

# Comparative Analysis of Piriform Aperture Development Across Age Groups in Ancient Children from Xinjiang, China

Análisis Comparativo del Desarrollo de la Abertura Piriforme en Diferentes Grupos de Edad en Niños Antiguos de Xinjiang, China

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**SUMMARY:** This study addresses the scarcity of research on the growth of the piriform aperture in ancient children by analyzing 36 child skulls from the Zaghunluq region of Xinjiang. The skulls were divided into six age groups, ranging from 2 to 19 years old. Using Computer-Aided Design (CAD) software, the study measured dimensions such as upper width, lower width, height, and total area, including the nasal bone area. Statistical analyses revealed significant growth spurts in specific dimensions across different age groups: upper width at ages 8-10 and 12-15, lower width at ages 6-7 and 17-19, height at ages 3-5 and 17-19, and projected area at ages 6-7 and 17-19. Developmental trends showed that lower width growth outpaced upper width before age 7, while both grew at similar rates from age 12-15 onwards. The study concluded that the piriform aperture and skull develop proportionally, with distinct growth patterns in its dimensions over childhood and adolescence.

**KEY WORDS:** Ancient pediatric populations; Piriform aperture; Comparative analysis; Age groups; Growth and development.

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## INTRODUCTION

The piriform aperture, located between the lateral maxillary bones, beneath the nasal bones, and above the incisive fossa, is characterized by its narrow superior aspect and broader inferior aspect, resembling the shape of a pear, which gives it its name. The margins of the piriform aperture are defined by the inferior margin of the nasal bones, the inner edges of the frontal processes of the maxillary bones, and the free margins of the palatine processes of the maxillary bones. Serving as the bony opening to the anterior part of the nasal cavity, the piriform aperture, along with its surrounding osseous and soft tissue structures, plays a crucial role in the respiratory function of the nose. Scholars have conducted extensive research on the piriform aperture, primarily focusing on differences related to sex, age, and ethnicity.

## Sex Differences in the Piriform Aperture

Significant sex differences in the piriform aperture have been demonstrated by various studies. For instance, Cantín *et al.* (2009) analyzed 90 human skulls (45 male, 45 female) from the Universidade Federal de São Paulo (UNIFESP). Their sex-based analysis revealed that male piriform apertures were generally larger than those of females. Specifically, the average height was measured at 50.83 mm for males and 47.53 mm for females, the upper widths at 17.61 mm for males and 17.21 mm for females, and the lower widths at 26.87 mm for males and 25.27 mm for females. The most significant difference was observed in the height, with measurements for male skulls consistently exceeding those for females.

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Further exploration by Hommerich *et al.* (2002) involved CT measurements of 116 patients, aged 5 to 82, from the Göttingen region in Lower Saxony, Germany. Grouping the subjects by decade, the study involved 57 males and 59 females. The results indicated that the average upper width of the piriform aperture was 16.0 mm in males, compared to 15.4 mm in females. Similarly, the average lower width was 23.6 mm in males and 22.6 mm in females, confirming that the widths of the piriform aperture were consistently greater in males across all age groups.

Adding to this body of research, Strapasson *et al.* (2017) conducted a study with a sample of 96 individuals from Brazil, consisting of 49 males and 47 females. They found that the width of the male piriform aperture was significantly greater than that of females. Complementing this, Zhai *et al.* (2015) utilized CT images to analyze the piriform aperture of 206 Han Chinese adults in Liaoning, comprising 100 males and 106 females. The study revealed significant sex differences in the shape of the piriform aperture: it was taller and narrower in males, while in females, it was shorter and more rounded.

Expanding on the geographical diversity, Moreddu *et al.* (2013) investigated 170 non-pathological patients in Marseille, France, consisting of 91 males and 79 females. The research found that the average width of the piriform aperture was 25.32 mm for males and 24.00 mm for females, while the average length was 36.35 mm for males and 32.54 mm for females. Statistical analysis indicated significant sex differences in both the shape and size of the piriform aperture. Lastly, Abdelaleem *et al.* (2016) performed CT scans on 250 patients without nasal diseases in Minia Governorate, Egypt, including 150 males and 100 females. The study measured the maximum height, width, and area of the piriform aperture, demonstrating significant sex differences across all measured parameters. Notably, sex identification based on the maximum width achieved an accuracy of 75.4 %, indicating that the size of the piriform aperture can be an effective tool for sex determination. Similarly, Asghar *et al.* (2016) conducted a study involving 40 Indian individuals—28 males and 12 females—and discovered significant sexual dimorphism in the shape and size of the piriform aperture.

### Age-Related Changes in the Piriform Aperture

Scholars have similarly investigated the patterns of growth and development in the piriform aperture as they correlate with advancing age. Pellnitz (1962) proposed that the development of the piriform aperture is not complete before the age of 20, based on observations of 1,001 samples from the Netherlands. Following this early work, Lang & Baumeister (1982) noted that the width of the piriform

aperture doubled from childhood to adulthood, indicating a significant developmental change.

Further expanding on this area of research, Kabakci *et al.* (2020a) conducted a study involving 200 Turkish adults aged 18-60, divided into four age groups: 18-30 years (59 participants), 31-40 years (72 participants), 41-50 years (45 participants), and 51-60 years (24 participants). They measured the height and width of the piriform aperture, as well as the ratio between these dimensions. Their findings indicated that the width of the piriform aperture increased with age, with the height showing a similar increase until the age of 51.

