Environment, Diet, and Craniofacial Development: A Study of Mixed Subsistence Strategies in the Great Lakes Watershed, AD 900-1600

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Abstract

The ecological richness of the Great Lakes Watershed has attracted human populations since the late Pleistocene Epoch and is now home to over 325,000 American and Canada residents. Anthropologists studying the cultural variability associated with the peopling of this region and the biological effects of shifts in subsistence strategies have focused their attentions on demographic change (Buikstra, 1978; Hart, 1999; Hutterer, 1983; Mayer and Porat, 2008; Price and Yosef, 2011) and the increased instances in pathologies such as pulmonary tuberculosis (Buikstra and Cook, 1978). This study examines the impact that a shift from foraging to small-scale agriculture had on craniofacial growth. Crania from 4 culture areas including biological material from 12 archaeological sites in Wisconsin (A.D. 900-1600) were compared in order to test the notion that craniometric traits associated with a diverse ecosystem would reflect a mixed subsistence strategy as opposed to an overreliance on plant domesticates.

Keywords: Diet, Environment, Archaeology, Craniofacial Growth, Craniometrics, North America

1. Early Agriculture in the American Great Lakes

The Great Lakes Watershed encompasses a region of nearly 95,000 square miles. Its system of drainage defines the landscape of seven modern American states and over 30,000 square miles of provincial Ontario (Canada). Along the southern border of the watershed, major drainage systems assigned to the Mississippi, Illinois, Missouri, and Ohio Rivers contribute to an industrial, agricultural economy of over one billion dollars in annual income. However, the human populations that live and work within the region's corn, wheat, and dairy producing segments today have not experienced the same kind of population pressures understood to have existed in the Late Woodland and Emergent Mississippian Periods (A.D. 400-1100). The diverse natural resources available throughout the watershed allowed prehistoric human populations to grow and diversify to a level that exceeds those of rural counties throughout southwestern Wisconsin and its border with Illinois. For Wisconsin's prehistoric and proto-historic Algonkian speakers, access to numerous river and lake wetland and bog environments allowed them to maintain a diverse diet throughout much of the period. As a result, human communities situated along the tributaries of the Wolf, Chippewa, and Wisconsin rivers were less reliant on monocrop agriculture, experiencing considerably less social, biological, and economic stress associated with the transition to agriculture. Between 2,200 and 1,000 years ago, indigenous peoples inhabiting the southern border of the Great Lakes and the land assigned to the Lower Ohio and Central Mississippi River watersheds were semi-sedentary foragers (McElrath et al., 2000).

Their subsistence strategies took advantage of the diverse plant and animal resources that were available throughout the region; however, during the Late Woodland Period, archaeological evidence appears to support the notion that communities began to rely on local cultigens as their subsistence strategies became mixed (transitioning toward a more traditional, horticultural model). Archaeological evidences also support the idea that a traditional, agricultural economy did not establish itself until the end of the Upper Mississippian Period (A.D. 1250-1500). Plant types associated with the understory of the Oak-Hickory and mixed Oak-Hickory and grassland biomes of southern Wisconsin, Illinois, and Ohio appear in the tributary systems assigned to the Mississippi, Missouri, Scioto, and Ohio Rivers (Simon, 2000, p. 41). The rich taxonomy of these plant communities and the large and small mammal's dependent upon them for survival provided local residents with a wide variety of hunted and gathered resources to exploit. Although archaeological evidence of a corn economy became increasingly expressed in sites to the south and east, populations continued to incorporate fruits and nuts of the sumac family and oily-seeded assemblages that drew heavily upon the plants of local wetlands and marshes in their diets. Some of these taxa—including sumpweed and maygrass—accompany annuals, such as squash, becoming early domesticates that by the middle of the Mississippian Period were strong economic competitors for monocrop systems such as corn. Lower Ohio and Missouri River valleys sites such as Sand Ridge (33HA17) and Bridgeton (23SL442) contain plant assemblages indicative of a mixed subsistence approach.

At these sites, starchy-grained seed resources, such as sump weed, chenopod, and sunflower are present, however, their volumetric expression in the diet of the local community does not exceed sixty to seventy percent (Simon, 2000, p. 41). Evidence of land clearing accompanies this trend yet the location and size of these horticultural plots support a limited, and likely, seasonal integration of the plant products into local diets. Additionally, the limited protection provided to fruiting portions of (later) domesticated expressions of these plants argues for an increased susceptibility to disease and periodic crop failure. In Illinois, Lohmann and Lindeman Phase sites, such as Range Site 3 (11S47) both floral and faunal assemblages support a mixed tradition within the region. Kathryn Parker's (2003) description of Lohmann Phase flora for the site typifies the kind of biodiversity that would have been present throughout the oak savannah ecosystem. Trees, including understory competitors, such as maple (*Acer* sp.), hickory, and pecan (*30ary asp*.) appear among the carbonized wood fragments of the site (Parker, 2003, p. 191), while wild expressions of black nightshade (*Solanum* sp.) and panic grass (*Panicum* sp.) were recovered alongside domesticated expressions of chenopod and erect knotweed. This botanical trend intensifies among archaeological sites to the north and west. Late Woodland Kekoskee Phase sites—expressing radiocarbon dates as late as the fifteenth century A.D.—in central and southern Wisconsin exhibit wares, the style of which demonstrate trade and contact with communities to the south. They also contain floral and faunal assemblages indicative of local exploitation with little to no evidence of agricultural-level domestication. This pattern is intensified among Horicon Phase sites, such as the Luedke site (47DO393), where assemblages exhibit seasonal exploitation of a wide variety of fish, fowl, and semi-domesticated plant resources (Salkin, 2000, p. 533).

The faunal remains recovered from middening associated with the Plantz site (47WN325) in Winnebago County adds to what is known of the biological diversity of meat resources within Late Woodland and Emergent Mississippian diets. In this case, faunal assemblages of the site contain over 200 species of animal, including deer and elk. The small mammals recovered from the Plantz site may be considered edge tolerant, reflecting physiologies common to riverine forest, lake, and marsh environments (Kuehn, 2008, p. 2). It was not until the late Oneota Period (c. A.D. 1400) that strong evidence appears for small, and eventually, large-scale farming in the region. The taxonomic richness of the local watershed meant that the prehistoric and proto historic populations of central and southern Wisconsin transitioned to agriculture relatively late, and that the urbanizing and economizing trends witnessed in central, southern Illinois and the American Bottom, did not typify life along the southern border of the Great Lakes. The question posed by the current study relates to the additional evidence that may support this trend, in this case patterns of craniofacial growth and development. Anthropologists studying the cultural and biological effects that accompany a transition from foraging to agriculture have focused their evaluation on the mortuary record and skeletonized expressions of pathologies such as pulmonary tuberculosis or iron deficiency anemia (Dennell, 1979; Hutchinson et al., 1998; Larsen, 1995). This study follows a similar format, but it addresses the craniofacial variability associated with nutritionally diverse diets, comparing and contrasting the craniofacial architecture of traditional foragers to agriculturalists from a variety of mid and high latitude environments. This study also attempts to determine whether or not variations in craniofacial architecture can be utilized to assess the degree of wild or semi-domesticated food stuffs within a community's core diet.

