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Anatomical Parameters and Growth of the Pediatric Skull Base: Endonasal Access Implications

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Abstract

Objectives Endoscopic endonasal anterior skull base surgery has expanding use in the pediatric population, but the anatomy of pediatric patients can lead to limitations. This study aims to characterize the important anatomical implications of the pediatric skull base using computed tomography (CT) scans.

Design This study is designed as retrospective analysis.

Setting The study setting comprises of tertiary academic medical center.

Participants In total, 506 patients aged 0 to 18 who had undergone maxillofacial and or head CTs between 2009 to 2016 were involved.

Methods Measurements included piriform aperture width, nare to sella distance (NSD), sphenoid pneumatization, olfactory fossa depth, lateral lamella cribriform plate angles, and intercarotid distances (ICD) at the superior clivus and cavernous sinus. These patients were then subdivided into three age groups adjusting for sex. Analysis of covariance (ANCOVA) models were fit comparing between all age groups and by sex.

Results Piriform aperture width, NSD, sphenoid sinus pneumatization as measured using lateral aeration and anterior sellar wall thickness, olfactory fossa depth, and ICD at the cavernous sinus were significantly different among all age groups ($p < 0.0001$). Our results show that mean piriform aperture width increased with each age group. The mean olfactory fossa depth also had consistent age dependent growth. In addition, ICD at the cavernous sinus showed age dependent changes. When comparing by sexes, females consistently showed smaller measurements.

Conclusion The process of skull base development is age and sex dependent. During preoperative evaluation of pediatric patients for skull base surgery piriform aperture width, sphenoid pneumatization in both the anterior posterior and lateral directions, and ICD at the cavernous sinus should be carefully reviewed.

Keywords
- skull base surgery
- anatomical differences
- olfactory fossa depth
- intercarotid distance

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Introduction

Pediatric endoscopic, endonasal skull base surgery is a viable and safe approach for skull base pathology including craniopharyngiomas, pituitary adenomas, Rathke cleft cysts, and juvenile nasopharyngeal angiofibromas.[1–7] Endoscopic approaches have evidence-based advantages compared with open procedures including improved visualization, cost effectiveness, and decreased blood loss.[4,8,9] Parasher et al and Chen et al demonstrated that the age at which endoscopic endonasal surgery (EES) is performed does not affect midface growth or craniofacial development.[10,11] Although endoscopic approaches have many benefits, they are not without potential complications including cerebrospinal fluid leak, meningitis, cranial neuropathy, and pneumocephalus.[4] In a recent study, Lenze et al showed a similar complication profile when comparing open and endoscopic approaches.[12] The favorable advantages combined with equivalent complication rates allow for the endoscopic approach to continue to grow in popularity and usage.

Endoscopic approaches in pediatric patients have some limitations due to the developing neurocranium and viscerocranium. Changing anatomy can lead to confined working areas and theoretically higher risks due to smaller distances between critical structures. The main limitation of EES include anatomy that limits the ability of rigid instruments to reach their intended location. For example, in pediatric patients, the boney structure of the piriform aperture can limit the lateral extent of resection.[13] The distance between the cavernous carotid arteries is important in preoperative planning, as a narrow distance can limit superior dissection. While incomplete pneumatization of the sphenoid sinus is not a contraindication to surgery, it does increase the complexity of the approach and requires an additional skillset, increased surgical time, and increased blood loss.[14–17]

The nature of pediatric endoscopic surgery relies on careful measurements to best illustrate the skull base and prepare the surgeon.[18] The aim of this study was to use a larger patient population and wider age range, identify and expand upon the important anatomical differences and variations between different pediatric age groups and genders in the preoperative evaluation for EES. This data can then be used for both educational purposes in this developing field as well as for advanced research and instrumentation development in the future.

Materials and Methods

Exclusion Criteria

Institutional review board approval was obtained for this study from Penn State Milton S Hershey Medical Center. A total of 1,143 patients with ages ranging from 0 to 18 years who had undergone maxillofacial CT from 2009 to 2016 were identified retrospectively using a radiological database at our institution. Patients with pre-existing conditions altering skull base anatomy including, craniofacial trauma, skull base trauma, previous sinus or skull base surgery, and congenital midface anomalies were excluded. Patients were also excluded if not every measurement was able to be taken due to lack of axial, coronal, or sagittal scans. All measurements were verified by an attending neuroradiologist and otolaryngologist.

Measurements

The maximum piriform aperture width (PA-w) was measured in the coronal plan (►**Fig. 1A**). Nare to sella distance (NSD) was measured as the length from the anterior maxilla to the anterior sella turcica (►**Fig. 1B**). Sphenoid sinus (SS) pneumatization was classified into three groups. In the sagittal plane we classified the sphenoid as conchal (►**Fig. 1D**), presellar (►**Fig. 1E**), or sellar (►**Fig. 1F**). The conchal type was defined as sella turcica entirely surrounded by bone and the sinus aeration not reaching the anterior sellar wall (ASW). The presellar type was defined as the anterior half of the sella exposed to air, with the posterior most aspect of the sinus ending at the ASW. The sellar type was defined as the sinus extending past the ASW. SS width was measured as the widest points on any coronal cut within the pneumatized SS (►**Fig. 1C**). ASW thickness was measured on the sagittal plane as minimum distance from ASW to the pituitary fossa (►**Fig. 1G**). If the tuberculum sella was surrounded by air the ASW thickness was considered 0 mm. SS width was measured as the widest aerated space in any part of the SS in the coronal plane.

The depth of the olfactory fossa (OF) was measured as described by Keros by taking the height from the cribriform plate to the inferior most aspect of the fovea ethmoidalis (►**Fig. 1H**).[19] Cribriform angles were measured in the coronal plane, on the same image as the OF depth, as the angle between the lateral lamella and the cribriform plate on each side (►**Fig. 1I**).

The intracarotid distance (ICD) was measured at the superior clivus (SC) and cavernous sinus (CS) in the axial plane. The ICD at the SC was measured as the minimum distance between the medial aspects of carotid canals at the SC inferior to the sellar floor (►**Fig. 1K**). The ICD at the CS was measured as the minimum distance between the medial aspects of the carotid prominence within the CS above the sellar floor (►**Fig. 1J**).

Descriptive analysis is displayed amongst small age increments to best display the trajectory of growth. The patients were then grouped into three age groups (<5 years, 5–12 years, ≥13 years) for statistical analysis as well as to 7 smaller age cohorts (0–2 years, 3–5 years, 6–8 years, 9–10 years, 11–12 years, 13–14 years, and 15–18 years). This <5, 5–12, and >13 years age groups were chosen because, full ossification has been shown to finish by 5 years, fixed growth happens between ages 5 and 12 years, and after 13 years most patients have entered puberty and growth is minimal.[20]

Statistical Analysis

Descriptive statistics were generated to describe the sample in terms of age and gender. Analysis of covariance (ANCOVA) was used to estimate adjusted means and 95% confidence intervals for each of the outcome measurements of nasal aperture, sphenoid bone widths, sphenoid bone thickness,

