continued



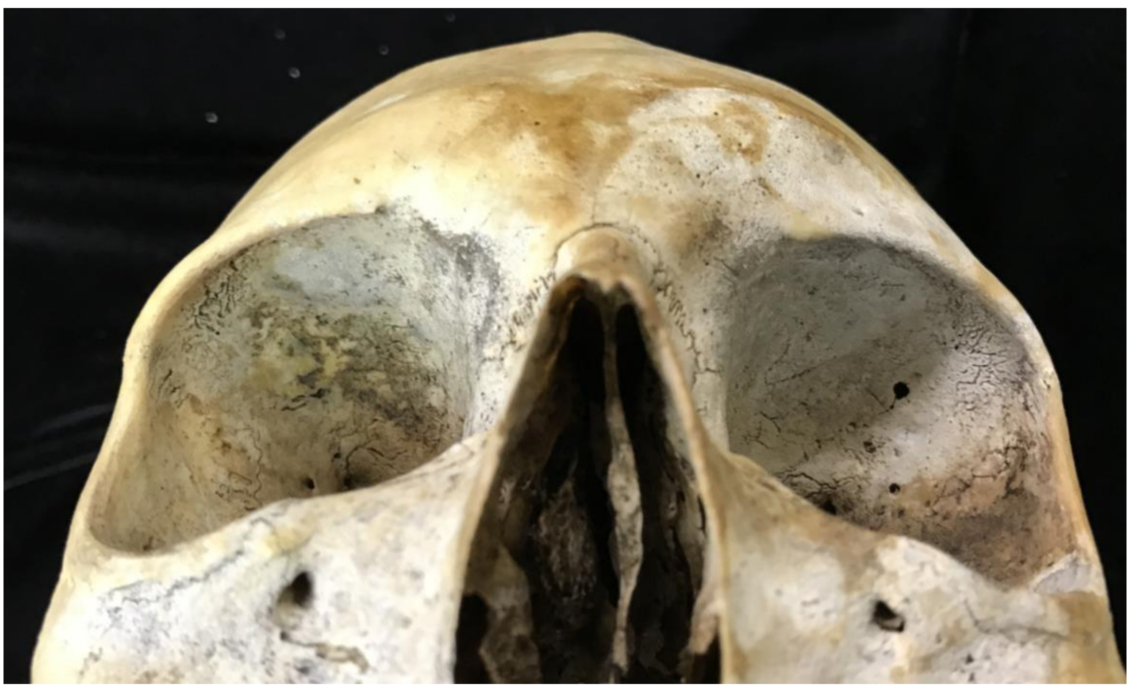


Orbital roof thickening (ORT), Continued



APPENDIX B

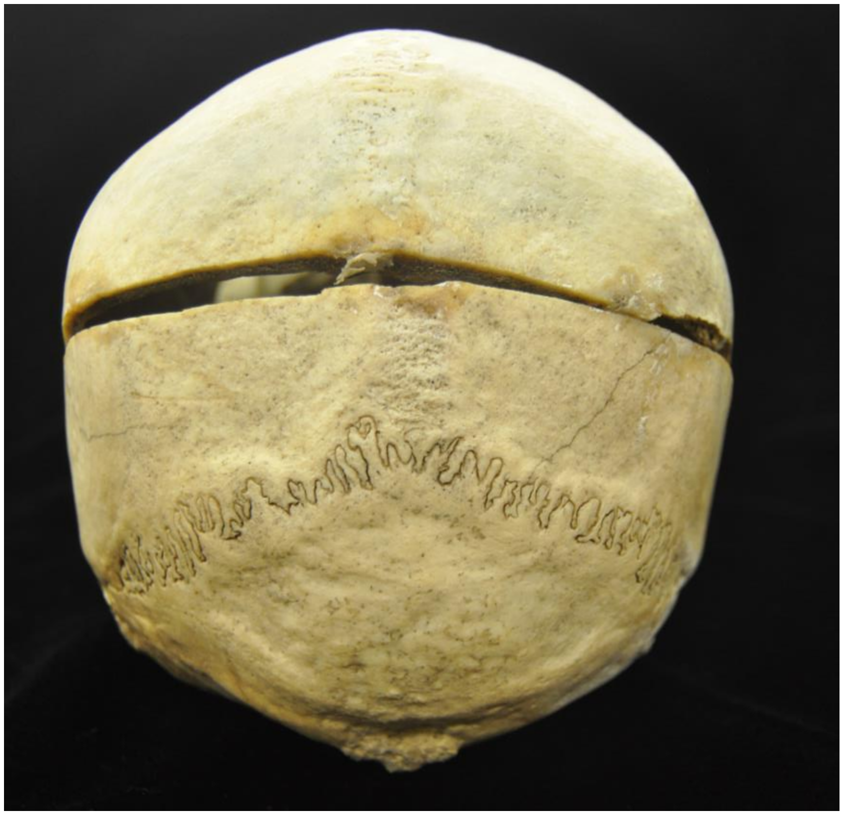
Macroscopic Orbital Porosities



