RESEARCH

Is pneumatization of middle turbinates compensatory or congenital?

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Objective: To determine the frequency of concha bullosa (CB) and the association between the degree of pneumatization and the severity of septum deviation in both paediatric and adult groups by CT evaluation and to investigate whether the pneumatization of middle turbinates is compensatory or congenital.

Method: We retrospectively reviewed digitally stored paranasal sinus CT images of 86 paediatric and 204 adult patients. The severity of the deviation and cross-sectional area of the pneumatized area of the CB were determined using tomography images. The septums were divided into three groups according to the severity of deviation. The cross-sectional area of the contralateral side divided by the cross-sectional area of the deviation was calculated and described as the interturbinate ratio.

Results: When bilateral CB was found, the pneumatization of the CB was more prominent on the contralateral side than on the deviation side in both the paediatric and the adult groups. However, we found that the interturbinate ratios were not statistically different between the paediatric and adult groups. Also, the interturbinate ratios were independent degrees of deviation in children and adults. The frequency of CB was low in the adult group compared with the paediatric group.

Conclusion: Interturbinate ratios were not statistically different between paediatric and adult groups and were independent of the severity of deviation. These findings suggest that the pneumatization process is not compensatory.

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Introduction

Pneumatization of the turbinate skeleton is termed as concha bullosa (CB). Bullous middle turbinate (BMT) was first described by Santorinus¹ in 1739 as a mutation of the anterior part of the middle turbinate into a bubble; such pneumatization is believed to represent an anatomical variation of ethmoid air cell development, and not the result of a prior pathological intranasal process. Since the development of endoscopic techniques and CT, anatomical variations of the nose and paranasal sinuses have been found to be common and

frequent. BMT is one of the most common anatomical variations of the middle meatus.^{2,3} Pneumatization of the superior turbinates appears to be less frequent, but pneumatization of the inferior turbinates appears to be extremely rare.

Paranasal sinuses become apparent in the third and fourth fetal months and continue to undergo expansion after birth during the development of the facial cranium; they reach their final size at 12 years of age.⁴ The ethmoid bulla develops on the lateral wall of the middle meatus by 12 weeks of gestation. Anterior and middle ethmoid cells develop from the ethmoid bulla. Pneumatization of the middle turbinate occurs as part of normal development of the ethmoid labyrinth. By 32 weeks of gestation, the ostium for the development

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Figure 1 (a) The boundary of the bulla was outlined on the bone window of CT images and the corresponding area was measured in square millimetres. (b) The angle between the axis of the septum and midline was measured as the *deviation angle* using DicomWorks v. 1.3.5 software (arrowheads show bullous middle turbinates)

of the middle turbinate cell is seen in the superoinferior portion of the middle turbinate.⁵ Although the exact mechanism of pneumatization of the turbinates has not been elucidated, two discrete hypotheses related to the development of a CB were proposed by Stammberger.⁶ The first suggests that after formation of the nasal septal deviation, unfilled space “*e vacuo*” provokes the development of CB. The second suggests that septal deviation and CB are two anatomical variants found incidentally and concomitantly.

To date, several studies had been focused on the pneumatized turbinate in adults and children separately.^{2,3,7–11} However, no study has compared the pneumatization of the middle turbinate between children and adults. In this article, the characteristics of pneumatization of the middle turbinate have been studied, and the similar and different aspects of data from children and adults were compared to investigate whether pneumatization of the middle turbinate is mainly compensatory or congenital.

