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Dimensional Changes in the Skulls of Ancient Children with Age in Xinjiang, China

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Many scholars have conducted research on the growth patterns of children's skulls in terms of skull size, head circumference, cranial cavity volume, and so forth. This study compared and analyzed 20 skull measurement indexes of different ages from 38 children's skulls (aged 2–15) and 87 adult female skulls (aged 20–40) at the Zaghunluq cemetery in Xinjiang, China, in an attempt to figure out how the size Children's of ancient children's skulls changed with age. Analysis of variance (ANOVA) showed that there were significant differences between the six age groups (2 years, 3–5 years, 6–8 years, 9–11 years, 12–15 years, and adults) in terms of metrical cranial traits, cranial area, and cranial cavity volume. The study indicated that the skull kept growing from ages 3 to 5, 12 to 15, and 15 to adulthood, implying that the skull sizes of ancient children in Xinjiang continued to increase with age. In addition, the study revealed that children aged 12 to 15 had skulls that were significantly smaller than those of adults. This finding showed that the skulls of ancient children in Xinjiang were not fully developed at the age of 15. It is also important to note that differences existed between age groups in both the developmental traits of the cranium and the rate at which the skull changes.

Keywords: children; skulls; size; age changes; Xinjiang; Zaghunluq

Introduction

Children's skulls grow and develop rapidly with age, undergoing significant morphological changes, and therefore, it is crucial to have a thorough understanding of the growth patterns of children's skulls. Many scholars have conducted research on the growth and development of children's skulls with age, including skull size, head circumference, and cranial cavity volume.

Numerous researchers have investigated the dimensional changes in the skulls of modern children. Smith et al. (2021) examined 65 males and 47 females (ages 3–20) in the Headspace project in the United Kingdom and employed Procrustes-based geometric morphometric methods to analyze and compare the growth patterns and degrees across a range of ages and genders. Based on Smith et al.'s (2021) findings, children between the ages of 3 and 10 displayed greater changes in the size and shape of their craniofacial features than those aged 11–20. Specifically, the study showed that the orbital and nasal regions underwent the most significant changes in head shape between ages 3 and 10, with comparatively less expansion in the cheeks and chin. The research also indicated that face expansion occurred around the lips and chin between ages 11 and 20 (Smith et al. 2021). Ran et al. (2017) measured and analyzed seven head measurement parameters in 20,000 children ages 4 to 17, including head length, head breadth, head height, head circumstance, face length, sagittal arc, and bitragion arc. Furthermore, the study by Ran et al. (2017) found that the head and face reached their full development at the ages of 16 to 17 for boys and 13 to 15 for girls, at which point the average size of a person's head had a tendency to stabilize. Waitzman et al. (1992) took fifteen measurements from a total of 542 CT scans of subjects aged 0–17 with normal skeletons and examined the growth patterns of the cranial vault, orbital region, and upper midface. The study by Waitzman et al. (1992) showed that the cranial vault expanded fast between the ages of 0 and 1, but this growth quickly plateaued, and that the upper midface developed more slowly between the ages of 0 and 1, but kept growing during childhood. Other researchers have measured and analyzed the craniofacial dimensions of modern children at various ages and have concluded that the craniofacial sizes of children from various generations differ. Little et al. (2006) compared the craniofacial measurements of 1037 indigenous children aged 6–13 years in southern Mexico in 1968, 1978, and

2000. The study by Little et al. (2006) indicated that the craniofacial dimensions underwent considerable secular changes over the course of 32 years: 1) both boys and girls possessed a shorter head length and a narrower bizygomatic breadth; 2) only girls exhibited an increase in head breadth over time; and 3) only boys experienced a considerable decline in the zygomandibular index.

