Relationship between anterior occlusion and frontal sinus size

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ABSTRACT

Objective: To determine the relationship between anterior occlusion and frontal sinus size.

Methods: The patient database at the Eastman Institute for Oral Health, University of Rochester, was searched for male patients older than 15 years and females older than 13 years of age. After applying inclusion and exclusion criteria, participants' photos and lateral cephalometric and posteroanterior radiographs were examined then classified into a control class I group ($n = 20$, 15.7 ± 2.7 years) and eight malocclusion groups ($n = 136$, 16.1 ± 2.1 years). The frontal sinus area on the lateral cephalometric radiograph and on the posteroanterior radiograph were measured and compared between groups.

Results: One-way analysis of variance demonstrated a significant difference among all nine groups ($P = .0001$). Pairwise comparison showed a significant difference between the class I group and all other malocclusion groups ($P < .05$) except the edge-to-edge group for both radiographs and except the bimaxillary protrusion group for the lateral cephalometric radiographs. Tukey's method was not able to demonstrate a significant difference among the subgroups of skeletal malocclusions ($P > .05$). Linear regression analyses with stepwise model selection demonstrated that anterior cranial base, mandibular plane angle, and upper incisor inclination commonly have a significant effect on frontal sinus size.

Conclusion: The frontal sinus size could be used as an indicator of harmonious anterior occlusion. There were no differences among the subgroups of each skeletal malocclusion. The anterior cranial base, facial height, and maxillary incisor inclination appear to have a significant effect on frontal sinus size. (*Angle Orthod.* 2017;87:752–758.)

KEY WORDS: Anterior occlusion; Cephalometrics; Frontal sinus

INTRODUCTION

Lateral cephalometric radiographs have been used for many years for diagnosis of skeletal and dental discrepancies through the use of various cephalometric analyses. A better understanding of the craniofacial complex and the effects of occlusion on its shape could provide indicators of normal occlusion and harmonious maxillomandibular relationships.

The human skeleton is a well-balanced dynamic system that responds to different mechanical stresses. Despite technological advances and the intense research studies conducted in the past, the functions and morphology of some structures are still a mystery. The paranasal sinuses, for example, occupy a significant amount of space in the cranium and have long been of interest in studies to determine their function and factors affecting their morphology and size. Many possible functions have been suggested for the paranasal sinuses. A summary by Rae et al.[1] included respiratory function, thermoregulation, and trauma protection as a means to decrease skull weight and many more. Preuschoft et al.[2] reported that paranasal sinuses have been developed in response to the biomechanical necessities of the skull architecture. Thus, of importance are the magnitude and the direction of the forces of mastication, which are major

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contributing mechanical stress inducers. These processes affect the degree of pneumatization.

The distribution of masticatory stress throughout the human skull has been demonstrated by several finite element studies.[3,4] These high magnitude stresses flow from the dental arches along the medial periphery of the orbits, defined by Toldt in 1914 as "nasal pillars".[4] Moreover, it was stated that a septum in the frontal sinus seems to be a consequence of stress distribution in the midline, which implies that these masticatory stresses reach the frontal sinus.[4] In addition, Throckmorton et al.[5] confirmed that orthognathic surgery provides a more harmonious maxillomandibular relationship, leading to a more favorable transmission of stresses along the craniofacial skeleton. Subsequently, Prado et al.[6] reported that 6 months after correction of a class II open bite malocclusion using maxillomandibular advancement with counterclockwise rotation, there was reduction of the frontal sinus size. The authors attributed the change in size as an adaption to stresses induced by a more favorable occlusion.

The frontal sinus originates from ethmoidal cells, which migrate into the frontal bone at the end of first year of life. According to Dolan et al.,[7] it becomes radiographically apparent at 8 years of age. Ruf et al.[8] reported that the pubertal development peak of the frontal sinus follows the body height peak by an average of 1.4 years. Koertvelyessey[9] reported a correlation between cold climates and degree of pneumatization of the frontal sinus. Amusa et al.[10] examined 24 dried skulls of a Nigerian population and reported 58% frontal sinus aplasia, suggesting further investigation as to whether a customary activity of carrying heavy loads on their heads played a role. Spaeth et al.[11] evaluated computed tomography (CT) images of 5,641 patients with ages ranging from birth to 25 years. They found that the right frontal sinus was constantly smaller than the left in both sexes and aplasia was 4.9% in males and 9.4% in females. Moreover, they affirmed that their results regarding frontal sinus size were in agreement with the data from previous X-ray studies. Brown et al.[12] found that, upon radiographic examination of the frontal sinus, there was no further expansion after age 15.68 for males and 13.72 for females.