Material and methods

Data collection

We retrospectively reviewed paranasal sinus CT images of 204 adult and 86 consecutive paediatric patients in the Radiology Department of Sema Hospital, Istanbul, Turkey. Images were taken for evaluation of headache of unknown origin, and/or nasal obstruction. The images were stored digitally. Patients with obvious sinonasal disease or history of inferior turbinate or septal surgery were excluded from the study. The CT images were obtained using a spiral CT scanner (SOMATOM Sensation 64; Siemens Healthcase, Erlangen, Germany) at a voltage of 120 kV, current of 200 mA and X-ray beam width of 1 mm. Low-dose X-ray parameters were used for children. The region extending from the frontal sinus to the sphenoid sinus was helically scanned to obtain contiguous coronal sections at 1 mm intervals. The window width and level were controlled so as to allow visualization of the

Figure 2 Bullous middle turbinate types: (a) lamellar type, (b) bulbous type, and (c) extensive type (arrowheads show bullous middle turbinates)

Table 1 Demographic features of paediatric and adult patients

Group	Paediatric			Adult		
	Number of patients	Age range (years)	Mean age $\pm$ SD (years)	Number of patients	Age range (years)	Mean age $\pm$ SD (years)
A	33	3–16	9.5 $\pm$ 3.3	35	19–75	41.1 $\pm$ 14.1
B	34	2–17	10.9 $\pm$ 3.8	88	19–90	38.9 $\pm$ 12.6
C	19	1–18	11.9 $\pm$ 3.9	81	19–72	40.4 $\pm$ 11.9
Total	86	1–18	10.6 $\pm$ 3.7	204	19–90	39.9 $\pm$ 12.6

SD, standard deviation.

Group A, straight septum; Group B, mild deviation; Group C, moderate-to-severe deviation.

mucosal and ostial lesions. In all cases, 1 mm thick contiguous high-resolution coronal CT sections were analysed with DicomWorks (v. 1.3.5).

Assessment of patient data

In bullous turbinate cases, the boundary of the bulla was outlined on bone window (window width: 1500, window length: 300) CT images and the corresponding area was measured in square millimeters using DicomWorks v. 1.3.5 software (Figure 1a). All data from patients were assessed by both an otolaryngologist and a radiologist. The angle between the axis of the septum and the midline was accepted as the *deviation angle* (Figure 1b). The cases were classified into three groups according to the septal deviation angle: Group A, straight or nearly straight septum with deviation angle smaller than 3°; Group B, mild deviation with deviation angle between 3° and 10°; and Group C, moderate to severe deviation with deviation angle higher than 10°.

BMTs were classified into three types according to the shape of the bullous change:¹ lamellar BMT was defined as pneumatization of the vertical lamella of the middle turbinate (Figure 2a); bulbous BMT was defined as pneumatization of the inferior or bulbous segment of the turbinate (Figure 2b); and extensive BMT was defined as pneumatization of both the vertical lamella and the inferior part or bulbous portion of the middle turbinate (Figure 2c). All cases were classified by category with the consensus of an otolaryngologist and a radiologist.

The cross-sectional area of the bullous part of BMT on each side of the septum was measured. The cross-sectional area of the contralateral side was divided by the cross-sectional area of the deviation side, and the resulting ratio was named the *interturbinate ratio* and calculated only for bilateral bullous turbinate cases.

Statistical analysis: All results were expressed as mean $\pm$ standard deviation. The data were analysed with SPSS® software, v. 11.0 (SPSS Inc., Chicago, IL). To compare the calculated ratios, one-way analysis of variance (ANOVA) and Tukey multiple comparisons, the independent-samples *t* test and the χ^2 test were performed. A probability value of $p < 0.05$ was considered statistically significant.

Ethical considerations

Permission was obtained from the local ethics committee of our institution to review the patients' medical charts and CT images from the picture archiving and communication system.

Results

Paranasal sinus CT images of 86 paediatric and 204 adult patients were included in this study. Demographic features of the paediatric and adult groups are summarized in Table 1.