2. The Effects of Plant Domestication

In *The Most Ancient East* (1928), prehistorian V. Gordon Childe outlined his thesis for the rapid spread of agriculture in the Old World. For Childe, the technologies associated with urbanization and the production of sustainable food resources was a revolutionary turning point in the history of humanity. Modern anthropologists in both the New and Old World today recognize the domestication of plants and animals to be important to population growth and community sustainability (Boserup, 1965; Hassan and Sengel, 1973). Increased risk becomes evident in the changing nature of mortuary populations reflecting a transition to farming. Often it is the case that demographic reconstructions exhibit shortened life expectances and higher rates of infant and adolescent mortality (Ubelaker, 1974). Beyond the demographic change, there is a shift in expressions of infectious disease and an overall decline in the taxonomic richness of human diets (Buikstra et al., 1986, p. 528). Archaeologists tracking an overreliance on starchy plants, such as *Iva annua*, during Illinois' Middle and Late Woodland Periods (Buikstra et al., 1986, p. 530) and a later replacement with maize, cite significant changes in dietary protein as an important initial consequence of the change in technology. Additionally, they recognize volumetric changes in carbon and nitrogen isotopes (Ambrose et al., 2003, p. 195) in bone chemistry. Among prehistoric farmers, an increase in dietary plant domesticates (if paired with a corresponding decrease in local animal protein resources) resulted in a diminished uptake of protein in bone collagen and its formation (Ambrose et al., 2003, p. 196).

In the continental United States and Southern Canada, the significant juxtaposition of animal and plant proteins is apparent with the wide scale introduction of sources of complex carbohydrates, such as maize, into indigenous diets. Katzenberg (2000) however, recognizes that the impact of plant carbohydrates from monocrops were significantly lower in regions where the collection of marine and freshwater food resources remained well expressed (Ambrose et al., 2003, p. 197). Studies of bone chemistry, examining populations reliant on a mixed subsistence diet, reveal that the varying amount of C3 and C4 plant products may be a factor of the degree to which domesticates were introduced into the community's diet (Warinner and Tuross, 2009). Evidence of this is often recovered from long bones, where carbon levels impact the volume of bone collagen, additional evidence is drawn from varying patterns of dental eruption and adult enamel thickness. Alkaline-cooked expressions of domesticates intensify these trends, resulting in up to a three percent increase in both carbon and oxygen enrichment in humerus and mandibular bone, as well as dental enamel (Warinner and Tuross, 2009). John Lukacs (1996) recognizes the significant variation that exists in patterns of growth and development and dental health when the remains of foragers, subsistence farmers, and traditional agriculturalists are compared. The samples for Lukacs's study were drawn from Southeast Asia and Southern Asia where the introduction of domesticated rice, water chestnut, and taro transformed, not only the local economy, but also the health and quality of life for related populations. Within a variety of prehistoric skeletal series from Mesolithic and Chalcolithic sites, Lukacs witnessed a six to seven percent rate of increase in dental caries when domesticates appeared in the archaeological record. This trend accompanied changing rates of dental development and a shift in mortuary profiles (Lukacs, 1996, p. 149). When areca nut, beans, peas, and bamboo appeared in the record the median age at death of women and men diminished. Within these profiles, sexually mature females were considered most at-risk during and after the dietary transition of the community.

The transition from collected foods to domesticate also affected the fertility profiles of human populations. Wenda Trevathan (2010) describes the pre-industrial, agricultural world to be one in which "infant mortality was high, fertility was high, and life expectancy was low" (Trevathan, 2010, p. 193). She recognizes that "most causes of mortality were infectious [in nature]" (194). Developmental studies of indigenous North American mortuary groups provide additional insight into this health consequence. Ethne Barnes (1994), in her study of microcephaly among Pueblo III and IV populations, recognized cranial agenesis to be a contributor to high mortality rates among children in isolated, agricultural groups. Along with this Southwestern example, she highlighted skeletal data from "Japan, Egypt, Ireland, and England" (Barnes, 1994, p. 158) in which children suffering from cranial microcephaly expressed projected cranial capacities below one thousand cubic centimeters. It was rarely the case that children exhibiting this delay in their growth and development would survive to a sexually reproductive age. This condition has traditionally been recognized as solely congenital in nature (an inherited as an autosomal, recessive trait), however, additional research employing a variety of animal models acknowledges contributing environmental factors, including diet. Recent studies of placental infections utilizing mice models recognize microcephaly as a byproduct of infection during early weeks of gestation (Kruske et. al., 1999; Li and Tsutsui, 2000; Rajab et. al., 2009).

Other studies, incorporating pregnant mothers whose children expressed a variation of suture agenesis (Matalon et.al., 2003; Pelizzo et.al., 2014; Pennell, 2004) attribute the condition to prolonged periods of vitamin D, A, zinc folate, and iron deficiency or depletion. In these cases, the diets of mothers were found to interact with developmental defects, often catalyzed by disease or infection. Congenital conditions, such as types of dwarfism, and craniofacial and prechordal cranial base field defects have been recognized as accompanying patterns of infant or adolescent mortality (Belo et.al., 1998; Khosravi et.al., 1998; Nagy et.al., 2012; Osumi-Yamashita et.al., 1997). Many of these instances have included the underdevelopment of the respiratory system and an increased possibility of fatal infection during initial stages of childhood growth (Ladinig et. al., 2014 and Zhang et. al., 2014). Recent research regarding the cause of sudden infant death and patterns of childhood asthma has emphasized the important consideration that should be given to the contributions of a weakened or compromised immune system (Alfelali and Khandaker, 2014; Pryce et. al., 2014; Bakhuizen et.al., 2014).

