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Original research

The relationship between frontal sinus dimensions and skeletal malocclusion

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Purpose
The aim of this retrospective research is to compare frontal sinus dimensions in skeletal Class I, skeletal Class II, and skeletal Class III individuals and to evaluate the relationship of these dimensions with anterior skull base length and some cephalometric values.

Materials and Methods
In this research, we used lateral cephalometric radiographs of 60 people aged 17 to 25. In individuals with skeletal Class I malocclusion, skeletal Class II malocclusion due to mandibular insufficiency, and skeletal Class III malocclusion due to mandibular excess, measurements of frontal sinus length and height as well as S-N, Co-A and Co-Gn lengths, ANB^0, FMA^0, SN-GoGn^0 angles values were performed. The length between the highest point and the lowest point of the frontal sinus was calculated as the height of the frontal sinus, and the length between the most anterior and the most posterior points of the frontal sinus was calculated as the length of the frontal sinus.

Results
The frontal sinus length and height were found to be higher in skeletal Class III individuals than in skeletal Class I and skeletal Class II individuals, however, there was no significant difference between skeletal Class I and Class II individuals.

Conclusion
The increase in frontal sinus height and length correlated positively with the decrease in the ANB angle and the increase in the SN and Co-Gn lengths. The dimensions of the frontal sinus may be an indicator for the remaining mandibular growth potential.

Keywords: *Frontal sinus, cephalometry, mandible, skeletal malocclusion, growth*

Introduction

Growth modification is frequently used in the treatment of skeletal Class II and Class III malocclusion during growth and development (1–3). In this treatment method, where functional appliances can be used, the growth and development of the nasomaxillary complex as well as the growth potential of the lower jaw in the sagittal direction are important for the treatment to be applied to the individual. The close relationship of the growth and development, spurt periods of the mandible with the general growth and development of the individual directly affects the stability and success of the treatment (4,5).

Various methods are used to accurately predict the growth and development periods of individuals. These methods include chronological age, tooth age, height and weight gain, menarche, and bone age (1). In the bone age method, one of the most reliable methods, hand-wrist radiographs are frequently used (6). These radiographs have advantages such as the spread of the calcification of many bones in the hand-wrist area

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over a wide range, different union times of the epiphysis and diaphysis, obtaining images close to the actual size, and low superposition. However, it has been noted that it has disadvantages such as exposure to radiation second time, loss of time, cost, being in a region far from the nasomaxillary complex, and being not ideal in representation due to being a small component of the skeletal system (7–9).

Ruf and Pancherz (10) have stated that the frontal sinuses, one of the paranasal sinuses, could be an indicator of the growth pattern of the nasomaxillary complex. Also, there are studies in the literature regarding the use of frontal sinuses in areas such as age, gender, and forensic medicine (11,12). It has been reported that the frontal sinus bud, which was located in the ethmoid region after birth, cannot be observed on radiography until the age of eight, and that most of its development is completed until the age of $13_{3/4}$ in females and $15_{1/2}$ in males. This growth in the frontal sinuses has been stated to coincide with the growth and spurt period observed 1.4 years on average after the maximum height increase (12,13).

Considering that mandibular growth can continue until the age of 18 in females and 20 in males, the prediction of mandibular growth and development in individuals with skeletal Class II malocclusion with mandibular insufficiency and skeletal Class III malocclusion with mandibular excess is important in terms of the success of orthodontic treatment (14). At this point, it has been reported that there might be a correlation between the frontal sinus, which completes its development at an earlier age, and skeletal malocclusion in the sagittal direction. Also, it has been stated that it could give an idea about the malocclusion that may occur and about the prediction of the possibility of orthognathic surgery (15).

In the light of this information, this study aims to compare frontal sinus dimensions in skeletal Class I, skeletal Class II, and skeletal Class III individuals and to evaluate the relationship of these dimensions with S-N, Co-A and Co-Gn lengths and ANB^0, FMA^0, SN-GoGn^0 angles values. The main null hypothesis tested in this research is that the frontal sinus dimensions are not related either with S-N, Co-A or Co-Gn lengths or ANB^0, FMA^0, SN-GoGn^0 angles values.

Material and Methods

Ethical statement

The ethics committee approval was obtained from Van Yuzuncu Yil University Faculty of Medicine Research Ethics Committee (2019/15-02). Informed consent was obtained for the use of cephalometric radiographs taken for diagnostic purposes.