Building on these findings, Topal *et al.* (2022) conducted a study on the computed tomography images of 393 patients from the Radiology Department of Istanbul Medipol University, categorized into two age groups: those under 60 (352 patients) and those aged 60 and above (41 patients). The research revealed significant age-related differences in the width of the piriform aperture, with patients over 60 having a larger piriform aperture than those under 60.

In a related study, Strapasson *et al.* (2017) analyzed CT images of 96 Brazilian participants aged 18 to 65 and found that for every decade increase in age, the average width of the piriform aperture increased by 0.67 mm. Complementing these findings, Lee *et al.* (2020) analyzed head CT sc piriform aperture is wider in Black individuals, with a shorter distance between the base of the ans and created three-dimensional models for 389 Korean adults (188 males and 201 females). They concluded that the accuracy of predicting nasal morphology based on the dimensions of the piriform aperture is enhanced when age is considered alongside sex, compared to traditional methods that rely solely on sex.

However, providing a counterpoint, Hommerich *et al.* (2002) studied 116 patients aged 5 to 82 from the Göttingen area of Lower Saxony, Germany, and found no significant age-related differences in the height or width of the piriform aperture. They suggested that the lack of significant findings could be due to the small sample size, potentially introducing a statistical bias.

### Ethnic Variations in the Piriform Aperture

Scholars have also explored ethnic variations in the piriform aperture. Cantín *et al.* (2009) studied 90 human skulls from the Universidade Federal de São Paulo, consisting of 45 males and 45 females, grouped by skin color to investigate differences across different races and sexes. Their research revealed that variations in the height of the

piriform aperture were more pronounced among different races (Black, White, and Brown), with significant statistical evidence ( $p < 0.05$ ). Notably, Black individuals exhibited greater lower widths of the piriform aperture compared to their Brown and White counterparts.

Building on these observations, Williams (1956) noted that the aperture and the nasal bones, as opposed to White individuals, who have a narrower aperture with a longer distance between these points. Subsequently, Hoffman *et al.* (1991) measured the piriform aperture data in 182 American subjects, both Black and White, and found that the average width of the lower part of the piriform aperture in White individuals was 23.7 mm, significantly smaller than the 26.7 mm average observed in Black individuals.

Further emphasizing regional differences, Hommerich *et al.* (2002) found that the piriform apertures of Central European populations (Caucasian) were relatively narrow. Similarly, Gardner (2015) examined the piriform apertures of 62 skulls from the Bass Collection at the University of Tennessee, using them to predict the racial attributes of the skulls with an accuracy of 77.4 %.

Adding to this diverse dataset, Ofodile (1994) observed the piriform apertures of 20 skulls from diverse populations, including the Ashanti of West Africa, Austrians, American Indians, and Black Americans. The findings indicated that the Ashanti's piriform apertures were oval-shaped; those of Austrians and American Indians were triangular, while the shapes of the Black Americans' apertures varied from oval to triangular. Ofodile (1994) also noted that the morphological differences in the piriform apertures among these groups were related to climatic conditions.

While these studies show distinctive variations, some researchers have reached different conclusions. After analyzing the piriform aperture data from populations in Europe, Asia, North America, and Africa, Qureshi *et al.* (2009) argued that the size of the piriform aperture area (PAA) should not be used as a basis for determining ethnicity.

While extensive research has addressed variations in the piriform aperture across sex, age, and ethnicity, there remains a notable gap concerning the age-related changes and developmental characteristics of this feature in ancient children. This study examines the piriform apertures of children from the Zaghunluq cemetery in Xinjiang, comparing them across different ages to investigate the growth patterns of ancient children's piriform apertures. Understanding these developmental patterns is crucial for gaining insight into the growth conditions and developmental variations of ancient children.

## MATERIAL AND METHOD

### Research materials

The Zaghunluq ancient tomb complex (Fig. 1) is situated in Zaghunluq Village, Tograklek Township, Qiemo County, within the Xinjiang Uyghur Autonomous Region, China. This site represents one of the most substantial burial grounds discovered on the northern slopes of the Kunlun Mountains. The materials analyzed in this study originate from the second cultural phase of the Zaghunluq cemetery, which dates back to the period spanning from the Spring and Autumn era to the Western Han Dynasty. This phase corresponds with the cultural period of the Qiemo state, approximately 2600-1900 years ago. The analyzed sample includes 36 children's skulls, ranging in age from 2 to 19 years. These specimens, which are predominantly well-preserved, are currently housed at the Xinjiang Uyghur Autonomous Region Museum.