Rossouw et al.[13] found a correlation between frontal sinus area on lateral cephalometric radiographs and maxillary length, mandibular length, symphysis width, and condylar length. It was suggested for use as a supplementary indicator for mandibular growth prediction. Dah-Jouonzo et al.[14] studied the correlation between the maxillomandibular relationship and paranasal sinus volume. Their results showed that the frontal sinus volume is affected more by vertical than anteroposterior changes and that the average volume of the sinus size is larger in class III followed by class II division 1, whereas both Class II division 2 and Class I have almost the same average volume.

The purpose of this study was to determine if a relationship exists between the frontal sinus size and anterior occlusion.

MATERIALS AND METHODS

A search was conducted through the Database at Eastman Institute for Oral Health, University of Rochester from 2009 to 2014. The goal was to identify female patients older than 13 years of age and males older than 15 years of age, adhering to the following exclusion criteria:

- History of seasonal allergies
- History of ear, nose, throat (ENT)-related diseases
- History of hormonal disturbances
- Craniofacial anomaly
- Previous orthodontic or orthopedic treatment

A total of 1226 patients were identified. Each patient's preorthodontic records were examined using Dolphin Software (11.7v, Dolphin Imaging and Management Solutions, Chatsworth, Calif) to ensure that both lateral and posteroanterior radiographs were acquired by the orthodontic department's X-ray machine (Orthopantomograph OP 200 D, 80Kv Instrumentarium Dental, Charlotte, N.C.). In addition, the head tilt in the posteroanterior radiograph was examined to ensure that the superior surface of the petrous bone was at a level ranging from the middle to lower one-fourth of the orbit. As demonstrated by Ghafari et al.,[15] there was shortening and elongation in different structures when posteroanterior radiographs were taken at different head tilts.

Subsequently, lateral cephalometric radiographs and clinical photographs were examined to classify patients into different groups (Table 1). Patients missing one or more incisors or having peg laterals or aplasia of the frontal sinus were excluded.

Once the different groups were determined, a pilot study of 20 patients was performed. A two-sample *t*-test determined that a sample of 19 participants in the control group and 152 participants in the experimental group would have 81% power to detect the proposed difference at a significance level of 5%. Participants were randomly selected to fulfill the required sample for each malocclusion group.

Once this procedure was completed, there were 20 participants in the class I group with a mean age of 15.7 ± 2.7 years. The malocclusion group had a mean age of 16.1 ± 2.1 years, consisting of 19 participants in the bimaxillary protrusion group, 19 in the open bite group, 19 in the skeletal class III with positive overjet

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Table 1. Criteria for Patients' Classification

Normal Occlusion	0°<ANB<4°, 125°<U1-L1<135°
Malocclusion	Bimaxillary Protrusion: 0°<ANB<4°, U1-APO>6 mm, L1-APO>4 mm Open bite: OB>1 mm Skeletal class III with anterior crossbite: ANB°≤0°, with all incisors in anterior crossbite Skeletal class III with positive overjet: ANB≤0°, with all incisors in positive overjet Skeletal class III with edge to edge bite: ANB≤0°, with all incisors in edge to edge contact Skeletal class II division 2: ANB≥4°, Mandibular plane <29°, U1-PP<110° Skeletal class II division 1 with contact: ANB≥4°, U1-PP≥110° and all lower incisors are in contact with maxillary teeth Skeletal class II division 1 without contact: ANB≥4°, U1-PP≥110° and all lower incisors not in contact with maxillary teeth

group, 19 in the skeletal class III with anterior crossbite group, 5 in the skeletal class III with edge-to-edge group, 17 in the skeletal class II division 2 group, 19 in the skeletal class II division 1 with anterior contact group, and 19 in the skeletal class II division 1 with no anterior contact group.