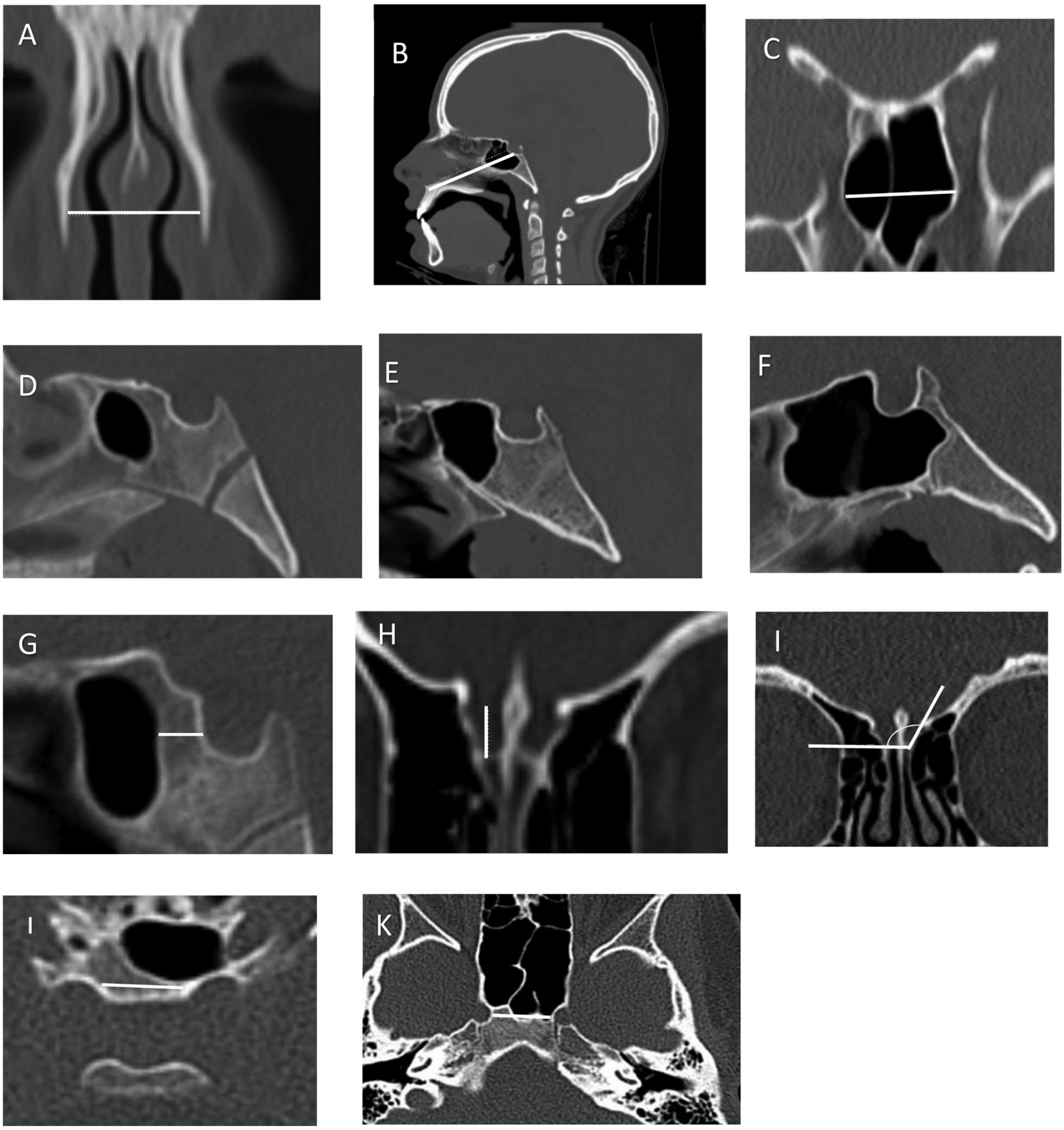

Fig. 1 Radiographic measurements. (**A**) Piriform aperture, (**B**) Nare to sella distance, (**C**) sphenoid sinus width, (**D**) conchal pneumatization, (**E**) presellar pneumatization, (**F**) sellar pneumatization, (**G**) anterior sellar wall thickness, (**H**) olfactory fossa depth, (**I**) left lateral lamella cribriform angle, (**J**) intercarotid distance cavernous sinus, (**K**) intercarotid distance superior clivus.

and intercarotid distances (ICD) for each of the prespecified age categories, with adjustment for gender. Overall tests comparing among the age categories were generated, and if $p < 0.05$ the comparison of each age group versus 15 to 18 years was reported. The association between age category and sphenoid pneumatization type was evaluated by a frequency table and Chi-square test. Age categories were collapsed into <5 years, 5 to 12 years, and ≥13 years, and ANCOVA models again fit for each outcome measure with adjusted means estimated and compared between all three age groups in the manner described. Adjusted means and 95% confidence intervals were also reported for gender from each of the ANCOVA models. Significance was defined as $p < 0.05$, and analyses were performed using SAS statistical software version 9.4 (SAS Institute Inc., Cary North Carolina, United States).

Results

Patient Cohort

A total of 1,143 patient charts were reviewed. Six hundred and thirty-seven patients were excluded, most commonly due to missing data. A total of 506 patients were included. There were 215 female (42.5%) and 291 male (57.5%) patients. The average age of the cohort was 11.9 years (SD: 4.9). Patients were then assigned to three different age

Table 1 Demographics

Outcome	Mean (SD) or *N* (%)
Age	11.9 (4.9)
Age group	
< 5	59 (11.7%)
5–12	181 (35.8%)
≥13	266 (52.6%)
Gender	
Female	215 (42.5%)
Male	291 (57.5%)

groups as follows: less than 5 years ($n = 59$, 11.7%), 5 to 12 years ($n = 181$, 35.8%), and greater than 13 years ($n = 266$, 52.6%) (►**Table 1**).

For the descriptive analysis, patients were also assigned to seven smaller age cohorts 0 to 2 years ($n = 26$, 5.1%), 3 to 5 years ($n = 49$, 9.7%), 6 to 8 years ($n = 49$, 9.7%), 9 to 10 years ($n = 49$, 9.7%), 11 to 12 years ($n = 67$, 13.2%), 13 to 14 years ($n = 67$, 13.2%), and 15 to 18 years ($n = 199$, 39.3%).

Width of the Piriform Aperture and Nare to Sella

When comparing between the three age groups there was a statistically significant difference between the three age groups (►**Table 2**, $p < 0.0001$). Smaller age ranges had a decreased PA-w, with confidence intervals for <5 years

Table 2 Difference in means among the three different age groups (<5, 5–12, and >13), adjusted for GENDER