Regarding head circumference growth patterns, Li et al. (2008) measured the head circumference of 750 newborns in Shanghai, China, over the course of three years. Li et al. (2008) observed that the head circumference of infants gradually increased with age but that the rate of growth slowed as infants grew older and that infants' head circumference at age 1 was roughly 1.3 times greater than it was at birth. Hou et al. (2014) performed a cephalometric analysis on 112 infants born in Baotou, China, over a six-year period beginning in 2006, measuring parameters like head circumference, cranial length, cranial breadth, and so on. The study by Hou et al. (2014) indicated that the cranium grew most rapidly during the first 12 months and thereafter slowed down and that the children's skull index approached that of an adult by age 6. Caino et al. (2009) examined five girls and three boys, aged 0.32–0.84 years, in Argentina over the course of 151 days to determine their head circumference. The study by Caino et al. (2009) found that there were three distinct phases in the growth patterns observed in the head circumference of 7 out of 8 infants: steep changes, stasis, and continuous growth, and the head circumference experienced the steepest shift with the largest amplitude at 0.79 cm.

Nellhaus (1968) found that the head circumference of infants aged 0–2 increased the fastest, while boys grew faster than girls; after the age of two, both boys and girls had steady growth in head circumference, but girls' head circumference expanded fast from 10 to 14 years, while boys did so from 12 to 16. Palmer et al. (1992) also discovered that children under the age of two experienced the fastest growth in head circumference. Elmali et al. (2012) found that the total increase in head circumference of Turkish children between the ages of 0 and 7 was 16.64 cm for boys and 16.23 cm for girls. Kumar et al. (1988) studied the mean head circumference between age groups in 1024 healthy school children (574 boys and 450 girls) aged 5–

10 years in Varanasi, India, and discovered that between the ages of 5 and 10, the overall increase in skull circumference for boys was 1.29 cm and for girls it was 1.86 cm, with the maximum gain at 6 to 7 years for boys and 8.5 to 9.5 years for girls. All of the aforementioned research indicated that growth spurts in head circumference occurred during the development of children's skulls, which varied between populations and genders.

Cranial cavity volume is another crucial aspect of studies on cranial growth in children. Tong et al. (2020) depicted a growth curve of children's cranial cavity volume utilizing the skull CT data from 954 normal Chinese children aged 0–18 years old. The study by Tong et al. (2020) showed that the volume of a children's cranial cavity grew quickly from 0 to 2 years old, but that the growth rate dropped gradually after the age of 2. Tong et al. (2020) also showed that cranial cavity volume, cranial length, cranial width, and cranial height increased gradually with age, with a significant positive correlation between age and cranial cavity volume ($r = 0.919$), cranial length ($r = 0.587$), cranial width ($r = 0.278$), and cranial height ($r = 0.598$) ($P<0.05$). Kamdar et al. (2009) examined a series of intracranial volume data in 123 children aged 0–6 at The New York Presbyterian Hospital and found that by the time a child was nine months old and six years old, the intracranial volume had doubled and tripled, respectively. Purkait (2011) examined the dynamics of cranial cavity volume growth in 1623 central Indian children from birth to 18 years, finding that the growth of cranial volume occurred in stages, with a rapid growth period lasting for one year after birth, followed by a period of moderate growth rate lasting for 5 or 6 years old, and culminating in a period of below-average growth around the time of maturity. According to the studies cited above, the cranial cavity volume of children increased with age and followed a specific growth pattern.

Due to a dearth of research materials, relatively few studies have been carried out on how ancient children's skulls changed with age. Okazaki (2004) measured the skulls of Japanese children of different ages from the Yayoi period, the Middle Ages (the Muromachi period), and the present day. Okazaki (2004) investigated the growth patterns of the cranium of Japanese people: 1) from birth until 6 to 9 years old, the modern Japanese cranial index tended to drop rapidly until puberty, when it began to decline more slowly. The cranial index of medieval humans, however, seemed to be dolichocephalic from the age of two years and onward, seemingly remaining constant with age; 2) with age, the lower part of the face grew in height considerably more rapidly than the upper part, and the shape of the nasal cavity changed from a wider-lower to a narrower-higher state. Li et al. (2021a) found that the skulls of 2-year-old children from the Zaghunluq cemetery in Xinjiang, China, had orbital heights that reached 92.7% of those of adults, but the orbital breadth was significantly narrower than in adults. Li et al. (2021a) also indicated that the orbital height and the orbital area exhibited no major changes after the age of two. Moreover, the study by Li et al. (2021b) showed that the foramen magnum size was the smallest at 2 years old and approached that of adults at 5 to 7 years old, and therefore, the foramen magnum most likely underwent a growth spurt between the ages of 2 and 5.