In the mid-1980s, archaeologists assessing the impact of agriculture examined the effect that increased plant domesticates had on a population's physical health. In their discussion of Brocquet-Appel and Masset (1982), Buikstra and Konigsberg (1985) highlighted the importance that demographic reconstructions may play in understanding the health effects of a transition to farming. Like Brocquet-Appel and Masset (1982), Buikstra found that "age-specific [probabilities] of death, as a function of the [estimated] age [at death]" (Buikstra and Konigsberg, 1985, p. 317) varied between periods of food collection and cultivation. In a later article, Buikstra recognized that within the prehistory of central Illinois this disparity was significant between the Middle Woodland and Mississippian periods (Buikstra et al., 1986, p. 536). Combining these findings with the work of Wills and Waterlow (1958), it is likely that changes in juvenile mortality rates would have accompanied the transition. Additionally, juvenile expressions of developmental delay and lower survivorship would be relatable to increased health risks expressed among adults. Mississippian evidence from Illinois, for example, portrays not only a diminishment in survivorship rates among farmers, but also the presence of an at-risk group within this economy, in this case, children between one and 12 years of age (Buikstra et al., 1986). Mortuary reconstructions of prehistoric populations along the eastern seaboard and the lower Mississippi River drainage identify a similar pattern, however mortuary risk was found to be paired with increased rates of fertility and eventually population growth (Bocquet-Appel, 2011; Lamphear, 1988; Schurr, 1998). Though these trends may seem contrary to expected health outcomes, recent and historic research among living urban populations supports the notion that fertility rates often increase significantly as a human population begins to experience dietary stress (Dietert et. al., 2010; Eberstein, 1989; Malveaux and Fletcher-Vincent, 1995; Froggatt et.al., 1971). It must be assumed, then, that a community-wide shift in rates of infection and disease would accompany corresponding patterns of higher juvenile mortality and increased rates of fertility, and that these trends would correspond to a shift in dietary content and its biochemistry. Skeletal patterns of growth and development would also correlate with this demographic and health pattern. (This would especially be the case among populations considered isolated and/or sedentary.)

Combining these events with what is currently known of biological stress and fitness, a clearer, ecologically-minded understanding of the relationships between plant and animal communities may be considered. Citing the contributions of Sewall Wright (1932) and a modern (synthetic) understanding of population fitness, John Hart (1999) argued that the transition to farming would have emphasized the close relationship between a cultigen, such as corn, and the human community that would be dependent upon it for its survival. Hart's research, like that of Boone (2002), supports a model of limited fitness for both communities. There would have been recognizable connections between the demographic profile of the cultigen group and the surrounding human populations producing it. For Hart, the measure of biodiversity within the cultigen would act as an indirect marker for the health and fitness of the dependent group (Hart, 1999, 154). Such coevolutionary relationships provide bioarchaeologists and demographic anthropologists with a complex, yet understandable, model for assessing the ecology of domestication. Eastern Woodland populations along with those of the upper Midwest become excellent resources for understanding the impact that agricultural intensification had on a society's quality of life (in this case, measured as its biodiversity). As was the case with Rindos (1984) and Buikstra et al. (1986), the intensification of domesticated plant crops correlates with higher expressions of human fitness (Hart, 1999, 157) and population growth, while at the same time accompanying increased rates of mortality among adolescents and adults.

3. Nutrition and Craniofacial Growth

The nutritive environment during embryotic, natal, and post-natal periods of human development provides a line of explanation for the nature of adolescent and adult cranial morphology. The craniofacial and cranial vault measurements collected and analyzed for this study are impacted by variations in growth fields associated, initially, with the development of the prechordal cranial base. The development of the blastemal desmocranium and its eventual chondrification and osteogenesis affect measures associated with the adult calvarium and the upper face. During morphogenesis and later, pre-pubescent cranial growth, the orientation and geometric architecture of both the cranial base and the maxillary and mandibular processes provide insight into the impact of community-wide dietary patterns (Barnes, 1994). By closely examining growth traits that are not strictly congenital in nature, assumptions may be made regarding the biochemistry of individual diets and the ecological stresses associated with life in a given environment. The current study compares and contrasts population-wide patterns of growth and development in archaeological contexts known to reflect residential pressures below or above the catchment potential of local (continental) watersheds.

The variations described here are arguably tied to the ossification of later adolescent and early adult expressions of the developing vicerocranium and neurocranium. (However, with regard to population-wide adult craniofacial geometric variation, most complex architectural expressions assigned to these regions may be recognized, initially, in patterns of infant and early adolescent bone growth.) This means that the biochemistry of an individual’s early diet may be understood indirectly through the measurement of later, adult expressions of these regions. Mid-and upper facial characteristics of the developing sphenoid bone present bioarchaeologists with the strongest supporting evidence for this relationship (Sealy et. al., 2000). As a child approaches the end of the first year of life, the already well-ossified elements of the sphenoid begin to fuse. At the time the sphenoid’s par nasal sinus pneumatizes, and the greater wings of the bone physically extend to meet both the maxillae and frontal bones of the skull, creating the first of several physical relationships that these cranial bones share with one another. As is the case with the natal palate, the sphenoid physically expands in an anterior and lateral fashion during early adolescence. By the fourth year of life, the sphenoid and associated ethmoid bones meet one another, establishing a geometric template for the surrounding, developing mid-face. Unlike other paranasal landmarks, the speno-ethmoidal region of the face does not attain its final size until the individual reaches early adulthood (Schaefer et. al., 2009).

The development of both the nasal bones and the architecture of the dental ridge (including the palatine bones) are also important in understanding the impact that patterns of diet and nutrition have on adult craniometics. At birth, the geometry of the nasal bones is identical to its adult form. The only change in nasal architecture is associated with growth and development patterns between the ages of three years and puberty and, eventually the adult size of the bone. In this case, the “length-to-width” proportionality of the bone will not change unless a confounding, environmental factor is present (Schafer et. al., 2009, p. 42). This means that geometric indices, modeling proportions of these bones across groups, provide important mid-facial characteristics relatable to specific ecosystems and/or food-based technological adaptations. If these bones are not present in an archaeological sample, or if their integrity is questionable, the nasal index becomes a potential resource for data acquisition (Bass, 2005). The palatine bones and the dental ridge of the lower face maintain identical geometry between natal and adult periods. Although their overall size fluctuates significantly from birth to puberty, the physical ratios (i.e. their width and height in relation to the sagittal and anthropological planes of the skull) associated with the horizontal and perpendicular plates of the hard palate maintain their proportionality (Schafer et. al., 2009, 42). This means that the shape of the bone in relation to the developing vicerocranium and the anterior portion of the endocranial surface remain constant. Any fluctuation in this proportionality may be explained environmentally. And, as is the case with the bones of the adult neurocranium, these cranial bones—their orientation and overall length-to-width proportions—are important points of comparison across archaeological samples.

