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The Pneumatization and Adjacent Structure of the Posterior Superior Maxillary Sinus and Its Effect on Nasal Cavity Morphology

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Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: The aim of this study was to observe the pneumatization degree and adjacent structure of the posterior superior maxillary sinus (PSMS) and its effect on nasal cavity morphology.

Material/Methods: The study included a total of 103 cases whose paranasal sinus CT scans had been analyzed. The pneumatization of the PSMS and its relationship with posterior ethmoid sinus (PEs) and sphenoid sinus (SS) were observed. The effects of the pneumatization of PSMS on nasal cavity width and morphology also were evaluated.

Results: 1) The PSMS was adjacent to orbit or middle nasal meatus (MNM) as type I in 5.82% of cases. The PSMS was adjacent to the orbit and superior nasal meatus (SNM) as follows: the superior part of medial wall of maxillary sinus (MMS) was not abutting on PEs as type II (4.35%) and abutting on PEs as type III (85.9%). If the type III was not accompanied by MMS shift toward medial it was identified as type IIIa (33.50%), and if it was accompanied MMS shift toward medial, it was identified as type IIIb (45.63%). The ethmomaxillary sinus (EMS) was identified as type IIIc (6.80%). The PSMS directly abutted on the SS as type IV in (3.88%). 2) The higher the degree of the pneumatization of PSMS was, the narrower the width of the upper part of the posterior nasal cavity (p<0.05 respectively).

Conclusions: The relationship of PSMS with the orbit, SNM, PEs, and SS should be identified pre-operation; it is important for safety and complete removal of retromaxillary lesions during endoscopic sinus surgery. The pneumatization degree of PSMS also should be considered as it can influence the morphology of posterior nasal cavity.

MeSH Keywords: **Endoscopy • Ethmoid Sinus • Maxillary Sinus • Nasal Cavity**

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Background

Understanding the anatomy of nasal sinuses and its variation is the premise of safe and effective endoscopic sinus surgery (ESS). Preoperative identification and intraoperative localization of the anatomic variations of the nasal sinuses is the key to successful ESS. Considerations include the identification of agger nasi cells, infraorbital ethmoid cells (Haller's cell), and sphenoethmoid cells (Onodi's cells); the variations of uncinate process; the level difference between cribriform plate and ethmoid roof [1,2], which will help in the safe and effective removal of lesions. Similarly, there are many variations in the maxillary sinus (MS) [3]. The posterior superior part of maxillary sinus (PSMS) can extended to the palate bone from the palate bone recess [4], which has a number of variations with regards to the orbit, posterior ethmoidal sinus (PEs), and sphenoid sinus (SS) [5].

In addition, residual lesions in the anterior ethmoidal sinus and posterior ethmoidal sinus after ESS have been reported widely during revision functional endoscopic sinus surgery [6]. The common anatomic factor associated with primary surgery failure was incomplete anterior ethmoidectomy (64%), and incomplete posterior ethmoidectomy (41%) [7], which may be related to the lack of awareness of the anatomical variations between PSMS and posterior ethmoidal cells [5]. However, there is little literature that focuses on anatomical variations. Our present study investigated the anatomical features and adjacent structures of PSMS, focusing on the relationship between PSMS and superior nasal meatus (SNM), PEs, and SS, with the goal of providing an image anatomy basis for completely clearing the lesion in the PEs.

It is well known that the anatomic width of the nasal cavity is related to the nasal ventilation function. Nasal cavity ventilation expansion surgery has become one of the effective methods for the treatment of obstructive sleep apnea syndrome (OSAS) for patients with nasal obstruction [7,8]. There are many considerations in the operation of the nasal cavity ventilation expansion including septoplasty, medial displacement and fixation of the middle turbinate (MT), and lateral displacement and fixation of the inferior turbinate (IT). However, previous literature does not report on the treatment of the posterior nasal cavity. Moreover, a great deal of literature has paid attention to the effect of the width of the anterior nasal cavity on nasal ventilation [9]. Few scholars have paid attention to the width of the posterior nasal cavity. In our study, in order to observe the effect of the pneumatized degree of PSMS on the morphology of the posterior nasal cavity, the width of the upper part and inferior part of the posterior nasal cavity also was also measured in different kinds of pneumatization of PSMS. In the present study, another objective was to help improve the understanding of the developmental and anatomical foundation for nasal obstruction or snoring in patients, and also to help choose the most suitable operation strategy for nasal cavity ventilation expansion surgery.