In the Xinjiang region of China, high temperatures, drought, and little precipitation have helped preserve numerous ancient humans remains, including those of children, in good shape. However, well-preserved skulls of children have yet to be discovered in other parts of China. This study compared and analyzed skull measurement indexes of different ages in children and adult females from the Zaghunluq cemetery in Xinjiang, China. The purpose of this study was to explore how the skull sizes of ancient children ages 2–15 changed as they got older. Additionally, the study compared the skulls of children with those of adults in order to provide some insights into the growth patterns of children's skulls in ancient China.

Materials and Methods

Research Materials

This study included human skulls unearthed from the Zaghunluq cemetery, one of the largest clusters of tombs discovered at the northern foot of the Kunlun Mountains in the village of Zaghunluq in Qiemo County, Xinjiang, China (Figure 1). With 138 tombs, the second phase of the Zaghunluq cemetery has the most tombs overall and so best illustrates the cemetery's major culture. In the second phase of the Zaghunluq cemetery, samples from six tombs were selected for carbon-14 dating, among which the ^{14}C sample from tomb 85QZM4 was dated to 740 ± 120 BC, the ^{14}C sample of the red willow branch from tomb 96QZIM1 was dated to 792 ± 60 BC, and the ^{14}C sample of the red willow branch from tomb 96QZIM14 was dated to 761 ± 61 BC. Radiocarbon dating shows that the samples from the three tombs are all around the same age, which can be considered the terminus post quem for the second phase of the Zaghunluq cemetery (Wang et al. 2016). In addition, the second phase of the Zaghunluq cemetery has been discovered to have possibly lasted far longer, extending up to the third century AD when compared to the age of the nearby Jiawa' airike cemetery, which belongs to a similar kind of civilization (Gong et al. 1997). Accordingly, it is tentatively inferred that the second phase of the Zaghunluq cemetery, which belongs to the Qiemo cultural period, has been dated from the 8th century BC to the mid-3rd century AD, or from the Spring and Autumn Period to the Western Han Dynasty (Wang et al. 2016). The Qiemo kingdom, along the ancient Silk Road, was an oasis city-state on the southern edge of the Tarim Basin, one of the thirty-six kingdoms in the western regions of the Han Dynasty (Xinjiang Museum cultural relics team, 1998; Xinjiang Museum et al.2003). The research materials are preserved in the Xinjiang Museum, including 38 children's skulls (2–15 years old) and 87 adult female skulls (20–40 years old) for comparative analysis, most of which are well maintained. Due to the challenge of identifying gender in children's skulls, gender comparisons were not done. Wang et al. (2016) conducted a detailed study on the structure and culture of the Zaghunluq cemetery, which served as a reference for examining the physical traits of the Zaghunluq people.

Research methods

With reference to *The Anthropometric Manual* (Shao, 1985) and *The Human Bone Manual* (White et al., 2018), the age of children's skulls was determined by a combination of factors, including the closure of the anterior fontanelle, the eruption of both baby teeth as well as permanent teeth, dental attrition, the ossification of the sphenoid bone, spheno-occipital syncondrosis fusion, and so forth. In order to investigate how the size of ancient children's skulls changed with age, 38 children's skull samples were divided into 5 age groups: the 2 year old group (2 samples), the 3–5 year old group (7 samples), the 6–8 year old group (8 samples), the 9–11 year old group (8 samples), and the 12–15 year old group (13 samples); additionally, the skulls of 87 adult females (20–40 years old) were compared with those of children (The comparison of skulls in different age groups is shown in Figure 2 and Figure 3).

