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Changes in the Skull Surface Area with Age Among Ancient Children in Xinjiang, China

Cambios en la Superficie Craneal con la Edad en Niños Ancestrales de Xinjiang, China

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SUMMARY: Within the current body of literature, the study of cranial growth and development in ancient children populations has received limited attention. The purpose of this study is to address this research gap by examining 36 children's skulls, excavated from the Zaghunluq cemetery in Xinjiang, as the primary research material. By analyzing the differences in the external surface areas of various parts of the skulls across diverse age groups, the study aims to explore the characteristics and patterns of skull growth and development among ancient children in Xinjiang. The analysis of variance (ANOVA) revealed significant differences in the surface areas of the zygomatic, temporal, frontal, occipital, parietal, and cranial bones among six age groups (2 years old, 3-5 years old, 6-7 years old, 8-10 years old, 12-15 years old, and 17-19 years old), while the surface area of the parietal bones showed no significant difference. This study found that the surface area of the zygomatic bone experienced rapid growth during the ages of 8-10 and 12-15. Likewise, the temporal bones exhibited a remarkable surge in surface area within the age range of 3-5. This early-stage rapid growth was then followed by a significant expansion of the occipital bone surface area when the children reached ages 6-7. As for the parietal bones, a significant increase in surface area was observed at both ages 3-5 and 8-10. Additionally, the frontal bone showcased a notable increase in surface area, specifically between the ages of 8-10. This period of growth also coincided with a primary phase of skull expansion, suggesting ages 8-10 represented a growth spurt in the surface area of the cranial bones among Zaghunluq children. Based on the observed variations in growth spurts in the surface area of different skull regions, the findings showed that the growth and development of Zaghunluq children's skulls predominantly occurred during the ages of 8-10, potentially indicating the onset of their adolescence during this period. Moreover, during the transition from childhood to adolescence, the skull might undergo a temporary slow growth.

KEY WORDS: Xinjiang; Zaghunluq Cemetery; Ancient children populations; Skull surface area; Skull growth patterns; Growth spurts.

INTRODUCTION

Childhood represents a critical phase in the growth and development of the skull, marked by accelerated growth and substantial morphological transformations. Variables such as head width, head length, head circumference, and cephalic index serve as key measurement parameters for inferring patterns of growth in children's cranial development. The scholarly community has conducted extensive investigations into age, sex, ethnicity, and chronological variations in craniofacial morphology among children through the measurement of data from both ancient and contemporary juvenile skulls. Additionally, some researchers have explored factors that impact the growth and development of the skull, including nutritional status, social environment, and local climate.

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Changes in Craniofacial Morphology with Age

Many researchers have sought to understand the dynamics of children's skull growth and development by measuring and analyzing skull data from various age groups. This body of research has uncovered characteristics of changes in children's craniofacial morphology that evolve with age. For instance, the study of Martini *et al*. (2018), underscored the importance of measuring the maximum head circumference, a standard procedure that offers insights into cranial and brain development in children.

As an example, Li *et al*. (2008), conducted a 3-year follow-up study measuring the head circumference of 750 infants born in Shanghai, China. The findings demonstrated a progressive increase in head circumference as the infants aged, following a slower rate of growth as they grew older. By the age of one, the head circumference was approximately 1.3 times larger than at birth.

Further supporting this trajectory, Martini *et al*. (2018), used 3D surface scans to measure the cranial parameters of 44 Caucasian children aged 4-12 months (29 boys and 15 girls). The findings showed that the average cranial volume of all children increased from 1174 ± 106 mL at 4 months to 1579 ± 79 mL at 12 months. Similarly, the maximum cranial circumference increased from 43.4 ± 9 cm to 46.9 ± 7 cm, and the cranial length increased from 23.6 ± 13 cm to 25.3 ± 13 cm.

Moreover, Chen (1990), conducted a 6-year longitudinal study on head circumference measurements of 126 newborns in Malaysia, comprising 65 boys and 61 girls. The findings showed that the growth rate of head circumference was highest during the initial months of infancy, subsequently experiencing a gradual deceleration as the subjects grew older. By the age of 5, the rate of head circumference growth showed minimal changes.

In a related study, Hou *et al*. (2014), conducted a 6-year longitudinal study, measuring head dimensions including head circumference, cranial length, and cranial width, in a cohort of 112 children born at the First Affiliated Hospital of Baotou Medical College in China. The study suggested a distinctive pattern of cranial growth, with the most rapid growth observed during the first year of life, followed by the next fastest periods of growth in the second and third years respectively. Cranial growth notably decelerated by the age of 6, at which point the cranial growth indices began to approximate those of adults.

Particularly, Merkel (1882), proposed a dual-stage model of rapid human head development: the initial stage, from birth to 7 years old, and the second stage, spanning from pubescence until the middle teens. The first stage primarily reflected rapid head growth, while the period from 7 years old to pubescence represented a relative plateau in growth. Subsequently, during pubescence, accelerated growth in head circumference and head length was observed, continuing until the age of 15 or 16. Afterwards, all measured traits exhibited minimal growth, increasing by no more than 1-2 % of the measurements taken during the maturity phase (as cited in Dokladal, 1959).

Echoing this approach, Farkas *et al*. (1992), conducted a study on 1,537 Caucasian individuals in North America, ranging in age from 1 to 18 years. They measured a variety of head dimensions, including head width, forehead width, head height, head length, and head circumference. The findings illustrated that between 0 and 1 year of age, both head circumference and head length displayed rapid growth, reaching 87.5 % and 87.1 % of their mature size within the first year, respectively. Between the ages of 1 and 4, the early rapid growth period occurred for both head height and head length. From 1 to 6 years, forehead width showed a phase of rapid growth, while head width and head circumference exhibited consistent and moderate growth during this period. Head length reached its mature size at age 10 (182.7 mm) in females, and at age 14 (189.2 mm) in males. The study also revealed that most head measurements in males reached maturity by the age of 15.

Additionally, Waitzman *et al*. (1992), utilized CT scan data to conduct 15 craniofacial measurements on a cohort of 542 children aged 1-17, examining the growth patterns of the craniofacial complex. The findings revealed that the overall size of the cranio-orbito-zygomatic bones reached over 85 % of adult size by the age of 5. The cranial vault experienced rapid growth during the first year after birth, followed by a decline in growth rate that was nearly complete by the age of 6. In contrast, the upper midface exhibited slower growth during infancy but continued to grow during childhood and early puberty.

Further expanding this body of knowledge, Ran *et al*. (2017), categorized a cohort of 20,000 Chinese children, aged between 4 and 17, into five age groups and conducted an analysis of seven cranial indices, including measurements of head length, head width, head height, head circumference, facial length, sagittal arc, and bitragion arc. The study showed a consistent increase in the mean values of all craniofacial dimensions with age, with higher growth rates observed in the 4-6 and 7-10 age groups. The study further reported that the craniofacial dimensions of boys in the 16-17 age group, along with those of girls in the 13-15 age group, were approaching maturity.

Meanwhile, Pavlica *et al*. (2018), conducted a comprehensive investigation into the long-term trends of craniofacial dimensions among the adult population in Vojvodina. Two surveys were carried out in 1975 and 2001-2006, involving measurements of craniofacial parameters such as head length, head width, morphological facial height, and facial width. The sample comprised 2600 individuals in the first survey (1300 males aged 20-60 and 1300 females aged 20-55) and 4504 individuals in the second survey (1965 males with a mean age of 40.10 ± 11.84 years and 2539 females with a mean age of 41.12 ± 10.75 years). The study revealed significant changes over the 33-year period, including a notable increase in head length among males, a decrease in head width and facial width among both males and females, and a significant increase in facial height. These findings indicate an evident trend in craniofacial reshaping among the adult population in Vojvodina, characterized by narrower heads and longer faces, consistent with the ongoing prevalence of dolichocephaly.