Material and Methods

Study design

We conducted a retrospective analysis of paranasal sinus computed tomography (CT) scans that were obtained for adult outpatients encountered in our hospital during March 2012 and December 2012. The CT scans were performed at the Radiological Department, Beijing Chaoyang Hospital, Capital Medical University. A total of 103 cases (206 sides) included 54 males (age 18 to 69 years old, mean age=35.6 years, SD=15.2) and 49 females (18 to 63 years old, mean age=35.8 years, SD=13.3) whose paranasal sinus CT, respectively. Enrollment criteria included: 1) no head and sinus injury history; 2) no history of sinonasal surgery; 3) no history of paranasal sinus neoplasms; and 4) age older than 18 years. On the contrary, if the patient had a history of sinus surgery, sinus trauma, or sinus tumor they were excluded. If a CT scan showed that a patient had sinonasal neoplasms, invasive fungal sinusitis, or craniofacial abnormalities, that patient was also excluded.

CT examination and analysis

The CT scanning range was from the superior margin of the frontal sinuses to the inferior margin of the maxillary alveolar process using LightSpeed GE 64-slice spiral CT (USA) by bone imaging algorithm. CT scans were obtained at: 0.625 mm section thickness, 0.5 mm interval, 120 to 320 mA, 120 kV. Viewing and measuring was by image system. In this study, the pneumatized posterior superior part of maxillary sinus (PSMS) was observed at all the planes with the horizontal portions of MT, mainly in the coronal plane (Figure 1).

Determination standard of ethmomaxillary sinus (EMS)

The diagnosis of ethmomaxillary sinus (EMS) was made when there were posterior ethmoidal cells occupying the superior part of the maxillary sinus (MS) while draining to the superior meatus. The location was between the posterior part of the MS and the orbital floor [10–12] (Figure 2E).

The measurement of nasal cavity width and the evaluation of the shift of the medial wall of MS

The measurement of nasal cavity width and the evaluation of the shift of the medial wall of MS (MMS) were observed in the coronal plane before the greater palatine nerve canal pass-through. The pneumatization of MMS toward medial and

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beyond the sagittal plane with the greater palatine nerve pass-through, and then the MMS shifting toward medial were identified (line M in Figure 2C–2F).

In order to evaluate the effect of different pneumatization of PSMS on nasal cavity width, the width of the nasal cavity was measured. The posterior nasal cavity width in attachment point of the MT and attachment point of the IT was measured as the evaluating indicator. In the present study observations, the

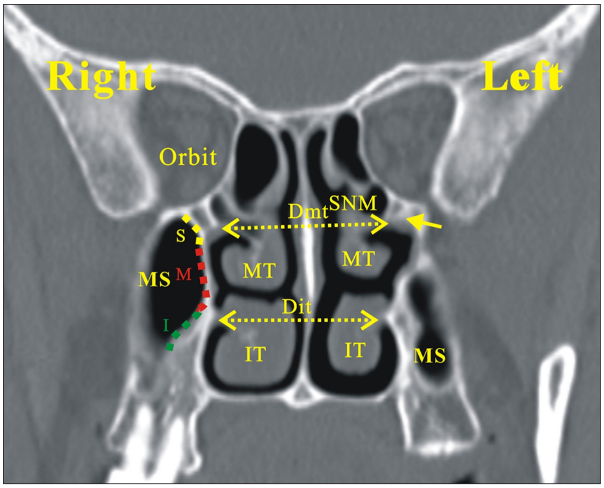

Figure 1. Figure 1 shows the attachment point of the horizontal portions of MT and the width of the posterior nasal cavity. In the left of the coronal plane, the MT attach between the orbit and MS (arrow). The MMS have only M section and I section, and the S section does not appear. In the right of the coronal plane, MMS was divided into three parts. S section was between the LP and attachment point of MT. M section was between MT and IT. I section was between IT and nasal floor. Figure 1 also shows that the distance between the MT roots (Dmt) were measured as index of the posterior superior part of nasal cavity width. The distances between the IT roots (Dit) were measured as index of the posterior inferior part of nasal cavity width.