Refer to *The Anthropometric Manual* (Shao, 1985) for data collection and measurement, including cranial length (g-op), cranial breadth (eu-eu), cranial height (ba-b), cranial basis length (enba-n), facial basis length (enba-pr), upper facial height (n-sd), bizygomatic breadth (zy-zy), nasal breadth (al-al) and nasal height (n-ns), and the commonly used indexes for skull measurement, including length and breadth index (eu-eu)/(g-op), length and height index(b-ba)/(g-op), breadth and height index(ba-b)/(eu-eu), protruding jaw index (enba-pr)/(enba-n), upper facial index (n-sd)/(zy-zy), craniofacial breadth index (zy-zy)/(eu-eu), craniofacial height index(n-sd)/(ba-b) and nasal index (al-al) /(n-ns), were calculated accordingly. According to the calculation method of Wu et al. (2007), the neurocranium and viscerocranium were cuboid in shape, and the nasal region was triangular; and thus the brain volume, facial cranial volume, and nasal area were calculated for each age group based on the following formulae: the brain volume = cranial length × cranial breadth × cranial height; the facial cranial volume = bizygomatic breadth × upper facial height × facial basis length; and the nasal area = 1/2 × nasal breadth × nasal height.

SPSS statistical software was used to do ANOVA and multiple comparisons (using the Least Significant Difference (LSD) test) to quantify and analyze the differences in the mean of skull measurements in different age groups. The metrical cranial traits and age-related changes in each age group are shown in Figure 4. The study selected metrical cranial traits that changed clearly with age between age groups that were close together and simultaneously calculated the rate of change. Because the

2 years old group had only two skull samples, it was excluded from the multiple comparisons. The formula for calculating the rate of age change:

The rate of age change (%) = 100%×(X_2−X_1)/X_1 (X_1 and X_2 represent the mean of the same measurements for the younger and older age groups, respectively).

Results

The comparisons of skull measurement traits and indexes among different age groups are shown in Table 1, and the comparisons of skull area and skull volume among different age groups are shown in Table 2.

Comparison of skull measurement traits between 2 years old and 3–5 years old

Based on the rate of change between 2 years old and 3–5 years old, the traits with greater changes (|change rate| ≥ 2%) were: cranial length (3.6%), cranial breadth (4.4%), cranial height (7.3%), length and height index (4.4%), cranial basis length (5.6%), upper facial height (12.6%), bizygomatic breadth (9.8%), upper facial index (4.8%), craniofacial breadth index (5%), craniofacial height index (5.7%), nasal height (17%), protruding jaw index (-6.6%), and nasal index (-12.9%).

Comparison of skull measurement traits between 3–5 years old and 6–8 years old

Multiple comparisons of the LSD showed that two measurement traits had significant differences between 3–5 years old and 6–8 years old, including nasal breadth (P=0.012) and nasal height (P = 0.028).

Based on the rate of change between 3–5 years old and 6–8 years old, the traits with greater changes (|change rate| ≥ 2%) were: cranial breadth (2.6%), facial basis length (2.1%), protruding jaw index (3.3%), upper facial height (7.2%), bizygomatic breadth (4.9%), upper facial index (2.8%), craniofacial breadth index (2.8%), craniofacial height index (5.4%), nasal breadth (12.4%), and nasal height (11%).

Comparison of skull measurement traits between 6–8 years old and 9–11 years old

Multiple comparisons of the LSD showed that no measurement traits had significant differences between 6–8 years old and 9–11 years old.

Based on the rate of change between 6–8 years old and 9–11 years old, the traits with greater changes (|change rate| ≥ 2%) were: cranial length (2.2%), cranial height (3.2%), breadth and height index (3.6%), facial basis length (5.6%), protruding jaw index (3.8%), craniofacial height index (-2.1%), nasal breadth (-2.4%), and nasal index (-3.5%).

Comparison of skull measurement traits between 9–11 years old and 12–15 years old

Multiple comparisons of LSD showed that four measurement traits had significant differences between 9–11 years old and12–15 years old, including cranial basis length (P=0.003), bizygomatic breadth (P=0.000), craniofacial breadth index (P=0.000) and nasal height (P=0.025).