The following measurements were obtained by retracing each subject's lateral cephalometric radiograph:

- SN (mm)
- SNA°
- SNB°
- ANB°
- Wits mm
- MP-SN°
- PP-MP°
- ODI°
- U1-L1°
- Overbite mm
- Overjet mm
- U1-SN°
- U1-PP°
- IMPA°
- FMIA°
- Occ to SN°
- U1-NA°
- U1-NA mm
- L1-NB°
- L1-NB mm
- U1-APO mm
- U1-APO°
- L1-APO mm
- L1-APO°
- PFH/AFH

Furthermore, both lateral and posteroanterior cephalograms were enhanced with a filter by Image J Software (1.48v; National Institutes of Health, Bethesda, Maryland), and then transferred to Adobe Photoshop (CS3; Adobe Systems Incorporated, San Jose, Calif) for tracing and measuring of the frontal sinus area on both radiographs (Figure 1). In the lateral cephalogram view, the ruler was used to scale the surface area to mm^2, whereas in the posteroanterior radiograph the ear rods were used. Consequently, the following measurements for the sinus area were generated:

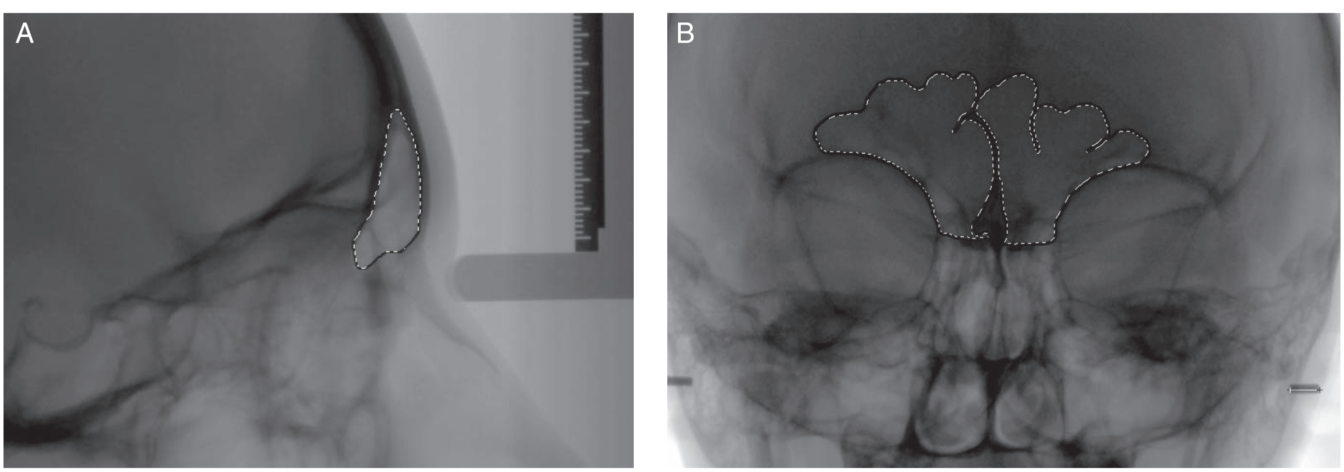

Figure 1. Tracing and measurements of frontal sinus area using Adobe Photoshop (Adobe Systems Incorporated, San Jose, Calif) after adding a filter using Image J 1.48v; National Institutes of Health, Bethesda, Maryland). (A) Lateral cephalometric radiograph. (B) Posteroanterior radiograph.

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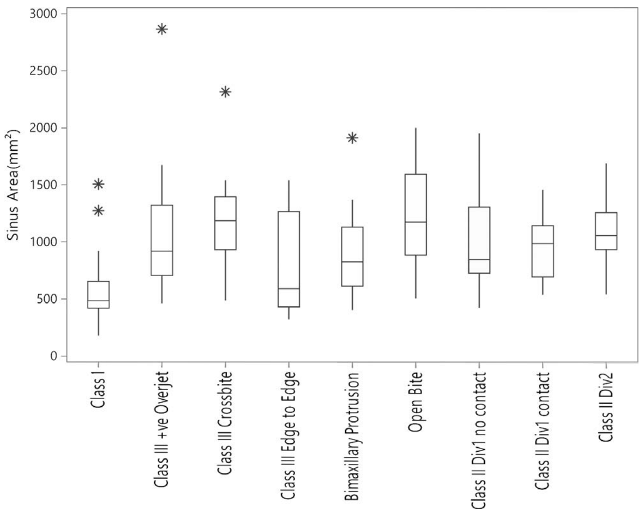

Figure 2. Means and standard deviations illustrated by a box plot for frontal sinus area on postero-anterior radiographs.