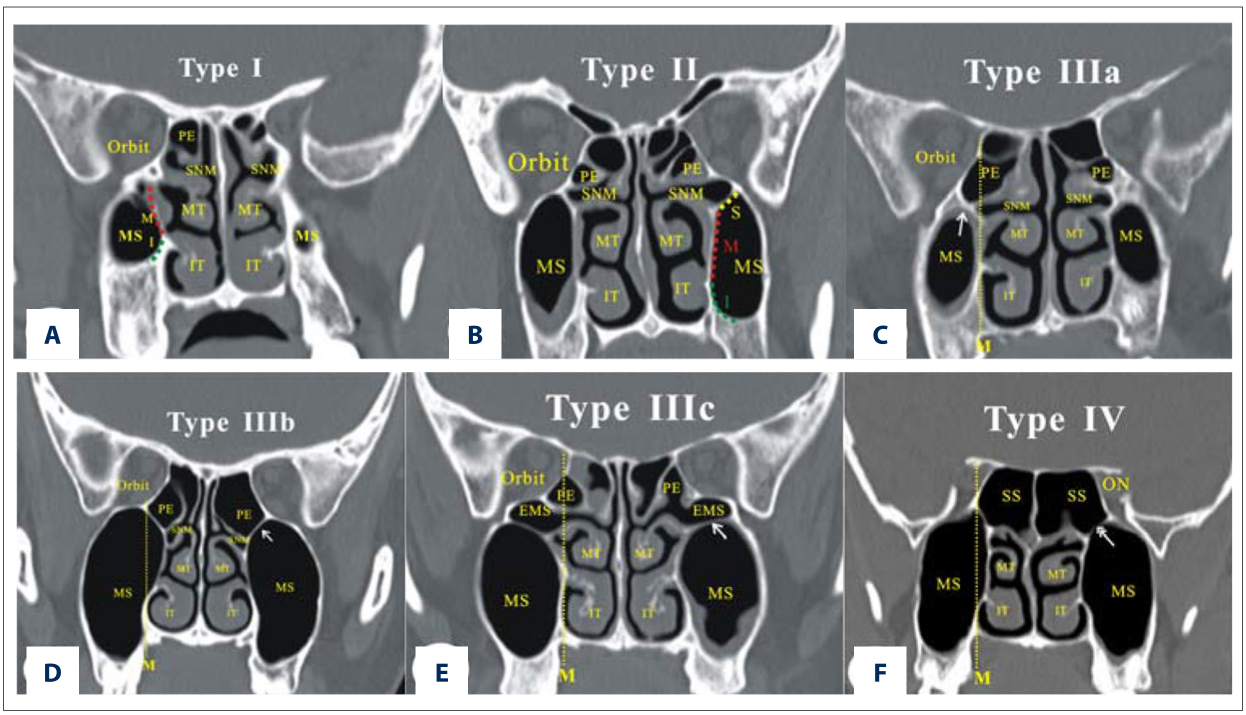

Figure 2. CT scan shows the pneumatized types and adjacent structure of PSMS. (**A**) Shows that the MT root was attached in the inferior-medial wall. The PSMS was only adjacent to the orbit. S section of MMS was not appeared (type I). (**B**) Shows that the MT roots were attached in the MMS. The PSMS was adjacent to the orbit and SNM, and not conjoined with PEs (type II). (**C**) Show that the superior part (S section) of MMS was abutting on PEs. The PSMS was adjacent to the orbit, PEs and SNM. In the same time, MMS did not shift toward medial (type IIIa). (**D**) Show that S section was abutting on PEs. The PSMS was adjacent to the orbit, PEs and SNM. In the same time, MMS shift toward medial (type IIIb). (**E**) Show that the ethmomaxillary sinus (EMS) was identified appeared. (**F**) Show that the sphenomaxillary plate (SMP) was appeared. S section was represented the superior part of MMS. M section was represented the middle part of MMS. I section was represented the inferior part of MMS was. MS – maxillary sinus; SS – sphenoid sinus; SNM – superior nasal meatus; the white arrow was indicate the ethmomaxillary plate; the double white arrow was indicate the SMP.

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Table 1. The types of PSMS adjacent structure.

Type	Adjacent structure		Accompany structure in subtypes	Prevalence	
Type I	Orbit or MNM			5.82%	(12/206)
Type II	Orbit+SNM			4.35%	(9/206)
Type III	Orbit+SNM+PEs	Type IIIa	EMP without the MMS shifting toward medial	33.50%	(69/206)
	Orbit+SNM+PEs	Type IIIb	EMP with the MMS shifting toward medial	45.63%	(94/206)
	EMS	Type IIIc	EMP only with EMS	6.80%	(14/206)
Type IV	Orbit+SNM+PEs+SS		SMP (Type III b+SS)	3.88%	(8/206)

MNM – middle nasal meatus; SNM – superior nasal meatus; PEs – posterior ethmoid sinus; MMS – medial wall of maxillary sinus; SS – sphenoid sinus; EMS – ethmomaxillary sinus; EMP – ethmomaxillary plate; SMP – sphenomaxillary plate.

distance of the MT roots between two sides were measured as index of the width of the superior part of the posterior nasal cavity. The distances of the inferior turbinate root between two sides were measured as index of the width of the inferior part of the posterior nasal cavity (Figure 1).

However, the distance between two sides of the MT may be varied in the different coronal planes because of the variation of pneumatization of PSMS, so determining the measuring point is important. In this paper, the measuring point was identified in the coronal plane before the greater palatine nerve pass-through.

