Correlation between the size of the maxillary sinus and vertical growth patterns: a 3-dimensional cone-beam computed tomographic study

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Abstract

Background The maxillary sinus has been considered as an important factor that affects the development of craniomaxillofacial bone. However, the correlation between the maxillary sinus and skeletal malocclusion is controversial. This study aimed to compare the dimensions of the maxillary sinus in patients with different vertical growth patterns and investigated the correlation between the maxillary sinus and craniofacial parameters.

Methods This descriptive study included 90 patients from age 15 to 20 years old. According to the vertical growth patterns that were classified by MP-FH (angle between the mandibular plane and Frankfort horizontal plane), they were equally divided into three groups: high-, low- and normal-angle, and the gender ratio was 1:1. Cephalometric tracings were conducted from CBCT images, which were also used to measure the dimensions and volume of the maxillary sinus. Data were analyzed with one-way ANOVA, Pearson's correlation coefficient, and multiple comparison LSD.

Results The variables of the maxillary sinus, including the volume, length, and width, among different groups, were significant($p<0.05$). The variables of mandibular body length were significantly correlated with the volume of the maxillary sinus ($p<0.01$), and the coefficient was 0.425.

Conclusions The maxillary sinus volume, length, and width were larger in low-angle patients. The mandibular body length had a significantly positive correlation with the maxillary sinus volume.

Background

The maxillary sinus is the biggest among all paranasal sinuses, and it has a great influence on the growth and development of the maxillary bone[1]. The specific function of the maxillary sinus is still unclear. There are two main hypotheses about it: one is that the sinus cavity is related to the physiology of breathing, and the other is that it plays an essential role in the structure of the skull, especially in the biomechanics[2].

The development of the maxillary sinus is closely related to the facial forms. Alberti[3] believed that a small, concave anterior wall of the maxillary sinus would result in a "flat face"; and a larger, convex anterior wall would cause a round face. Some scholars had explored the correlation between the jawbone as well as congenital diseases, including cleft lip and cleft palate, and the size of maxillary sinus[4-6]. They found that patients with cleft lip and palate had a relatively smaller maxillary sinus volume. Moreover, the impacted canines also led to a smaller maxillary sinus[7], and the maxillary sinus volume of patients with mouth breathing was relatively smaller[8]. For the sagittal direction of the craniofacial bones, Oktay[9] found that the volume of the maxillary sinus was larger in Class [illegible] female patients. Endo[10] alleged that the upper anterior facial height and upper posterior facial height were related to the volume of the maxillary sinus. From the perspective of the craniomaxillofacial vertical growth, as far as we know, only one study found that the maxillary sinus volume of patients with a high angle was relatively smaller[11]. Furthermore, some scholars found a statistically significant correlation between the volume of the maxillary sinus and the size of the mandible[12]. Therefore, we have reasons to believe that the size of the maxillary sinus could influence the patient's occlusion and appearance.

However, there were still some limitations in these published studies. For example, only two-dimensional radiographs were analyzed, or the age ranges of the patients were too wide. Furthermore, the correlations between maxillary sinus volume and other parameters related to the craniofacial region, such as mandibular body length, are still unclear. Nowadays, CBCT (cone-beam computed tomography) has been widely utilized, which could create a 3D view with a higher diagnostic capability[13]. In this case, CBCT should have a higher priority in obtaining the information of maxillary sinus.

When it comes to the clinical significance, the size of the maxillary sinus is closely linked to the orthodontic movement of the posterior teeth and the placing of mini-screws because of the maxillary sinus and the posterior teeth are adjacent[14, 15]. Therefore, the size of the maxillary sinus has a specific impact on clinical orthodontic treatment. If the average volume of the maxillary sinus is larger in low angle patients, we should be more careful in moving the posterior maxillary teeth, especially when treating without CBCT. Besides, the extended development of the mandible can continue until 18 to 20 years old[16], which became the leading cause of relapse of non-surgical masking therapy of Class III[17]. On the other hand, the maxillary sinus of adolescents aged 12 to 15 have approximately grown to the size of an adult[8, 10]. So if the maxillary sinus is correlated with mandible, it can be used to predict the growth trend and increment of the mandible to some extent, and it has specific clinical significance for such Class III patients. Therefore, the purposes of this study were to evaluate the morphology and volume of the maxillary sinus of patients with different vertical growth patterns and investigate whether there were any correlations between the maxillary sinus and other parameters related to the craniofacial region, such as mandibular body length.