Based on the extensive body of research, it is evident that craniofacial measurements undergo significant changes throughout different stages of growth and development. In addition, these studies highlight the distinct patterns of craniofacial changes observed with increasing age, providing valuable insights into the variations in craniofacial growth among children. Overall, the findings contribute to a better understanding of the intricate dynamics involved in craniofacial development, emphasizing the importance of considering age-related factors when assessing and interpreting craniofacial measurements.

Sexual Dimorphisms in Craniofacial Morphology

A significant body of research involves the measurement and comparison of craniofacial data from children of different sexes, with the aim of assessing sexual dimorphisms in cranial growth and development. For instance, Weston *et al*. (2007), proposed that human skulls exhibit sexual dimorphism.

Furthering this line of inquiry, Danborno *et al*. (2008), conducted measurements of head dimensions, including head length, head width, and head circumference, and calculated the cephalic indices among 377 Nigerian children aged 5 to 15 years (173 boys and 204 girls). The findings revealed that head length and cephalic indices increased with age for both boys and girls. However, significant differences were observed between boys and girls in terms of head length, head circumference, and cephalic indices. The disparities in head length and cephalic indices were statistically significant, with boys exhibiting greater average head length while girls demonstrated greater average cephalic indices.

Expanding the scope of research, Zaki *et al*. (2008), calculated head circumference and relative head circumference (relative head circumference = {head circumference (cm)/height or length (cm)} × 100) in a sample of 27,826 Egyptian children (14,048 boys and 13,778 girls) aged 0-18. The results revealed a gradual increase in head circumference with age for both boys and girls, with the most rapid growth observed during the first two years of life. Moreover, boys exhibited significantly higher average head circumference values compared to girls ($P < 0.001$). Zaki *et al*., also observed sexual dimorphisms in relative head circumference. This pattern was not significant during infancy, yet from the second year after birth, boys started to display significantly higher values than girls ($P < 0.05$), a trend that persisted until the age of 12, excluding at the age of 10. From the age of 14 onwards, girls began to register significantly higher values than boys ($P < 0.001$), which could be attributed to girls' earlier maturation, thus shedding light on the developmental trajectories of sexual dimorphisms.

In another scholarly work, Hautvast (1971), collected craniofacial measurement data, including head length, head width, head circumference, morphologic face height, and bizygomatic breadth, from elementary school students in 1961 (360 boys, 359 girls), 1963 (129 boys, 102 girls), and 1964 (117 boys, 97 girls). The results showed that boys had significantly higher average values for head length, head width, head circumference, and bizygomatic breadth at each age group compared to girls. Boys also had significantly higher morphologic face height than girls in the 7-11 age group, but the sexual dimorphism in morphologic face height decreased at the age of 12 and 13 due to the earlier onset of puberty in girls.

When viewed as a whole, these studies provide compelling evidence for both shared trends and differences in cranial development between boys and girls. This highlights the significance of considering sexual dimorphisms in future research on cranial growth and development.

Ethnic and Racial Variations in Craniofacial Morphology

The issue of potential ethnic variations in craniofacial morphology among children has been a topic of differing viewpoints. For instance, Nellhaus (1968), reported that there was no significant difference in the head circumference among children aged 0-18 across different countries or races. Nellhaus also proposed a growth curve for head circumference applicable to all races (Nellhaus,1968). However, contrasting perspectives have emerged from numerous studies, suggesting substantial differences in head circumference among children from diverse ethnic groups.

To investigate the potential differences in head circumference between Japanese and Caucasian children, Tsuzaki *et al*. (1990), measured the head circumferences of 42,392 Japanese children aged 0-4 (22,017 boys and 20,375 girls) and compared them to the data from children in the United States and the United Kingdom. The results indicated significant ethnic differences in head circumference between Japanese and Caucasian children. The researchers also suggested that the smaller head circumference observed in Japanese children was likely a reflection of the smaller stature characteristic of the Japanese population.

In a separate study, Ayatollahi *et al*. (2006), measured the head circumference of 2,228 Iranian school-aged children (6.5-11.5 years old, 1,160 boys, and 1,068 girls). They compared their results with those of their peers in Turkey, Ireland, Japan, and the United States. The findings revealed that the average head circumference of Iranian children was generally lower than that of their same-aged counterparts in the Far East, Europe, and the Americas.

Ethnic variations in craniofacial morphology extend beyond childhood and also manifest in adult populations. In a study conducted by Ball *et al*. (2010), the 3D head shape data of more than 2,000 Chinese individuals aged 18 to 70 and 4,000 Caucasians aged 18 to 65 were compared. Their analysis revealed that Chinese individuals tended to have rounder heads than their Caucasian counterparts, with a flatter back and forehead, as observed from the standard reference plane (the horizontal plane passing through the point above the eyebrows and parallel to the Frankfurt Plane).

Similarly, Ran *et al*. (2016), conducted a comparative analysis of adult craniofacial dimensions across multiple countries. The study included individuals from Japan (2,880 males, 2,450 females; aged 20-65), Kenya (133 males, 74 females; aged 18-60), South Korea (2,613 males, 2,614 females; aged 18-60), the Netherlands (560 males, 680 females; aged 18-65), the United States (1,120 males, 1,260 females; aged 18-65), and China (11,164 males, 11,150 females; aged 18-60). The results indicated significant differences ($p < 0.05$) in most craniofacial data among these six countries, with Asian individuals typically having rounder heads, and flatter backs of heads and foreheads, compared to those of individuals from Africa, the United States, and Europe.

In a more recent study, Bhaskar *et al*. 2020), utilized 3D modeling software (Rapidform 6) to construct 3D facial images of individuals from Zimbabwe (n = 201, 107 males and 94 females) and the United States (n = 100, 50 males and 50 females). These images were used to compare the 3D facial features of the two groups. The findings indicated that Zimbabwean males exhibited prominent cheekbones, forehead, lateral supraorbital, and infraorbital regions, as well as a wider supraorbital area compared to American males. Meanwhile, compared to American females, Zimbabwean females demonstrated less pronounced cheekbones but had a more prominent middle forehead area, alae nasi base, and lateral zygomatic region.

Factors Influencing Variations in Craniofacial Morphology

A wealth of research has indicated that the variations in cranial growth and development are the results of multiple factors, such as nutritional status, social environment, and local temperature. In a study conducted by Ivanovic *et al*. (2000), they proposed that the head circumference could serve as a key indicator for understanding both nutritional status and brain development. This research was conducted within Chile's Metropolitan Region, where a representative sample of 4,509 students, aged 5 to 22, was selected. The selection criteria included factors such as grade, gender, school type, and geographic area. In this study, anthropometric measurements, including body weight (W), height (H), and head circumference (HC), were collected. The findings suggested a significant positive correlation between the head circumference of the students and their respective socioeconomic status.

In another study, Ounsted *et al*. (1985), conducted longitudinal measurements of head circumference from birth until seven years old on 270 British children born between 1970 and 1977. These were then compared with corresponding data for children born in the same region during the early years of the 20th century. The findings indicated that children born in the 1970s had significantly larger head circumferences than those born at the beginning of the 20th century.

In a different investigation, Friess *et al*. (2002), utilized 3D laser surface scanning technology to analyze craniofacial dimensions in 66 modern human skull specimens from 11 different geographic regions (including three adult males and females per region). They measured the surface area of the neurocranium and zygomatic region and compared their findings with those of Late Pleistocene Neanderthals and Middle Pleistocene warm-climate fossils. The results suggested that residents in colder regions had a smaller cranial surface area-to-volume ratio than those in tropical regions, suggesting the potential influence of environmental factors on cranial surface area.