Statistical analyses

The averaged data for the width of the posterior nasal cavity was measured and presented as the mean ± standard deviation (SD).The differences between the upper part (between the attachment point of the MT) and inferior part of the posterior nasal cavity width (between the attachment point of the IT) in the same group were evaluated using the paired *t*-test, with significance defined as a *p* value of 0.05. Furthermore, differences of the width of the nasal cavity in different pneumatization groups of PSMS were evaluated by analysis of variance (ANOVA). Post hoc tests used the Fisher's least significant difference (LSD), with significance defined as a *p* value of 0.05. All statistical analyses were performed with the SPSS Package, version 17 (SPSS, Chicago, IL, USA).

Result

The types of PSMS adjacent structure

In order to conveniently explain the adjacent structure of the PSMS, the medial wall of maxillary sinus (MMS) was divided into three parts from the lamina papyracea (LP) to the nasal floor by attachment point of the MT and the IT. The superior part of MMS (S section) was between the LP and attachment point of the MT. The middle part of MMS (M section) was between the middle and inferior turbinate attachment point. The inferior part of MMS (I section) was between IT attachment point and nasal floor (Figure 1).

The horizontal portions of MT first attached in the LP, and then run toward the posterior and inferior. The attachment point of the horizontal part of MT may change with the observation plane, which was observed in the coronal plane series in this study. We found that the attachment point of the MT horizontal part had variation because of the pneumatization of PSMS. In most cases, the horizontal portions of MT passed through the MMS (94.18%) (Figure 2 type II, III, and IV). However, in a few cases, the pneumatization of PSMS was insufficient, and did not reach the attachment site of MT. The MMS did not contact directly with the MT. The MT was attached in the inferior- medial wall of the orbit or between orbit and MS (5.82%). In this situation, the S section of MMS did not appear, and MMS had only M section and I section (Figure 1). This variation above will lead to adjacent structures of PSMS showing the great difference.

Furthermore, the extension of PSMS toward the palatine bone and posterior ethmoid sinus may lead to the MMS shift toward medial and morphologic change of the nasal cavity, based on the relationship of PSMS with the surrounding structure, especially with the orbit, SNM, PEs, and SS. In the present study, the PSMS was divided into four types (Table 1).

Type I: The horizontal parts of MT were attached in the inferior-medial wall of the orbit or in the palace between orbit and MS, which did not attach the MMS (Figure 2A). The PSMS was only adjacent to the middle nasal meatus (MNM), or adjacent to the orbit and MNM; S section of MMS did not appear (5.82%).

Type II: The horizontal parts of MT were attached and pass through the MMS (Figure 2B). The PSMS was adjacent to the

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orbit and SNM. The superior part of MMS (S section) was adjacent to SNM and not abutting on posterior ethmoid sinus (4.35%). There also was without the ethmomaxillary plate (EMP) (Figure 2B).

Type III: The EMP is the partition between the PEs and MS. When the superior part (S section) of MMS was abutting on PEs (85.9%; 177/206 sides), The EMP was visible (Figure 2C–2E). Thus, the Type III of the pneumatized of PSMS was considered.

Based on the difference of the adjacent structure of PSMS and the MMS shift toward medial or not, type III pneumatization of the PSMS was also divided into three subtypes: the PSMS was adjacent to the orbit, PEs, and SNM, which were not accompanied by MMS shift toward medial (Figure 2C); type IIIa were identified (33.50%), accompanied by MMS shift toward the medial (Figure 2D); type IIIb were identified (45.63%).

Moreover, the PSMS could be occupied by an enlarged posterior ethmoidal air cell draining into SNM. In this situation, the ethmomaxillary sinus (EMS) was identified (6.80%). Both sides were type IIIc in six cases (twelve sides) and unilateral were type IIIc in two cases (two sides). In this situation, the EMP also exists and belongs to type III. However, in this situation, PSMS was only adjacent to enlarged PEs (EMS), and was not adjacent to the orbit and SNM (Figure 2E). So, this special type was classified as type IIIc.

Type IV: The excessive pneumatization of PSMS extended toward the SS simultaneously accompanied with excessive pneumatization of the SS extended toward the retromaxillary area, which may lead to PSMS directly abutted on the anterior-inferior part of the SS (Figure 2F). In this situation, the sphenomaxillary plate (SMP) appeared and type IV was considered. Such variation is a rare type; a total of 3.88% cases (eight sides) were observed in this study. Unilateral were type IV in four cases (four sides), bilateral were type IV in two cases (four sides). Type IV was the result of type IIIb continued pneumatization backward. At the same time, the PSMS was composing the inferior-medial walls of the optic nerve tube.

Effect of the pneumatization of PSMS on nasal cavity width and morphology

Based on the present observation, according to the influence of the different type of PSMS pneumatization on nasal morphology, the pneumatization degree of PSMS was divided into three degrees. In order to evaluate the effect of different pneumatization of PSMS on nasal cavity width, the width of nasal cavity was measured.