Methods

Study samples

This study collected 90 patients who visited the Department of Orthodontics of Xiangya Hospital of Central South University from 2015 to 2019 and met the inclusive criteria. They were equally divided into three groups according to the mandibular plane angle (MP-FH): the low angle group(MP-FH$\leq$23.8), the mean angle group (23.8 < MP-FH < 32.8) and the high angle group (MP-FH $\geq$ 32.8)[18, 19]. Moreover, there were 30 cases in each group, and the proportion of males and females was 1:1.

Inclusion criteria: (1) The permanent dentition had erupted entirely except for the third molar (2) The age of the patient was 15-20 years old (3) There were no dysplasia or extracted teeth (4) There was no obvious pathological change in the maxillary sinus such as inflammation, mucosal cyst or tumor (5) Except for the mild to moderate abnormalities in the cranial and maxillofacial sagittal orientation, there were no obvious deformities of the craniofacial bone, such as cleft lip and palate (6) There was no apparent craniofacial asymmetry (7) The orthodontic treatment had not been performed before.

CBCT and cephalometric analyses

All subjects who met the inclusion criteria underwent CBCT scanning (KaVo 3D eXam) of the oral and maxillofacial region by the same radiologist in the Center of Stomatology, Xiangya Hospital, Central South University. All subjects were seated, keeping the Frankfort plane parallel to the horizontal plane, lips naturally closed, posterior teeth in centric occlusion, breathing calmly, without chewing, and swallowing, adjusting the crosshairs so that the scan baseline was in the occlusal plane. The scanning parameters are shown in Table 1.

The DICOM files were imported into Dolphin 9.0 software (Dolphin Imaging and Management Solutions, Chatsworth, CA), and the measurements were performed twice in one week by reconstructing the lateral cephalograms from DICOM after the correction of head position in the coronal, sagittal, and vertical planes. The major cephalometric measurement items are shown in Table 2.

Assessment of maxillary sinus

All maxillary sinus measurements were performed separately on the left and right sides. Using the Dolphin 9.0 (Dolphin Imaging and Management Solutions, Chatsworth, CA) software, the maxillary sinus borders were framed in the sinus measuring module, and the maxillary sinus was separated from the paranasal sinus (see Figure 1). The sensitive parameter was set to 25 (see Figure 2). The maxillary sinus measurement data are shown in Table 3.

Statistical analyses

All measurements were performed by the author over a period of time, and data analyses were performed using the SPSS (Version 23.0, SPSS Inc, Chicago, IL) software. Kolmogorov-Smirnov test and Q-Q plot were used to test whether the data were normally distributed. The correlations between the maxillary sinus and vertical growth patterns were analyzed by one-way ANOVA and multiple comparison LSD because the data were divided into three groups according to MP-FH, as well as the correlations between the maxillary sinus and skeletal sagittal malocclusions, which were divided into three groups according to ANB. The correlations between the maxillary sinus and other parameters related to the craniofacial region were analyzed by the Person correlation coefficient because they were continuous variables. The data were statistically significant at $P<0.05$.

Results

The age and standard deviation of the included patients are shown in Table 4. One-way ANOVA analysis showed there was no significant difference in mean age between the various vertical growth patterns (Table 5) ($P>0.05$). The results of this study showed that the average volume of the right maxillary sinus was $17297.75 \pm 6153.71 mm^3$, and the average volume of the left maxillary sinus was $16973.45 \pm 6008.41 mm^3$. There was no significant difference between bilateral maxillary sinuses, which is consistent with the previous studies[9, 20, 21] . Therefore, only the right maxillary sinuses were compared between the three groups of vertical growth patterns. The results are shown in Table 6. The high angle group has a relatively smaller maxillary sinus volume than the mean angle group and the low angle group, and the difference is significant.

This study found that the average maxillary sinus length and width of the high-angle patients were smaller than those of the low-angle group, and the difference was significant (see Table 7).

However, this study found there was no significant difference in maxillary sinus volume between patients with various skeletal sagittal malocclusions (see Table 8).

The representative results of cephalometric measurements are shown in Figure 3 and Figure 4. We found that the volume of the maxillary sinus was correlated with the length of the mandible (see Table 9).

However, we did not find a statistically significant correlation between maxillary sinus volume and SN (see Table 10).