4. Methods and Materials

This study is an osteological analysis of the effects that subsistence strategies have on the cranial growth and development of select human populations. Measurements and indices collected from archaeological samples and published anatomical databases (Table 1) were compared across a variety of archaeological, ecological, and socio-economic environments (Table 2).

All of the archaeological samples directly studied in relation to the current project are housed by the Department of Anthropology at the Milwaukee Public Museum (Milwaukee, Wisconsin). (Figure 1 depicts the locations of the Wisconsin prehistoric and historic archaeological materials.) All other craniometric measurements were drawn from publications of the Peabody Museum of Archaeology and Ethnology, a morphometric study of Alan Morris and Isabelle Ribot from the American Journal of Physical Anthropology (2006), and data gathered and published by William Howells (1965-1980). After gathering craniometric measurements, a distinction was made between subjects. Male and female crania were segregated into three subsistence types: a mixed subsistence strategy, small-scale farming, and surplus agriculture. Although the anthropological literature, at times, does not support the identification of a mixed subsistence strategy, (in this case, distinct from horticulturalism or small-scale farming) this descriptor was utilized to further test the impact that an increased emphasis on surplus production would have had on population health. The distinction effectively isolated cultivation or selective weeding strategies from those utilizing larger tracts of land in an intensive fashion. Additionally, there was no archaeological evidence for permanent cultivation. Table 3 organizes the sample populations by sample size and subsistence strategy.

Twenty-six osteological landmarks were selected for the current study. A total of 12 distinct craniometric measurements were estimated and seven indices were calculated during the data collection process (see Table 4). The measurements highlighted two anatomical locations within the architecture of the skull, the neurocranium and the splanchnocranium (without the mandible). Measurements of the alveolus (incorporating cranial landmarks of the alveolar process in the left and right maxillae, and the left and right palatine bones) were collected, however qualitative assessments of the condition of the alveolus were made prior to taking the measurements. Often it is the case that due to the nature of the front maxillary sinuses and the fragility of the bone that surrounds these anatomical voids, cranial landmarks such as the orale (*ol*) and the infradentale superius (*ids*) become sources of measurement error. The qualitative assessments of this region included a determination of the condition of dental elements such as the right and left first incisors. If, for example, incisors were lost or removed postmortem or if there was significant taphonomic decay within a primary or secondary burial context, the damage was noted and a judgment was made relating to a technician's ability to accurately measure a geometric segment that incorporated the affected landmark (please refer to Table 1 and Figure 2 for anatomical locations and measurements gathered). Three indices became an integral part of the study's cross-cultural and ethnohistorical model of comparison. These indices were chosen in order to reduce the impact that inherited cranial variability played in the diversity expressed among the populations sampled. Mean expressions of these calculated indices were compared between populations and subsistence strategies.

$$\text{Cranial Index (CI)} = \frac{\text{XCB} \times 100}{\text{GOL}}$$

The cranial index or cephalic index (CI) (Bass, 2005, p. 70) provided an initial measure of the mathematical relationship that exists between the width of a human cranium and its length. In order to decipher how the growth and development of the splanchnocranium varied in relation to the neurocranium, the CI was initially compared to the facial height index. According to Bass (2005) and Stewart (1940), this comparison allows a researcher to acknowledge the brachycranic nature of anatomically modern crania while isolating and comparing the overall shape of the mid-face across populations.

$$\text{Total Facial Height} = \frac{n\text{-}pr \times 100}{zy\text{-}zy}$$

In order to further separate strictly heritable characteristics from lifestyle contributions an additional index was generated. The nasal index (NI)—expressing a measure of the overall height and width of the nasal opening—was compared to all group variances. This comparison allowed researchers to further understand the degree to

$$\text{Nasal Index (NI)} = \frac{\text{NLB} \times 100}{\text{NLH}}$$

Which each craniometric character varied in relation to a diverse range of mean expressions and lifestyles. Overall, the design of this data-gathering model accounted for cranial variations in mean expressions that were relatable, chiefly, to historic or cultural patterns of subsistence and diet. This allowed for the mathematical separation of subsistence and dietary trends from microevolutionary events associated with the diversification of human populations over the last four to five thousand years. In addition to the indices described above, four measurements were compared for their ability to isolate microevolutionary variation from group-level patterns of growth and development (Table 3). Variations in the average expressions of the maximum cranial length (GOL), the maximum cranial breadth (XCB), the minimum frontal breadth (WFB), and the upper facial breadth were generated and compared across subsistence types. The range of GOL and WFB measures reflected variations produced by qualities of individual diet and growth patterns associated with infancy and adolescence stress.

The data accumulated for this study was tested utilizing a non-parametric procedure, designed to generate and evaluate inferences about population differences. In this case, a chi-square test was used to determine the degree to which the subsistence strategy of a population was reflected in the shape and size of sexually mature males and females in each archaeological sample.

$$X^2 = \sum \frac{(f_o - f_e)^2}{f_e}$$

Once estimated, this test for independence was further analyzed with a comparison of z-scores representative of the distribution of cranial and nasal indices across select groups. By comparing z-score distributions, it was assumed that variations in mean expressions of cranial and nasal shape would be relatable to a historic or prehistoric diet. Furthermore, it was believed that the overlap witnessed between distributions would allow future researchers to address how this craniofacial, comparative model could be used to assess the presence and degree of a mixed subsistence strategy, or a strategy that integrated technologies relatable to either subsistence or production surplus. As identified by Ribot and Morris (2006) and two earlier publications by Ribot (2002, 2004), the data analyzed in studies such as these draws upon both direct and previously published observations, and thereby does not take into consideration “inter- and intra-observer errors” (Ribot and Morris, 2006, p. 17). Additionally, sexual dimorphism, as it is expressed in anatomically modern humans, is not recognized as a confounding factor in the current study. As Ribot and Morris (2006) correctly point out, the studies of Howells (1996) and Pietrusewsky (1995, 2000) do not adequately account for the lack of impact that gender has on craniometric variation across populations (Ribot and Morris, 2006, p. 17). Gender was not considered in either the one-way analysis of variance (ANOVA) or the standardized z-score comparison across populations for the current study. All of the comparisons made here are composite in nature. Additionally, the subsets of craniometric data corresponded to regional, behavioral variations within the recent history of anatomically modern humans. This means that the patterns of growth and development, in reference to the splanocranium and neurocranium of the data for the study, are species specific. The variations in craniometrics assigned to the sexually mature adults relate principally to habitual patterns of diet and do not correspond to the level of variability recognized in relation to genetic isolation.