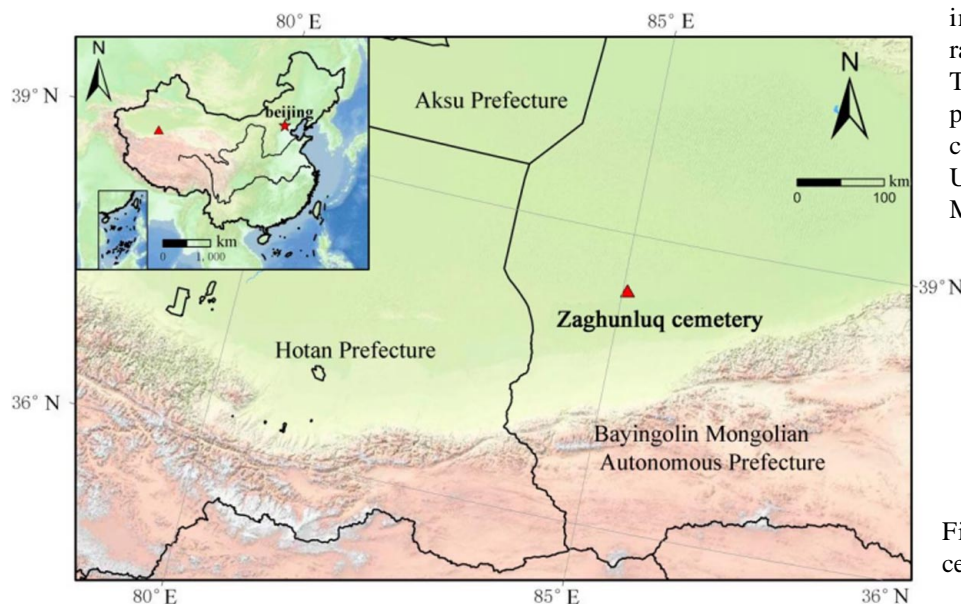


Fig. 1. The site of Zaghunluq cemetery.

## Research methods

### Age determination and grouping

Referencing the Manual of Human Measurement (Shao, 1985) and Human Osteology (White & Folkens, 2005) a comprehensive age determination was performed on the child skulls based on criteria such as the closure of

the anterior fontanelle, the eruption status of deciduous and permanent teeth, and tooth wear. For comparative purposes, the samples were categorized into six age groups based on the results of the age determination (Figs. 2 and 3): Age 2 group (2 specimens), Ages 3-5 group (7 specimens), Ages 6-7 group (6 specimens), Ages 8-10 group (11 specimens), Ages 12-15 group (8 specimens), and Ages 17-19 group (2 specimens), totaling 36 specimens.

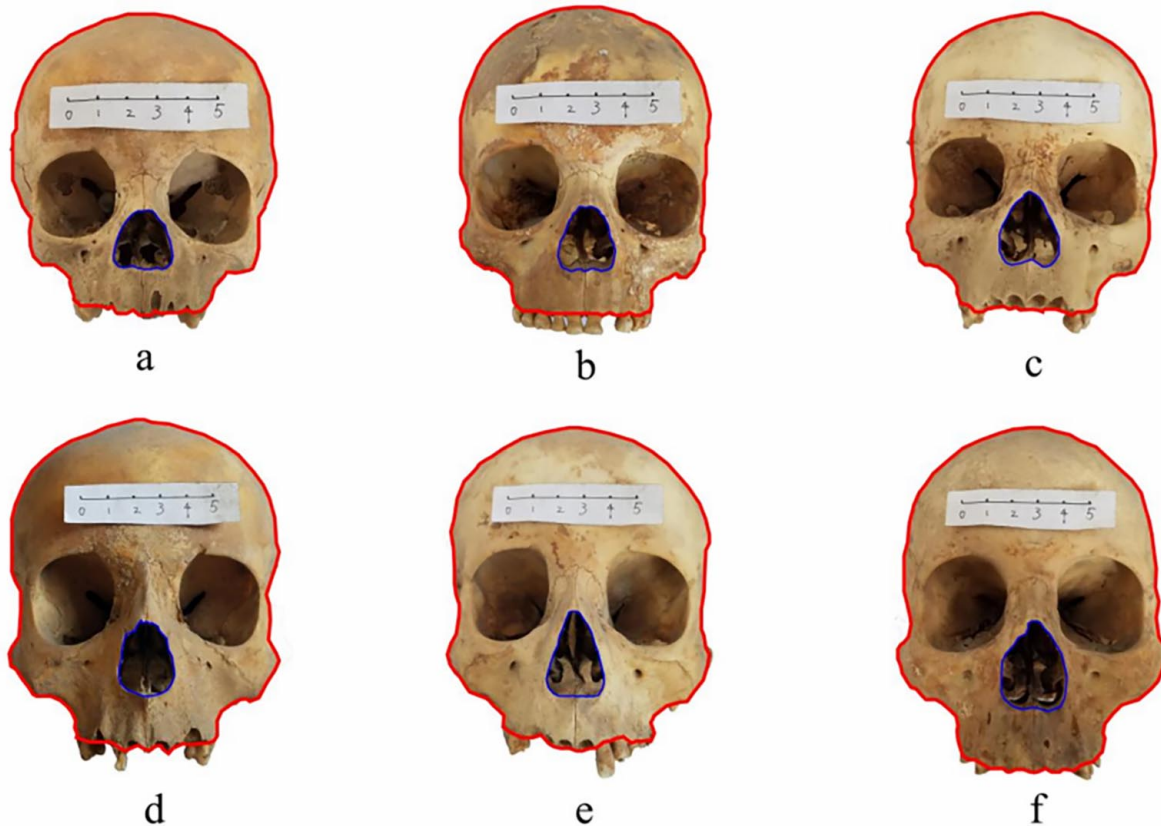


Fig. 2. Comparative outlines of the piriform aperture and frontal views of the skulls by age group. a. Age 2 group b. Ages 3-5 group c. Ages 6-7 group d. Ages 8-10 group e. Ages 12-15 group f. Ages 17-19 group.