Based on the rate of change between 9–11 years old and 12–15 years old, the traits with greater changes (|change rate| ≥ 2%) were: cranial height (3.7%), length-height index (2.0%), cranial basis length (7.2%), facial basis length (4.8%), protruding jaw index (-2.0%), upper facial height (9.7%), bizygomatic breadth (9.2%), upper facial index (4.5%), craniofacial breadth index (8.4%), craniofacial height index (5.9%), nasal breadth (3.4%), nasal height (8.6%), nasal index (-4.6%).

Comparison of skull measurement traits between 12–15 years old and adulthood

Multiple comparisons of LSD showed that nine measurement traits had significant differences between 12–15 years old and adulthood, including cranial length (P=0.044), cranial basis length (P=0.000), facial basis length (P=0.000), upper facial height (P=0.000), bizygomatic breadth (P=0.000), upper facial index (P=0.017), craniofacial breadth index (P=0.000), nasal breadth (P=0.000), and nasal height (P=0.000).

Based on the rate of change between 12–15 years old and adulthood, the traits with greater changes (|change rate| ≥ 2%) were: cranial length (2.4%), cranial basis length (6.2%), facial basis length (6.6%), upper facial height (11.8%), bizygomatic breadth (6.7%), upper facial index (6.6%), craniofacial breadth index (5.5%), craniofacial height index (12.7%), nasal breadth (12.3%), and nasal height (11.0%).

Age-related changes in nasal area

Based on multiple comparisons of the LSD and the rate of change in nasal area, there was a significant difference (P=0.017) between 3–5 years old and 6–8 years old with a difference of 82.8 mm^2 and a higher rate of change (24.4%); and there was a significant difference (P=0.000) between 12–15 years old and adulthood with a difference of 113.8 mm^2 and a higher rate of change (24.2%). Also, there was a difference of 54.8 mm^2 between 2 years old and 3–5 years old with a higher rate of change (19.2%); there was a decrease of 7 mm^2 (-1.7%) between 6–8 years old and 9–11 years old; and there was a difference of 53.9 mm^2 between 9–11 years old year old and 12–15 years old with a higher rate of change (13.0%). As a result, the growth of the nasal area was most prominent between 6–8 years old and 15 years old to adulthood.

Age-related changes in facial skull volume

Based on multiple comparisons of the LSD and the rate of change in facial cranial volume, there was a significant difference (P=0.008) between 9–11 years old and 12–15 years old with a difference of 124.2 mm^3 and a rate of change (25.7%); and there was a significant difference (P=0.000) between 12–15 years old and adulthood with a difference of 164.9 mm^3 and a rate of change (27.1%). Also, there was a higher rate of change (24.4%) between 2 years old and 3–5 years old, while there were lower rates of change in two other age groups, with 11.2% between 3–5 years old and 6–8 years old, and 9.3% between 6–8 years old and 9–11 years old. As a result, the growth of the facial cranial volume happened primarily between 12–15 years old and 15 years old to adulthood.

Age-related changes in brain volume

ANOVA showed that there were significant differences (P=0.000) among the five age groups. There was a higher rate of change (16.3%) between 2 years old and 3–5 years old, which was a period of rapid growth of brain volume, while there were lower rates of changes in the remaining age groups, with 4.2% between 3–5 years old and 6–8 years old, 7.1% between 6–8 years old and 9–11 years old, 5.9% between 9–11 years old and 12–15 years old, and 4.6% between 12–15 years old and adulthood.

Conclusion

Age-related characteristics of metrical cranial traits in ancient children

The study showed that skull size gradually increased from age 2 through ages 12 to 15, then into adulthood. A growth spurt occurred in cranial length from the age of 15 to adulthood; cranial breadth and cranial height continued to increase without significant growth spurts; growth spurts occurred in cranial basis length from 12 to 15 years old and from 15 to adulthood; a growth spurt occurred in facial basis length from the age of 15 to adulthood; a growth spurt occurred in upper facial height from the age of 15 to adulthood; growth spurts occurred in bizygomatic breadth from 12 to 15 years old and from 15 to adulthood; growth spurts occurred in nasal breadth from 6 to 8 years old and from 15 to adulthood; and growth spurts occurred in nasal height at ages 6 to 8, 12 to 15, and 15 to adulthood. The above metrical cranial traits showed that growth spurts for children occurred from the age of 15 to adulthood, indicating that the craniums of ancient children in Xinjiang were not fully developed at the age of 15.