Moreover, Pan *et al*. (2014), conducted a study on 295 modern human skulls excavated from 18 archaeological sites in Asia, Africa, Europe, the Americas, and Oceania. Using 3D laser scanning technology, they measured the surface area of the neurocranium and the zygomatic part of the face. The study examined the patterns of variation in craniofacial size among populations at different latitudes and their correlation with average annual temperature. The findings demonstrated that human craniofacial morphology exhibits adaptability, with latitude-related variations in craniofacial surface area observed globally and a close association with local temperature. Specifically, there was a positive correlation between the surface area of the neurocranium and latitude and a negative correlation with temperature. The surface area of the zygomatic region and the cephalic index (calculated as the ratio of the zygomatic area to the neurocranium area) were both negatively correlated with temperature but showed no significant correlation with latitude. As latitude increased, there was a significant increase in the neurocranial surface area. Meanwhile, an increase in the average annual temperature was associated with a significant decrease in the surface areas of both, the neurocranium and zygomatic region, as well as the cephalic index.

Throughout the years, traditional approaches to studying variations in human cranial morphology have primarily been dependent on visual observations and linear measurements, encompassing a range of data, such as skull length, width, height, circumference, arc length, chord length, and angles. Due to limitations in research methodologies and technological capabilities, few scholars have measured and investigated the three-dimensional (3D) data of human skulls, such as the curvature surface area and other such metrics. Research pertaining to the skulls of ancient children has been particularly sparse, predominantly due to the limited availability of specimens. However, in recent years, the application of innovative technologies such as CT and 3D scanning in the study of human physical characteristics has enabled the acquisition and study of more extensive 3D images of the skull. This paper explored the application of these new technologies to study human cranial characteristics and the growth patterns and traits of ancient children's skulls. In this research, we analyzed 36 children's skulls excavated from the Zaghunluq cemetery in Xinjiang. Through the use of CT scanning and 3D skull reconstruction, we extracted data on the external surface area from various parts of the skull, including the zygomatic, temporal, occipital, parietal, frontal, and cranial regions. These data facilitated comparisons across different age groups, thereby shedding light on the growth patterns and characteristics of these ancient child skulls.

MATERIAL AND METHOD

Research Materials

The Zaghunluq ancient tomb complex, one of the largest burial sites discovered at the northern foothills of the Kunlun Mountains, is located in Zaghunluq village, Toghraklek township, Qiemo county, within the Xinjiang Uygur Autonomous Region, China (Fig. 1). The Zaghunluq site encompasses tombs from three distinct archaeological periods. This study focuses on materials from the second cultural phase, which dates from the Spring and Autumn period to the Western Han Dynasty, corresponding to the Qiemo cultural period, extending from the 8th century BC to the mid-3rd century AD (Xinjiang Museum Cultural Relics Team, 1998). From this second cultural phase, 138 tombs were excavated, uncovering a variety of burial practices. These practices include single burials for both adults and children, joint burials for adults and children, joint burials for adults with children, and disarticulated burials for children. The excavations have yielded approximately 530 sets of human remains (Wang *et al*., 2016). For this study, we selected 36 child cranial specimens, aged between 2 and 19 years, while excluding incomplete child cranial samples.

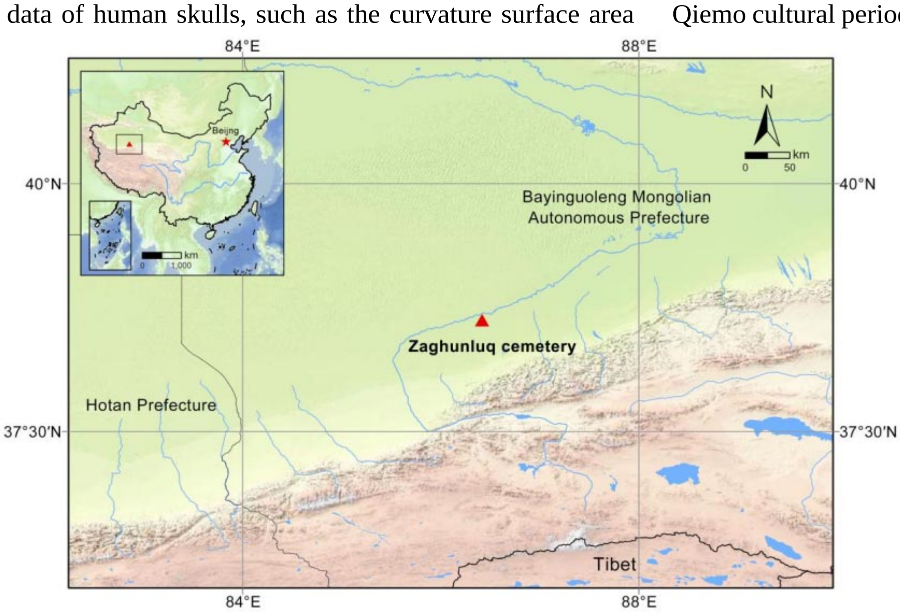

Fig. 1. Geographical location map of Zaghunluq cemetery.

Research Methodology

1. CT Scanning and 3D Reconstruction. The study employed the Prospeed Dual-Slice Spiral CT Scanner from the American company GE for the scanning procedure. The scanning parameters were set to a voltage of 120 kV, a current of 150 mA, a slice thickness of 2 mm, and a pitch of 1.5 mm. All CT images of the children's cranial specimens were consistently acquired by a single radiologist at the Department of Radiology, Second People's Hospital of Urumqi, Xinjiang, using the same CT machine. The obtained CT images were saved in the format of two-dimensional (2D) Digital Imaging and Communications in Medicine (DICOM) files. Subsequently, the visualization and processing software Materialise Mimics, version 13.0, was employed to perform a 3D reconstruction of the skulls.

2. Age Grouping and Craniometry. Referring to The Anthropometric Manual (Shao, 1985) and The Human Bones Manual (White *et al*., 2018), age determination of the children's skulls was conducted based on factors such as the closure status of the anterior fontanelle, the eruption status of deciduous and permanent teeth, and the degree of tooth wear. To facilitate comparison, the 36 skull samples were divided into six age groups based on the age estimation results: a 2-year-old group (2 cases), a 3-5-year-old group (7 cases), a 6-7-year-old group (6 cases), an 8-10-year-old group (11 cases), a 12-15-year-old group (8 cases), and a 17-19-year-old group (2 cases).

Craniometry involves measuring surface areas of different skull regions. To begin, the CT data for each child's skull was imported into the 3D image processing software, Materialise Mimics. Thereafter, thresholding was applied to set CT values and create mask1 in green. Next, the “Region Growing” tool was utilized to remove redundant data and obtain mask 2 in yellow. Subsequently, using the "Calculate 3D from Mask" option within the Segmentation menu, the 2D image of mask 2 (Yellow 1) was reconstructed to obtain a 3D volumetric model. Finally, the obtained model was transferred to the complementary software, Materialise 3-matic, affiliated with Materialise Mimics. Measurements were then taken for the surface areas of the zygomatic bone, temporal bone, occipital bone, parietal bone, frontal bone, and the cranial bone. The methods for measuring each assessed parameter are detailed below.

The method for measuring the surface area of the zygomatic bone (Fig. 2A) involved delineating its boundaries using the zygomaticomaxillary suture, zygomaticofrontal suture, and zygomaticotemporal suture in conjunction with the outer edge between these sutures. Within these boundaries, the external surface area of the zygomatic bone was defined as its surface area. Measurements were primarily taken from the right zygomatic bone. However, in instances where the right zygomatic bone was damaged, the left was used as a substitute. The total zygomatic bone area is twice that of a single side.