**Imaging of the piriform aperture and frontal view of the skull.** The skulls were positioned on the Frankfurt plane for imaging, with a scale placed directly on the skull's surface to ensure it and the imaging plane were on the same horizontal level. Photographic documentation of the piriform aperture and frontal view was conducted for all 36 child skulls. Throughout the imaging process, the camera's lens plane was kept perpendicular to the Frankfurt plane, with all photographs consistently taken by the same individual.

**Skull CT scanning and three-dimensional modeling.** This study utilized a Prospeed Dual-Row Helical CT scanner from GE, USA, for scanning. The scanning parameters were set at 120 kV voltage, 150 mA current, a slice thickness of 2 mm, and a pitch of 1.5 mm. All CT

images were acquired by the same physician using the same CT device to scan the children's skulls. The obtained CT images were saved in two-dimensional digital imaging and DICOM (Digital Imaging and Communications in Medicine) file format.

Three-dimensional processing software, Materialise Mimics Research (version 21.0), was used to read the CT data of each skull and perform three-dimensional reconstructions to obtain three-dimensional models of the skulls. The models were imported into 3-matic Research software version 13.0, where the Frankfurt plane and the mid-sagittal plane of the skull were defined. A coordinate system was established to obtain frontal projections of the skull, facilitating subsequent measurements.

**Measurement and statistical methods for the piriform aperture.** Measurements were conducted using AutoCAD 2022 to determine the following dimensions of the piriform aperture and skull:

1. Upper width of the piriform aperture: the distance between the left and right nasal sutures at the lower junction of the maxillary bone and nasal bone (Lang & Baumeister, 1982) (Fig. 3 uw).
2. Lower width of the piriform aperture: the widest distance across the piriform aperture between the frontal processes of the maxillary bones on either side of the mid-sagittal plane (Hommerich *et al.*, 2002) (Fig. 3 lw).
3. Height of the piriform aperture: the vertical distance from the nasion (N) to the nasal spine (Ns), where the nasal spine is the lowest point at the base of the anterior nasal

spine at the lower edge of the piriform aperture (Cantín *et al.*, 2009) (Fig. 3 h).

4. Upper facial height: the straight-line distance from the nasion (N) to the anterior point of the upper alveolar process (Pr) .
5. Facial width: the straight-line distance between the zygomatic points (zy) on each side.

The study calculated ratios including the upper width to lower width of the piriform aperture, the lower width of the piriform aperture to facial width, and the height of the piriform aperture to upper facial height. Using AutoCAD 2022, outlines of the piriform aperture and the frontal view of the skull were traced, and the actual areas were calculated based on the scale provided (Fig. 3).

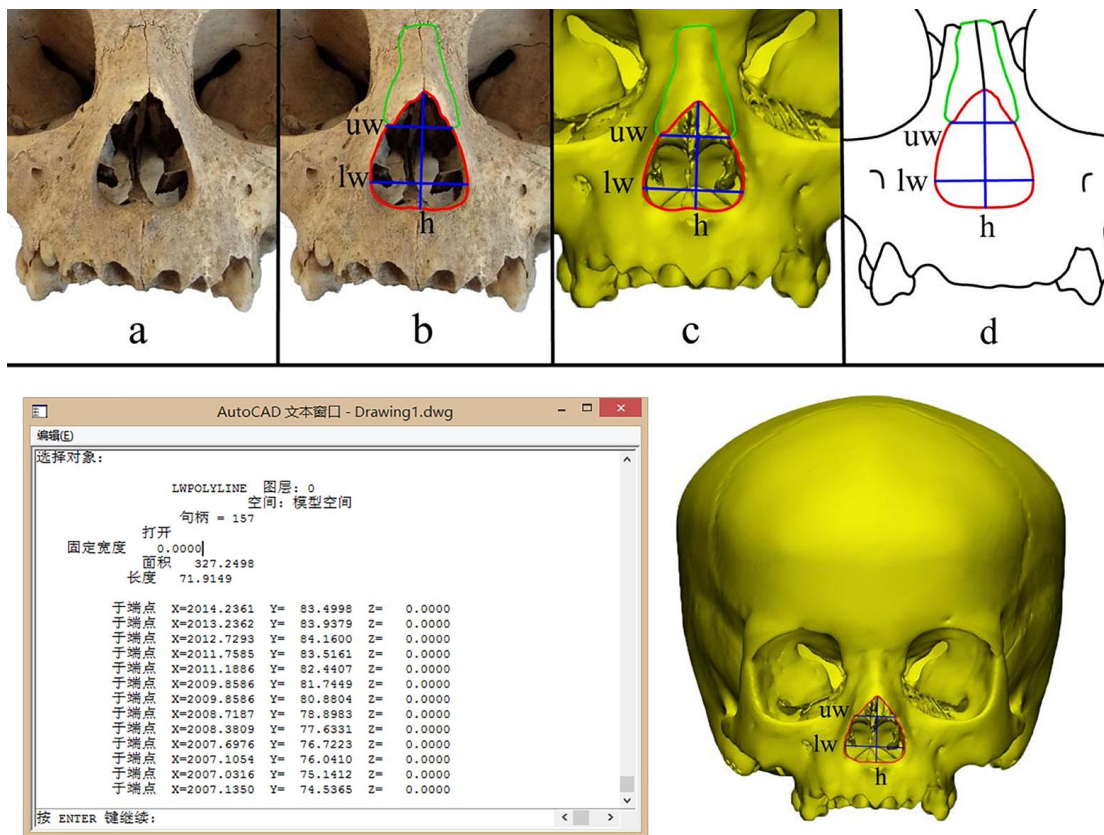


Fig. 3. Using CAD to Calculate the Frontal View Area of the Piriform Aperture. uw: upper width; lw: lower width; h: height; green: nasal bone

Using SPSS Statistics 19 software, variance analysis and multiple comparisons (using the LSD method) were conducted on the measurement values across different age groups. Additionally, the rate of change between ages was calculated using the following formula:

Age Change Rate (%) =  $100\% \times (X_2 - X_1) / X_1$ , where  $X_1$  and  $X_2$  represent the average values of the same measurement for the younger and older age groups, respectively.