Age-related characteristics of skull index in ancient children

In terms of skull index, there were two indexes with significant age-related changes, including upper facial index (P=0.000) and craniofacial breadth index (P=0.000). Upper facial index showed that a growth spurt for children occurred from the age of 15 to adulthood, and craniofacial breadth index showed that growth spurts for children occurred from 12 to 15 years old and from 15 to adulthood. The other six skull indexes, including length and breadth index (P=0.425), length and height index (P=0.874), breadth and height index (P=0.446), protruding jaw index (P=0.175), craniofacial height index (P=0.064), and nasal index (P=0.038), showed no significant age-related changes.

Age-related characteristics of skull area and volume in ancient children

The findings demonstrated that from the ages of 2 to 15 and throughout adulthood, brain volume continued to increase without any appreciable growth spurts. However, growth spurts occurred in facial cranial volume from 12 to 15 years old and from 15 to adulthood, and growth spurts occurred in nasal area from 6 to 8 years old and from 15 to adulthood.

Discussion

Skull growth patterns in ancient children

The study compared and analyzed age-related changes in measurement indexes in the skulls of 38 children and 87 adult females from Zaghunluq Cemetery, revealing skull growth patterns in ancient children in Xinjiang. According to age-related changes in each of the metrical cranial traits, cranial and facial dimensions increased gradually, while the nasal index decreased overall. The length, breadth, and height of the cranium were the most significant indices of cranial growth. From the age of 15 to adulthood, there was a marked increase in cranial length (P=0.044), and cranial breadth and cranial height continued to increase without any notable growth spurts. The findings are contrary to that of Ran et al. (2017), who found that seven head measurement parameters (head length, head breadth, head height, head circumstance, face length, sagittal arc, and bitragion arc) showed an increase with age. Ran et al. (2017) indicated that the seven head measurement parameters increased significantly in children ages 4 to 6 and 7 to 10 years old. Ran et al. (2017) also found that the head and face reached their full development at the ages of 16 to 17 for boys and 13 to 15 for girls, at which point the average size of a person's head had a tendency to stabilize. The increase in craniofacial size was mainly shown in bizygomatic breadth and facial basis length. A growth spurt occurred in bizygomatic breadth from 3 to 5 years old (9.8%), and bizygomatic breadth increased significantly from 12 to 15 years old (9.2%) and from 15 to adulthood (6.7%), while facial basis length increased significantly from the age of 15 to adulthood (6.6%). The findings broadly reflect those of Waitzman et al. (1992), who also found that the upper midface developed more slowly between the ages of 0 and 1, but kept growing during childhood. It is mainly because the growth rate of nasal height was greater than that of nasal breadth, and the nasal index decreased overall, with the most significant decline (-12.9%) at the age of 3–5, and continued to decline at the ages of 9–11 and 12–15, with change rates of -3.5% and -4.6%, respectively. In short, the skull kept growing from ages 3 to

5, 12 to 15, and 15 to adulthood, implying that the skull sizes of ancient children in Xinjiang continued to increase with age. Moreover, the study revealed that children aged 12 to 15 had skulls that were significantly smaller than those of adults. These finding showed that the skulls of ancient children in Xinjiang were not fully developed at the age of 15.

In addition to cranial and facial dimensions and nasal index, a growth spurt occurred in upper facial height from the age of 15 to adulthood; growth spurts occurred in bizygomatic breadth from 12 to 15 years old and from 15 to adulthood; and a growth spurt occurred in upper facial index (upper facial height/bizygomatic breadth) from the age of 15 to adulthood. In contrast to Okazaki (2004), who discovered that modern Japanese people exhibited rapid growth in their upper facial height from birth to the age of roughly 6 to 9 years, which is followed by relatively modest growth until late adolescence.