The shallow pneumatization of PSMS: Present observation found that type I and type II had similar nasal cavity morphology and nasal cavity width was little affected by pneumatization of PMMS in the coronal plane before the greater palatine nerve canal. So type I and type II were classified into the same class as the shallow pneumatization of PSMS (12.62%; 13/103). For the shallow pneumatization of PSMS, the nasal cavity width in attachment point of the MT (31.79±3.67 mm) was significantly wider than the attachment point of the IT (29.74±2.92 mm) (p<0.05), and MMS was not shifted toward the medial (Table 2). The morphology nasal cavity looked like an "open cup" in the coronal plane (Figure 2A, 2B).

The moderate pneumatization of PSMS: The pneumatization of MS was not significant for type IIIc, because PSMS was occupied by PEs. So the MMS shift toward medial in type IIIc was inconspicuous, which was similar with type IIIa, and was classified into the same class as moderate pneumatization of PSMS (35.92%; 37/103). For moderate pneumatization of PSMS, the nasal cavity width in attachment point of the MT (29.13±3.38 mm) was slightly smaller than the attachment point of the IT (30.21±2.55 mm) (p<0.05). The medial wall of MS was shifted inconspicuously toward the medial (Table 2). The morphology nasal cavity looked like a "rectangle" in the coronal plane (Figure 2C, 2E).

The excessive pneumatization of PSMS: Type IV is result of type IIIb continued pneumatization backward with the total characteristics of the type IIIb. So type IV and type IIIb that had a similar effect on the nasal cavity morphology was classified into the same class as the excessive pneumatization of PSMS (51.46%; 53/103). For excessive pneumatization of PSMS, the nasal cavity width in attachment point of the MT (23.77±3.64) was greatly smaller than the attachment point of the IT (28.90±3.23 mm) (p<0.05). The MMS was shifted greatly toward the medial (Table 2). The morphology nasal cavity looked like a "trapezoid or flask" in the coronal plane (Figure 2D, 2F).

We found that in most cases, the pneumatized types of PSMS were similar between two sides 87.4% (90/103), only in thirteen cases (12.6%) were the pneumatized types of PSMS different between two sides. For different pneumatization types of bilateral PSMS, if one side had type IIIb or type IV, all were classified as excessive pneumatization of PSMS (six cases). Type IIIc + type IIIa (three cases) were classified as moderate pneumatization of PSMS. One side type IIIa or type IIIc did not affect nasal morphology while contralateral type II or type I (four cases) were classified as shallow pneumatization of PSMS.

The inferior part of the posterior nasal cavity showed similar width in the three kinds of pneumatization of PSMS; only in the group with moderate pneumatization (30.21±2.55 mm) was it slightly wider than the excessive pneumatization group (28.90±3.23) (p<0.05). However, the widths in the upper part of the posterior nasal cavity were significant difference

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Table 2. Effect of the pneumatization of PSMS on nasal cavity width (means ±SD).

Measuring position	Shallow pneumatization	Moderate pneumatization	Excessive pneumatization	Post hoc tests
	Type I and II (n=13)	Type IIIa and IIIc (n=37)	Type IIIb and IV (n=53)	LSD-test
Dmt	31.79±3.67	29.13±3.38	23.77±3.64	S *vs.* M p=0.028 S *vs.* E p=0.000 M *vs.* E p=0.000
Dit	29.74±2.92	30.21±2.55	28.90±3.23	S *vs.* M p=0.634 S *vs.* E p=0.383 M *vs.* E p=0.044
Paired test	T=2.892 *p*=0.015 df=12	T=–2.074 *p*=0.046 df=36	T=–11.417 *p*=0.000 df=52	

Dmt – distance between middle turbinate roots; Dit – distance between inferior turbinate roots; S – shallow pneumatization; M – moderate pneumatization; E – excessive pneumatization.

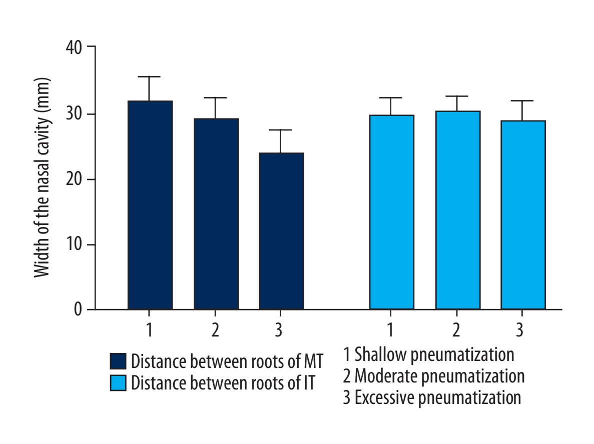

Figure 3. Compare the nasal cavity width among three degrees of pneumatization of PSMS.

among the three groups ($p<0.05$, respectively) (Table 2). The higher the degree of pneumatization of PSMS was made, the narrower the width of the upper part of the posterior nasal cavity, which means that excessive pneumatization of PSMS would make the upper part of MMS shift toward medial obviously, leading to the narrowing of the upper part of posterior nasal cavity (Figure 3).