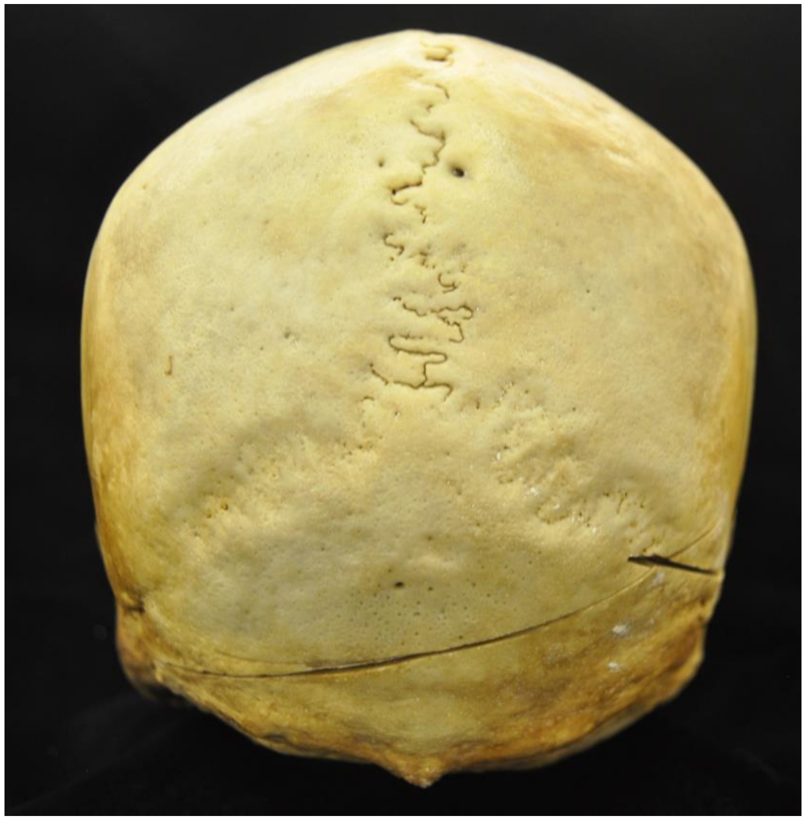
Macroscopic Orbital Porosities, continued

Macroscopic Ectocranial Porosities

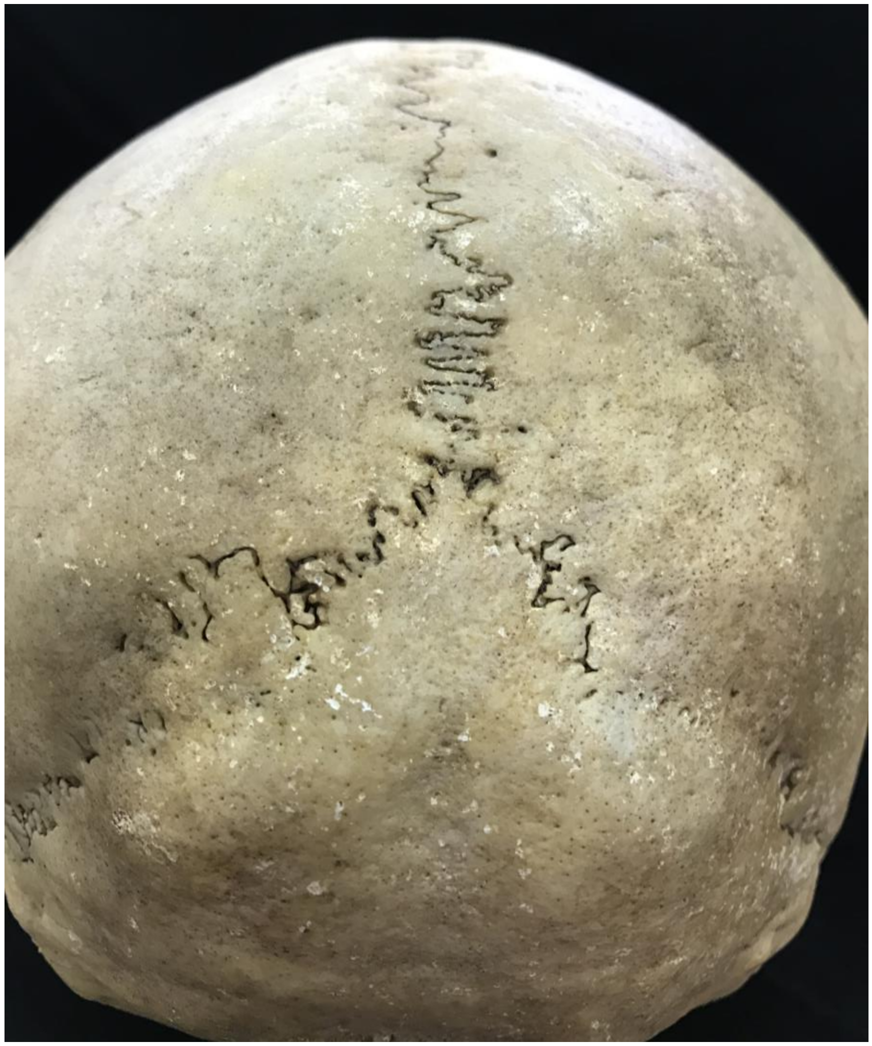
Macroscopic Ectocranial Porosities, continued