The method for measuring the surface area of the temporal bone (Fig. 2B) involved delineating its boundaries using the zygomaticotemporal suture, frontotemporal suture, sphenotemporal suture, and occipitotemporal suture in conjunction with the outer edge between these sutures. Within these boundaries, the external surface area of the temporal bone was defined as its surface area. Measurements were primarily taken from the right temporal bone. However, in instances where the right temporal bone was damaged, the left was used as a substitute. The total temporal bone area is twice that of a single side.

For the measurement of the occipital bone surface area (Fig. 2C), the occipital bone was categorized into four

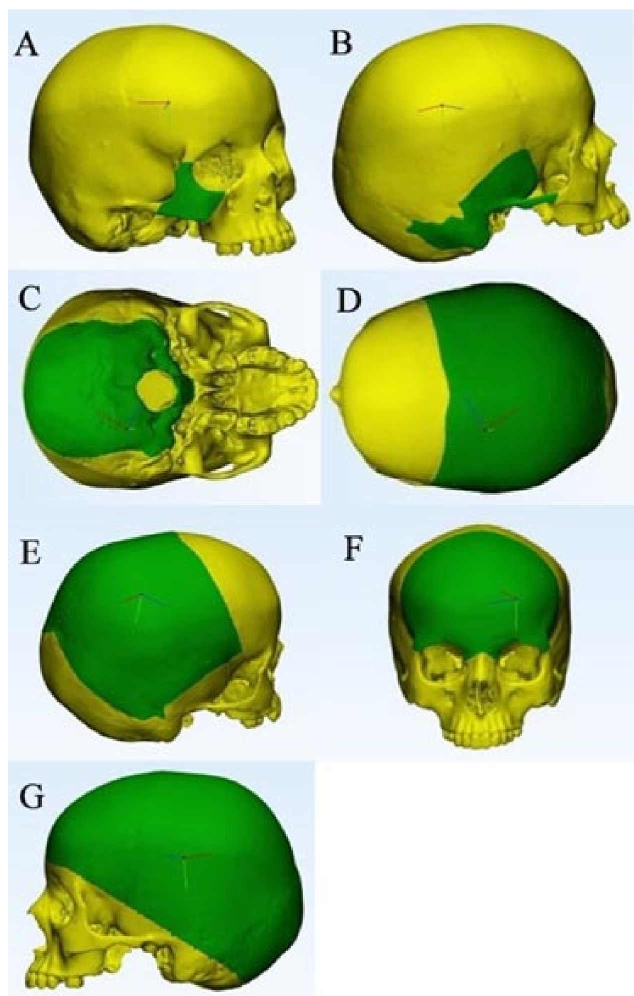

Fig. 2. Measurement of skull surface area.

parts: the squamous part at the posterior, the basilar part at the anterior, and the lateral parts on each side. The surface area of the occipital bone is the sum of the areas of these four parts.

The method for measuring the surface area of the parietal bone (Figs. 2D & 2E) involved defining its boundaries using the squamosal suture, coronal suture, and lambdoid suture in conjunction with the outer edge between these sutures. Within these boundaries, the external surface area of the parietal bone was defined as its surface area. In this study, the areas of both the left and right parietal bones were fully measured. When the anterior fontanelle in children had not completely closed, the fontanelle area was not included in the calculation of the parietal bone area.

For the measurement of the frontal bone's surface area (Fig. 2F), the frontal bone was categorized into three parts. The frontal squama corresponds to the forehead region. Additionally, the orbital part constitutes the roof of the orbit, delineated from the frontal squama by the upper orbital margin. Lastly, the nasal part, positioned between the orbital sections on both sides, resembles a horseshoe shape.

In the methodology for measuring the surface area of the cranial bone (Fig. 2G), this study considered the portions of the frontal, parietal, and occipital bones above the orbital region to represent the cranial bone's surface area. Specifically, the boundary was determined by the plane formed by the point above the midpoint of the eyebrows (on) and the upper margin points of the external auditory meatus on both sides (po). Measurements were taken of the cranial external surface area above this plane. This measurement approach retained as much of the cranial vault as possible while excluding the influences of the orbital and nasal regions. With only three defined points, the procedure simplified the measurement process, minimizing potential errors from manual operations.

3. Statistical Methods. The SPSS 13.0 software was utilized to perform ANOVA and multiple comparisons on the surface area measurements of different skull regions across age groups. For these comparisons, we employed the least significant difference (LSD) method and excluded groups with only two samples, namely the 2-year-old and the 17-19-year-old groups. The threshold for statistical significance was set at $p < 0.05$. The rate of change between age groups was calculated using the following formula:

Rate of change between ages (%) = 100% × (X2 - X1) / X1, where X1 and X2 represent the mean values of corresponding measurements in two distinct age groups.

RESULTS

The surface area measurements of various skull regions from a sample of 36 ancient children are outlined in Table I, while Table II provides a detailed comparison of these areas across different age groups.

1. Comparison of Zygomatic Bone Surface Area Across Different Ages

Using the data presented in Table I, the average surface areas of the zygomatic bone were determined for six age groups from the Zaghunluq cemetery: 2 years old (2 cases), 3-5 years old (7 cases), 6-7 years old (6 cases), 8-10 years old (11 cases), 12-15 years old (8 cases), and 17-19 years old (2 cases). The corresponding measurements are 1289.08 mm^2, 1451.91 mm^2, 1677.37 mm^2, 1977.64 mm^2, 2314.18 mm^2, and 2577.89 mm^2, respectively, as detailed in Table II. The surface area of the zygomatic bone in children showed a gradual increase with age, as illustrated in Figure 3A. Based on the ANOVA, significant differences in zygomatic bone surface area among the different age groups of children were observed (P = 0.000). LSD multiple comparisons revealed no significant difference between the 3-5-year-old group and the 6-7-year-old group (P = 0.148). However, significant differences were observed between the 6-7-year-old group and the 8-10-year-old group (P = 0.040), as well as between the 8-10-year-old group and the 12-15-year-old group (P = 0.009). Calculations revealed rates of change in zygomatic bone surface area as follows: 12.63 % between the 2-year-old and 3-5-year-old groups, 15.53 % between the 3-5-year-old and 6-7-year-old groups, 17.90 % between the 6-7-year-old and 8-10-year-old groups, 17.02 % between the 8-10-year-old and 12-15-year-old groups, and 11.40 % between the 12-15-year-old and 17-19-year-old groups, as detailed in Table II.

2. Comparison of Temporal Bone Surface Area Across Different Ages

Using the data presented in Table I, the average surface areas of the temporal bone were determined for six age groups from the Zaghunluq cemetery: 2 years old (2 cases), 3-5 years old (7 cases), 6-7 years old (6 cases), 8-10 years old (11 cases), 12-15 years old (8 cases), and 17-19 years old (2 cases). The corresponding measurements are 4109.78 mm^2, 4906.09 mm^2, 5705.76 mm^2, 6275.28 mm^2, 6782.92 mm^2, and 7187.84 mm^2, respectively, as detailed in Table 2. The surface area of the temporal bone in children showed a gradual increase with age, as illustrated in Figure 3B. Based on the ANOVA, significant differences in temporal bone surface area among the different age groups of children were observed (P = 0.000). The LSD multiple comparisons demonstrated that there was no

Table I. Surface areas of various skull regions in ancient Zaghunluq children.