Table 2 Frequency and localization of bullous middle turbinates according to the severity of septal deviation in children and adults

Group	Localization of bullous turbinate	Paediatric		Adult	
		Number of patients	%	Number of patients	%
A	CB absent	12	36.4	18	51.4
	Unilateral	5	15.2	5	14.3
	Bilateral	16	48.5	12	34.3
B	CB absent	12	35.3	30	34.1
	Unilateral				
	Deviation side	2	5.9	1	1.1
	Contralateral side	8	23.5	20	22.7
	Bilateral	12	35.3	37	42
C	CB absent	7	36.9	45	55.5
	Unilateral				
	Deviation side	0	0	0	0
	Counter side	5	26.2	17	20.9
	Bilateral	7	36.9	19	23.4
Total		86		204	

CB, concha bullosa.

Group A, straight septum; Group B, mild deviation; Group C, moderate-to-severe deviation.

Table 3 Frequency of each type of bullous middle turbinate according to the severity of septal deviation in children and adults

Group	Number of each type of bullous turbinate					
	Paediatric			Adult		
	Lamellar	Bulbous	Extensive	Lamellar	Bulbous	Extensive
A	20	2	15	10	5	14
B	26	1	7	59	2	34
C	10	4	5	33	6	16
Total	56 (62.2%)	7 (7.8%)	27 (30.0%)	102 (56.9%)	13 (7.2%)	64 (35.8%)

Group A, straight septum; Group B, mild deviation; Group C, moderate to severe deviation.

The χ^2 test was used for comparison of types of bullous middle turbinate between children and adults ($p > 0.05$).

Frequencies and localization of BMT in paediatric and adult patients according to each deviation group are summarized in Table 2. In Groups A and C, the frequency of BMT was higher in children than in adults but almost equal in Group B. The frequencies of the BMT were 64%, 65% and 63% in Groups A, B and C, respectively, in children, and 50%, 66% and 45% in Groups A, B and C, respectively, in adults. In unilateral BMT cases the frequency of each type of BMT was higher in the contralateral side than the deviation side in children and adults (Table 2). Frequencies of each type of BMT according to the severity of septal deviation in children and adults are summarized in Table 3. Among the BMT types, the frequency of the *lamellar* type of BMT was highest, and the frequency of the *bulbous* type was lowest in both paediatric and adult patients. In the paediatric group, the frequency of the extensive type of BMT was higher than in the adult group, but the difference was not statistically significant (χ^2 test, $p > 0.05$) (Table 3 and Figure 3).

The interturbinate ratios for bilateral bullous turbinate cases in the paediatric and adult groups are summarized in Table 4. When compared, the interturbinate ratios were not statistically different in both the paediatric and the adult groups (the mean $\pm$ standard deviation of interturbinate ratios were 1.99 ± 1.56 in children and 1.86 ± 2.17 in adults). Interturbinate ratios were not affected by the severity of deviation in both children and adults (Table 4, Figure 4).

Figure 3 The percentage of turbinate types in 86 children and 204 adults

Discussion

The paranasal or accessory sinuses of the nose begin their development as evaginations of the mucosa during the third and fourth fetal months, and continue to undergo expansion after birth during the development of the facial cranium and teeth. The first accessory sinus to develop is the ethmoidal labyrinth.^{5,8} Ethmoid sinus budding can be detected at 11–12 gestational weeks.¹² The ethmoidal labyrinth forms two recesses: the ethmoidofrontal and the ethmoidomaxillary. These recesses expand to the frontal bone and the maxilla. Then they subsequently excavate these bones and in this way give rise to the frontal and maxillary sinuses. By the age of 12 years, the ethmoid sinus has almost reached adult proportions. Pneumatization of the body of the sphenoid bone starts last.⁷

The precursor structures of nasal turbinates (the ethmoturbinal and maxilloturbinal) appear between the eighth and tenth weeks of fetal life. The maxilloturbinal gives rise to the inferior nasal turbinate, whereas the ethmoturbinal gives rise to the uncinate process, middle turbinate, superior turbinate and, where present, supreme turbinate.¹³ The middle concha is formed by the medial part of the ethmoid bone. Pneumatization of the middle concha is an extension of normal pneumatization of ethmoid air cells.^{2,10,14}

According to Lothrop,¹⁵ in approximately 55% of cases of middle turbinate pneumatization, anterior ethmoid cells originating from the middle meatus region have been found to pneumatize the turbinate. Posterior ethmoid cells, originated from the superior meatus, are responsible for pneumatization in 45% of cases.