5. Results

The similarities and differences in mean expressions across populations were tested with a one-way analysis of variance (ANOVA) procedure. In each subsistence category, within- and between-group variability was compared. Significant differences were recognized in association with indices assigned to the cranial vault, upper face, and nasal aperture. The cranial (CI) and nasal (NI) indices demonstrated the highest expression of variability across subsistence types. Mean scores for cranial indices ranged from 75.96 for foragers to 79.06 for agriculturalists. The crania of agriculturalists, across a variety of geographies and archaeological timelines, expressed cranial shapes indicative of a wider upper facial breadth in relation to the overall length of the skull. When a multi-regional, pooled sex comparison was made in relation to populations that were reliant on semi-domesticated food resources and wild game, a cranial shape, similar, if not identical to foraging samples, was expressed. Mixed subsistence agriculturalists presented cranial indices ranging between 69.03 and 74.56 (at a 95% confidence interval) while samples associated with an increased reliance on domesticates and surplus levels of production expressed indices ranging between 77.05 and 80.83. As described above, samples expressing a range of higher values for the index were traditional agriculturists.

The entire Wisconsin sample reflected cranial indices ranging from 71.04 to 82.58, the distribution of which overlapped significantly with foragers and subsistence agriculturalists. Within these CI distributions a secondary pattern appeared. Pooled sex samples from throughout the Wisconsin sample were segregated into prehistoric and historic periods, the cranial index distribution ranged, in this case, from 71.04 to 78.19 for prehistoric populations, while historic populations ranged from 77.20 to 82.58. Pooled foraging samples overlapped with both the prehistoric, proto historic, and historic Wisconsin groups, ranging from 72.87 to 80.11. In order to determine which element of the index varied clearly across all subsistence types, the maximum cranial length was independently studied. Historic Wisconsin crania presented lengths that were elongated in relation to those of the pre-contact period, in this case expressing an average decrease of 7.37mm between periods. Similar patterns were recognized among samples from Transcaucasia and southern and southeastern Africa; pooled samples from these two regions expressed an average length of 180.25mm. This length was similar to the mean score of 185.01mm for the prehistoric group from Wisconsin. When comparing cranial lengths across subsistence types, a general trend was recognized in the data. Moving from a mixed strategy to one focused on subsistence as opposed to one expressing agricultural surpluses, mean cranial lengths decreased from 184.40mm to 175.84mm. Along with this trend in cranial length, there was a corresponding, yet diminished, fluctuation in cranial breadth; in this case, it increased between periods and subsistence strategies. As watershed communities increased the amount of domesticates in their adaptation, breadth measures increased by an average of 1.37mm. When comparisons of the shape of the upper face were made between subsistence types, additional lines of division were recognized. Populations reliant on subsistence-level, collected or semi-domesticated food resources express slender or narrow facial shapes with upper facial indices that reach 59.00 (Martin's 1928 index ranges identify lepteny to be expressed between 55.00 and 59.99). This trend in the data runs parallel to the increase in cranial breadth described above. The comparison of mid-facial shape to the overall shape of the skull varied across all datasets.

The factor analysis of z-scores (depicted in Figure 3) demonstrated a distinction between subsistence strategies similar to the trend in cranial facial and cranial breadth. The distributions of z-scores for Great Lake samples and other Old World populations, drawn from taxonomically rich watersheds, shifted away from agricultural cranial models, expressing dolichocranic (low and narrow) shapes and sizes paired with nasal index ranges that mirrored those of anatomically modern human models. Additionally, when all three groups were compared in relation to mid-face-to-cranial shape scores, populations reliant on a mixed subsistence strategy remained distinct from both historic-era foraging and agricultural models.

6. Discussion

If the shape of the cranial vault and the growth patterns associated with the adolescent and adult mid-face are impacted by chronic patterns of diet, they may present bioarchaeologists with an additional tool for life history reconstruction. The range of values recorded in the current study demonstrates the impact made in relation to varying degrees of dietary admixtures (in these case mixtures. With regard to the composite expression of mid-facial to overall cranial shape and size indices, small, but significant distinctions appear. This trend in the distribution of scores increased when a major watershed was present. Barnet Pavao-Zuckerman's (2007) study of Creek subsistence practices under European colonization and trade identified the important impact that the local availability of collected and hunted resources had on the delayed adoption of Eurasian domestics by indigenous North American communities (Pavao-Zuckerman, 2007, p. 5). As was witnessed in the Mississippi River and Great Lake watersheds, taxonomic richness in ecosystems native to the American Southeast supported the intense penetration of fur and deerskin economies. However, the availability of a wide range of plant and animal resources did not support the diffusion of subsistence practices, such as the adoption of new domesticates (Pavao-Zuckerman, 2007, p. 5).

James Watson's (2008) study of faunal remains among the Virgin River Pueblo tradition (300 B.C.-A.D. 1200) revealed similar exploitative patterns in relation to demographic and environmental stress. In this case, Watson highlighted the effect that food availability had on community size and the relative proximity of group residential patterns to important local resources (2008, p. 449). In the American Southwest, the size and number of mammalian resources—common to prehistoric subsistence strategies—correlated with a community's location within an ecosystem. As the Southwest became increasingly arid, human groups began to exploit small and large mammals closer to their elevation in the landscape (Watson, 2008, p. 450). Similar adaptations have been recorded for populations living within ecosystems impacted by new patterns of culture contact, population growth, and precipitation (Freeman, 2012; Schmitt and Lupo, 1995).