**RESULTS**

**Age-related changes in the upper width of the piriform aperture**

In the Zaghunluq Cemetery, the average upper widths of the piriform aperture across age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were as follows: 14.43 mm, 13.24 mm, 12.93 mm, 13.89 mm, 15.23 mm, and 16.11 mm, respectively. Significant increases in the upper width were observed between the ages of 8-10 and 12-15 years (Fig. 4-a). Variance analysis revealed significant differences across the age groups (P=0.020). LSD multiple comparison tests showed that the differences between the 2-year and 3-5-year groups were not significant (P=0.303), as were the differences between the 3-5-year and 6-7-year groups (P=0.700), and the 6-7-year and 8-10-year groups (P=0.195). However, a significant difference was noted between the 8-10-year and 12-15-year groups (P=0.050), while the difference between the 12-15-year and 17-19-year groups was not significant (P=0.443). Analysis of age-related rate changes indicated that significant growth in the upper width of the piriform aperture occurred primarily between the ages of 8-10 years (7.42 %) and 12-15 years (9.64 %) (Table I).

**Age-related changes in the lower width of the piriform aperture**

In the Zaghunluq Cemetery, the average lower widths of the piriform aperture across the age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were measured at 19.01 mm, 19.43 mm, 21.56 mm, 21.11 mm, 22.21 mm, and 23.51 mm, respectively. Excluding the 8-10 year group, a general trend of increasing lower width with age was observed (Fig. 4-b). Variance analysis confirmed significant differences in the lower width among the age groups (P<0.001), indicating a progressive increase in lower width with age. LSD multiple comparisons revealed that the differences between the 2-year and the 3-5-year groups were not significant (P=0.644), while significant differences were observed between the 3-5-year and 6-7-year groups (P=0.002), and between the 8-10-year and 12-15-year groups (P=0.044). No significant differences were found between the 6-7-year and 8-10-year groups (P=0.441), or between the 12-15-year and 17-19-year groups (P=0.155). Analysis of the rate of change showed that significant increases in the lower width of the piriform aperture occurred primarily between the ages of 6-7 (10.96 %) and 17-19 (5.85 %) (Table I).

**Age-related changes in the height of the piriform aperture**

In the Zaghunluq Cemetery, the average heights of the piriform aperture for the age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were 19.68 mm, 21.73 mm, 23.95 mm, 24.49 mm, 25.71 mm, and 30.24 mm, respectively. These measurements reflect a gradual increase in the height of the piriform aperture with age (Fig. 4-c). Variance analysis confirmed significant differences in height across the age groups (P=0.000), indicating that the height of the piriform aperture increases with age. LSD multiple comparisons showed that the differences between the 2-year and 3-5-year groups were not significant (P=0.263), as were the differences between the 3-5-year and 6-7-year groups (P=0.086), the 6-7-year and 8-10-year groups (P=0.639), and the 8-10-year and 12-15-year groups (P=0.253). However, a significant difference was noted between the 12-15-year and 17-19-year groups (P=0.016). An analysis of the rate of change showed that the most significant growth in the height of the piriform aperture occurred between the ages of 3-5 years (10.42 %) and 17-19 years (17.62 %) (Table I).

Table I. Measurements related to the piriform aperture in Zaghunluq children and comparisons across different age groups.

Age Group	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	2 vs 3-5	3-5 vs 6-7	6-7 vs 8-10	8-10 vs 12-15	12-15 vs 17-19	2 vs 3-5	3-5 vs 6-7	6-7 vs 8-10	8-10 vs 12-15	12-15 vs 17-19
Upper width (mm)	2	14.43	7	13.24	6	12.93	11	13.89	8	15.23	2	16.11	0.020*	0.303	0.700	0.195	0.050*	0.443	-8.24	-2.34	7.42	9.64	5.77
Lower width (mm)	2	19.01	7	19.43	6	21.56	11	21.11	8	22.21	2	23.51	0.000**	0.644	0.002*	0.441	0.044*	0.155	10.96	10.96	-2.08	5.21	5.85
Height (mm)	2	19.68	7	21.73	6	23.95	11	24.49	8	25.71	2	30.24	0.000**	0.263	0.086	0.639	0.253	0.016*	10.42	10.22	2.25	4.98	17.62
Piriform aperture area (mm <sup>2</sup> )	2	303.49	7	333.01	6	394.85	11	397.38	8	435.42	2	531.91	0.000**	0.450	0.028*	0.918	0.099	0.017*	9.90	18.62	0.51	9.57	22.30
Piriform aperture area-nasal bone (mm <sup>2</sup> )	2	365.39	7	445.06	6	557.08	11	614.78	8	659.03	2	731.58	0.000**	0.128	0.004**	0.084	0.144	0.159	21.80	25.17	10.36	7.20	11.01