For excessive pneumatization of PSMS, the positions of the MMS shift toward medial varied, which will lead to the nasal cavity showing different morphology in different coronal planes. However, our study found that the medial shift of MMS showed regularity. The first type is formed mainly because of the MT shift toward the medial (40/53). The pneumatization of MS extends toward the MT, leading to the upper part of the posterior nasal cavity becoming narrow, looking like a "trapezoid" in the coronal plane (Figure 4A). The second type is formed mainly because of the IT shift toward the medial (5/53). The pneumatization of MS extends toward the IT, leading to the inferior part of the posterior nasal cavity becoming narrow, looking like an "open cup flask" in the coronal plane

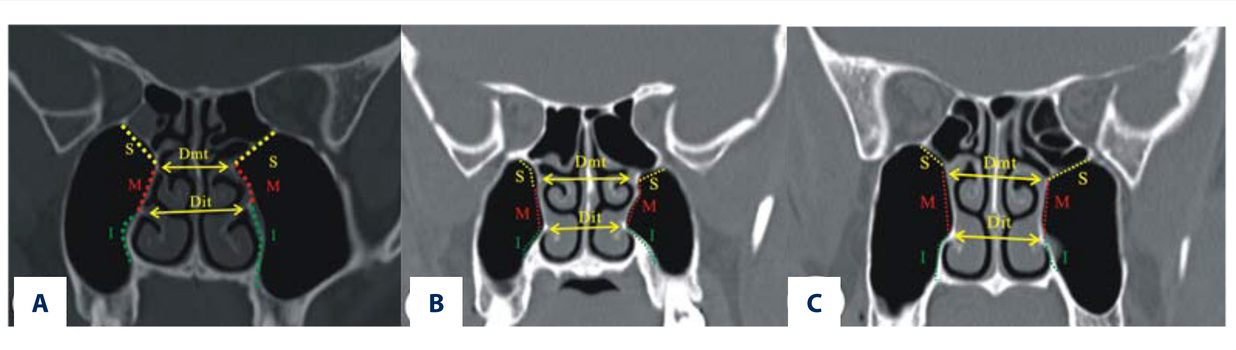

Figure 4. The morphology of posterior nasal cavity in the excessive pneumatization of PSMS. (**A**) Shows the morphology of posterior nasal cavity looks like a "trapezoid". (**B**) Shows the morphology of posterior nasal cavity looks like an "open cup flask". (**C**) Shows the morphology of posterior nasal cavity looks like a "straight mouth flask".

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(Figure 4B). The third type is formed mainly because the M section of the MMS shifts toward the medial (8/53). The pneumatization of MS extend toward between the MT and IT, leading to the posterior nasal cavity becoming narrow entirety, looking like a "straight mouth flask" in the coronal plane (Figure 4C).

Discussion

Functional endoscopic sinus surgery

The anatomic variations of the paranasal sinus are a major challenge in endoscopic sinus surgery (ESS). Detailed knowledge of the anatomic variations in the paranasal sinus region is critical for the safe and complete removal of lesion using ESS. In the absence of imaging navigation, complete posterior ethmoidectomy is difficult for doctors less experienced in ESS [13], for fear of LP, orbital, and optic nerve injury. The common anatomical factors associated with primary surgery failure are incomplete anterior ethmoidectomy (64%) and incomplete posterior ethmoidectomy (41%) [14]. A large percentage of patients demonstrate residual ethmoid cells present on the LP and skull base, with a lower number found posterior to the middle turbinate basal lamella [15]. Therefore, the understanding of the adjacent structures of the PSMS is helpful to improve the posterior ethmoidectomy of FESS [5].

The basal lamella is an important anatomical landmark for FESS surgery. In this study first, we found that in most of the cases (94.18%), the horizontal parts of MT were attached on the MMS, because of sufficient pneumatized PSMS. The horizontal parts of MT are adjacent to the apertura maxillaris at the front, and the rear is adjacent to the PEs. However, there are a few cases were pneumatization of PSMS was insufficient (5.82%). The horizontal parts of the MT were pass-through LP or between LP and MS, which may increase the difficulty of locating apertura maxillaris, and increases the risk of injury of LP when opening the basal lamella in ESS.