Specimen Number	Age (Years)	Age Group	Zygomatic surface area (mm^2)	Temporal surface area (mm^2)	Occipital surface area (mm^2)	Parietal surface area (mm^2)	Frontal surface area (mm^2)	Cranial surface area (mm^2)
98QZIM109D	2	2	1346.46	3636.26		27410.94	11726.26	
1specimen number is missing	2.2	2	1231.7	4583.3	11537.56	24239	10887.19	47634.75
96XQLM2:_D-scratch	3-4	3-5	1334.14	5091.42		25402.32	12122.06	47338.08
M89A	3-4	3-5	1287.12	4361.28		28763.04	12444.25	
3 specimen number is missing	3-4	3-5	1649.72	5903.64				
M102_C	3-4	3-5	1294.54	4515.74		29383.3	12512.68	
5 specimen number is missing	4-5	3-5	1815.34	5933.42	12005.39		11176.64	50921.18
M111_4	4-5	3-5	1419.92	4098.78		25959.73	11442.87	
M159F	4-5	3-5	1362.58	4438.34	11041.02	25589.37	12396.73	49038.33
98QZIM147H	6-7	6-7	1916.92	5560.2	12822.13	28373.49	14017.27	53933.65
196QZIM44W	6-7	6-7	1472.28			28529.97	11203.97	50928.85
96QZIM4Q	6-7	6-7		6706.64	13760.09	26445.88	12047.03	
M147A	6-7	6-7	1679.12	4801.44	12144.37	29256.92	12870.78	51219.52
M147E	6-7	6-7	1444.04	5114.94	12857	24620.49	11497.1	45689.28
98QZIM111B	6-7	6-7	1874.48	6345.56	13276.39	25535.07	11685.86	49551.95
M11B	8-10	8-10	1827.96	5563.04			13805.16	
2 specimen number is missing	8-10	8-10	2026.28	6278.86	14415.46	30236.92	13111.06	56073.86
96QZIM12-B	8-10	8-10	2046.88	6826.98	13317.25	27267.85		52091.9
98QZIM154Y	8-10	8-10	1948.32	5668.02	11214.1	26089.1	12384.82	47666.12
98QZIM154U	8-10	8-10	1819.04	6047.62	13989.32	29382.67		56883.56
4 specimen number is missing	8-10	8-10	2010.1	5835.12		28794.49	14020.09	52715.56
98QZIM147M	8-10	8-10	1986.4	6456.2	15139.99	28706.42	13672.26	54153.68
98QZIM118B	8-10	8-10	1922.28	5814.28	14597.48	30543.84	14941.67	56135.02
M154C	8-10	8-10	2039.82	6164.76	14660.55	26319.5	12664.3	51362.32
96QZIM44H	8-10	8-10	2223.14	8257.78	13733.82	30599.01	15578.15	58624.54
96QZIM44Y	8-10	8-10	1903.8	6115.42	13778.07	25997.17	13490.57	50557.17
98QZIM160A	12-15	12-15	2087.3	5291.1		28207.79	13257.35	53031.74
98QZIM24C	12-15	12-15	1819.86	7088.44	13613.11	28569.14	13455.33	54258.04
98QZIM154M	12-15	12-15	2462.58	6202.46	14492.73	26862.29	14987.14	55728.62
98QZIM155	12-15	12-15	2718.16	6766.06	12983.36	28444.41	15605.78	54860.71
96QZIM4F	12-15	12-15	2472.88	8296.76	15014.1	27459.3	11743.27	50492.46
98QZIM119_C	12-15	12-15	1912.22	6847.52	13935.55	34366.89	15542.52	61118.62
96QZIM14E	12-15	12-15	2028.86	6755.54	13342.65	28297.44	14715.35	53447.28
98QZIM147-O	15	12-15	3011.58	7015.44	14041.31	31058.72	14843.34	59093.23
96QZIM44L	17-19	17-19	2771.32	7187.84	15336	32300.31	16522.12	61148.16
98QZIM123B	17-19	17-19	2384.46	_	_	28457.31	12478.17	53870.98

significant difference between the 3-5-year-old group and the 6-7-year-old group (P = 0.093), the 6-7-year-old group and the 8-10-year-old group (P = 0.190), and the 8-10-year-old group and the 12-15-year-old group (P = 0.176). Calculations revealed rates of change in temporal bone surface area as follows: 19.38 % between the 2-year-old and 3-5-year-old groups, 16.30 % between the 3-5-year-old and 6-7-year-old groups, 9.98 % between the 6-7-year-old and 8-10-year-old groups, 8.09 % between the 8-10-year-old and 12-15-year-old groups, and 5.97 % between 12-15-year-old and 17-19-year-old groups, as detailed in Table II.

3. Comparison of Occipital Bone Surface Area Across Different Ages

Using the data presented in Table I, the average surface areas of the occipital bone were determined for six age groups from the Zaghunluq cemetery: 2 years old (2 cases), 3-5 years old (7 cases), 6-7 years old (6 cases), 8-10 years old (11 cases), 12-15 years old (8 cases), and 17-19 years old (2 cases). The corresponding measurements are 11537.56 mm^2, 11523.21 mm^2, 12972.00 mm^2, 13871.78 mm^2, 13917.54 $mm^2$2, and 15336.00 mm^2, respectively, as detailed in Table II. As indicated by Figure 3C, the surface area of the occipital bone exhibited subtle variations in the early stages, followed by a steady increase with age in the later stages. Based on the ANOVA, significant differences in occipital bone surface area among the different age groups of children were observed (P = 0.011). The LSD multiple comparisons demonstrated that there was no significant difference between the 3-5-year-old group and the 6-7-year-old group (P = 0.068), the 6-7-year-old group and the 8-10-year-old group (P = 0.087), and the 8-10-year-old group and the 12-15-year-old group (P = 0.920). Calculations revealed rates of change in occipital bone surface area as follows: -0.12% between the 2-year-old and 3-5-year-old groups, 12.57 % between the 3-5-year-old and 6-7-year-old groups, 6.94 % between the 6-7-year-old and 8-10-year-old groups, 0.33 % between the 8-10-year-old and 12-15-year-old groups, and 10.19% between the 12-15-year-old and 17-19-year-old groups, as detailed in Table II.

4. Comparison of Parietal Bone Surface Area Across Different Ages

Using the data presented in Table I, the average surface areas of the parietal bone were determined for six age groups from the Zaghunluq cemetery: 2 years old (2 cases), 3-5 years old (7 cases), 6-7 years old (6 cases), 8-10 years old (11 cases), 12-15 years old (8 cases), and 17-19 years old (2 cases). The corresponding measurements are 25824.97 mm^2, 27019.55 mm^2, 27126.97 mm^2, 28393.70 mm^2, 29158.25 mm^2, and 30378.81 mm^2, respectively, as detailed in Table II. The surface area of the parietal bone in children showed a gradual increase with age, as illustrated in Figure 3D. Based on the ANOVA, there were no significant differences in parietal bone surface area among the different age groups of children (P = 0.190). The LSD multiple comparisons demonstrated that there was no significant difference between the 3-5-year-old group and the 6-7-year-old group (P = 0.931), the 6-7-year-old group and the 8-10-year-old group (P = 0.240), and the 8-10-year-old group and the 12-15-year-old group (P = 0.437). Calculations revealed rates of change in parietal bone surface area as follows: 4.63% between the 2-year-old and 3-5-year-old groups, 0.40 % between the 3-5-year-old and 6-7-year-old groups, 4.67 % between the 6-7-year-old and 8-10-year-old groups, 2.69 % between the 8-10-year-old and 12-15-year-old groups, and 4.19% between 12-15-year-old and 17-19-year-old groups, as detailed in Table II.

Table II. Age comparison of the surface area of different parts of the skull of ancient children in Zaghuluq.