### Age-related changes in the projected area of the piriform aperture

In the Zaghunluq Cemetery, the average projected areas of the piriform aperture for the age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were 303.49 mm<sup>2</sup>, 333.01 mm<sup>2</sup>, 394.85 mm<sup>2</sup>, 397.38 mm<sup>2</sup>, 435.42 mm<sup>2</sup>, and 531.91 mm<sup>2</sup>, respectively. These measurements indicate a general increase in the projected area of the piriform aperture with age (Fig. 4-d). Variance analysis revealed significant differences in projected areas across age groups ( $P=0.000$ ), demonstrating that the projected area of the piriform aperture enlarges as age increases. LSD multiple comparisons showed that the difference between the 2-year and 3-5-year groups was not significant ( $P=0.450$ ), while significant differences were observed between the 3-5-year and 6-7-year groups ( $P=0.028$ ), and between the 12-15-year and 17-19-year groups ( $P=0.017$ ).

No significant differences were noted between the 6-7-year and 8-10-year groups ( $P=0.918$ ), or between the 8-10-year and 12-15-year groups ( $P=0.099$ ). Analysis of the rate of change indicated that significant growth in the projected area of the piriform aperture occurred primarily between the ages of 6-7 years (18.62 %) and 17-19 years (22.30 %) (Table I).

### Age-related changes in the projected area of the piriform aperture and nasal bone region

In the Zaghunluq Cemetery, the average projected areas of the piriform aperture and nasal bones for the age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were 365.39 mm<sup>2</sup>, 445.06 mm<sup>2</sup>, 557.08 mm<sup>2</sup>, 614.78 mm<sup>2</sup>, 659.03 mm<sup>2</sup>, and 731.58 mm<sup>2</sup>, respectively. These measurements reflect a general increase in the projected area of the piriform aperture plus nasal bones with age

(Fig. 4-e). Variance analysis confirmed significant differences in projected areas across these age groups ( $P=0.000$ ), indicating that the projected area of the piriform aperture plus nasal bones increases with age. LSD multiple comparisons revealed that the differences between the 2-year and the 3-5-year groups were not significant ( $P=0.128$ ), while significant differences were observed between the 3-5-year and 6-7-year groups ( $P=0.004$ ). No significant differences were noted between the 6-7-year and 8-10-year groups ( $P=0.084$ ), the 8-10-year and 12-15-year groups ( $P=0.144$ ), or the 12-15-year and 17-19-year groups ( $P=0.159$ ). According to the rate of change analysis, significant increases in the projected area of the piriform aperture plus nasal bones occurred primarily between the ages of 3-5 years (21.80 %) and 6-7 years (25.17 %) (Table I).

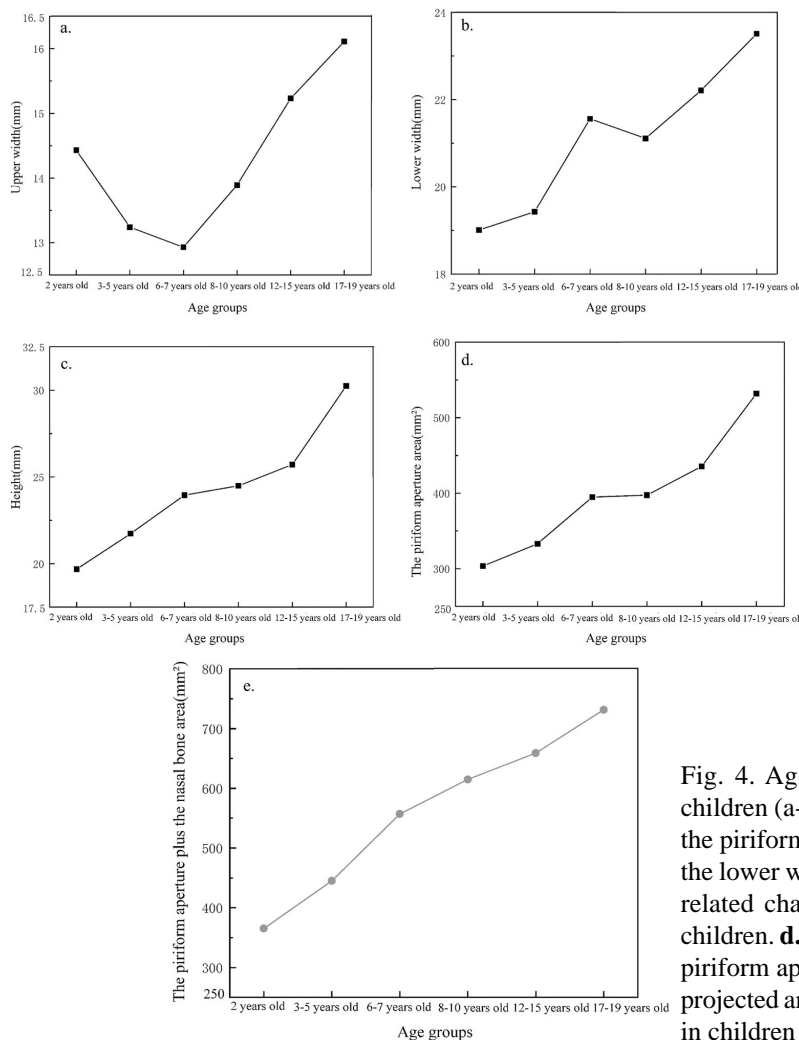


Fig. 4. Age-related changes in the piriform aperture of children (a-e). **a.** Age-related changes in the upper width of the piriform aperture in children. **b.** Age-related changes in the lower width of the piriform aperture in children. **c.** Age-related changes in the height of the piriform aperture in children. **d.** Age-related changes in the projected area of the piriform aperture in children. **e.** Age-related changes in the projected area of the piriform aperture and nasal bone region in children