Furthermore, we found that there were great differences in the adjacent structure of the PSMS because of the different pneumatization of PSMS (Table 1). In our study the adjacent structure of the PSMS were divided into four types, based on the relationship of the PSMS with the PEs and SS.

For type I (Figure 1, 2A), the PSMS was only adjacent to the MNM, or adjacent to the orbit and MNM (5.82%). For type I, the PEs were often smaller and the pneumatization of PEs was insufficient, which suggests the need to pay attention to the expanded aperture of sinus maxillaries that still have some distance to the middle nasal basal lamella and PEs, even after removing the posterior fontanelle. If preoperative evaluations are not careful enough, this may lead to loss of anatomic orientation about the maxillary sinus ostium, LP and PEs during ESS.

For type II, the horizontal parts of MT were attached and passthrough the medial wall of MS (Figure 2B). The PSMS was adjacent to the orbit and SNM. The superior part of MMS (S section) was adjacent to SNM and not abutting on PEs (4.35%). Therefore, incision of middle nasal basal lamella was only done through entering the SNM, and not really an open PEs. The lateral of the SNM was directly adjacent to the LP. Therefore, after the opening of the middle nasal basal lamella, it is still necessary to open the PEs inward and upward continually, as should take care of the LP directly located on the lateral of SNM.

The EMP is the partition between the ethmoid and maxillary sinus. When the superior part (S section) of MMS was abutting on PEs (85.9%; 177/206 sides), the EMP was visible (Figure 2C–2E), and type III of PSMS was considered. If the PSMS was adjacent to the orbit, PEs, and SNM, it could accompany a MMS shift toward medial (type IIIb) or not (type IIIa). For type IIIa and IIIb, PSMS was mainly adjacent to the orbit, PEs, and SNM. The lateral of the SNM was directly adjacent to the S section of MMS, the EMP, and the PEs. Therefore, incision of middle nasal basal lamella was through entering the SNM, and also accompany by opening of PEs. Most of the time, the PEs were also partially extended into the lateral of SNM. Therefore, after the opening of the middle nasal basal lamella, it is still necessary to open the PEs outward continually, which should take care of the incomplete posterior ethmoidectomy and resulting residual lesions. In addition, for type IIIb, the S section of MMS often is wider, which can completely block the ethmoidectomy, hinder formation of spacious drainage channel, and impact the endoscopic view. So, in this situation, for completely ethmoidectomy and remove of the lesions, resect the S section of MMS including the EMP partially is needed.

Moreover, the extension of excessively pneumatized PEs into the maxillary sinus was called as EMS (Figure 2E). The presence of EMS was 6.80% in our study, which was higher than previous reports of about 0.7~2% [10–12]. Our study results suggest that the EMS was not a rare variation that would be taken care of during the FESS. The EMS was bilateral in six of eight cases (75%) and unilateral in two of eight cases (25%), these results were similar with data reported by Şirikçi et al. [11]. In this situation, the EMP also exists, which belongs to type III. However, our study, the PSMS was only adjacent to the EMS, and not adjacent to the orbit and SNM, so this special type was classified as type IIIc (Figure 2E). The presence of EMS may affect the ESS approach, as well as the removal of the lesions in the EMS. Therefore, it may be important to recognize EMS prior to endoscopic surgery. First, if the lesion occurs in the EMS, it may be mistaken for lesions in the MS, and mislead the surgeon to only perform a middle meatus antrostomy

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(MMA), which may result in residual lesions in the EMS. If the lesions occur in both EMS and MS simultaneously, EMS may also be mistaken for a part of the MS, thus no treatment of lesions in EMS and only in the MMA, which may also lead to residual lesions in EMS. Second, if the surgeon is unaware of the presence of EMS, it may lead to loss of anatomic orientation during ESS [11]. If the EMS is mistakenly considered to be the anatomic variation of the maxillary sinus ostium, the identification of the maxillary sinus ostium is confused. Third, if the appearance of a large EMS can reduce the MMS and corresponds to the middle nasal meatus, it may make it difficult to open the maxillary sinus ostium. In addition, in the choice of the endoscopic endonasal transmaxillary transpterygoid approach in the skull base requires dissection the posterior wall of the maxillary sinus [16]. The presence of the EMS will increase the difficulty of this approach. The posterior wall of the MS adjacent structure changes because of the EMS occupying the PSMS. The EMS and posterior wall of the MS together, adjacent to the pterygopalatine fossa, instead of the original posterior wall of the MS only. In this situation, exposure of the anterior wall of the true pterygopalatine fossa is required for resection of EMP sufficiently. Finally, if inflammation occurs in EMS, in order to obtain sufficient drainage of EMS, the resection of EMP or opening and enlarging the superior nasal meatus should be made to obtain larger drainage.