Discussion

The study's purpose was to investigate whether there is any correlation between the size of the maxillary sinus and skeletal morphological indexes. For the vertical analyses, as far as we know, there was only one related research publications. Okşayan[11] found that the maxillary sinus lengths and widths were shorter in patients with a high angle, but there was no significant correlation between the volume and vertical growth patterns. However, our research found that the maxillary sinus length, width, and volume of high angle patients were smaller than those of low angle patients. Therefore, the conclusions of these two studies are basically the same, and the discrepancy is perhaps due to the age range of the patients included. The average age of patients enrolled by Okşayan was 29.90 ± 10.91, which was much wider. Although, in general, the development of the maxillary sinus has reached the size of an adult at the age of 15[8], many physiological and pathological factors affect the volume of maxillary sinus over time[22, 23]. Considering that the growth of the mandible lasts 18 to 20 years[16], the age of the patients included in this study was 15 to 20 years old, in order to match the longitudinal growth of the mandible and its correlation with the maxillary sinus. Therefore, the ages of included patients probably lead to the support of distinction in the results of these studies.

For the sagittal analyses between the craniofacial bones and maxillary sinus, previous studies were controversial. Oktay[9] found that the maxillary sinuses of females with Class II were relatively larger. Moreover, Weng Jiahua[21] and Dah-Jouonzo[24] also found that the maxillary sinus is larger in patients with skeletal Class II. In contrast, Endo[10] found there was no significant correlation between the volume of the maxillary sinus and the sagittal skeletal malocclusion. In this study, we found no significant difference in the volume of the maxillary sinus in patients with different sagittal skeletal deformities. The reason for this difference might be that the ages of the included patients varied greatly, and the accuracy of the two-dimensional measurement was different from that of the three-dimension measurement. The patients included by Oktay were 6 to 30 years old and were analyzed using panoramic radiographs, while for Weng Jiahua and Endo, the included patients were 12 to 16 years old, the former using CBCT and the latter using the lateral cephalometric radiographs for the study.

For the correlation between the maxillary sinus and mandibular body length, as far as we know, we have only found relevant research based on two-dimensional lateral cephalograms[12]. This two-dimensional study asserted that the length and cross-sectional area of the maxillary sinus were positively correlated with the length of the mandible[12]. However, the three-dimensional measurement of the maxillary sinus has been dramatically improved due to the advancement of digital technology. Traditional two-dimensional planar radiographic pictures lose much information, omitting the perspective from the third dimension[25]. However, three-dimensional digital cone-beam CT (CBCT) has many advantages compared with previous technologies, such as lower radiation, shorter imaging time, low cost[26, 27], and relatively complete maxillary sinus information.

Meanwhile, the prediction of mandibular growth is intractable, but quite a crucial issue. Because in clinical practice, the cause of recurrences in many adolescents with skeletal Class III is the continued growth of the mandible after orthodontic treatment[17]. At present, even the most classic prediction of the mandibular growth using the wrist radiograph is not effective enough[28]. Hand-wrist radiographs can predict the peak of growth and development, but there is no significant correlation with the quantity of mandibular growth[29]. The cervical vertebral maturation (CVM) method could not validly predict the mandibular growth peak[30]. For the first time, this study found that the volume of the maxillary sinus was positively correlated with the length of mandible. Moreover, we did not find a significant correlation between maxillary sinus volume and SN, which means that maxillary sinus has a more intimate relationship with the jaw bone than the whole skull. If the prediction formula established by adding the maxillary sinus as one of the referential indicators can effectively predict the growth and development trend of the mandible, it will be of certain guiding significance for the clinical orthodontic treatment of skeletal Class III patients. This predictive effect is for further research, requiring a larger sample size, and conducting a long-term longitudinal study and statistical analysis.

The results of this study indicate that the maxillary sinus is larger in low angle patients. Therefore, low-angle patients need a more careful evaluation of the shape and size of the maxillary sinus when implanting mini-screws in the maxilla or moving the posterior maxillary teeth to avoid penetrating the maxillary sinus[31]. At the same time, the study results indicate that the volume of the maxillary sinus is positively correlated with the length of mandible. Therefore, for adolescent patients who are skeletal Class III with larger maxillary sinus volume, the possibility of further development of the mandible after orthodontic treatment is higher, and the possibility of recurrence is correspondingly increased. These possibilities mean that orthognathic surgery for this type of skeletal Class III patient might be more appropriate as a treatment selection.