Another important finding was that after a rapid increase in brain volume between the ages of 3 and 5, the rate of growth slowed down, but brain volume continued to grow until maturity. There are some similarities and differences between this study and the results of Tong et al. (2020). Tong et al. (2020) showed that the volume of a child's cranial cavity grew quickly from 0 to 2 years old, but that the growth rate dropped gradually after the age of 2. This does not appear to be the case. Comparison of these results with those of Tong et al. (2020) confirms that cranial volume increased gradually with age, with a significant positive correlation between age and cranial volume. Furthermore, as Purkait (2011) revealed, the growth of the skull volume happened in stages with significant growth spurts, unlike the results presented here, which showed that there were no growth spurts in cranial volume.

In summary, various age groups exhibited different growth rates for each metrical cranial trait, and growth spurts mainly occurred in the skull at ages 6 to 8, 12 to 15, and 15 to adulthood. These findings are consistent with those of Caino et al. (2009), who found that phases of steep changes, stasis, and continuous growth occurred in the head circumference of infants and are in agreement with Nellhaus's (1968) findings, which showed that girls' head circumference expanded fast from 10 to 14 years, while boys did so from 12 to 16.

Reflections on the limitations of this study

The study compared and analyzed the skull sizes of 38 children and 87 adult females from Zaghunluq Cemetery, Xinjiang, revealing age-related changes in the skull sizes of ancient children. However, due to the limited number of skull samples in children (only 38 samples) and the paucity of relevant literature, the generalizability of the research findings should be further investigated. For a more complete picture of ancient children's growth patterns in terms of skull size, more samples, particularly those aged 0–2 years, are needed. In addition, due to the challenge of identifying gender in 38 children's skulls, gender comparisons with 87 adult female skulls were not performed. It is hoped that more intact ancient children's skulls will be unearthed in the future, and various research methodologies will be developed for further exploration of the growth patterns and age-related changes in the skulls of ancient children.

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Fig.1 The Site of Zaghunluq Cemetery

Fig.2 Comparison of Skulls in Different Age Groups of Zaghunluq Ancient Children

Fig.3 Comparison Line Map of Skulls in Different Age Groups of Zaghunluq Ancient Children

Fig.4 Metrical Cranial Traits and Age-related Changes of Zaghunluq Ancient Children's Skulls (in %)

Table 1. Comparison of Metrical Cranial Traits and Index in Different Age Groups of Zaghunluq Ancient Children

		Aged 2 years		Aged 3–5 years		Aged 6–8 years		Aged 9–11 years		Aged 12–15 years		Adult		ANOVA	LSD				Change Percentage (%)				
Martin number	Measurement items	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	P	3–5 and 6–8	6–8 and 9–11	9–11 and 12–15	12–15 and adult	2 and 3–5	3–5 and 6–8	6–8 and 9–11	9–11 and 12–15	12–15 and adult
1	Cranial length (g-op) (mm)	2	160.0	7	165.7	8	168.1	8	171.8	13	174.5	87	178.7	0.000	0.508	0.290	0.391	0.044*	3.6	1.5	2.2	1.6	2.4
8	Cranial breadth (eu-eu) (mm)	2	125.0	7	130.5	8	133.9	7	134.1	13	135.7	87	137.5	0.003	0.196	0.940	0.495	0.246	4.4	2.6	0.2	1.2	1.3
17	Cranial height (ba-b) (mm)	2	114.0	4	122.3	6	123.5	8	127.4	13	132.1	84	133.2	0.006	0.827	0.397	0.223	0.653	7.3	1.0	3.2	3.7	0.8
1：8	Length and breadth index (eu-eu)/(g-op)	2	78.2	7	78.8	8	79.7	7	78.4	13	77.8	87	77.1	0.425	0.695	0.574	0.771	0.560	0.8	1.1	-1.6	-0.8	-0.9
1：17	Length and height index(b-ba)/(g-op)	2	71.2	4	74.3	6	73.8	8	74.2	13	75.7	84	74.6	0.874	0.843	0.850	0.430	0.365	4.4	-0.7	0.5	2.0	-1.5
17：8	Breadth and height index(ba-b)/(eu-eu)	2	91.3	4	92.9	6	92.7	7	96.0	13	97.4	84	97.1	0.446	0.973	0.399	0.664	0.899	1.8	-0.2	3.6	1.5	-0.3
5	Cranial basis length (enba-n) (mm)	2	81.0	4	85.5	6	84.5	8	85.8	13	92.0	84	97.7	0.000	0.720	0.572	0.003*	0.000*	5.6	-1.2	1.5	7.2	6.2
40	Facial basis length	2	77.9	4	76.8	6	78.4	8	82.8	13	86.8	83	92.5	0.000	0.584	0.086	0.057	0.000*	-1.4	2.1	5.6	4.8	6.6