- Sinus area on the lateral cephalometric radiograph
- Sinus area on the posteroanterior radiograph

One-way analysis of variance with Tukey's multiple comparison was conducted to compare the sinus areas among the groups. Linear regression analysis with stepwise model selection was performed to study the correlation between anterior occlusion and sinus area. To determine the reproducibility of the results, 20 participants were randomly selected 2 months following the initial measurements, and two investigators retraced the lateral cephalometric radiographs in Dolphin and the frontal sinus on both lateral and posteroanterior radiographs in Photoshop (SAS 9.4v; SAS Institute Inc., Cary, N.C.).

RESULTS

The reliability of the measurements was tested by concordance correlation coefficient. The intrarater reliability was determined to be higher than 0.94 for all measurements, and the interrater reliability was higher than 0.95 for all measurements.

Table 3. Linear Regression Analysis With Stepwise Model Selection for Frontal Sinus Area on Posteroanterior Radiographs

Independent Variable	B[a]	SE[a]	*t* Value	*P* Value
SN mm	33.39	7.14	4.68	<.0001
SNB°	42.47	13.52	3.14	.002
MP-SN°	12.16	6.45	1.88	.06
U1-PP°	−20.72	8.88	−2.33	.02
FMIA°	−46.85	12.58	−3.72	.0002
U1-Na°	22.31	8.03	2.78	.01
L1-NB°	−47.73	13.68	−3.49	.0005

[a] B is the unstandardized regression coefficient; SE is the standard error of B.

Aplasia of the frontal sinus was 2.8% unilateral and 6.3% bilateral in the sample.

Frontal Sinus Area on Posteroanterior Radiographs

Means and standard deviations of frontal sinus area are illustrated in a box plot (Figure 2). One-way analysis of variance showed a significant difference among the nine groups ($P = .0001$). Pairwise comparison by Tukey's method is summarized in Table 2. There was a significant difference between class I and all malocclusion groups ($P < .05$) except the edge-to-edge group. There was no significant difference between the different skeletal class II groups nor between the different skeletal class III groups.

The linear regression with model selection showed that the variables in Table 3 had a significant effect and were responsible for 21% of the variation in frontal sinus size on posteroanterior radiographs. All other covariates were removed from the model as their *P* values were higher than .2.

Frontal Sinus Area on Lateral Cephalometric Radiographs

Means and standard deviations of frontal sinus area are illustrated in a box plot (Figure 3). One-way analysis of variance showed a significant difference among the nine groups ($P = .0003$). Pairwise compar-

Table 2. Pairwise Comparison of Frontal Sinus on Posteroanterior Radiograph

	Bimaxillary Protrusion	Class I	Class II div1 Contact	Class III Crossbite	Class II div2	Class III Edge to Edge	Class II div1 No Contact	Class III Positive Overjet
Class I	0.0233*							
Class II division 1 contact	0.6815	0.0075*						
Class III crossbite	0.0287*	<0.0001*	0.0743					
Class II division 2	0.1439	0.0003*	0.2838	0.5211				
Class III edge to edge	0.6456	0.3161	0.4688	0.0612	0.1563			
Class II division 1 no contact	0.5801	0.0049*	0.8864	0.1001	0.3493	0.4143		
Class III positive overjet	0.1191	0.0002*	0.2494	0.5223	0.9762	0.143	0.3126	
Open bite	0.0123*	<0.0001*	0.0353*	0.7441	0.3407	0.0376*	0.0494*	0.3344

*$P < .05$.