Study design

This retrospective research was carried out using lateral cephalometric radiographs, found in the archives of Van Yuzuncu Yil University, Faculty of Dentistry, Department of Orthodontics, of 60 individuals (35 females, 25 males) between the ages of 17-25 who were admitted for orthodontic treatment between 2014-2018.

The study group included cephalometric radiographs of individuals who had not previously received orthodontic treatment, had no cleft lip-palate and systemic syndrome, no frontal sinus pathology, and had skeletal Class I, skeletal Class II malocclusion due to mandibular deficiency, and skeletal Class III malocclusion due to mandibular excess. Lateral cephalometric radiographs with poor image quality for measurement and in which the frontal sinus dimensions could not be observed were excluded from the study.

Imaging protocols

All lateral cephalometric radiographs were taken with the Sirona Orthophos XG (Bensheim, Germany) imaging system. Lateral cephalometric radiographs were imported into the NemoCeph NX 2005 software package (Nemotec, Madrid, Spain). To minimize magnification, it was calibrated with a ruler of known length on the forehead bar before measuring length values on cephalometric radiographs. Lateral cephalometric radiographs were drawn by a single investigator (YT) (Figure 1).

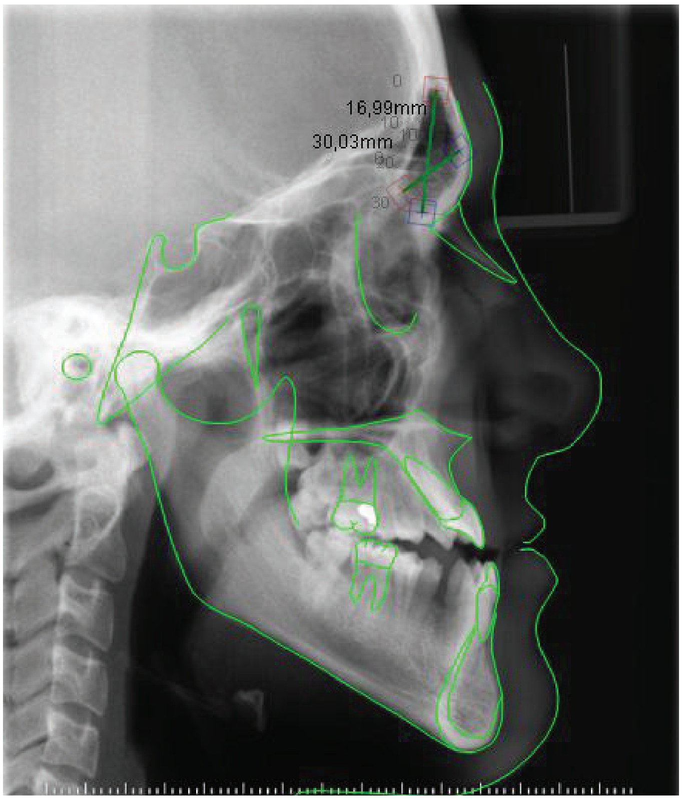

Figure 1. *Determining cephalometric points and evaluating values.*

Sample size determination

According to previous studies; the standard deviations (Σ) for frontal sinus width varies between 3 and 4 (16). Therefore, standard deviation was considered as 3.5. For the 95% of confidence coefficient and approximetaly 80% power value the effect size (d) was assumed as 1.5, and Z value 1.96 was used for the 0.05 type I error rate. The sample size was found to be approximately 20 by using the equation for sample size calculation ($n = Z^2\ \Sigma^2\ /d^2$)

Image analysis

Thirteen points are marked, and three angles and five length values are calculated (Table 1). According to the angle ANB,