Only limited data of clinical case material could be collected, which resulted in mainly a cross-sectional study with the imaging findings from CBCT. Considering that the maxillary sinus volume has basically completely developed after the age of 15[8], the cross-sectional data of orthodontic patients in this age group were used to analyze the correlation between the volume of the maxillary sinus and the length of the mandible. However, there is no doubt that stronger evidence can be obtained from a longitudinal study, which could more precisely validate the trends of growth and development. Therefore, next, our team will collect more information, especially from the ENT and growth and development disciplines, as well as expanding the sample size and including more measurement indicators, and conducting longitudinal tracking to obtain more convincing evidence.

Conclusion

1. This study found a statistically significant correlation between the size and volume of the maxillary sinus and the vertical growth patterns of patients. The length, width, and volume of the maxillary sinus in hyperdivergent patients were smaller than those in the hypodivergent patients.
2. This study, for the first time, found a statistically significant correlation between the maxillary sinus volume and the mandibular body length. The larger the volume of the maxillary sinus, the longer the length of the mandible.

Abbreviations

MP-FH: angle between the mandibular plane and Frankfort horizontal plane

CBCT: cone-beam computed tomography

ANB: The angle formed by the line connecting Nasion to Subspinale and the line connecting Nasion to the Supramentale

SN: The distance between Sella turcica and Nasion

CVM: cervical vertebral maturation

Declarations

Ethics approval and consent to participate

This was a cross-sectional study, with approval of our institutional review board. The study followed the tenets of the Declaration of Helsinki for research involving human subjects. The patients included in this retrospective study were collected from a consecutive series of patients who had been referred to the Department of Orthodontics of Xiangya Hospital of Central South University.

Consent for publication

Not applicable.

Availability of data and materials

The dataset used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable

Authors' contributions

XYL designed the study and organized the research, literature research, writing the manuscript, and carried out proofreading, HYY joined in literature research, FJQ joined in the statistical analysis. LF took part in the analysis of data, LYH developed the concept, participated in the design of the study, literature research, writing of the manuscript, and provided the fund. All authors have read and approved the manuscript and ensure that this is the case.

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Tables

Table 1 Scanning parameters

Parameters	Visual scope (cmcm)	Tube voltage (kV)	Tube current (mAs)	Size of stereo pixel (mm^3)	Scanning thickness (mm)	Scanning time (s)
Numbers	168	120	37	0.3	0.25	26.9

Table 2 The major cephalometric measurement items

Measurement items	Definition
SNA	The intersection of the line connecting Nasion and Subspinale with the plane of the anterior skull base
SNB	The angle between the line connecting Nasion to Supramentale and the plane of the anterior skull base
ANB	The angle formed by the line connecting Nasion to Subspinale and the line connecting Nasion to the Supramentale
Mandibular plane angle (MP-FH)	The angle between the mandibular plane MP and the Frankfort horizontal plane FH
Mandibular body length (Go-Gn)	Actual distance between Gonion and Gnathion
Wits appraisal	The Wits appraisal is measured as a distance between the perpendicular lines from Subspinale(point A) and Supramentale(point B) as they intersect the functional occlusal plane. The relative distance between the intersection points of the noted two perpendicular lines on the functional occlusal plane represents the Wits appraisal.
Facial angle (FH-NPo)	The angle between the line connecting Nasion to Pogonion and the Frankfort horizontal plane
Angle of Convexity (NA-APo)	the angle between the line connecting Nasion to Subspinale and the extension of the line connecting Pogonion to Subspinale
Y Axis angle (SGn-FH)	Sella Gnathion to Frankfurt Horizontal Plane
Posterior-anterior Ratio (S-Go/N-Me)	Reflecting the direction of facial growth
UAFH (N-ANS)	Upper anterior facial height, vertical distance from Nasion to the anterior nasal spine
LAFH (ANS-Gn)	Lower anterior facial height, vertical distance from the anterior nasal spine to Gnathion
SN	The distance between Sella turcica and Nasion

Table 3 Main measurement data of maxillary sinus

Measurement items	Definitions
Maxillary sinus length	Maximum horizontal distance between the anterior and posterior borders of the maxillary sinus
Maxillary sinus height	Maximum vertical distance between the upper and lower boundaries of the maxillary sinus
Maxillary sinus width	Maximal distance of maxillary sinus cross section
Maxillary sinus volume	Maxillary sinus cavity volume[21]