The excessive pneumatization of PSMS can extended toward the SS simultaneously accompanied with the excessive pneumatization of the SS extended toward the retromaxillary area, which may lead to the PSMS directly abutted on the anterior-inferior part of the SS (Figure 2F). In this situation, type IV was considered in our study (Figure 2F). Such variation is a rare type, a total of 3.88% cases (eight sides) were observed in our study; unilateral were type IV in four cases (four sides); bilateral were type IV in two cases (four sides). This variation has been reported in 11–15% of cases [1,2,17]. Type IV is the result of type IIIb continued pneumatization backward. At the same time, the PSMS is composed of the inferior-medial walls of the optic nerve tube. The SMP should be recognized in preoperation in order to avoid injury to the orbital apex and optic nerve during MS or SS surgery [3]. Furthermore, if the SS is mistaken for posterior ethmoidal cells during the ESS and the search for the SS is continued, in the absence of navigation, it will lead to serious complications [17].

Effect of the pneumatization of PSMS on nasal cavity width and morphology

It is known that the anatomic width of nasal cavity is related to the nasal ventilation function. Because of decreasing nasal cavity cross-sectional area and increasing nasal airflow resistance, nasal obstruction is associated with obstructive sleep apnea syndrome (OSAS), and nasal obstruction increases the proportion of oral breathing [18]. The nasal cavity ventilation expansion surgery has also become one of the effective methods for the treatment of OSAS patients with nasal obstruction [7,8]. The primary object is to enlarge the effective ventilation volume of the nasal cavity. There are many aspects in the operation of nasal cavity ventilation expansion, and it is important to determine the narrowest location accurately before operation. Our study found that the pneumatization of PSMS toward the palatine bone and posterior ethmoid sinus may lead to MMS shift toward the medial and a morphologic change of the nasal cavity. This may lead to increased nasal ventilation resistance. According to the influence of the different types of PSMS pneumatization on nasal morphology, the pneumatization degree of PSMS was divided into three degrees. The inferior part of the posterior nasal cavity showed similar width in the three kinds of pneumatization of PSMS, and only in the group with moderate pneumatization (30.21±2.55 mm) was it slightly wider than the excessive pneumatization group (28.90±3.23) ($p<0.05$). However, the widths in upper part of the posterior nasal cavity were significant difference among the three groups ($p<0.05$ respectively) (Table 2). The higher the degree of pneumatization of PSMS was made, the narrower the width of the upper part of the posterior nasal cavity, which means that excessive pneumatization of PSMS would make the upper part of MMS shift toward the medial obviously, leading to the narrowing of the upper part of posterior nasal cavity(Figure 4). This may be the developmental and anatomical foundation for a part of nasal obstruction or snoring patients.

Three types of retromaxillary pneumatization were described by Herzallah et al. [5] depending on the degree of lateral extension (type I, pneumatization of PE air cells lateral to MMS line is <3 mm; type II, 3–6 mm; and type III, >6 mm). This assessment also can reflect the effect of the degree of retromaxillary pneumatization on the morphology of the nasal cavity, but this classification does not contain all the types of the retromaxillary pneumatization [5]. Furthermore, the accurate numerical measurement in the clinic is not convenient. The lateral extension degree of PEs will be a change in different coronal planes, which may also affect the results of the measurements and further affect the classification of retromaxillary pneumatization. Therefore, this article is based on the pneumatized influence of PSMS on the morphology of the nasal cavity. The main consideration is the influence of different pneumatization of PSMS on the nasal width which may be related to nasal ventilation function.

Our study also found that the positions of MMS shift toward medial were variations for the excessive pneumatization of PSMS, which will lead to the nasal cavity showing different morphology in the coronal plane. The first type is form mainly because of the pneumatization of MS extends toward the MT

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(40/53), leading to the upper part of the posterior nasal cavity becoming significantly narrow, and looking like a "trapezoid" (Figure 4A). The second type is form mainly because of the pneumatization of MS extends toward the inferior turbinate (5/53), leading to the inferior part of the posterior nasal cavity becoming narrow, and looking like a "open cup flask" (Figure 4B). The third type is formed mainly because the M section of MMS shifts toward the medial (8/53), leading to the posterior nasal cavity becoming narrow entirely, looking like a "straight mouth flask" (Figure 4C). The different types of nasal cavity morphology may require different operation strategies during the nasal cavity ventilation expansion surgery.

Conclusions

The relationship of PSMS with the orbit, SNM, PEs, and SS were varied because of the different pneumatization of PSMS. This should be identified in pre-operation; it is important for safety and completely removed the retromaxillary lesions during ESS. The pneumatization degree of PSMS also should be considered, which can influence the morphology of posterior nasal cavity and may further lead to nasal obstruction.

Conflict of interest

The authors have no relevant competing interests to declare in relation to this manuscript.

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