Table 1: *Definition of points, angles and lengths used in the research.*

A-point (A)	The deepest point on the maxillary alveolar process's outer contour.
B-point (B)	The deepest point on the mandibular alveolar process's outer contour.
Sella (S)	Midpoint of sella
Nasion (N)	The most anterior point of the frontonasal suture
Gonion (Go)	Intersection of the lines tangent to the ramus's posterior border and the mandible's lower border
Gnathion (Gn)	The point on the bony chin that is the most anterior and inferior.
Porion (Po)	Uppermost point of the external auditory meatus
Orbitale (Or)	Lowermost point of the bony orbita
Condylion (Co)	The most posterosuperior point on the curvature of the average of the right and left outlines of the condylar head
SN-GoGn^0	The angle between the anterior cranial base (SN) and the mandibular plane (GoGn)
ANB^0	The angle between the N-A and N-B lines
FMA^0	The angle between the Go-Gn and Frankfurt Horizontal (Po-Or lines
S-N	The distance between S point and N point
Co-A	The distance between Co point and A point
Co-Gn	The distance between Co point and Gn point
SH	The highest point of frontal sinus
SL	The lowest point of frontal sinus
SA	The most anterior point of the frontal sinus
SP	The most posterior point of the frontal sinus
FSH	The length between the highest point (SH) and the lowest point (SL)
FSL	The length between the most anterior (SA) and the most posterior (SP) points

which is the angle between the Nasion, A, and B points, three equal groups were created consisting of skeletal Class I (20 individuals, $0^0 \leq ANB \leq 4^0$), skeletal Class II due to mandibular deficiency (20 individuals, $4^0<ANB$) and skeletal Class III due to mandibular excess (20 individuals, $ANB <0^0$). Moreover, the part located between the sella (S) and nasion (N) points was calculated as the anterior skull base length, the part between the condilion (Co) and A points was calculated as the effective maxillary length, and the part between the condilion (Co) and gnathion (Gn) points was calculated as the effective mandibular length Furthermore, the Sella-Nasion-Gonion-Gnathion plane angle (SN-GoGn) and the Frankfort-mandibular plane angle (FMA), two commonly used angles, were analyzed in terms of the groups' vertical values (17,18).

In order to evaluate the dimensions of the frontal sinus, four points were determined on the inner surface of the cortical bone that limit the frontal sinus. These are defined as the highest point of the frontal sinus (SH), the lowest point of the frontal sinus (SL), the most anterior point of the frontal sinus (SA), and the most posterior point of the frontal sinus (SP). The length between the highest point and the lowest point of the frontal sinus was calculated as the height of the frontal sinus (FSH), and the length between the most anterior and the most posterior points of the frontal sinus was calculated as the length of the frontal sinus (FSL) (19). The points of the frontal sinus were determined by another researcher (VK) (Figure 2).

Inter-observer error rate was evaluated using the intraclass correlation coefficient. Ten randomly selected cephalometric radiographs were drawn again three weeks after the first measurements by the same researchers. It was determined that the intraclass correlation coefficient for all repeated measurements was 0.815.

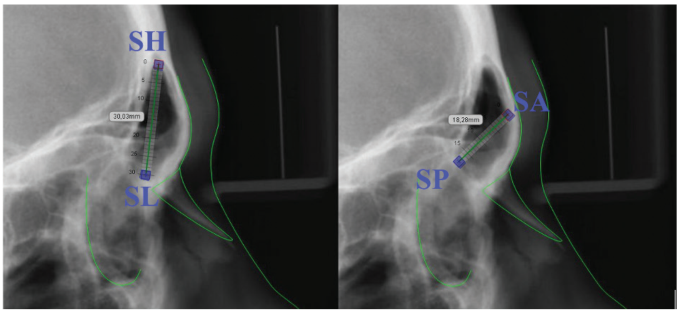

Figure 2. *Points used to calculate the height and length of the frontal sinus.*

Statistical analysis

Statistical analysis was performed using SPSS for Windows version 21.0 (IBM SPSS Armonk, NY, USA) statistical software package. Pearson's Chi-Square test, and One-way Analysis of Variance (ANOVA) was performed to compare the means of groups in terms of continuous variables. Following the analysis of variance, the Duncan multiple comparison test was used to determine the different groups. Pearson's correlation coefficient was calculated separately for each group to determine the correlation between these variables. The confidence interval was set to 95% and p values less than 0.05 were considered as statistically significant

Results

The demographic data of the individuals included in the study are shown in Table 2. There was no significant difference

Table 2: *Demographic variables of the study.*

		Skeletal Class I	Skeletal Class II	Skeletal Class III	p[1]
n (%)	Female	13 (65%)	13 (65%)	11 (55%)	0.754
	Male	7 (35%)	7 (35%)	9 (45%)	
	Total	20 (100%)	20 (100%)	20 (100%)	
Age (year) Mean±SD		19.74±2.5	19.85±2.3	20.24±2.3	

SD: Standard deviation [1]Pearson chi-square test (p<0.05).