Outcome	Overall *p*-value	Age groups	Difference between means	Lower CL	Upper CL	*p*-Values
Piriform aperture width	<0.0001	<5 vs. >13 y	−3.22	−3.81	−2.63	<0.0001
		5–12 vs. <5 y	2.16	1.547	2.771	<0.0001
		5–12 vs. >13 y	−1.06	−1.45	−0.665	<0.0001
Nare to sella	<0.0001	<5 vs. >13 y	−17.8	−19.3	−16.3	<0.0001
		5–12 vs. <5 y	10.74	9.175	12.30	<0.0001
		5–12 vs. >13 y	−7.02	−8.03	−6.02	<0.0001
Sphenoid sinus width	<0.0001	<5 vs. >13 y	−20.4	−23.3	−17.5	<0.0001
		5–12 vs. <5 y	12.79	9.762	15.83	<0.0001
		5–12 vs. >13 y	−7.62	−9.58	−5.67	<0.0001
Anterior sellar wall	<0.0001	<5 vs. >13 y	8.91	8.141	9.671	<0.0001
		5–12 vs. <5 y	−7.18	−7.97	−6.38	<0.0001
		5–12 vs. >13 y	1.73	1.214	2.238	<0.0001
Olfactory fossa depth	<0.0001	<5 vs. >13 y	−0.83	−1.16	−0.499	<0.0001
		5–12 vs. <5 y	0.54	0.191	0.879	0.0008
		5–12 vs. >13 y	−0.29	−0.516	−0.074	0.0052
Left LC angle	0.0196	<5 vs. >13 y	5.76	0.890	10.62	0.0155
		5–12 vs. <5 y	−5.00	−10.1	0.058	0.0535
		5–12 vs. >13 y	0.76	−2.50	4.014	0.8480
Right LC angle	0.0004	<5 vs. >13 y	7.66	2.653	12.67	0.0010
		5–12 vs. <5 y	−4.07	−9.27	1.133	0.1581
		5–12 vs. >13 y	3.59	0.241	6.942	0.0323
ICD cavernous sinus	<0.0001	<5 vs. >13 y	−2.51	−3.15	−1.87	<0.0001
		5–12 vs. <5 y	1.74	1.073	2.410	<0.0001
		5–12 vs. >13 y	−0.77	−1.20	−0.339	<0.0001
ICD superior clivus	0.0097	<5 vs. >13 y	−0.47	−1.21	0.269	0.2924
		5–12 vs. <5 y	0.92	0.154	1.695	0.0138
		5–12 vs. >13 y	0.45	−0.044	0.948	0.0827

Note: ►**Table 3** includes the adjusted means and 95% confidence intervals for each outcome for the age groups collapsed as <5, 5–12, and >13, adjusted for gender. The overall test indicating whether there is a significant difference among these age groups is listed as the "overall *p*-value" for each outcome on ►**Table 2**. As long as the overall *p*-value is <0.05 then it is appropriate to proceed to evaluate the pairwise comparisons. All pairwise comparisons among the groups are listed in ►**Table 2**, with corresponding average differences, 95% CIs, and *p*-values.

(17.6 ± 0.45) and >13 years (20.82 ± 0.21) having over about a 3.2 mm difference (►**Table 3**).

When comparing the three age groups NSD was statistically significant between all groups $p < 0.0001$ (►**Table 2**). There were significant differences of 10.74 mm among the model adjusted mean <5 years (61.03 ± 1.14) cohort to the 5 to 12 years (71.77 ± 0.66) (►**Table 3**; ►**Fig. 2**). When comparing the 5 to 12 age range and >13 age range the older age group had an adjusted mean distance of 7.02 mm longer.

Sphenoid Sinus Pneumatization, Width, and Anterior Sellar Wall Thickness

Among sphenoid pneumatization types and age, the Fisher exact *p*-value was <0.0001 (►**Table 4**). All patients in the 0 to 2 ($n = 26$) years range were classified as conchal. 89.8% ($n = 44$) of patients in the 3 to 5-year range were classified as conchal, 6.1% ($n = 3$) and 2.1% ($n = 2$) were presellar and sellar, respectively. 46.9% ($n = 23$) of patients of 6 to 8 year group were conchal, 38.8% ($n = 19$) had sellar anatomy, and 14.3% ($n = 7$) had presellar anatomy. 79.6% ($n = 39$) in the 9 to 10 age group had sellar aeration. 83.6% ($n = 56$) in the 11 to 12 age group had sellar aeration. 89.6% ($n = 60$) in our 13 to 14 age group had sellar aeration. In our final age group 15 to 18 93.0% ($n = 185$) had sellar aeration.

The SS width for <5 age group was 16.54 ± 2.21, for 5 to 12 age group was 29.33 ± 1.26, and for >13 age group was 36.96 ± 1.04 (►**Table 3**). When comparing confidence intervals for SS width for <5 age range to the 5 to 12 age range there was a difference of approximately 13 mm. When comparing <5 years to >13 years the mean showed a difference of 20.42 mm (►**Table 2**, $p < 0.0001$).

Patients <5 years had an ASW thickness of 8.99 ± 0.579 which was significantly larger in the 5 to 12 years (1.81 ± 0.33) and >13 years (0.9 ± 0.268) ($p < 0.001$, ►**Tables 2** and **3**, ►**Fig. 3**).

Table 3 Model-estimated means among outcomes in 3 different age groups (<5, 5–12, and >13), adjusted for GENDER

Outcome	Age groups	LS means	Lower CL	Upper CL
Piriform aperture width	<5	17.60	17.15	18.04
	5–12	19.76	19.50	20.01
	>13	20.82	20.61	21.02
Nare to sella distance	<5	61.03	59.89	62.17
	5–12	71.77	71.11	72.42
	>13	78.79	78.26	79.33
Anterior sellar wall	<5	8.99	8.411	9.572
	5–12	1.81	1.480	2.144
	>13	0.09	−0.186	0.358
Sphenoid sinus width	<5	16.54	14.33	18.75
	5–12	29.33	28.07	30.60
	>13	36.96	35.92	37.99
Olfactory fossa depth	<5	2.76	2.508	3.010
	5–12	3.29	3.150	3.437
	>13	3.59	3.471	3.706
Left LC angle	<5	123.1	119.4	126.8
	5–12	118.1	116.0	120.2
	>13	117.3	115.6	119.1
Right LC angle	<5	122.2	118.4	126.0
	5–12	118.1	115.9	120.3
	>13	114.5	112.7	116.3
ICD cavernous sinus	<5	9.29	8.802	9.779
	5–12	11.03	10.75	11.31
	>13	11.80	11.57	12.03
ICD superior clivus	<5	15.73	15.17	16.30
	5–12	16.66	16.34	16.98
	>13	16.21	15.94	16.47