John Richards (1992) in his study of late prehistoric ceramics at Aztalan (47JE0001) emphasized the "broad mosaic of productive plant [and animal] communities within southeastern Wisconsin" (Richards, 1992, p. 80). He described the watershed surrounding and penetrating the site to be characterized by "diverse and abundant aquatic zones" (80). The productive nature of this landscape would have ensured Wisconsin populations, throughout the late prehistoric and early historic periods, with adequate food resources, rich in both collected and semi-domesticated plants and animals. The biodiversity of the diets, dependent upon the presence of such a large, taxonomically rich ecosystem, would result in not only greater estimates of community health, but would have also impacted the quality of local patterns of biological growth and development. Characteristics for this unique growth pattern were reflected in the dolichocrany of Wisconsin crania. A similar type of ecological richness was described by Edward Lugenbeal (1976) at the Smith site (21KC003). The context of Lugenbeal's study of Laurel and Blackduck ceramics recovered from the site highlighted, not only, the cultural contact that existed between western Wisconsin and northern Minnesota, but it also addressed the similarities in human, ecological patterns across the region. In his description of the Rainy River watershed during the Woodland Period, Lugenbeal emphasized the diverse taxonomy of the region's pine and broadleaf forest ecosystem (Lugenbeal, 1976, p. 23). Reviewing the accounts of European explorers and later homesteaders, Lugenbeal found the environment to express large tracts of dense coniferous and deciduous canopy separated by rich aquatic environments similar to those described in Richards (1992). Additionally, the meadows and wetlands that developed between stands of balsam fir (*Abiesbalsamea*), white pine (*Pinusstrobus*), and American elm (*Ulmusamericana*) presented indigenous populations with a highly productive habitat, including thousands of acres of wild rice, "berries, fleshy fruits, and greens" (Lugenbeal, 1976, p. 27). The region's fauna would have mirrored the biodiversity witnessed throughout the watershed of the Upper Mississippi River system. Oral accounts of European visitors identified large, easily harvestable populations of "moose, elk, deer, bear, and wolverine" (Lugenbeal, 1976, p. 28). Later archaeological reconstructions recognized over 35 species of large and small game, exploited by indigenous populations throughout the prehistoric and historic periods. Many of these animals, such as the red fox (*Vulpesfulva*) and beaver (*Castor canadensis*) became important resources for historic-era trade economies within the region. Pollen profiles support the idea that the ecosystem, like that of the Great Lakes Watershed, remained biologically stable throughout the pine-hardwood and later prairie periods, and that the taxonomic richness of the region remained significantly higher than watersheds to the south and east. Ecological stability would have been beneficial for population growth and sedentism. Additionally, the richness of the region, and the fact that local cultigens do not appear in the record until the early eighteenth century, highlights the importance of this food availability and its contribution to the human ecology of the region. The current study compared subsistence practices across a variety of landscapes, organizing each archaeological and historic population into specific subsistence categories. Instead of focusing on local patterns of faunal and floral evidence, attention was given to the effects that dietary admixtures had on mid-facial and overall cranial shape and size. In this case, populations that were known to have a larger expression of collected, naturally occurring foodstuffs exhibited craniofacial and nasal shapes that were significantly different from groups incorporating domesticated plant remains into their diet. As the expression of domesticated or semi-domesticated food resources increased in the diet, craniofacial breath also increased. The only exception to this pattern occurred among populations inhabiting a taxonomically rich landscape where long, narrow cranial shapes accompanied gracile nasal features.

Human and non-human mammalian models, regarding the diversity of food resources, resource-related food stress, and skeletal anatomy have demonstrated the significant and predictable impact that adolescent diet has on the developing axial skeletal system—specifically, the quantitative and qualitative characteristics of the base of the skull and the dental arcade. McGraw and Daegling's (2012) recent discussion of the relationship between food availability and primate growth patterns supports the notion that naturally occurring, foraged foods result in significant variations in skeletal morphology and biomechanical processes. Richard Dapson's (1968) study of growth patterns among adolescent and adult short-tailed shrews (*B. brevicauda*), for example, highlighted the effects of seasonal food resource availability on the growth of the cranial vault (118). So, too, among human populations, food stress impacts the growth and development, and the anatomical patterns associated with adult groups.

Ishida and Dodo's (1990) study of the thickness of the frontal and parietal eminences of Neolithic populations in Japan revealed the significant impact that variation in an environment and community isolation had on traditional racial models for craniometric variation within Asian-Pacific populations. Ishida and Dodo (1990) also stressed the importance of addressing external factors for early cranial growth, including diet.

In the current study, food acquisition is considered to be a selective pressure experienced by populations in both a seasonally, migratory, and/or sedentary life history experience. Studies of early experimental, agricultural techniques in the Near East, at sites such as Jarmo (Iraq) portray non-domesticated, foraged resources as important alternatives to crop failure (Warnock, 1998; Braidwood, 1972). This study raises similar concerns regarding Late Woodland and Mississippian populations living throughout the Mississippi and Great Lakes Watersheds. Charles Cobb's (2013) assessment of the Mississippian Chiefdom supports the idea that many of the smaller communities surrounding centers of trade and political administration were reliant on these prehistoric municipalities for ideological and sociological support, yet their day-to-day needs required them to remain self-sufficient. Cobb notes that sites such as Cahokia, Kincaid, and Lake George—given their location within the southern portion of the Mississippi watershed—would have been ideal locations for material storage and redistribution though the receipt of stored resources and their dietary quality may not have been adequate enough to support the entire watershed. Additionally, if food acted as an element of tribute or was incorporated into a system of wealth redistribution and taxation, small satellite communities may have experienced subsistence stress. Given the taxonomic richness of the surrounding landscape, communities within the chiefdom may have relied on traditionally collected resources in order to meet their subsistence needs, thus providing community members with a more biochemically diversified diet. The watershed, for both Old and New World populations highlighted in the current study, would have provided community members with the means to adapt to food stress, resulting in a uniquely similar cranial pattern of growth and development. Finally, the crania examined from Aztalan burials expressed qualitative signs of iron deficiency anemia, such as dental/enamel hypoplasia and enamel pigmentation. This pattern of nutritional stress, however, was not witnessed among study specimens recovered from the surrounding landscape and earlier archaeological periods. The cranial shapes of satellite communities conformed to patterns witnessed among foraging and mixed-subsistence environments while the material recovered from Aztalan appeared to be indicative of diets rich in local and regional Mississippian period cultigens. The same pattern was visible within horticultural and early agricultural populations within Eurasia.

7. Conclusion

The quantitative and qualitative assessment of a community's cranial growth patterns is important in determining the impact that a long-term change in diet may have had on its members. Bjork's (1955) study of adolescent and adult facial and cranial growth patterns emphasized the connection that exists between the architecture of the hard palate, the cranial base, the shape of the upper face, and the cranial vault. Their study of over two hundred individuals compared morphological differences at two important periods in human growth and development—twelve and twenty years. This study builds upon these measurements, incorporating indices relating to adult cranial sizes and shapes. As was the case with Bjork (1955), strong mathematical relationships were identified in relation to the angle and size of the hard and soft dental arcades and the length of the skull. These geometric patterns are witnessed not only among populations with varying diets, but also among groups expressing varying modes of subsistence and political order. Variations in facial and cranial vault shape correlates with variations in the subsistence strategy and the location of a community within a continental watershed. Although further testing is required, the shape of the face and braincase provides bioarchaeologists with a tool to reconstruct the life history and the cultural ecology of study subjects. When cross-referenced with dietary reconstructions drawn from trash middens, additional details regarding the relationships among communities in taxonomically rich watersheds may be better understood.