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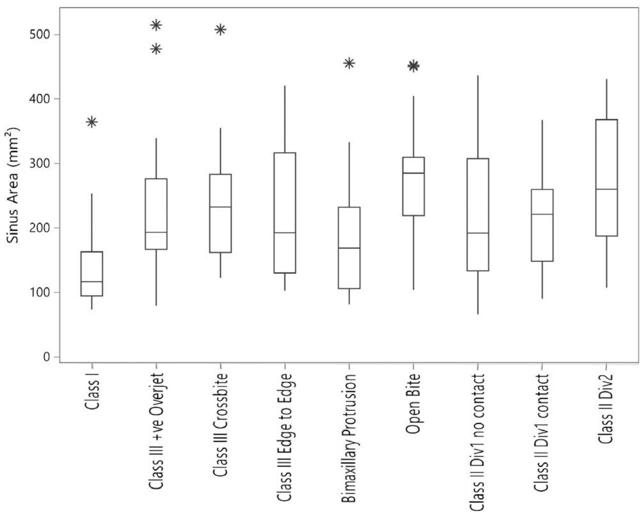

Figure 3. Means and standard deviations illustrated by a box plot for frontal sinus area on lateral cephalometric radiographs.

ison by Tukey's method is summarized in Table 4. There was a significant difference between class I and all malocclusion groups ($P < .05$) except the edge-to-edge and bimaxillary protrusion groups. However, there was no significant difference between the different skeletal class II groups nor between the different skeletal class III groups.

The linear regression with model selection showed that the variables in Table 5 had a significant effect and were responsible for 32% of the variation in frontal sinus size on lateral cephalometric radiographs. All other covariates were removed from the model because their *P* values were higher than .2.

DISCUSSION

The stomatognathic system is part of the craniofacial complex and a relationship exists between them. The more familiar we are with this relationship, the better our understanding and its use in the orthodontic specialty. The purpose of this study was to determine if a relationship exists between anterior occlusion and the frontal sinus size.

Table 5. Linear Regression Analysis With Stepwise Model Selection for Frontal Sinus Area on Lateral Cephalometric Radiographs

Independent Variable	B[a]	SE[a]	*t* Value	*P* Value
SN mm	10.61	1.52	6.98	<.0001
MP-SN°	238.68	116.38	2.05	.04
PP-MP°	−236.28	116.31	−2.03	.04
U1-L1°	12.29	2.84	4.33	<.0001
U1-SN°	246.96	116.54	2.12	.04
U1-PP°	−235.63	116.39	−2.02	.04
FMIA°	−12	2.78	−4.31	<.0001
PFH/AFH	−203.82	139.22	−1.46	.15

[a] B is the unstandardized regression coefficient; SE is the standard error of B.

The results demonstrated that the sinus size was significantly smaller in the class I group compared to all the other malocclusion groups, except the skeletal class III edge-to-edge group on posteroanterior radiographs and both the class III edge-to-edge group and the bimaxillary protrusion group on lateral cephalometric radiographs. The ability to detect a significant difference between the class I group and the bimaxillary protrusion group on only one of the radiographs emphasizes the importance of using biplanar radiographs or cone beam computed tomography (CBCT) for a more three-dimensional perspective. The findings could, in accordance with Wolff's law[16] stated in 1892, explain that the internal architecture of bone changes according to changes in function.

Gross et al.[17] reported that occlusal forces dissipate along three main trajectories: Maxillonasal, Maxillozygomatic, and Maxillopterygoid. Force delivery from the anterior part of the dental arches along the medial periphery of the orbit to the frontal sinus could explain the difference in sinus size between different groups.[3,4] Thus, the class I group with a more harmonious anterior occlusion and skeletal relationship would allow for more adequate force delivery along the maxillonasal trajectory, which would result in a smaller sinus size as reported by the current study.