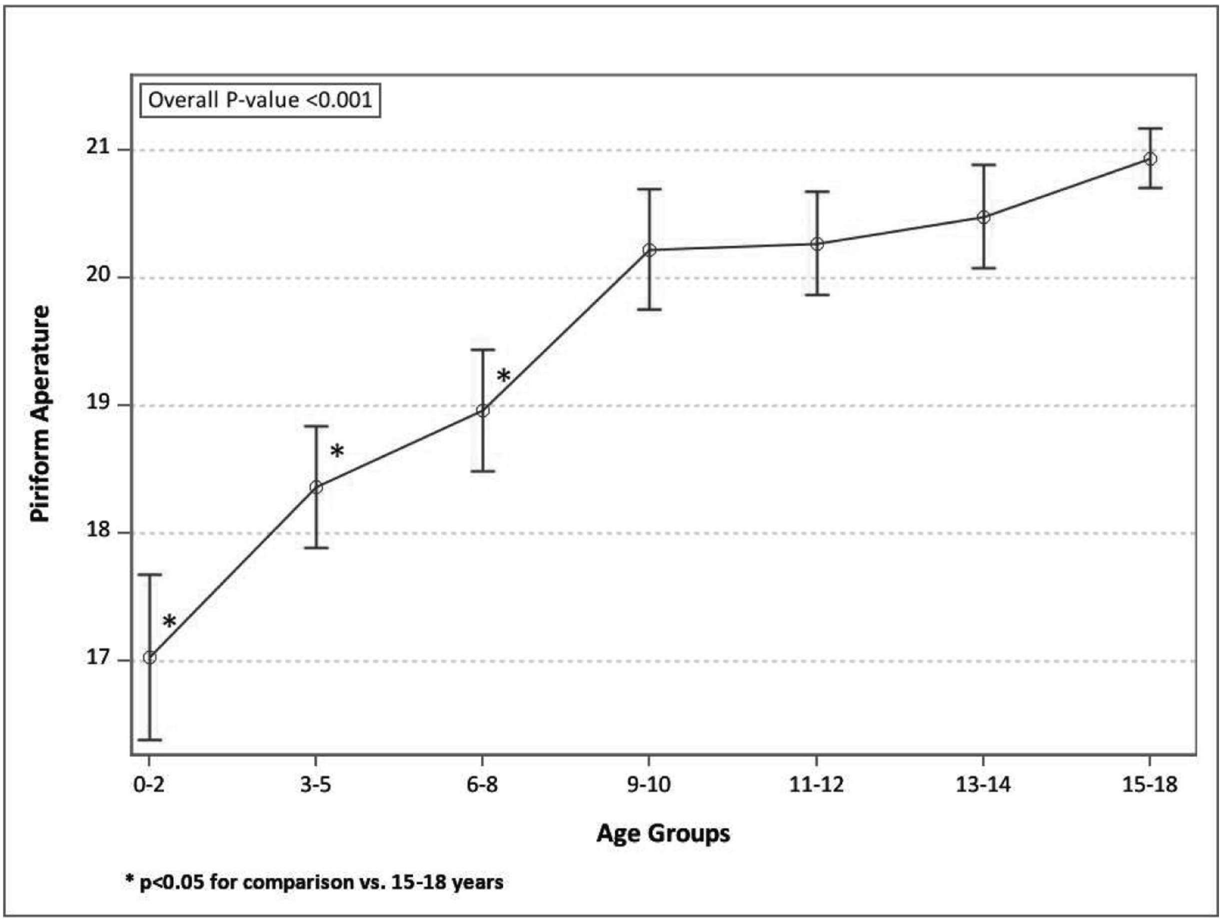

Fig. 2 Piriform aperture (mm) by age (years), The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

Table 4 Frequency table of age groups by sphenoid pneumatization type

	Sphenoid pneumotype				
	Conchal($N=103$)	Presellar($N=38$)	Sellar($N=365$)	Total($N=506$)	*p*-Value
Age groups, *n* (%)					<0.0001[a]
0–2	26 (100.0%)	0 (0.0%)	0 (0.0%)	26 (5.1%)	
3–5	44 (89.8%)	3 (6.1%)	2 (4.1%)	49 (9.7%)	
6–8	19 (38.8%)	7 (14.3%)	23 (46.9%)	49 (9.7%)	
9–10	4 (8.2%)	6 (12.2%)	39 (79.6%)	49 (9.7%)	
11–12	7 (10.4%)	4 (6.0%)	56 (83.6%)	67 (13.2%)	
13–14	1 (1.5%)	6 (9.0%)	60 (89.6%)	67 (13.2%)	
15–18	2 (1.0%)	12 (6.0%)	185 (93.0%)	199 (39.3%)	

[a]Fisher Exact *p*-value.

Olfactory Depth and Lateral Lamella Angles

The <5 years showed an olfactory depth of 2.76 ± 0.252, the >13 years age group showed an olfactory depth of 3.59 ± 0.119 ($p < 0.0001$, ►**Tables 2** and **3**). The 5 to 12 year range was 3.29 ± 0.14 which was 0.54 mm larger than the <5 year range ($p < 0.001$, ►**Table 2**, ►**Fig. 4**).

When comparing the left LC angle there was only statistically significant difference among t < 5 years (123.1 ± 3.7 degrees) and >13 years (118.1 ± 2.1) (►**Table 2**, $p < 0.05$). When comparing among the right-sided angles there was only a significant difference among <5 years (122.2 ± 3.8) and >13 years (114.5 ± 1.8), and 5 to 12 years (118.1 ± 2.2),

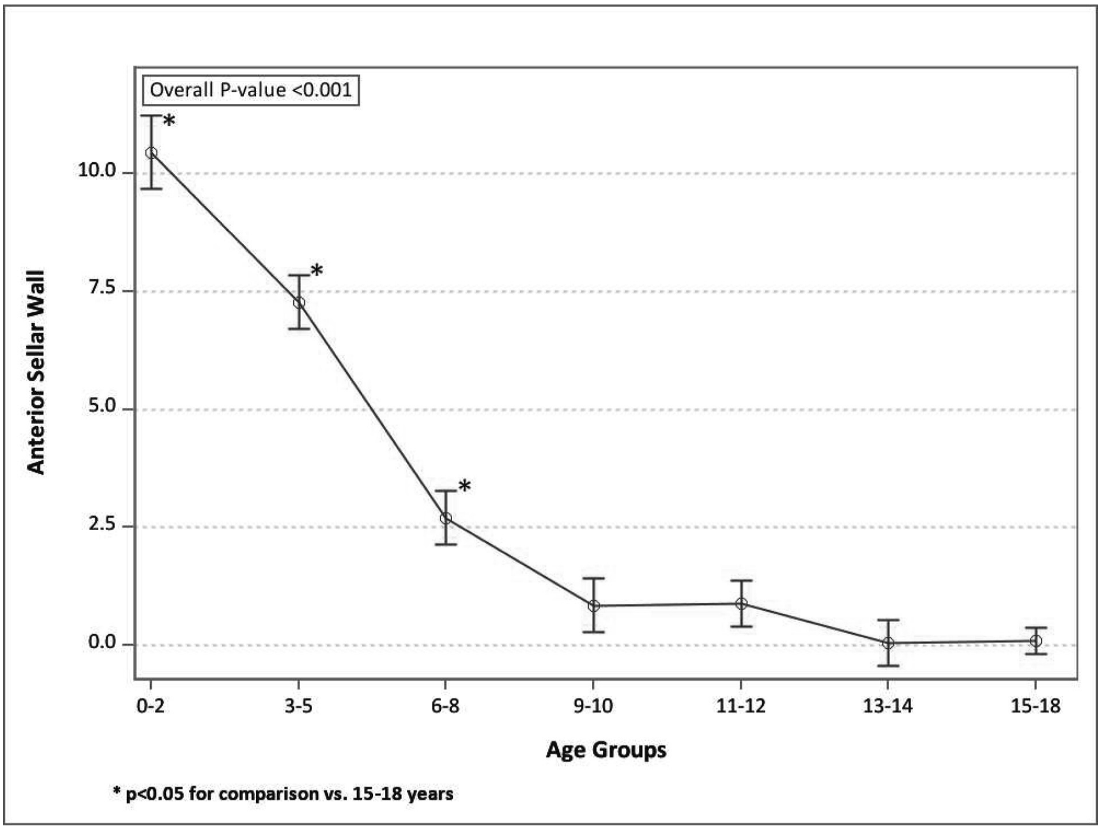

Fig. 3 Anterior sellar wall thickness (mm). The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