Table 4 Age and gender of different vertical growth patterns groups

Vertical growth patterns	Number of samples	Ages		t	P
		Males	Females		
Low-angle	30	18.9±1.76	18.8±1.82	0.31	0.758
Mean-angle	30	19.1±1.73	19.0±1.03	0.124	0.902
High-angle	30	17.5±1.81	18.5±1.69	-1.672	0.106

Table 5 Multiple comparisons of ages between the three groups

(I) Groups	(J) Groups	Average difference (I-J)	Standard errors	Significance	95% Confidence intervals	
					Upper	Lower
Low-angle	Mean-angle	-.06667	.38227	.862	-.8265	.6931
	High-angle	.63333	.38227	.101	-.1265	1.3931
Mean-angle	Low-angle	.06667	.38227	.862	-.6931	.8265
	High-angle	.70000	.38227	.070	-.0598	1.4598
High-angle	Low-angle	-.63333	.38227	.101	-1.3931	.1265
	Mean-angle	-.70000	.38227	.070	-1.4598	.0598

Table 6 LSD of maxillary sinus volume and mandibular plane angle

(I) Vertical growth patterns	(J) Vertical growth patterns	Average difference (I-J)	Standard errors	Significance	95% Confidence intervals	
					Upper	Lower
High-angle	Mean-angle	-2221.94667*	901.70743	.016	-4014.1878	-429.7055
	Low-angle	-2980.79000*	901.70743	.001	-4773.0312	-1188.5488
Mean-angle	High-angle	2221.94667*	901.70743	.016	429.7055	4014.1878
	Low-angle	-758.84333	901.70743	.402	-2551.0845	1033.3978
Low-angle	High-angle	2980.79000*	901.70743	.001	1188.5488	4773.0312
	Mean-angle	758.84333	901.70743	.402	-1033.3978	2551.0845

* $P < 0.05$

Table 7 ANOVA of maxillary sinus length, width and height in patients with different vertical growth patterns

Groups	Sum of squares	Degrees of freedom	Mean squares	F	Significance
Maxillary sinus length	180.694	2	90.347	3.670	0.029*
Maxillary sinus width	112.381	2	56.190	3.360	0.039*
Maxillary sinus height	36.878	2	18.439	0.475	0.623

* $P < 0.05$

Maxillary sinus length and width were significantly different in patients with different vertical growth patterns, and maxillary sinus length and width of the high-angle patients were smaller than those of the low-angle group. While for the maxillary sinus height, there was no significant difference between different vertical growth patterns.

Table 8 ANOVA of maxillary sinus volume in patients with different skeletal sagittal malocclusions

	Sum of squares	Degrees of freedom	Mean squares	F	Significance
Intergroups	36460434.771	2	18230217.386	1.357	.263
Intragroups	1168584111.580	87	13432001.283		
Total	1205044546.352	89			

Patients were divided into different skeletal sagittal malocclusion groups according to their ANB. Class Ⅰ (2.2°≤ANB≤5.8°); Class Ⅱ (ANB≥5.8°); Class III (ANB≤2.2°).

Table 9 Correlation between maxillary sinus volume and mandibular body length

		Maxillary sinus volumes	Mandibular body lengths
sinus volumes	Pearson correlation	1	.425**
	Sig. (double-tailed)		.000
	Number of cases	90	90
body lengths	Pearson correlation	.425**	1
	Sig. (double-tailed)	.000	
	Number of cases	90	90

**. At the 0.01 level (double-tailed), the correlation is significant.

Table 10 Correlation between maxillary sinus volume and SN

		Maxillary sinus volume	SN
Maxillary sinus volume	Pearson Correlation	1	.153
	Sig. (2-tailed)		.149
	N	90	90
SN	Pearson Correlation	.153	1
	Sig. (2-tailed)	.149	
	N	90	90