	(enba-pr) (mm)																				
40：5	Protruding jaw index (enba-pr) /(enba-n)	2	96.2	4	89.9	6	92.9	8	96.4	13	94.5	83	94.8	0.175	0.306	0.159	0.352	0.839	-6.6	3.3	3.8	-2.0	0.3
48	Upper facial height (n-sd) (mm)	2	44.3	7	49.9	8	53.5	8	53.9	13	59.1	84	66.1	0.000	0.241	0.892	0.050	0.000*	12.6	7.2	0.8	9.7	11.8
45	Bizygomatic breadth (zy-zy) (mm)	2	92.5	7	101.6	7	106.6	8	107.9	13	117.8	82	125.7	0.000	0.062	0.635	0.000*	0.000*	9.8	4.9	1.2	9.2	6.7
48：45	Upper facial index (n-sd)/(zy-zy)	2	54.5	7	57.1	8	58.7	8	58.3	13	60.9	83	64.9	0.000	0.584	0.882	0.309	0.017*	4.8	2.8	-0.7	4.5	6.6
45：8	Craniofacial breadth index (zy-zy)/(eu-eu)	2	74.1	7	77.8	7	80.0	7	80.2	13	86.9	82	91.7	0.000	0.291	0.958	0.000*	0.000*	5.0	2.8	0.3	8.4	5.5
48：17	Craniofacial height index(n-sd)/(ba-b)	2	38.8	4	41.0	6	43.2	8	42.3	13	44.8	82	50.5	0.064	0.767	0.883	0.638	0.096	5.7	5.4	-2.1	5.9	12.7
13	Nasal breadth (al-al) (mm)	2	18.4	7	18.6	8	20.9	8	20.4	13	21.1	86	23.7	0.000	0.012*	0.525	0.338	0.000*	1.1	12.4	-2.4	3.4	12.3
55	Nasal height (n-ns) (mm)	2	31.1	7	36.4	8	40.4	8	40.9	13	44.4	85	49.3	0.000	0.028*	0.788	0.025*	0.000*	17.0	11.0	1.2	8.6	11.0
13：55	Nasal index (al-al) /(n-ns)	2	59.0	7	51.4	8	51.9	8	50.1	13	47.8	85	48.1	0.038	0.832	0.400	0.223	0.782	-12.9	1.0	-3.5	-4.6	0.6

Table 2. Comparison of Area and Volume of the Skull in Different Age Groups of Zaghunluq Ancient Children

	Aged 2 years		Aged 3–5		Aged 6–8 years		Aged 9–11 years		Aged 12–15 years		Adult		ANOVA	LSD				Ch ange Percentage (%)				
Measurement items	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	P	3–5 and 6–8	6–8 and 9–11	9–11 and 12–15	12–15 and adult	2 and 3–5	3–5 and 6–8	6–8 and 9–11	9–11 and 12–15	12–15 and adult
brain volume(mm^3)	2	2279.3	4	2649.8	6	2759.9	7	2956.4	13	3131.4	84	3274.6	0.000*	0.588	0.263	0.236	0.129	16.3	4.2	7.1	5.9	4.6
facial cranial volume(mm^3)	2	319.5	4	397.6	5	442.0	8	483.2	13	607.4	79	772.3	0.000*	0.518	0.480	0.008	0.000	24.4	11.2	9.3	25.7	27.1
Nasal area(mm^2)	2	285.3	7	340.1	8	422.9	8	415.9	13	469.8	85	583.6	0.000*	0.017	0.833	0.073	0.000	19.2	24.4	-1.7	13.0	24.2