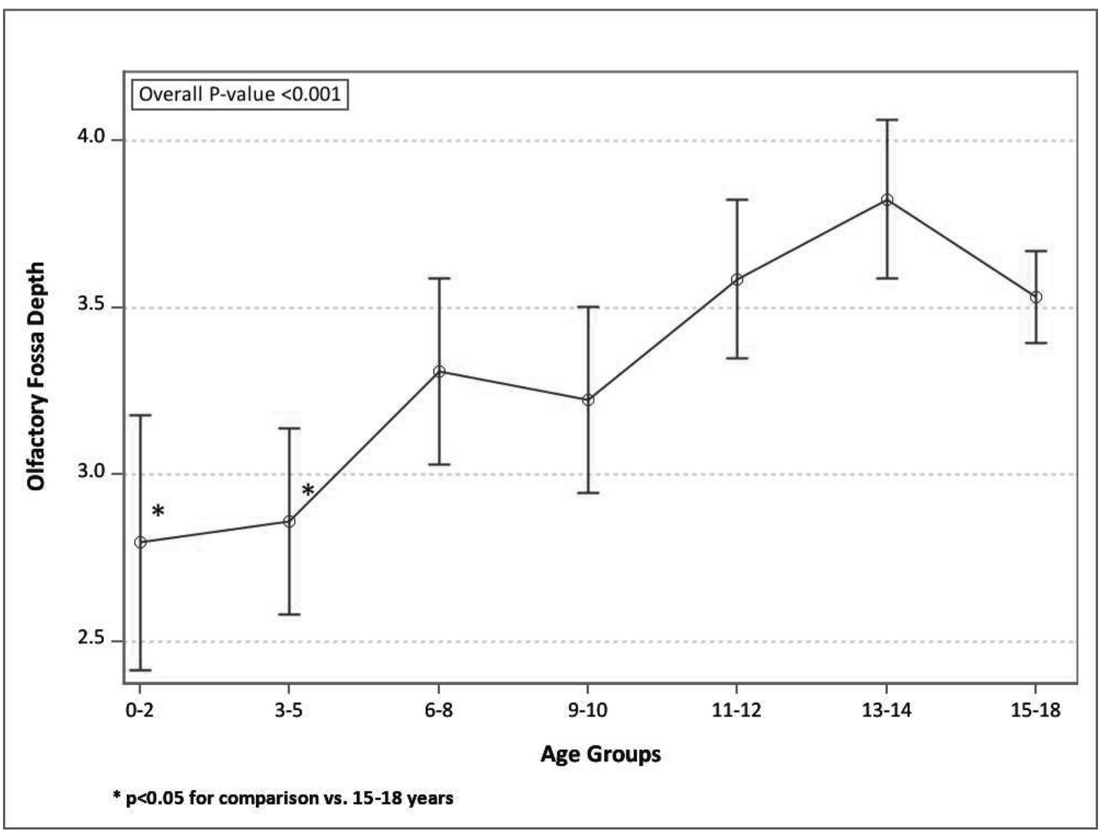

Fig. 4 Depth of olfactory fossa (mm). The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

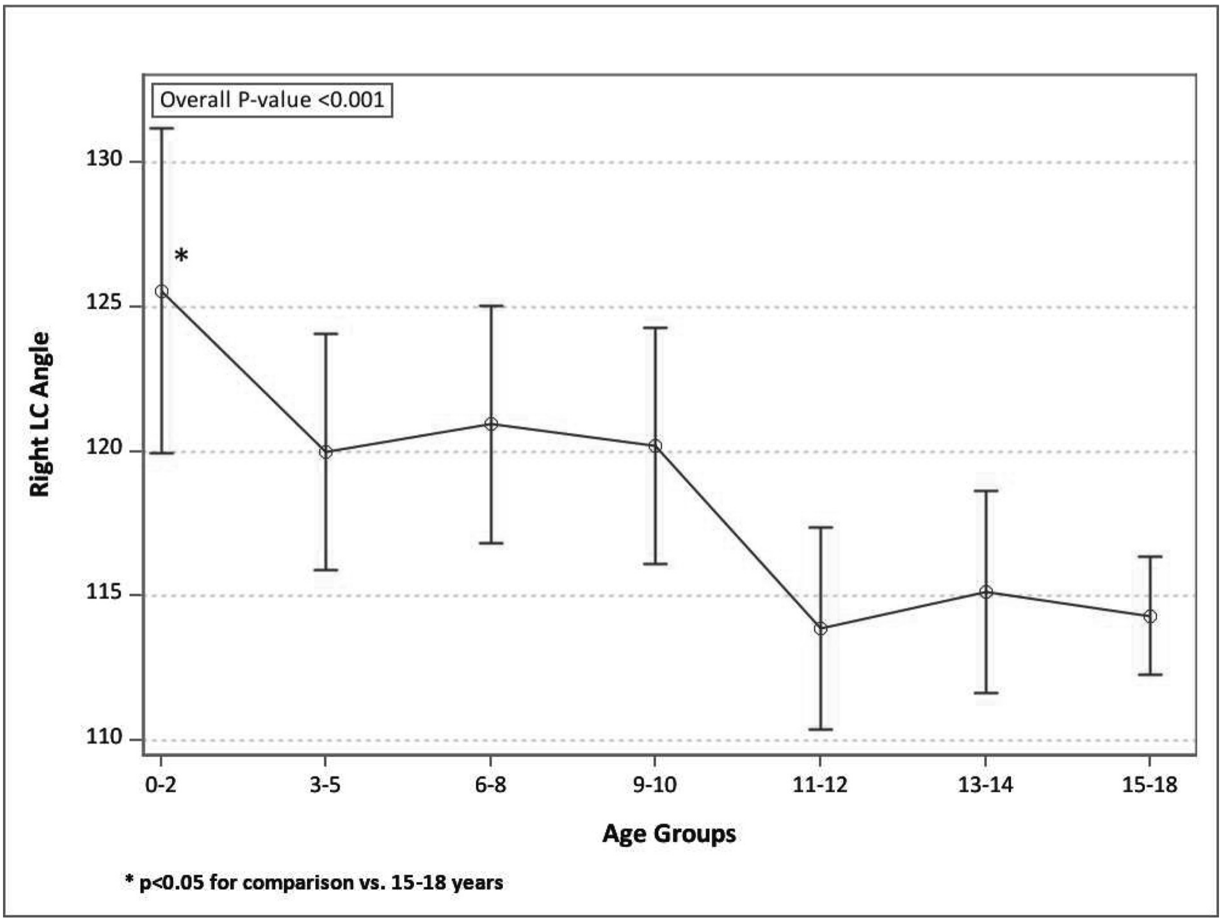

Fig. 5 Right lateral lamella cribriform angle (degrees). The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

compared with >13 years (114.5 ± 1.8), (►**Table 2**, p <0.05). As the age groups increased the data showed a decrease in angles (►**Table 3**, ►**Figs. 5** and **6**).

Intercarotid Distances

Estimated means showed that between the three age groups as age increased there was a statistically significant increase at the ICD-CS (►**Table 2**, p <0.0001). Our <5 range was 1.74 mm smaller than the 5 to 12 years (►**Table 2**). This distance increased with <5 years (9.29 ± 0.488) being 2.51 mm smaller than >13 (11.80 ± 0.23) (►**Table 3**). When looking at ICD-SC there was no similar increase as age increased. Our results did show that in our patient population <5 years and 5 to 12 year ranges were significantly different (►**Table 2**, p <0.05).

Comparison between Sexes

Females had consistently smaller measurements than males when measuring NSD 4.3 mm (p <0.001), SS width (1.98 mm, p <0.05), and OF depth measurement (0.48 mm, p <0.001) (►**Table 5**). All other measurements were non-significant between groups.

Discussion

Pediatric ESS requires more careful consideration and selection due to its narrower and relatively smaller anatomy when compared with the adult population.[9,18] As the uses of skull base procedures continue to expand in the pediatric population, the need to better understand and characterize the pediatric skull base becomes more integral. Tatreau et al previously described several potential anatomical limitations regarding endoscopic skull base surgery in pediatric patients.[13] Many other studies have sought to describe portions of the pediatric skull base all with smaller patient populations.[3,18,21,22] The aim of this paper is to describe and analyze age-related changes in the pediatric skull base in a large group of patients. This paper provides a framework for presurgical anatomical considerations for different ages in the pediatric population, provides important associations between specific measurements, and is the first paper to compare depth the of between pediatric age groups.