Figures

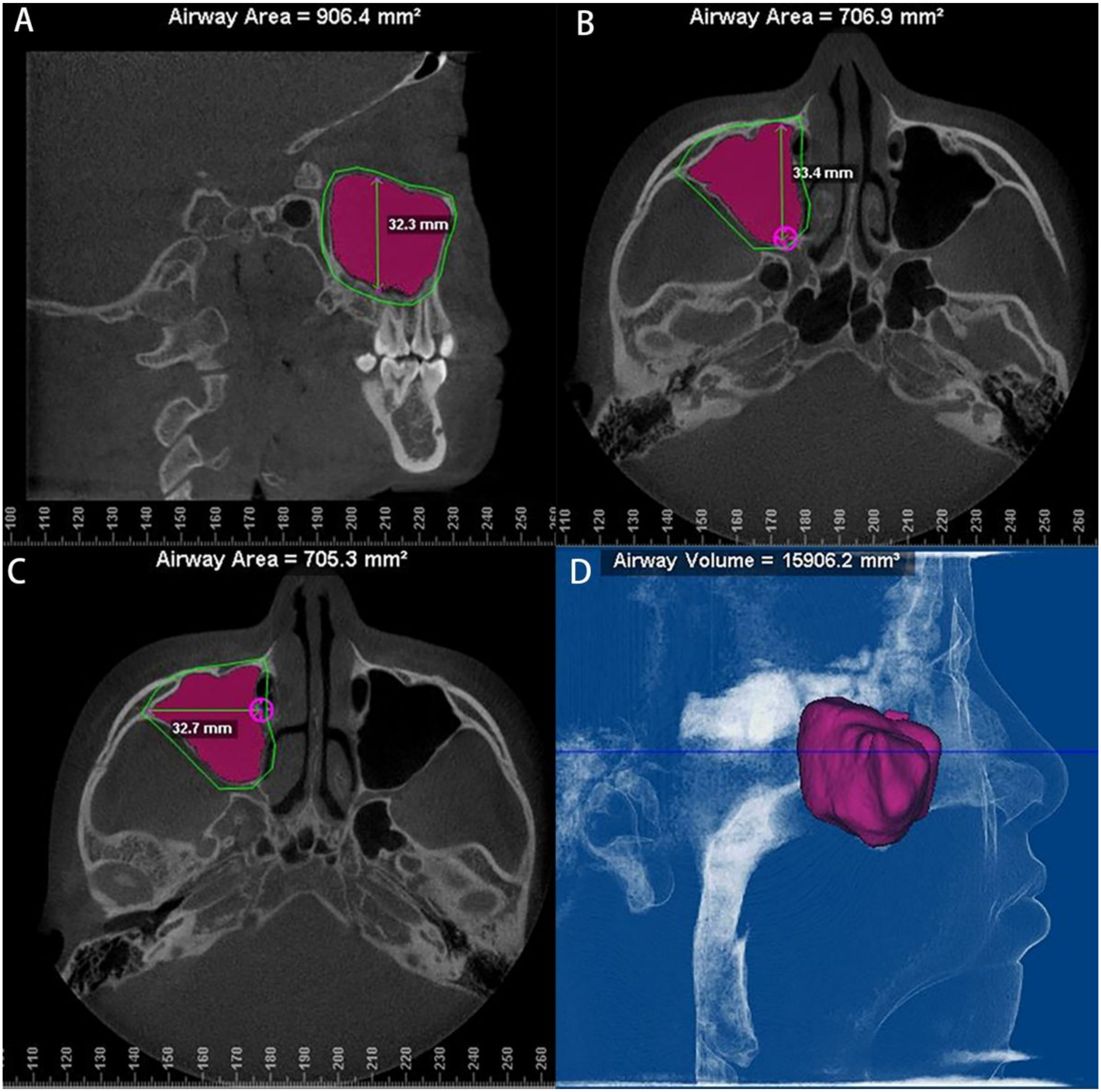

Figure 1

The length, width, height, and volume of Maxillary sinus A: Maxillary sinus height B: Maxillary sinus length C: Maxillary sinus width D: The 3D view and volume of the maxillary sinus