**Ratio of superior to lower widths of the piriform aperture**

The ratios of superior to lower widths of the piriform aperture across six age groups (2 years, 3-5 years, 6-7 years, 8-10 years, 12-15 years, 17-19 years) were calculated in the Zaghunluq Cemetery (Table II). Analysis revealed that this ratio exhibited a decreasing trend from ages 2 to 7, increased slightly between ages 8 to 10, and gradually stabilized at 0.68 from ages 12 to 15 onwards. This pattern suggests that the growth of the lower width of the piriform aperture outpaces that of the upper width until the age of 6-7 years. Beyond the age of 12 years, the growth rates of the superior and lower widths align and progress in synchrony.

**Ratio of lower width of the piriform aperture to facial width**

In the Zaghunluq Cemetery, facial widths of skulls across six age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens) —were recorded as follows: 89.08 mm, 100.67 mm, 107.08 mm, 111.27 mm, 118.26 mm, and 120.79 mm, respectively. These measurements show a progressive increase in facial width with age. The ratios of the lower width of the piriform aperture to the facial width for these age groups were analyzed (Table II). The ratios were found to oscillate between approximately 0.19 and 0.21, indicating that the growth of the lower width of the piriform aperture is generally proportional to the increase in facial width in children.

**Ratio of piriform aperture height to upper facial height**

In the Zaghunluq Cemetery, the upper facial heights of skulls across six age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens) —were measured as follows: 45.13 mm, 42.68 mm, 52.63 mm, 58.18 mm, 59.66 mm, and 58.07 mm,

respectively. These results indicate that the upper facial height increases with age. The ratios of piriform aperture height to upper facial height for these age groups were analyzed (Table II). It was observed that the ratios fluctuated between approximately 0.43 and 0.52, suggesting that the growth of the piriform aperture height is generally proportional to the growth in upper facial height in children.

**Ratio of projected area of the piriform aperture to the frontal view projected area of the skull**

In the Zaghunluq Cemetery, the average projected areas of the frontal view of skulls for six age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were measured as 13,849.97 mm<sup>2</sup>, 14,875.35 mm<sup>2</sup>, 15,838.54 mm<sup>2</sup>, 16,746.82 mm<sup>2</sup>, 17,569.41 mm<sup>2</sup>, and 18,525.45 mm<sup>2</sup>, respectively. The ratios of the piriform aperture's projected area to the skull's frontal view projected area for these groups were calculated (Table II). It was observed that the ratios (S piriform aperture/ S frontal view of skull) consistently ranged between 0.02 and 0.03, indicating that the development of the piriform aperture and the skull's frontal view are proportionally aligned in children.

**Ratio of the projected area of the piriform aperture plus nasal bones to the frontal view projected area of the skull**

In the Zaghunluq Cemetery, the average projected areas of the piriform aperture plus nasal bones for the age groups—2 years (2 specimens), 3-5 years (7 specimens), 6-7 years (6 specimens), 8-10 years (11 specimens), 12-15 years (8 specimens), and 17-19 years (2 specimens)—were recorded as 365.39 mm<sup>2</sup>, 445.06 mm<sup>2</sup>, 557.08 mm<sup>2</sup>, 614.78 mm<sup>2</sup>, 659.03 mm<sup>2</sup>, and 731.58 mm<sup>2</sup>, respectively. The ratios of these areas to the frontal view projected areas of the skulls (S piriform aperture + nasal bones /S frontal view of skull) were calculated

Table II. Ratio of the piriform aperture in Zaghunluq children and comparisons across different age groups.

Age Group	2 Years	3-5 Years	6-7 Years	8-10 Years	12-15 Years	17-19 Years
N	2	7	6	11	8	2
Upper width (mm)	14.43	13.24	12.93	13.89	15.23	16.11
Lower width (mm)	19.01	19.43	21.56	21.11	22.21	23.51
upper width / Lower width	0.759	0.681	0.600	0.658	0.686	0.685
Lower width (mm)	2	7	6	11	8	2
Bizygomatic breadth (mm)	19.01	19.43	21.56	21.11	22.21	23.51
Lower width / Bizygomatic breadth	89.08	100.67	107.08	111.27	118.26	120.79
Height (mm)	19.68	21.73	23.95	24.49	25.71	30.24
Upper facial height (mm)	45.13	42.68	52.63	58.18	59.66	58.07
Height / Upper facial height	0.436	0.509	0.455	0.421	0.431	0.521
Piriform aperture are (mm <sup>2</sup> )	303.49	333.01	394.85	397.38	435.42	531.91
Anterior area of skull (mm <sup>2</sup> )	365.39	445.06	557.08	614.78	659.03	731.58
S <sub>piriform aperture</sub> /S <sub>anterior view of skull</sub>	13848.97	14875.35	15838.54	16745.82	17569.41	18525.45

and found to consistently range between 0.02 to 0.04 (Table II). This indicates that under normal circumstances, the development of the piriform aperture plus nasal bones in children is proportionate to the growth of the frontal aspect of the skull.