Piriform aperture is the first major limitation in endoscopic surgery as it constitutes a fixed bony restriction of lateral movement of surgical instruments. We wanted to determine if this width would be significantly different in

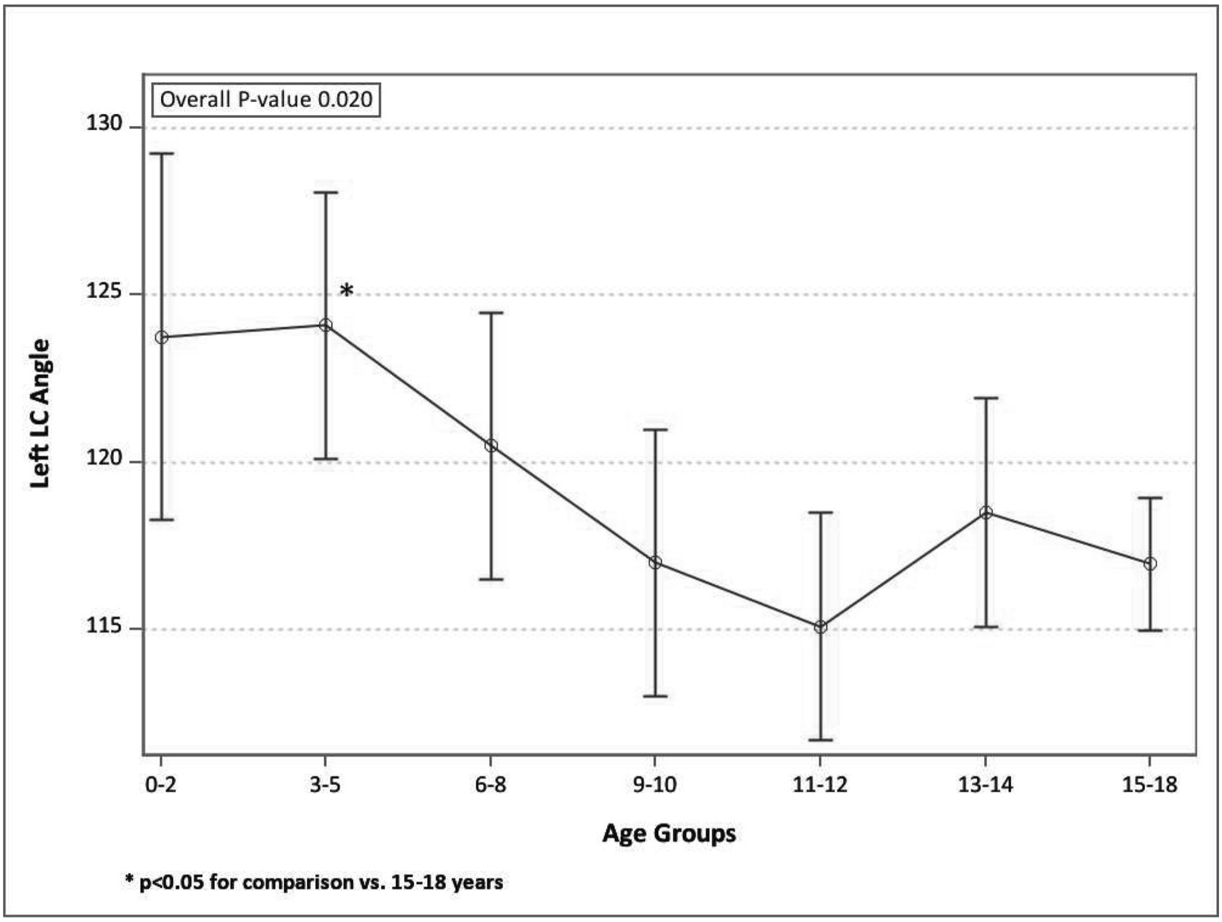

Fig. 6 Left lateral lamella cribriform angle (degrees). The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

Table 5 Model-estimated means and 95% CI for sex from each model (with three age groups in model)

Outcome	Gender	LS means	Lower CL	Upper CL	*p*-Value
Piriform aperture width (mm)	Female	19.27	19.01	19.53	0.1236
	Male	19.51	19.29	19.73	
Nare to sella (mm)	Female	68.38	67.71	69.05	<0.001[a]
	Male	72.68	72.11	73.25	
Sphenoid sinus width (mm)	Female	26.62	25.32	27.91	0.0110[a]
	Male	28.60	27.50	29.70	
Anterior sellar wall (mm)	Female	3.58	3.238	3.917	0.6080
	Male	3.68	3.395	3.970	
Olfactory fossa	Female	2.97	2.823	3.116	<0.001[a]
	Male	3.46	3.334	3.582	
Left LC angle	Female	119.4	117.2	121.5	0.8200
	Male	119.7	117.8	121.5	
Right LC angle	Female	118.2	116.0	120.4	0.9195
	Male	118.3	116.5	120.2	
Intercarotid distance cavernous sinus (mm)	Female	10.70	10.42	10.99	0.9684
	Male	10.71	10.47	10.95	
Intercarotid distance superior clivus (mm)	Female	16.06	15.73	16.38	0.1455
	Male	16.34	16.06	16.62	

[a] $p < 0.05$.

children potentially limiting lateral dissection. Small increases in the PA-w increases angular movement of instruments in the posterior nasal cavity and skull base. Our study confirms previous studies that show an increase in PA-w as age increases (►Fig. 2).[13,22]

NSD is the distance required to access the anterior most area of the sellar compartment, a key measurement point for any transsphenoidal approach around the hypophysis or surrounding lesions. Banu et al reported that through the first 12 years of life NSD had steep growth of 11.4 mm with plateauing after age 10. Additionally, Banu et al showed that NSD was sex dependent with females being 3.8 mm shorter than males.[23] Our data showed similar results, with most growth happening in the first 12 years of life and a statistically significant difference of 4.3 mm among sexes with males larger than females (►Fig. 7).

SS pneumatization is an important consideration in transsphenoidal surgery. Our results support the current literature that there is a relationship between age and pneumatization. As age progresses, pneumatization progresses through a conchal to sellar pattern.[20,26] Although lack of pneumatization is not considered a contraindication to endoscopic approaches, anterior–posterior sphenoid pneumatization can lead to more drilling increasing the risk for iatrogenic complications. ASW was measured to help determine the amount of drilling necessary to reach the cranial fossa. Tatreau et al showed that by age 6 to 7 years the anterior wall was fully pneumatized in all patients.[13] Our results are similar to Tatreau and show a majority of the pneumatization is complete by 6 to 8 years and would not need any additional drilling within the SS in the anterior posterior direction.