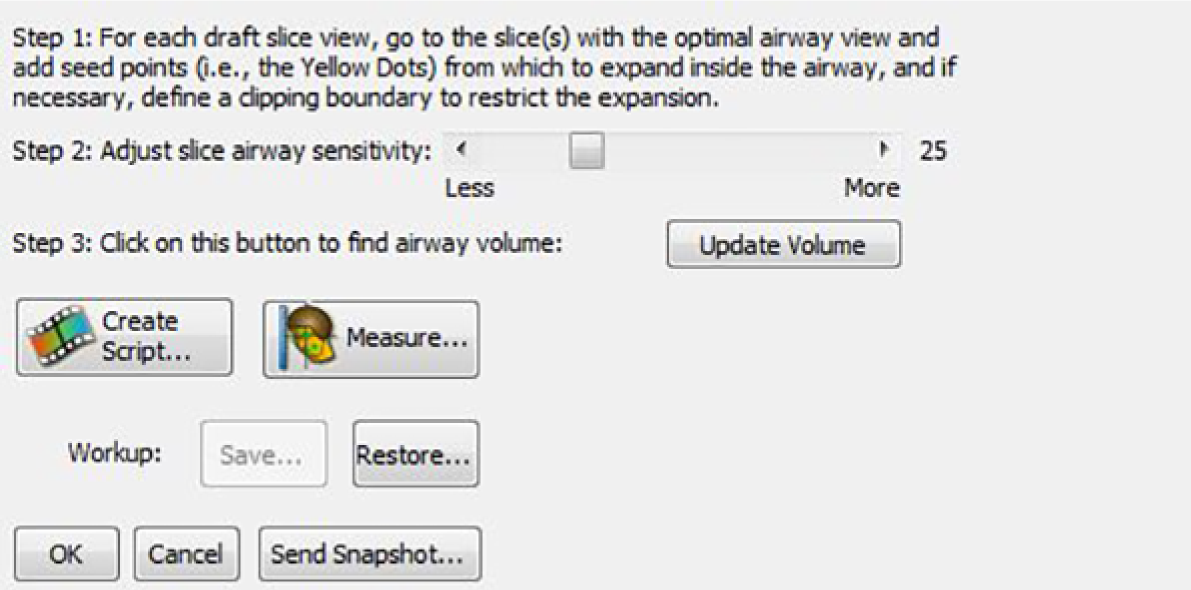

Figure 2

Measurement parameters and methods of the maxillary sinus The sensitivity was set to 25 among all measurements