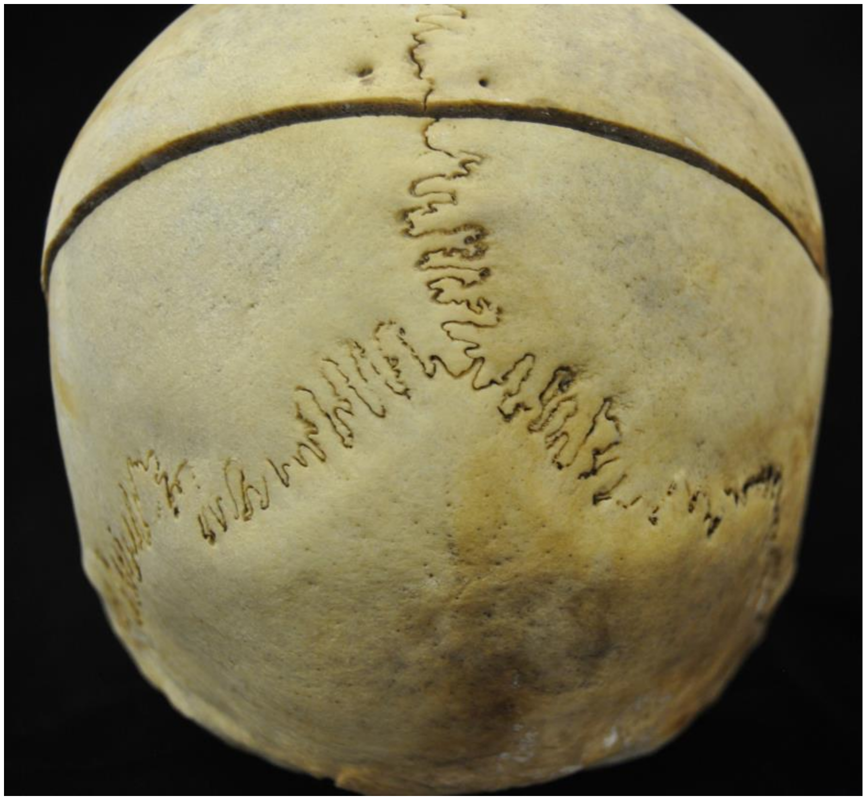
Macroscopic Ectocranial Porosities, continued

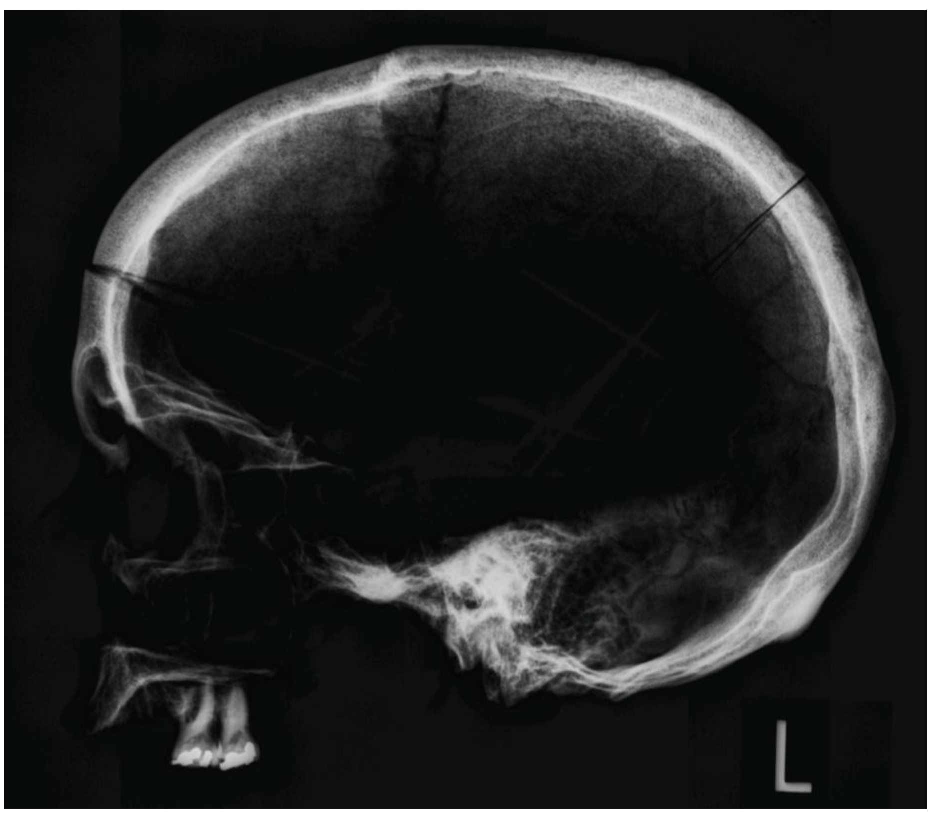


Macroscopic Ectocranial Porosities, continued



Porotic Hyperostosis: Macroscopic and Radiographic





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