Measurement	2 Years		3-5 Years		6-7 Years		8-10 Years		12-15 Years		17-19 Years		ANOVA	LSD			Rate of Change （%）				
	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	P	3-5 vs. 6-7	6-7 vs. 8-10	8-10 vs. 12-15	2 vs. 3-5	3-5 vs. 6-7	6-7 vs. 8-10	8-10 vs. 12-15	12-15 vs. 17-19
Zygomatic surface area	2	1289.1	7	1451.9	5	1677.4	11	1977.6	8	2314.2	2	2577.9	0.000	0.148	0.040	0.009	12.63	15.53	17.90	17.02	11.40
Temporal surface area	2	4109.8	7	4906.1	5	5705.8	11	6275.3	8	6782.9	1	7187.8	0.001	0.093	0.190	0.176	19.38	16.30	9.98	8.09	5.97
Parietal surface area	2	25825.0	5	27019.6	6	27127.0	10	28393.7	8	29158.3	2	30378.8	0.190	0.931	0.240	0.437	4.63	0.40	4.67	2.69	4.19
Frontal surface area	2	11306.7	6	12015.9	6	12220.3	9	13740.9	8	14268.8	2	14500.2	0.001	0.741	0.012	0.315	6.27	1.70	12.44	3.84	1.62
Occipital surface area	1	11537.6	2	11523.2	5	12972.0	9	13871.8	7	13917.5	1	15336.0	0.011	0.068	0.087	0.920	-0.12	12.57	6.94	0.33	10.19
Cranial surface area	1	47634.7	3	49099.2	5	50264.7	10	53626.4	8	55253.8	2	57509.6	0.018	0.623	0.068	0.295	3.07	2.37	6.69	3.03	4.08

Note: * denotes p <0.05. In the above measurements, surface area is in mm^2

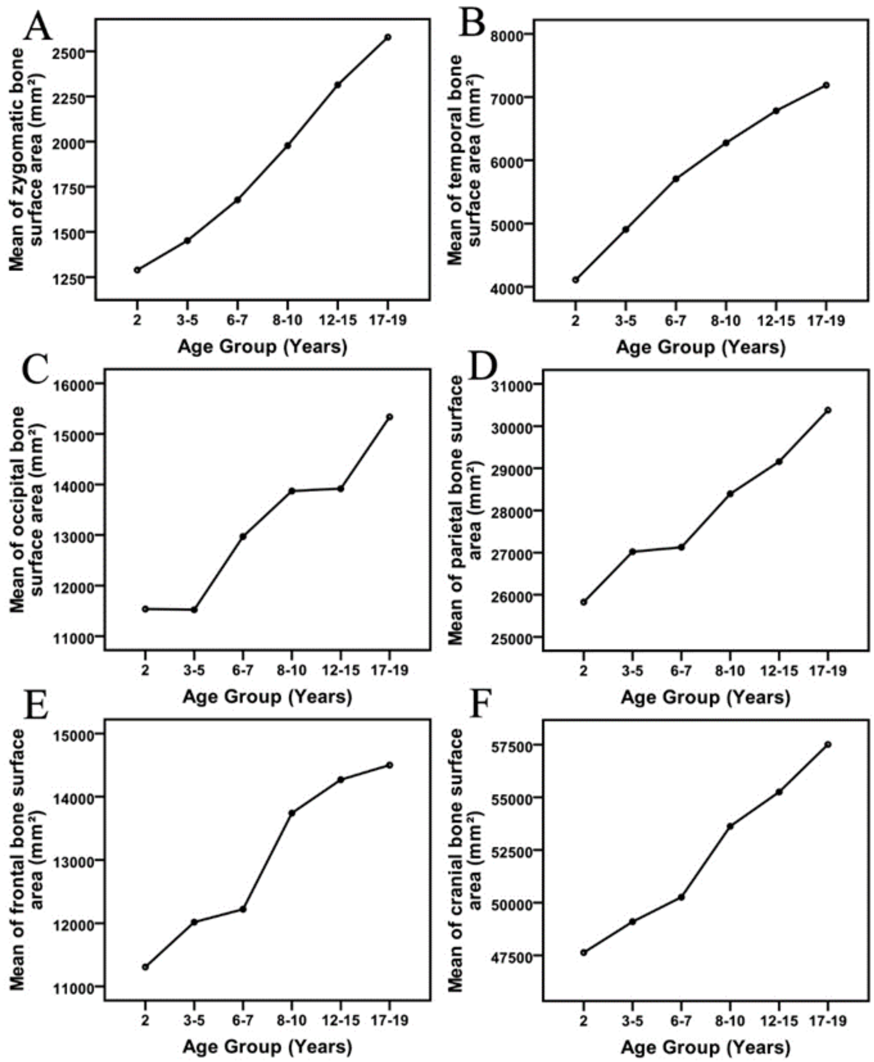

Fig. 3. Age-related changes in skull surface area.

5. Comparison of Frontal Bone Surface Area Across Different Ages

Using the data presented in Table I, the average surface areas of the frontal bone were determined for six age groups from the Zaghunluq cemetery: 2 years old (2 cases), 3-5 years old (7 cases), 6-7 years old (6 cases), 8-10 years old (11 cases), 12-15 years old (8 cases), and 17-19 years old (2 cases). The corresponding measurements are 11306.72 mm^2, 12015.87 mm^2, 12220.34 mm^2, 13740.90 mm^2, 14268.76 mm^2, and 14500.15 mm^2, respectively, as detailed in Table II. The surface area of the frontal bone in children showed a gradual increase with age, as illustrated in Figure 3E. Based on the ANOVA, significant differences in frontal bone surface area among the different age groups of children were observed (P = 0.001). The LSD multiple comparisons demonstrated that there was no significant difference between the 3-5-year-old group and the 6-7-year-old group (P = 0.741), nor between the 8-10-year-old group and the 12-15-year-old group (P = 0.315). However, a significant difference was found between the 6-7-year-old group and the 8-10-year-old group (P = 0.012). Calculations revealed rates of change in frontal bone surface area as follows: 6.27 % between the 2-year-old and 3-5-year-old groups, 1.70 % between the 3-5-year-old and 6-7-year-old groups, 12.44 % between the 6-7-year-old and 8-10-year-old groups, 3.84 % between the 8-10-year-old and 12-15-year-old groups, and 1.62 % between 12-15-year-old and 17-19-year-old groups, as detailed in Table II.

6. Comparison of Cranial Bone Surface Area Across Different Ages

Using the data presented in Table I, the average surface areas of the cranial bone were determined for six age groups from the Zaghunluq cemetery: 2 years old (2 case), 3-5 years old (7 cases), 6-7 years old (6 cases), 8-10 years old (11 cases), 12-15 years old (8 cases), and 17-19 years old (2 cases). The corresponding measurements are 47634.75 mm^2, 49099.20 mm^2, 50264.65 mm^2, 53626.37 mm^2, 55253.84 mm^2, and 57509.57 mm^2, respectively, as detailed in Table II. The surface area of the cranial bone in children showed a gradual increase with age, as illustrated in Figure 3F. Based on the ANOVA, significant differences in cranial bone surface area among the different age groups of children were observed (P = 0.018). The LSD multiple comparisons indicated that there was no significant difference between the 3-5-year-old group and the 6-7-year-old group (P = 0.623), nor between the 8-10-year-old group and the 12-15-year-old group (P = 0.295). However, there was a near-significant difference between the 6-7-year-old group and the 8-10-year-old group (P = 0.068). Calculations revealed rates of change in cranial bone surface area as follows: 3.07 % between the 2-year-old and 3-5-year-old groups, 2.37 % between the 3-5-year-old and 6-7-year-old groups, 6.69 % between the 6-7-year-old and 8-10-year-old groups, 3.03 % between the 8-10-year-old and 12-15-year-old groups, and 4.08 % between 12-15-year-old and 17-19-year-old groups, as detailed in Table II.