A wider SS allows for greater visibility and working room during endoscopic surgery. SS width was measured to determine lateral aeration which can lead to decreased drilling, better visualization, and improved instrument maneuverability. Our data agrees with previous data and shows decreased SS widths younger than 12 when compared with patients older than 12 (►Fig. 8). In addition, our results show a significant difference among sexes of approximately 2 mm. When combining both results of ASW and SS width we agree with prior authors that pneumatization is age dependent and the earliest pneumatization begins in the anterior posterior direction with gradual and later lateral pneumatization.[13,24,25]

The lateral lamella of the OF is the thinnest bone of the ethmoid roof and a potential site of skull base injury during endonasal surgery. No past literature has yet to compare the

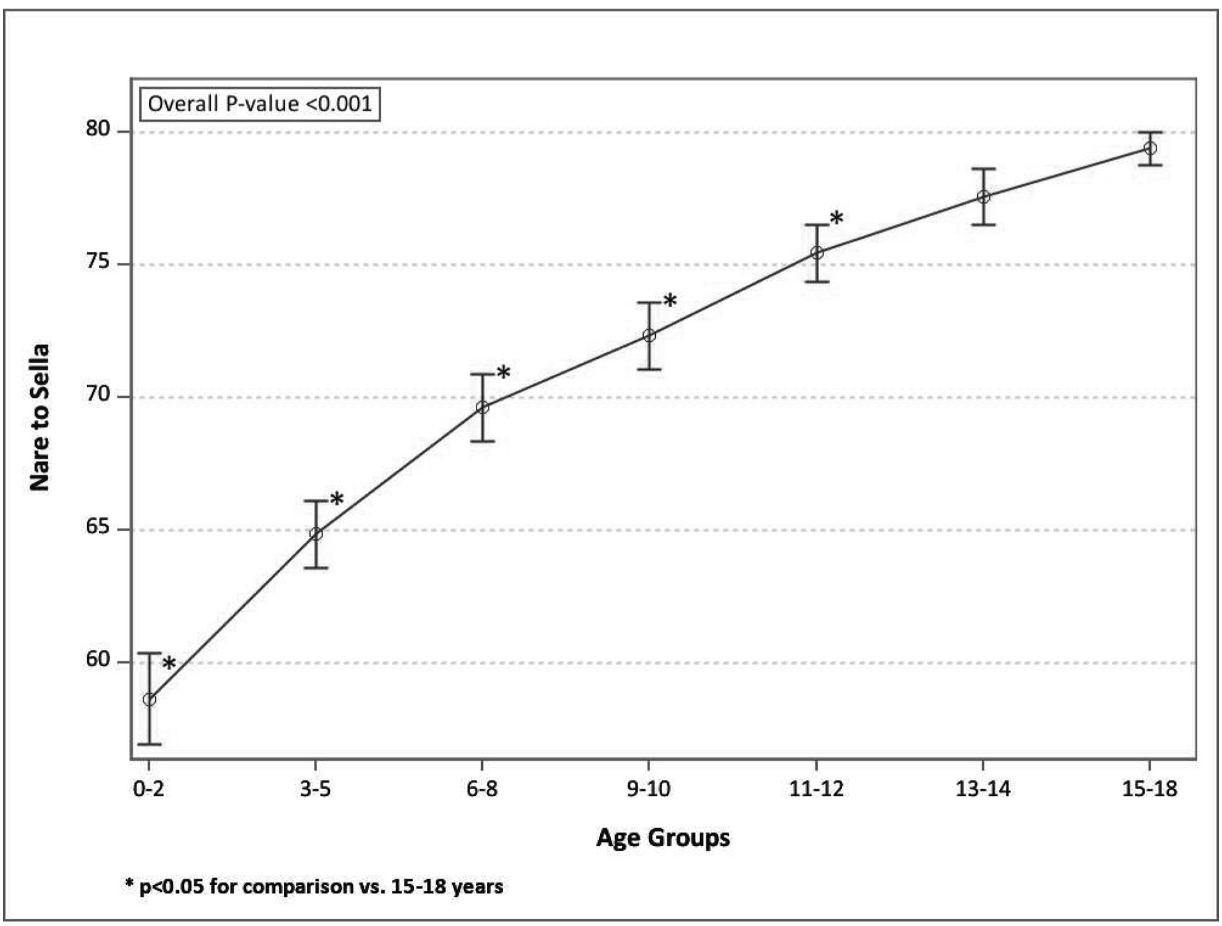

Fig. 7 Nare to sella distance (mm). The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

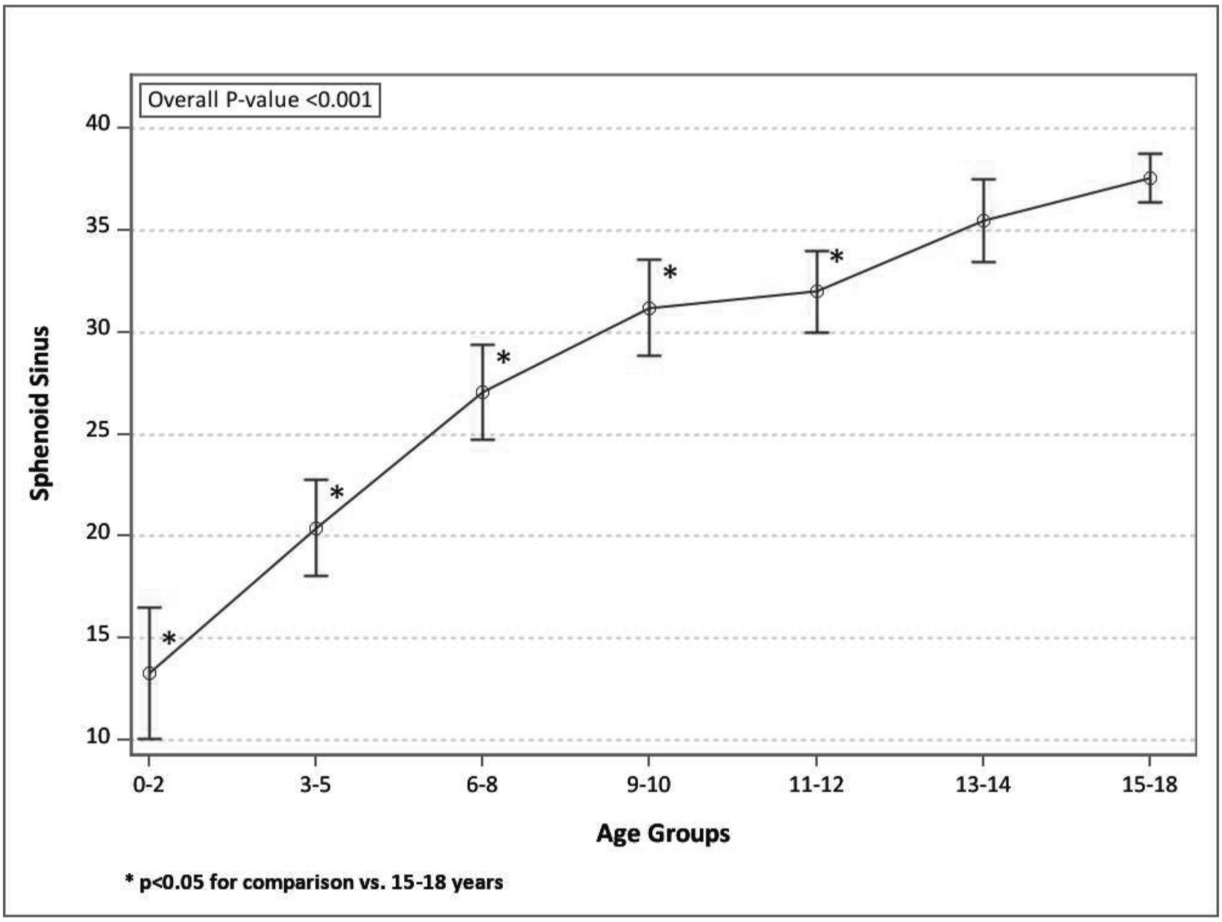

Fig. 8 Sphenoid sinus width (mm). The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

depth of the OF and lateral lamella angles in the pediatric population. The OF was measured from the cribriform plate to the fovea ethmoidalis as described by Keros.[22] Although our research shows significant differences among all age groups and sexes with respect to OF depth, the difference was found to be less than 1 mm. We believe this is not clinically significant when considering iatrogenic injury to the cribriform, as the depth and narrowness of the OF will not change greatly within that range. Asal et al reported that the relationship of lower lateral lamella cribriform plate angles with Keros III would be more dangerous during ESS because of increased risk of trauma to the lateral lamella and intracranial penetration.[26] We believe this is not clinically significant when considering iatrogenic injury to the cribriform, as the depth and narrowness of the OF will not change greatly within that range. Asal et al reported that the relationship of lower lateral lamella cribriform plate angles with Keros III would be more dangerous during ESS because of increased risk of trauma to the lateral lamella and intracranial penetration.[26] No formal analysis was performed but our data suggests a similar observation, there is hypothesis that lesser the angle of the lateral lamella, more of the skull base covered by thin bone.[27] This is important to consider in patients with low Keros scores.