Table 3: *Comparison of ANB angles S-N, Co-A and Co-Gn lengths among groups.*

	Groups	Mean±SD	Minimum	Maximum	p[2]
ANB (⁰)	Skeletal Class I	2.26±1.00[a]	1.0	3.7	0.001
	Skeletal Class II	6.10±1.07[b]	5.0	9.0	
	Skeletal Class III	-2.34±1.35[c]	-6.0	-8.0	
S-N (mm)	Skeletal Class I	67.56±3.57	62.2	75.8	0.570
	Skeletal Class II	66.76±2.85	62.0	73.4	
	Skeletal Class III	66.59±2.71	62.3	71.6	
Co-A (mm)	Skeletal Class I	82.46±5.03	68.4	93.2	0.089
	Skeletal Class II	83.52±4.86	75.7	92.2	
	Skeletal Class III	79.87±5.92	68.9	90.0	
Co-Gn (mm)	Skeletal Class I	110.83±5.99[a]	98.2	121.3	0.007
	Skeletal Class II	106.95±7.19[ab]	95.4	119.6	
	Skeletal Class III	114.28±7.93[ac]	102.5	128.3	

SD: Standard deviation [2]Oneway ANOVA test; (p<0.05) [a, b, c]: shows the difference between groups in the same row.

between the groups in terms of female-male ratio and mean age. No significant difference was found between the skeletal Class I, Class II and Class III groups in terms of SN and Co-A lengths, while the Co-Gn length was longer in skeletal Class III individuals than in skeletal Class II individuals (Table 3).

The frontal sinus length and height were found to be higher in skeletal Class III individuals than in skeletal Class I and skeletal Class II individuals, however, no significant difference was found between skeletal Class I and Class II individuals (Table 4).

When measured vertically, the SN-GoGn angle ranged between 31.2±6.0 and 33.2±4.3 degrees; the FMA angle was between 22.8±3.7 and 23.7±4.1 degrees. Furthermore, no significant differences in SN-GoGn and FMA values were found between the groups (Table 5).

As a result of the correlation analysis, it was determined that there was a negative correlation between the frontal sinus height and length, and the ANB angle, and a positive correlation between the S-N and Co-Gn lengths (Table 6).

Discussion

The results of the present study, in which frontal sinus dimensions were compared in individuals with skeletal Class I, Class II and Class III malocclusion,and the relationship between these dimensions and the anterior skull base length and some cephalometric values were evaluated, showed that the Co-Gn length was longer in skeletal Class III individuals than in class II individuals and the frontal sinus length

Table 5: *Comparison of FMA and SN-GoGn between groups.*

	Groups	Mean±SD	Minimum	Maximum	p[2]
FMA (⁰)	Skeletal Class I	23.1±3.7	17.0	27.9	0.740
	Skeletal Class II	23.7±4.1	17.0	31.3	
	Skeletal Class III	22.8±3.7	16.2	29.2	
SN-GoGn (⁰)	Skeletal Class I	31.8±4.6	22.4	38.3	0.429
	Skeletal Class II	33.2±4.3	22.9	41.0	
	Skeletal Class III	31.2±6.0	17.6	38.9	

SD: Standard deviation; [2]Oneway ANOVA test; (p<0.05) FMA: SN-GoGn:

Table 4: *Comparison of frontal sinus height and length between groups.*

	Groups	Mean±SD	Minimum	Maximum	p[2]
FSH (mm)	Skeletal Class I	24.44±4.20[a]	16.05	31.33	0.001
	Skeletal Class II	24.00±4.22[a]	16.14	31.50	
	Skeletal Class III	29.87±3.91[b]	24.75	36.73	
FSL (mm)	Skeletal Class I	14.03±2.93[a]	9.04	19.74	0.001
	Skeletal Class II	13.81±2.57[a]	9.55	18.77	
	Skeletal Class III	17.23±3.68[b]	11.54	25.16	

SD: Standard deviation; [2]Oneway ANOVA test; (p<0.05) FSH: Height of the frontal sinus; FSL: Length of the frontal sinus a, b, c: shows the difference between groups in the same row

Table 6: *Correlation analysis of the height and length of the frontal sinus between the ANB angle and length of ANB S-N, Co-A, and Co-Gn.*

	ANB (⁰)	S-N (mm)	Co-A (mm)	Co-Gn (mm)
Height of the frontal sinus	-0.539**	0.322*	0.100	0.443**
Length of the frontal sinus	-0.452**	0.301*	0.141	0.384**

*: p<0.05; **: p<0.01

and height was higher in skeletal class III individuals than in Class I and Class II individuals. Besides, it was determined that there was a negative correlation between the frontal sinus height and length, and the ANB angle, and a positive correlation between the S-N and Co-Gn lengths.