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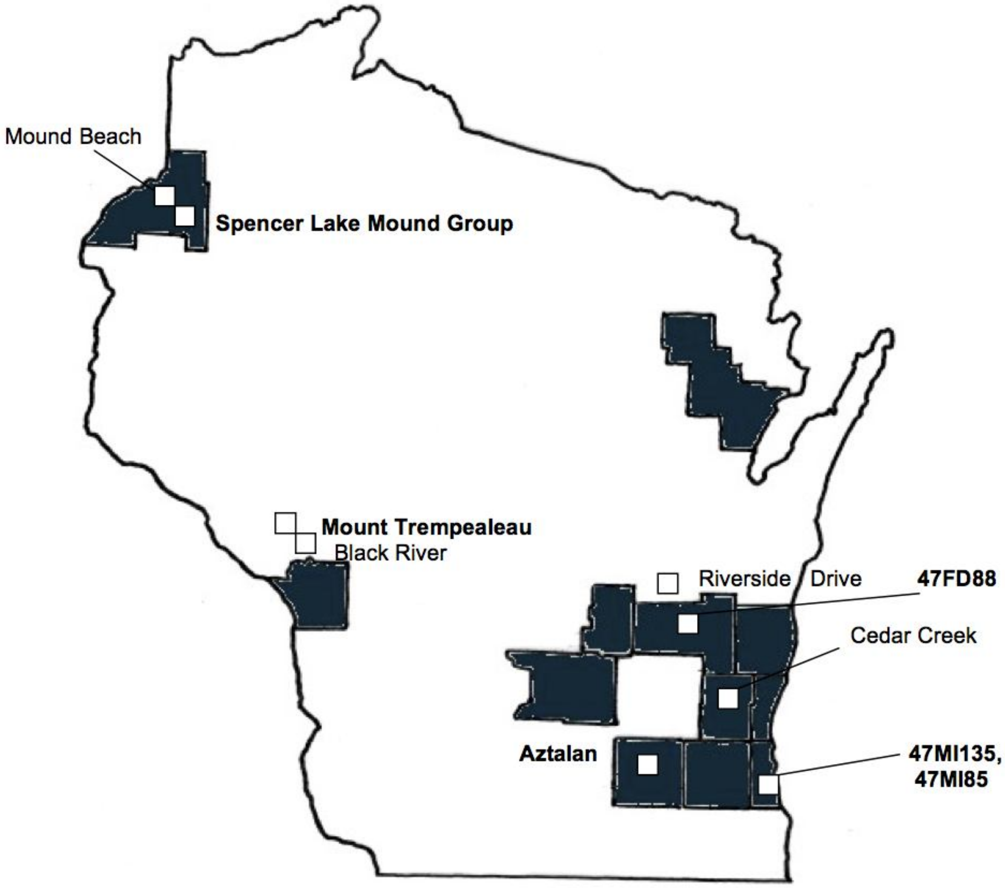

Figure 1: A Map Showing the Locations where Prehistoric and Historic Archaeological Material was Recovered

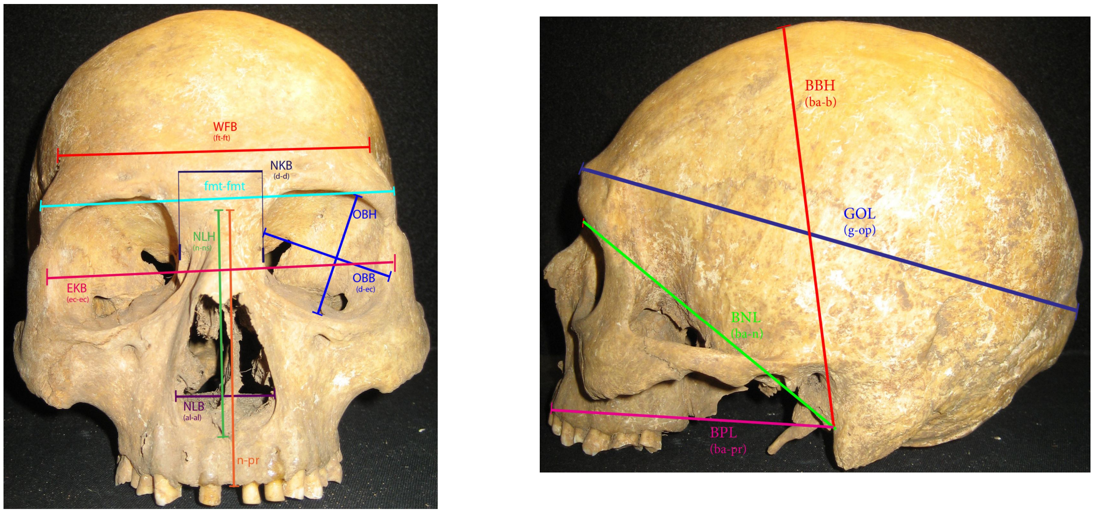

Figure 2: Frontal and Lateral Planes Depicting the Measurements Used to Determine Cranial and Craniofacial Size and Shape