The group with the largest sinus size was the open bite group, which might be attributed to less transmission of occlusal forces along the nasal pillars, which

Table 4. Pairwise Comparison of Frontal Sinus on Lateral Cephalometric Radiograph

	Bimaxillary Protrusion	Class I	Class II div1 Contact	Class III Crossbite	Class II div2	Class III Edge to Edge	Class II div1 No Contact	Class III Positive Overjet
Class I	0.0836							
Class II division 1 contact	0.5434	0.0196*						
Class III crossbite	0.0468*	0.0002*	0.1648					
Class II division 2	0.0159*	<0.0001*	0.0654	0.6029				
Class III edge to edge	0.5706	0.0936	0.8612	0.469	0.292			
Class II division 1 no Contact	0.4563	0.0136*	0.8905	0.2103	0.0867	0.9314		
Class III positive overjet	0.1867	0.0024*	0.4743	0.4983	0.2438	0.7739	0.5631	
Open bite	0.0041*	<0.0001*	0.0226*	0.3651	0.7288	0.1914	0.0319*	0.1146

*$P < .05$.

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could be due to a lack of contact between maxillary and mandibular incisors and to weaker muscles associated with the hyperdivergent morphology.[18] The open bite group was followed closely by the skeletal class III with anterior crossbite group, the skeletal class III with positive overjet group and the skeletal class II division 2 group. There was no significant difference in frontal sinus size among participants with the same skeletal classification and different anterior occlusions.

Both linear regressions with model selection conducted demonstrated that the anterior cranial base length (SN), the facial divergence (SN-MP), and the inclination of the maxillary incisor in relation to the palate (U1-PP) were statistically significant variables explaining frontal sinus size. This suggests that patients with a long anterior cranial base or retroclined maxillary incisors or anterior open bites will have larger frontal sinus size.

Other covariates had a significant effect limited to a single plane of the sinus. The relationship of the mandible to the cranial base (SNB) and lower incisor inclination (L1-NB) had a significant effect on the width of the sinus, whereas the inclination between maxillary and mandibular incisors had a significant effect on the depth of the sinus.

Both regression models did not fully explain the variation in sinus size. This highlights the role played by other factors such as bone density and forces of the muscles of mastication in determining the frontal sinus size. However, changes in occlusion and jaw relationships will affect sinus size, as shown by Prado et al.[6]

The current results differ from a few studies[11,13] due to differences in the methodology. Dah-Jouonzo et al.[14] demonstrated that their class III group followed by class II division 1 had the largest frontal sinus and that the class I and class II division 2 groups had the same sinus size. Their sample consisted of CBCTs of surgical patients. Consequently, the class I group might have included open bite cases, which was reported by our study to have one of the largest frontal sinuses. This could explain the difference in hierarchy of frontal sinus size reported between the two studies.

The current sample had multiple groups, and the exclusion and inclusion criteria were very rigid. These made it challenging to attain a large CBCT sample, especially because many CBCTs were taken without including the complete frontal sinus in the field of view. Thus, lateral cephalometric and posteroanterior radiographs were used for the study. According to Spaeth et al.,[11] the results from their CT study were comparable to previous radiographic studies.

In the current study, the sample size for the class II division 2 group was small, consistent with the 3.4% prevalence of this type of malocclusion as reported by Ast et al.[19] Also, the sample size of the edge-to-edge group was small due to the low incidence of class III,[20] and the results related to this group should be interpreted with caution. Furthermore, the sample overall was too small to permit additional stratification by ethnicity or gender or to conduct a linear regression specific to each skeletal group.

In the future, it may be interesting to conduct investigations to assess if changes in the frontal sinus size can be used as an indicator for treatment stability. For example, when the alteration of the internal bony architecture following orthognathic surgery is almost complete, delaying the removal of appliances until after sinus remodeling may lead to less physiological rebound. Similarly, an investigation could be conducted to determine whether frontal sinus remodeling could be used as an indicator that the condylar remodeling[21] observed during growth modification using class II correctors has occurred and whether less relapse would occur if removal of the such appliances were delayed until this stage.

CONCLUSION

A significant relationship was found between anterior occlusion and the frontal sinus size. The following was deduced:

- The frontal sinus size could be used as an indicator of harmonious anterior occlusion.
- There were no differences in frontal sinus size among the subgroups of each skeletal malocclusion.
- Clinical use of CBCT or biplanar radiographs could provide a better estimate of actual sinus size than using the lateral cephalometric radiograph only.
- SN, MP-SN, and U1-PP have a significant effect on frontal sinus size
- Further studies should be conducted to delineate further clinical implications of changes in sinus size.

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