DISCUSSION

Age-Related Changes and Population Comparisons of Zygomatic Bone Surface Area

Based on calculations, the zygomatic bone surface area of 3-5-year-old children from the Zaghunluq cemetery constituted 62.74 % of that observed in the sub-adult group. This value is lower than the measurements reported by Waitzman *et al*. (1992), who found that by the age of 5, the overall size of the "cranio-orbito-zygomatic" region exceeded 85% of adult size. Potential reasons for this discrepancy could be attributed to variations in research methodologies, differences in racial populations, and substantial variations in sample sizes.

Among the ancient children excavated from the Zaghunluq cemetery, individual variations in zygomatic bone surface area ranged from 1231.70 mm^2 to 3011.58 mm^2. Notably, this surface area displayed a gradual increase with age, as evidenced by the average zygomatic bone surface area in the sub-adult group measuring 2314.18 mm^2 (or 23.1 cm^2). In comparison with the findings of Pan *et al*. (2014), (see Table III), the zygomatic bone surface area of the Zaghunluq population surpasses those of populations from regions such as Yunnan, Suizhou, Yanghai, Central Europe, among Native Americans, and in areas of Australia and Indonesia. Conversely, it is smaller than those of populations from Taojiazhai, Shenmu, Datong, Jiangjialiang, Yinniugou, Lama Cave, Zhanzi Mountain, and Shuiquan, as well as among the Zulu in South Africa and populations in Tanzania and Kenya. The zygomatic bone surface area of the Zaghunluq population, characterized by an average annual temperature of 13°C, closely aligns with the mean value of 23.8 cm∑ as reported by Pan *et al*. (2014). This mean value was calculated from 11 population samples from regions with average annual temperatures below 15 °C, namely Yunnan, Taojiazhai, Shenmu, Datong, Jiangjialiang, Yinniugou, Lama Cave, Zhanzi Mountain, Shuiquan, Yanghai, and Central Europe. This observation aligns with the "significant linear correlation between the local temperature and the individual's zygomatic bone surface area" proposed by Pan *et al*. (2014). It is noteworthy that the Yanghai population, which is also located in the Xinjiang region, exhibits a zygomatic bone surface area of 22.2 cm^2, slightly smaller than that of the Zaghunluq group. Building on these observations, the zygomatic bone area observed in the Zaghunluq population of Xinjiang serves as a pivotal case study for exploring the relationship between zygomatic bone surface area and climatic factors. This essentially supports the hypothesis proposed by Pan *et al*. (2014), that posits a notable decrease in the zygomatic bone area as the average annual temperature rises.

Age-Related Changes and Population Comparisons of Cranial bone Surface Area

Among the ancient children excavated from the Zaghunluq cemetery, individual variations in cranial bone surface area ranged from 45,689.28 mm^2 to 61,148.16 mm^2. Notably, this surface area displayed a gradual increase with age, as evidenced by the average cranial bone surface area in the sub-adult group measuring 55,253.84 mm^2 (or 552.54 cm^2). In comparison with the findings of Pan *et al*. (2014), (see Table III), the cranial bone surface area of the Zaghunluq population surpasses those of populations from regions such as Yunnan and Australia. Conversely, it is smaller than those of populations from Suizhou, Taojiazhai, Shenmu, Datong, Jiangjialiang, Yinniugou, Lama Cave, Zhanzi Mountain, Shuiquan, and Yanghai, as well as among the Zulu in South Africa and populations in Tanzania, Kenya, Central Europe, Native Americans, and Indonesia. It is noteworthy that the Yanghai population, which is also located in the Xinjiang region, exhibits a cranial bone surface area of 582.5 cm^2, slightly larger than that of the Zaghunluq group.

Considering these measurements, the environmental conditions of the Zaghunluq region might provide further insights into these variations. Situated in the Xinjiang region with an average annual temperature of 13°C and a latitude of 38 °N, the cranial bone surface area measurements of the Zaghunluq population in this study align with the conclusions drawn by Pan *et al*., (2014). Their findings suggest that as latitude increases, the cranial bone area notably enlarges, while an increase in average annual temperature leads to a significant reduction in cranial bone area.

Variation Traits in Skull Surface Area among Ancient Children

The age-related variations in the surface areas of different skull regions in ancient Zaghunluq children revealed that the surface areas of the zygomatic, temporal, parietal, frontal, and cranial bones all increased with age. While the occipital bone surface area manifested subtle variations in the early stages, it underwent significant growth with age during the later stages, indicating an overall pattern of increasing with age.

The surface areas of various regions in the skulls of Zaghunluq children consistently exhibit an expansionary trend. This not only exemplifies the growth and development of their cranial structures but also, to a certain extent, reflects the continuous increase in skull dimensions from childhood to adolescence. Such observations are in line with numerous other research findings. Danborno *et al*. (2008), studied 377 Nigerian children aged 5–15 (173 boys and 204 girls), measuring their head length, width, and circumference and calculating the cephalic index. Their findings indicate that both head length and cephalic index expanded with age for both genders. In a similar vein, Zaki *et al*. (2008), measured and calculated the head circumference and relative head circumference of 27,826 children in Cairo, Egypt (14,048 boys and 13,778 girls) between the ages of 0 and 18. Their results showed a consistent increase in head circumference for both genders across all age groups, with the most substantial growth occurring in the initial two years.

In contrast, distinct growth patterns are evident in the surface areas of Zaghunluq children's skull regions, especially pronounced during growth spurts. Notably, growth spurts in surface areas of various skull bones are observed at specific age intervals: the zygomatic bone at 8-10 years (17.90 %) and 12-15 years (17.02 %); the temporal bone at 3-5 years (19.38 %); the occipital bone at 6-7 years (12.57 %); the parietal bone at both 3-5 years (4.63 %) and 8-10 years (4.67 %); the frontal bone at 8-10 years (12.44 %); and the cranial bone during the 8-10 years range (6.69 %). These data suggest Zaghunluq children predominantly experience cranial growth spurts at ages 8-10. This pattern is largely consistent with the findings of Ran *et al*. (2017), which suggest that seven cranial measurements, including head length, head width, head height, head circumference, facial length, sagittal arc, and occipital arc, increase with age, with relatively higher growth rates observed in the 4-6 year and 7-10-year age groups.

Furthermore, within the same age stages, variations in the growth rates of surface areas across different skull regions are observed in Zaghunluq children. For instance, during the ages of 3-5 years in Zaghunluq children, there's a significant increase in the surface areas of the zygomatic, temporal, and parietal bones. Notably, the temporal bone surface area displays the most pronounced growth. This suggests that the skull might undergo processes of elongation, vertical expansion, and broadening during this period. During the ages of 6-7 years in Zaghunluq children, there's a significant increase in the surface areas of the zygomatic, temporal, and occipital bones. These observations align with Merkel's (1882), findings that there are two predominant phases of accelerated cranial development in humans: from birth to 7 years and during adolescence to mid-adolescence. The cranial growth observed in Zaghunluq children aged 3-5 and 6-7 years corresponds to the first of these phases. Moreover, during the ages of 8-10 years in Zaghunluq children, significant growth occurs in the surface areas of the zygomatic bone, parietal bone, frontal bone, and cranial bone. Notably, the frontal bone surface area displays the most pronounced growth. Meanwhile, the surge in the cranial bone surface area is in tandem with the significant growth of the parietal and frontal bone surface areas. This pattern aligns with the findings that partially overlap with those of Ran *et al*. (2017). Their research indicates increasing trends in seven cranial measurements with age, with the growth rates being particularly pronounced in the 4-6- and 7-10-year age groups. In addition, during the ages of 12-15 in Zaghunluq children, a significant increase is observed in the surface area of the zygomatic bone, implying that zygomatic bone growth continues into adolescence. This observation closely aligns with the findings of Waitzman *et al*. (1992),

Table III. Zygomatic area and cranial surface area in different populations (Pan *et al*. 2014).