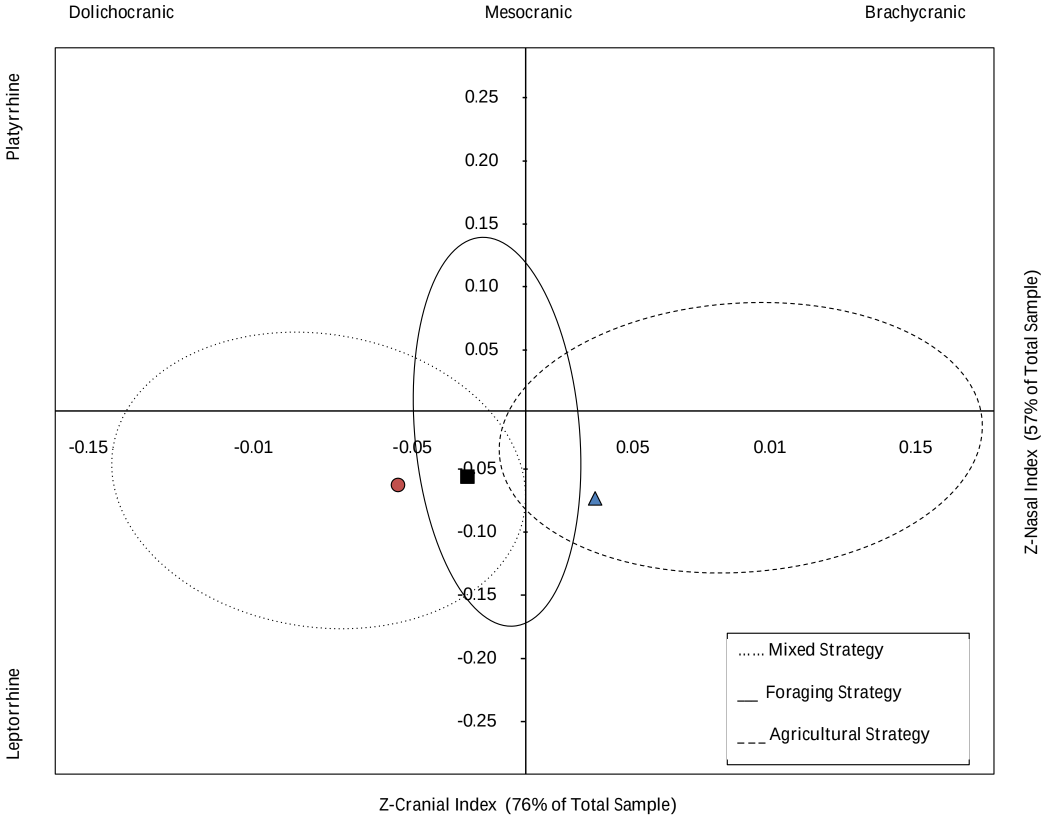

Figure 3: Distribution of Combined Z-scores for Mixed, Foraging, and Agricultural Strategies. Composite Averages are Distinguished by Shape

Table 1: Metric Traits and Variables

Anatomical Location	Description	Code from Bass (2005)
Cranial Vault	Basion-Porion height (*ba-po*)	BPL
	Maximum cranial length (*g-op*)	GOL
	Maximum cranial breadth (*eu-eu*)	XCB
Face	Interorbital breadth (*d-d*)	DKB
	Biorbital breadth (*ec-ec*)	EKB
	Upper facial breadth (*fmt-fmt*)	fmt-fmt
	Upper facial height (*n-pr*)	n-pr
	Nasal height (*n-ns*)	NLH
	Nasal breadth (*al-al*)	NLB
	Orbital breadth (*ec-ec*)	OBB (left)
	Minimum frontal breadth (*ft-ft*)	WBF
	Bizygomatic breadth (*zy-zy*)	ZYB

Table 2: Craniometric Samples

Language Community/ Culture	Geographic Region/Site	Time Period	Literary/Osteometric Source
Middle Holocene	Sub-Sahara, Africa	5000-2000 BP	Morris and Ribot (2006)
Eastern Georgian	Rustavi, Georgia	3800-3600 BP	Abdushelishvili, M. (1950)
Kavkasioni (Osetes)	Osetia Highlands, Georgia	3200-3000 BP	Bunak et al. (1960)
	Bebnisi, Georgia	3000-2000 BP	
Inner Georgian	Dvani, Georgia	3000-2000 BP	Bunak et al. (1960)
Southern Georgian	Tkviavi, Georgia	3000-2000 BP	Bunak et al. (1960)
Koban Culture	Samthavro, Georgia	2900-2400 BP	Abdushelishvili, M. (1954)
Abkhazian Culture (Black Sea Variant)	Abkhazia, Georgia	2900-2400 BP	Abdushelishvili, M. (1955)
Pontic-Zagrossian	Armenia	2700 BP	Bunak V. (1946)
Late Holocene	Malawi, Africa	2000-500 BP	Morris and Ribot (2006)
Late Woodland Period			
	47MI135	1600-900 BP	Farley et al. (2009)
	47MI85		
	47YT33		
	Black River, Wisconsin		Farley et al. (2009)
	Cedar Creek, Wisconsin		
Mississippian Period	47JE01	1000-500 BP	Farley et al. (2009)
	47TR33		
Protohistoric/Historic Period	47BT02	400-200 BP	Farley et al. (2009)
	47FD88		
	Fort Berthold, North Dakota		Howells, W. (1965-1980)
	Butte des Mortes, Wisconsin		Farley et al. (2009)
	Lake Lenwood, Wisconsin		
Khoi-San	Malawi, Africa		HistoricMorris and Ribot (2006)

Table 3: Comparative Samples

Subsistence Details	Geographical/Archaeological Source	N	Males	Females
Mixed Subsistence Strategy (foraging/semi-domestication)	Middle and Late Holocene, Africa	56	29	27
	Late Woodland Period, Wisconsin	8	7	1
Small Scale Agriculture (limited, multi-household subsistence)	Eastern Georgian	11	5	6
	Inner Georgian	4	1	3
	Southern Georgian	5	2	3
	Historic Period, Wisconsin	9	5	4
Agriculture (multi-household surplus)	Mississippian Period, Wisconsin	3	2	1
	Historic Period, North Dakota	69	42	27
		165	93	72

Table 4: Craniometric Measurements and Indices

Measurement	Measurement Criteria	Measure/Index
Maximum Cranial Breadth	Moore-Jansen et.al. (1994)	Breadth-Length Index
Maximum Cranial Length	Moore-Jansen et.al. (1994)	Breadth-Length Index
Basion-Prosthion Length	Moore-Jansen et.al. (1994)	
Minimum Frontal Breadth	Moore-Jansen et.al. (1994)	MFB Comparison
fmt—fmt	Bass (1995), Sefcakova et.al. (2006)	fmt-fmt Comparison
Nasal Breadth	Bass (1995)	Breadth-Height Index
Nasal Height	Bass (1995)	Breadth-Height Index
Upper Facial Height	Moore-Jansen et.al. (1994)	Facial Height Index
Bizygomatic Breadth	Moore-Jansen et.al. (1994)	Facial Height Index
Orbital Breadth	Bass (1995), Sefcakova et.al. (2006)	Orbital Index
Interorbital Breadth	Bass (1995), Sefcakova et.al. (2006)	Orbital Index

Table 5: ANOVA Summary of Group Variation

Variable	F-score	Significance	N
Maximum Cranial Length (GOL)	3.404	0.020	111
Maximum Cranial Breadth (XCB)	5.253	0.002	111
Cranial Index (CI)	12.880	0.000	111
Upper Facial Index (UFN)	7.682	0.001	90
Nasal Index (NI)	16.449	0.000	108