## DISCUSSION

Variance analysis, multiple comparisons, and analysis of change rates over age indicate that, except for the 12-15 year age group, differences in the upper width of the piriform aperture of ancient children from the Zaghunluq site are not significant between the age groups. This suggests that the lateral development of the nasal bone may be complete by the age of two. Conversely, the lower width, height, and projected area of the piriform aperture, including the area with the nasal bones, all exhibit an increasing trend with age. Notably, the growth spurts for the lower width and projected area occur at ages 6-7 and 17-19 years, while those for height are at ages 3-5 and 17-19 years. The projected area including the nasal bones also shows significant growth spurts between 3-5 years and 6-7 years. Further, analyses of the ratios of the lower width of the piriform aperture to facial width, and the height of the piriform aperture to upper facial height, show that these dimensions increase in tandem in children. Analyses of the ratios of the piriform aperture area to the frontal view area of the skull indicate that the piriform aperture develops in proportion to the skull. This supports the views presented by Topal *et al.* (2022) who argue that the width of the piriform aperture increases with the width of the skull. However, a declining trend in the ratio of superior to lower widths indicates that the lower width of the piriform aperture grows faster than the upper width in children.

It is important to acknowledge that our analysis does not include skulls of ancient children under two years old. Lin *et al.* (2016) categorized 54 pediatric patients from Mackay Memorial Hospital, Taiwan, China, into five age groups—under one month, 1-3 months, 4-11 months, 12-36 months, and over 36 months—and measured the interprocess distance (IPD) between the maxillary processes on either side of the piriform aperture. The findings showed that the IPD in neonates under one month averaged 3.57 mm, 4.08 mm in the 1-3 months group, 5.19 mm in the 4-11 months group, 6.61 mm in the 12-36 months group, and 9.20 mm in the over 36 months group, thus establishing a growth curve for the piriform aperture. Statistical analysis indicated (Lin *et al.*, 2016) that the expansion of the IPD began around four months of age, with continuous expansion lasting until about ten years of age. However, since our study does not include ancient infant skulls, their findings cannot be directly compared with ours regarding the initial expansion point of the IPD, warranting further investigation.

Significant temporal differences exist in the growth and development of the piriform aperture in children. In 2004, Okazaki (2004), measured 144 pediatric skulls from the Yayoi period, the Muromachi period, and the modern era in Japan, identifying morphological differences between the piriform apertures of ancient and modern children. The scarcity of available comparative literature data currently hampers the systematic exploration of developmental discrepancies in piriform apertures across historical epochs. Future research will focus on acquiring more extensive data sets from both ancient and modern children to outline and compare their developmental profiles more clearly.

Finally, the nasal bone, as an integral part of the facial skeleton, shares a close relationship with the piriform aperture. Studies have demonstrated that the morphology of the nasal bone considerably affects the shape of the piriform aperture (Kabakci *et al.*, 2020b). Most research on age-related variations in the nasal bone has concentrated on fetal development during pregnancy (Goynumer *et al.*, 2011; Sharma *et al.*, 2013; Papisozomenou *et al.*, 2016). Due to the delicate margins of the piriform aperture, measurements of its projected area can be susceptible to inaccuracies. To address this issue, we have also measured and analyzed the combined projected area of the piriform aperture and the nasal bones to enhance the precision of our data.

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ZHANG, H.; ZHANG, P.; WANG, Y.; ZENG, Y.; WAILI, A.; LI, H. & LIU, B. Análisis comparativo del desarrollo de la abertura piriforme en niños antiguos de Xinjiang, China, según diferentes grupos de edad. *Int. J. Morphol.*, 44(2):363-372, 2026.

**RESUMEN:** Este estudio aborda la escasez de investigaciones sobre el crecimiento de la abertura piriforme en niños antiguos mediante el análisis de 36 cráneos infantiles de la región de Zaghunluq, Xinjiang. Los cráneos se dividieron en seis grupos de edad, desde los 2 hasta los 19 años. Mediante software de diseño asistido por computadora (CAD), se midieron dimensiones como el ancho superior, el ancho inferior, la altura y el área total, incluyendo el área del hueso nasal. Los análisis estadísticos revelaron importantes picos de crecimiento en dimensiones específicas en diferentes grupos de edad: ancho superior entre los 8 y los 10 años y entre los 12 y los 15 años, ancho inferior entre los 6 y los 7 años y entre los 17 y los 19 años, altura entre los 3 y los 5 años y entre los 17 y los 19 años, y área proyectada entre los 6 y los 7 años y entre los 17 y los 19 años. Las tendencias de desarrollo mostraron que el crecimiento del ancho inferior superó al del ancho superior antes de los 7 años, mientras que ambas crecieron a ritmos similares a partir de los 12-15 años. El estudio concluyó que la abertura piriforme y el cráneo se desarrollan proporcionalmente, con patrones de crecimiento distintos en sus dimensiones durante la infancia y la adolescencia.

**PALABRAS CLAVE:** Poblaciones pediátricas antiguas; Abertura piriforme; Análisis comparativo; Grupos de edad; Crecimiento y desarrollo.

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