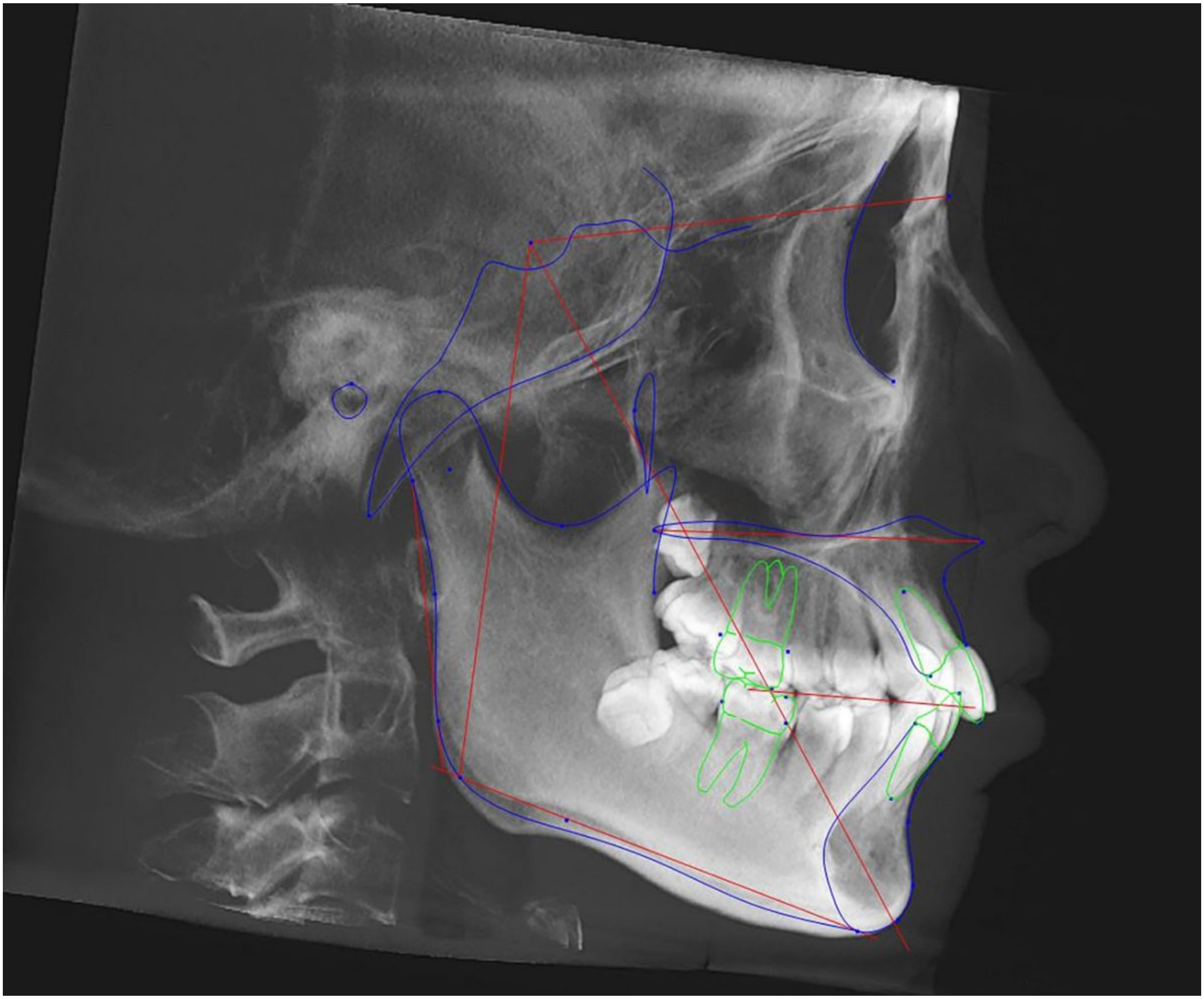

Figure 3

The lateral cephalogram and cephalometry

SKELETAL PATTERN			
SNA (°)	83.0	82.0	3.5
SNB (°)	80.0	80.9	3.4
ANB (°)	3.0	1.6	1.5
Wits Appraisal (mm)	2.7	-1.0	1.0
Facial Angle - (FH-NPo) (°)	86.8	88.6	3.0
Convexity - (NA-APo) (°)	5.2	4.9	3.0
A-B to Facial Plane (°)	-5.5	-3.5	3.0
FMA - (MP-FH) (°)	21.4	23.9	4.5
MP - SN (?	27.4	33.0	6.0
Y-Axis -- Downs - (SGn-FH) (°)	62.1	60.3	3.4
Facial Plane to SN (SN-NPog) (°)	80.7	80.5	4.0
Posterior Face Height - (SGo) (mm)	87.1	82.5	5.0
Anterior Face Height - (NaMe) (mm)	120.5	128.5	5.0
P-A Face Height - (S-Go/N-Me) (%)	72.3	65.0	4.0
Mand' Body Length - (Go-Gn) (mm)	81.3	75.2	4.4
DENTAL PATTERN			
Occ Plane to FH (°)	4.9	6.8	5.0
Overbite (mm)	4.4	2.5	2.0
Overjet (mm)	3.8	2.5	2.5
U1 - SN (°)	114.0	102.8	5.5
U1 - NA (°)	31.0	22.8	5.7
U1 - NA (mm)	6.1	4.3	2.7
FMIA (L1-FH) (°)	56.8	64.8	8.5
IMPA (L1-MP) (°)	101.8	95.0	7.0
L1 - NB (°)	29.3	25.3	6.0
L1 - NB (mm)	6.9	4.0	1.8
Interincisal Angle - (U1-L1) (°)	116.7	130.0	6.0
Anterior Cranial Base (SN) (mm)	68.5	75.3	3.0

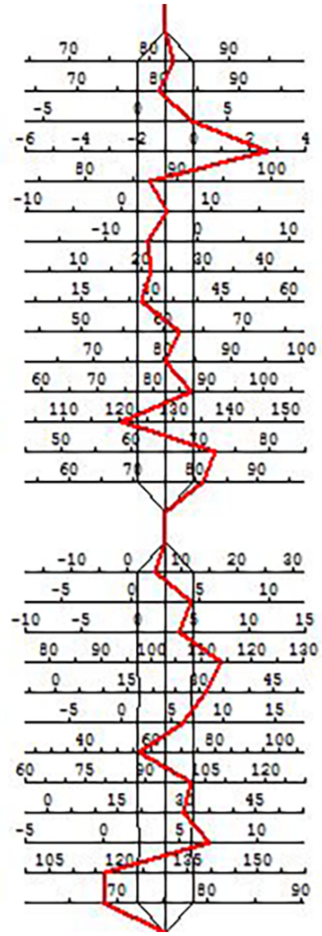

Figure 4

The example of results from cephalometrics analysis