Theories for pneumatization of turbinates

Pneumatization of the middle and superior turbinates according to anatomical definition occurs in the bony structures of the ethmoid complex. Because the middle turbinate is part of the ethmoid complex, CB is typically seen in patients with a highly pneumatized ethmoid sinus.¹⁶ The process of pneumatization of the ethmoid cells and secondary sinuses is considered an active achievement of the nasal mucosa (to be precise, of the ectodermal Schneiderian membrane).³ For the middle turbinate, it has been well demonstrated that pneumatization can originate from the middle nasal

Table 4 Interturbinate ratios for bilateral bulbous middle turbinate cases in each deviation group for children and adults

Group	Paediatric			Adult			p-value	t-value
	Number of bilateral BMT cases	Range of interturbinate ratio	Mean interturbinate ratio $\pm$ SD	Number of bilateral BMT cases	Range of interturbinate ratio	Mean interturbinate ratio $\pm$ SD		
A	16	1.07–7.4	2.33 $\pm$ 1.84	12	0.89–2.7	1.31 $\pm$ 0.47	>0.05	–1.848
B	11	0.36–4.05	1.64 $\pm$ 1.17	37	0.13–6.33	1.7 $\pm$ 1.31	>0.05	0.215
C	6	0.14–3.64	1.71 $\pm$ 1.56	19	0.22–16.5	2.51 $\pm$ 3.74	>0.05	0.451
Total	33	0.14–7.4	1.99 $\pm$ 1.56	68	0.13–16.5	1.86 $\pm$ 2.17	>0.05	–0.298

SD, standard deviation.
Group A, straight septum; Group B, mild deviation; Group C, moderate-to-severe deviation.
The interturbinate ratios were not statistically different in the paediatric age group and in the adult group (independent-samples *t*-test).
In the interturbinate ratios, there was no statistically significant difference according to the severity of deviation in both children and adults (one-way analysis of variance; *F*-values were 1.283 and 0.779, respectively).

meatus *per se*, the frontal recess, the suprabullar or retrobullar recess (former terminology, lateral sinus) and, rarely, from the ethmoid infundibulum or even the agger nasi region. Pneumatization of the middle turbinate (if it occurs) and the ethmoid sinuses continues to grow during childhood and adolescence. The occurrence of CB and its enlargement thereafter may be determined by genetic or non-genetic factors. It is a common belief that when septal deviation and bilateral CB are present, middle turbinate pneumatization is more prominent on the contralateral side than on the deviation side. Therefore, pneumatization on the contralateral side is frequently termed as *compensatory*. But how accurate is this terminology? Whether the development of CB has a congenital origin or develops through a compensatory mechanism has not been exactly elucidated yet. Two discrete hypotheses related to the development of CB were proposed. The first one favours the compensatory theory and suggests that after the formation of the nasal septal deviation unfilled space *e vacuo* provokes the development of CB. The second one, the congenital theory, suggests that septal deviation and CB are two anatomical variants found incidentally and concomitantly.⁶

Chaiyasate et al¹⁷ studied anatomical variations in the paranasal sinuses of twins to find out if these variations are the result of genetic or environmental influences. In their monozygotic twin group, the presence or absence of CB had an intrapair similarity of 70%, whereas this ratio was 25% in dizygotic twin group. The higher CB similarity ratios in monozygotic than in dizygotic twins suggests a genetic (congenital) influence. These data suggest that genetic (congenital) factors may have an influence on the pneumatization process. They also came to the conclusion that paranasal sinus pneumatization, septal contour and the depth of the olfactory fossa were possibly influenced by genetic factors.