Specimen	**Latitude**	**Average annual temperature (°C)**	**Zygomatic area (cm^2)**	**Cranial surface area(cm^2)**	**Specimen description**
Yunnan	25°N	14.9	20.6 ± 0.54	551.9 ± 6.8	About 400 years ago, Yunnan, China
Suizhou	32°N	15.5	20.8 ± 0.83	565.6 ± 7.56	About 2400 years ago, Hubei, China
Taojiazhai	37°N	3.2	24.2 ± 1.01	585.9 ± 10.33	About 2000 years ago, Qinghai, China
Shenmu	39°N	8.9	23.5 ± 0.76	597.3 ± 7.50	About 4800 years ago, Shaanxi, China
Datong	40°N	5.8	24.7 ± 0.89	594.9 ± 13.55	About 1500 years ago, Shanxi, China
Jiangjialiang	40°N	7.7	27.0 ± 0.86	579.9 ± 7.42	About 6850 years ago, Hebei, China
Yinniugou	41°N	5	24.5 ± 0.80	594.2 ± 9.40	About 2400 years ago, Inner Mongolia, China
Lamadong	41°N	8.6	24.0 ± 0.84	603.6 ± 6.65	About 2,000 years ago, Liaoning, China
Zhenzishan	42°N	1.9	25.4 ± 0.76	593.2 ± 8.77	About 600 years ago, Inner Mongolia, China
Shuiquan	42°N	7.5	25.3 ± 0.56	605.3 ± 9.69	About 2,400 years ago, Inner Mongolia, China
Yanghai	43°N	12	22.2 ± 0.73	582.5 ± 6.47	About 2,500 years ago, Xinjiang, China
South African Zulus	33°S	16	24.5 ± 0.72	578.1 ± 11.55	Modern times, Johannesburg and other places
Tanzania	7°S	26	23.8 ± 1.65	546.1 ± 12.1	Modern times, Johannesburg and other places
Kenya	1°S	17.7	24.5 ± 0.73	574.2 ± 9.28	Modern times, Dar es Salaam, *etc.*
Central Europe	54°N	9.1	22.1 ± 0.59	597.7 ± 7.95	Modern times, Nairobi, *etc.*
American Indians	29°N	24	22.2 ± 0.79	603.6 ± 9.30	About 7000-8000 years ago, Florida, USA
Australian	15°S	23	18.4 ± 1.30	518.0 ± 13.17	Modern, Cooktown, etc.
Indonesia	6°S	28	21.7 ± 1.70	574.3 ± 5.48	Modern, Indonesian islands

which posit that the "cranio-orbito-zygomatic" region undergoes slower growth during infancy but continues to grow throughout childhood and early adolescence. Similarly, for Zaghunluq children aged 17-19 years, there is a noticeable increase in the surface area of the parietal and zygomatic bones, while other regions continue to exhibit slow growth. This might suggest that cranial growth has entered a mature phase.

CONCLUSIONS

In this study, cranial CT data was employed to reconstruct 3D virtual representations of skulls and to measure the external surface areas of their distinct regions. Using SPSS statistical software, we analyzed the age-related changes in the surface areas of these skull regions to investigate the growth and developmental patterns of ancient children's skulls. Based on the results and discussions detailed above, we infer the following growth patterns for skull regions: The zygomatic bone demonstrates growth spurts at ages 8-10 and 12–15; the temporal bone at ages 3-5; the occipital bone at ages 6-7; the parietal bone at both ages 3-5 and 8-10; the frontal bone at ages 8-10; and the cranial bone at ages 8-10. Such differential growth trajectories across the skull suggest that Zaghunluq children's cranial development is most pronounced around ages 8-10. Consequently, this might indicate the onset of puberty in Zaghunluq children to be around 8-10 years old. Furthermore, as they transition from childhood to adolescence, there might be a brief stagnation or deceleration in cranial growth.

Lastly, this study focused solely on pediatric skull specimens without a comparative analysis involving adult skull samples. Thus, evaluating the developmental stages of adolescent skulls from late puberty to maturity remains challenging. Additionally, because the individuals from whom the specimens were obtained were at a young age, accurately determining their gender proves difficult, thereby hindering an examination of potential gender-specific growth patterns among Zaghunluq children. Furthermore, the 2-year-old age group was represented by only two samples, preventing its inclusion in multiple comparisons. As a result, it remains challenging to study the growth patterns of skulls during early infancy, a period often marked by rapid and significant developmental changes. These limitations underscore the need for a more complete collection of ancient children's skull specimens and the adoption of advanced research methods and techniques. Such efforts would provide a holistic understanding of the growth and developmental trajectories of ancient children's skulls from birth to maturity.

LI, H.; ZHANG, S.; ZHANG, P.; YANG, X.; ZHOU, C.; WAILI, A.; CHEN, H.; ZHANG, H.; WANG, B. & XIAO, X. Cambios en la superficie craneal con la edad en niños ancestrales de Xinjiang, China. *Int. J. Morphol., 43(6)*:1883-1896, 2025.

RESUMEN: Dentro de la literatura actual, el estudio del crecimiento y desarrollo craneal en poblaciones de niños ancestrales ha recibido poca atención. El propósito de este estudio es abordar esta brecha de investigación mediante el examen de 36 cráneos de niños, excavados en el cementerio de Zaghunluq en Xinjiang, como material principal de investigación. Mediante el análisis de las diferencias en las superficies externas de varias partes de los cráneos en diversos grupos de edad, el estudio busca explorar las características y los patrones de crecimiento y desarrollo craneal en niños ancestrales de Xinjiang. El análisis de varianza (ANOVA) reveló diferencias significativas en las áreas de superficie de los huesos cigomático, temporal, frontal, occipital, parietal y craneal entre seis grupos de edad (2 años, 3-5 años, 6-7 años, 8-10 años, 12-15 años y 17-19 años), mientras que el área de superficie de los huesos parietales no mostró diferencias significativas. Este estudio encontró que el área de superficie del hueso cigomático experimentó un crecimiento rápido durante las edades de 8-10 y 12-15. Del mismo modo, los huesos temporales exhibieron un aumento notable en el área de superficie dentro del rango de edad de 3-5. Este crecimiento rápido en la etapa temprana fue seguido por una expansión significativa del área de superficie del hueso occipital cuando los niños alcanzaron las edades de 6-7. En cuanto a los huesos parietales, se observó un aumento significativo en el área de superficie tanto a las edades de 3-5 como de 8-10. Además, el hueso frontal mostró un aumento notable en la superficie, específicamente entre los 8 y los 10 años. Este período de crecimiento también coincidió con una fase primaria de expansión craneal, lo que sugiere que entre los 8 y los 10 años se produjo un impulso de crecimiento en la superficie de los huesos craneales de los niños Zaghunluq. En base a las variaciones observadas en los impulsos de crecimiento en la superficie de las diferentes regiones craneales, los hallazgos mostraron que el crecimiento y desarrollo de los cráneos de los niños Zaghunluq ocurrió predominantemente entre los 8 y los 10 años, lo que podría indicar el inicio de su adolescencia durante este período. Además, durante la transición de la infancia a la adolescencia, el cráneo podría experimentar un crecimiento temporal más lento.

PALABRAS CLAVE: Xinjiang; Cementerio Zaghunluq; Poblaciones de niños ancestrales; Superficie craneal; Patrones de crecimiento craneal; Impulso de crecimiento.

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