The internal carotid artery typically limits the lateral limit of dissection in EES. Other papers have analyzed intercarotid artery distance at CS and SC either in a smaller patient size or in Chinese patients only.[13,18,23,28] We sought to characterize the ICD at both the SC and CS to determine if there was a significant difference among age groups. Previous literature has argued that ICD at the CS of <10 mm makes trans-sphenoidal approach disadvantageous.[29] Tatreau et al noted only in 0 to 24-month-old patients was an ICD-CS <10 mm present.[13] Other literature reports that age <5 years was an appropriate cut-off value for EEA.[4,23] Our data shows that for a large majority of patients the ICD-CS will only be greater than 10 mm after the age of 5 years (►**Fig. 9**), more than doubling the age that Tatreau et al reported. We therefore agree that the age cutoff of <5 seems to be more consistent with Kassam et al and Li et al with respect to ESS and ICD-CS.[4,23]

One may ask the practicality of analyzing these numbers, but we do feel there is a value in researching these parameters. As already discussed, understanding the dimensions and angles of the skull base and being able to compare one patients' measurements to a larger population can aid in surgical planning. It can sometimes be difficult to predict the level of difficulty in maneuvering within a pediatric nose

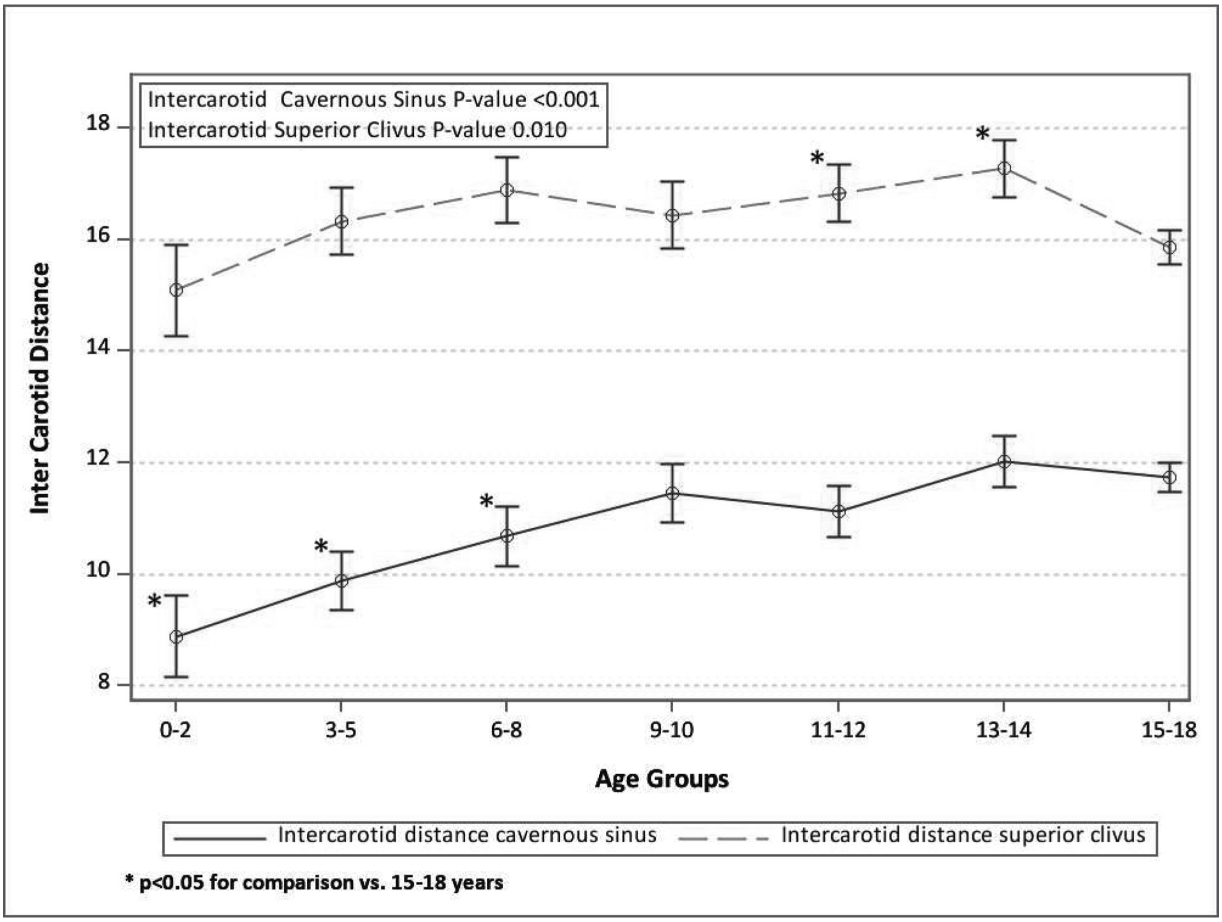

Fig. 9 Intercarotid distance (degrees) The measurement was reported as adjusted means for each patient age group in years. Error bars represent 95% confidence intervals.

based on 2D CT images. Comparing metrics to age matched averages in this paper will help the surgeon evaluate whether their current patient may have relatively more difficult corridors to navigate. Second, with expanding endonasal surgical procedures in children, there is value in developing additional training tools such as 3D models, and these numbers can lead that process. Third, some adult or traditional instrumentation is less effective in surgical procedures on a child, due to differences in lengths and angulations. This papers data can also help guide development of pediatric-specific instrumentation for improved surgical dissection.

Limitations for this study include its retrospective nature and limited sample size. Previous reports have suggested that head circumference percentile charts are not appropriately standardized for non-White populations. While there was insufficient data to evaluate this in this study, this is an important topic warranting further investigation.[30] Another topic of future interest includes looking into the specifics of gender-related skull base changes stratified by age.

Conclusion

The process of skull base development is age and gender dependent. During preoperative evaluation of pediatric patients undergoing skull base surgery, PA-w, sphenoid pneumatization, and ICD all need to be carefully reviewed. Piriform aperture width and sphenoid pneumatization are likely not a contraindication for surgery but can create challenges in surgical visualization and maneuverability in younger patients. Intercarotid artery distance can be considered a relative contraindication because of the narrow surgical anatomy in patients <5 years old. The results of this study should assist skull base surgeons in evaluation and preparation of pediatric patients of different age groups, help to develop future pediatric specific instrumentation, and build upon the existing literature in characterizing pediatric skull base anatomy.

Conflict of Interest
None declared.

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