Comparisons with other studies

There are many studies on the incidence of BMT types in the adult population. In previous studies,^{2,9,11} the frequency of the lamellar, bulbous and extensive types of BMT had been reported to range from 45.0% to 52.4% (47.9 $\pm$ 3.9), 21.0% to 33.3% (28.5 $\pm$ 6.6) and 14.3% to 34.0% (21.3 $\pm$ 11.0), respectively, in adults. In our study, the lamellar type was 56.9%, the bulbous type was 7.2%, and the extensive type was 35.8%. Such wide discrepancy in the reported prevalence of middle turbinate pneumatization may be owing to factors such as inherent differences in study populations, differences in criteria for pneumatization and sensitivity of the method of analysis.¹³ Our findings were compatible with literature findings of other less frequent bulbous types of BMT. We could not find any data related to the frequency of BMT types in children. In our study, among the BMTs, the lamellar type was 62.2%, the bulbous type was 7.8%, and the extensive type was 30.8% in children (Table 2).

Figure 4 The mean *interturbinate ratios* for bilateral bullous middle turbinate cases in each deviation group for (a) children and (b) adults. Group A, straight septum; Group B, mild deviation; Group C, moderate-to-severe deviation. The interturbinate ratios were not statistically different in the paediatric age group and in the adult group (independent-samples *t*-test). In interturbinate ratios, there was no statistically significant difference according to severity of deviation in both children and adults (one-way analysis of variance; *F*-values were 1.283 and 0.779, respectively)

The incidence of CB frequency varies from 4.2% to 58.0% in children^{8,18,19} and from 14.0% to 80.0% in adults.^{2,9–12} In our study, the incidence of BMT was 63.9% and 54.4% in children and adults, respectively. Pneumatization of ethmoid cells and secondary sinuses is considered an active achievement of nasal and sinus mucosa during fetal development and adolescence. Because the pneumatization process is a dynamic one, pneumatized nose structures may be explained by varying features during the development period. Therefore, the high incidence of BMT in children compared with adults in this study may be explained by the continuing development process of the nose and paranasal sinuses throughout adolescence.

Calhoun *et al*²⁰ and Unlü *et al*⁹ reported no statistically significant association between a CB and septal deviation on the opposite site. Uygur *et al*¹¹ proposed that deviation does not cause CB formation but augments the pneumatization of pre-existing CB in the contralateral side with respect to deviation. According to our study, the pneumatization of the concha was more prominent on the contralateral side than on the deviation side when bilateral BMT was found in both children and adults. Our study has two main results. First, interturbinate ratios were independent of the severity of deviation in both children and adults (one-way ANOVA). Second, when *each deviation group* (straight septum group, mild deviation group and moderate-to-severe deviation group) was taken into

consideration separately, the *interturbinate ratios* were not statistically different in children and adults (independent-samples *t*-test) (Table 4). Our findings are not consistent with the compensatory theory. According to the compensatory theory, after formation of the nasal septal deviation, unfilled space *e vacuo* provokes the development of CB.⁶ This theory suggests that, as the deviation increases, the concha in the contralateral side would be greater in size as a result of the compensatory pneumatization process. As is known, the compensatory process takes several years. If the compensatory theory is valid, then (1) as the deviation degree increases, the middle turbinate pneumatization in the contralateral side should increase and the *interturbinate ratio* should be higher proportionally; (2) a longer period for the compensatory process is more probable in adults than in children with septal deviation. That is why middle turbinate pneumatization in the contralateral side should increase and the *interturbinate ratio* should be higher in adults than children. However, our findings indicate just the opposite. We found similar *interturbinate ratios* in children and adults and we also observed that the *interturbinate ratios* were independent of the severity of deviation.

In conclusion, according to our study, the degree of pneumatization in the contralateral side to the deviation was independent of age and severity of deviation; therefore, our findings suggest that pneumatization is not a compensatory process and may be of genetic origin.

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