It has been stated that the frontal sinus, which is thought to play a role in the development of respiratory functions and the architecture of the skull, is also effective in nasomaxillary complex and mandible taking its final shape (13,20). Although it has been stated that the frontal sinus continues to grow until the age of 18-20, it expands greatly at the age of 12 in parallel with the pubertal and growth and spurt period, and then reaches its maximum width and length until the age of 14-16 (20). Besides, it has been reported that each individual has a unique frontal sinus shape as in fingerprints, and its volume is affected by factors such as race, environmental factors, the individual's growth and development pattern, and gender. In studies comparing frontal sinus volumes between genders, it was observed that males have a larger volume than females (11,13). For this reason, individuals in the age range of 17-25 with equal ratios of males and females were included in our study in order to prevent the frontal sinus from being affected by age and gender-related changes.

The two-dimensional lateral cephalometric films have been frequently used in studies in which the frontal sinus dimensions were evaluated in cases such as skeletal malocclusion, gender, pubertal spurt, and forensic medicine (12,16). Lateral cephalometric films, which are routinely taken as one of the orthodontic diagnostic materials, have disadvantages such as being two-dimensional and superimposition of hard tissues. However, the use of lateral cephalometric films was preferred in the calculation of frontal sinus dimensions in our study due to the additional radiation and costs of three-dimensional imaging techniques.

There are studies in the literature comparing frontal sinus dimensions and area with lateral cephalometric radiographs in individuals with skeletal Class I, Class II and Class III malocclusion. In one of these studies, Yassaei *et al*. (16) have reported that frontal sinus size and volume are larger in individuals with skeletal Class III malocclusion than in individuals with skeletal Class I and Class II malocclusions. Similarly, in a study by Prashar *et al*., (21) in which only the frontal sinus area was evaluated, it was reported that it was larger in individuals with skeletal Class III malocclusion than in individuals with Class I and Class II malocclusions. In another study comparing individuals with skeletal Class I and Class II malocclusions, no significant difference was observed between the two groups in terms of frontal sinus dimensions (22). In our study, consistent with the results of current studies, it was found that frontal sinus height and length were higher in individuals with skeletal Class III malocclusion than in skeletal Class I and Class II individuals, and no significant difference was observed between skeletal Class I and Class II individuals.

Again, as a result of the correlation analysis, it was observed that there was a negative correlation between the frontal sinus height and length, and the ANB angle, and a positive correlation between the S-N and Co-Gn lengths. In a study by Tehranch *et al*., (17) in which no skeletal classification was made in the sagittal direction, frontal sinus dimensions were evaluated from lateral and posteroanterior cephalometric radiographs in 144 individuals. As a result of the study evaluating cephalometric values such as SN-FH, Mand-SN, Occ-SN, total of posterior angles, face angle, Jarabak index, ANB, SNA, SNB, Wits, and Y-axis angle, consistent with our findings, it was stated that there was a negative correlation between the frontal sinus dimensions and ANB angle, and that the location of the nasion point might change due to the frontal sinus dimensions and accordingly the dimensions of the anterior skull base were affected. In another study in which skeletal Class I and Class III individuals were compared and cephalometric values such as maxillary length, mandibular length, condylar length, symphysis width, FMA angle, and ANB angle were evaluated, a negative correlation was reported between frontal sinus area and ANB, and a positive correlation between that and mandibular length (22).

The treatment of skeletal class III individuals with excessive mandibles through both growth and development and adulthood is difficult. The goal of this research was to examine if there was a relationship between the height and length of the fronral sinus, which completed most of the mandible's growth according to the growth spurt period. At this point, the observation that individuals with large frontal sinus height and length are more likely to be in skeletal class III individuals than skeletal class I and skeletal class II individuals suggests that we should consider the possibility of mandible breakthrough in individuals in the growth and development period in the future.

Two-dimensional measurements made from lateral cephalometric radiographs and small sample size are among the major limitations of this study. Hence, further research in which frontal sinus dimensions are evaluated with three-dimensional methods in larger sample sizes should be performed.

Conclusion

Within the limitations of our study, it was determined that the increase in frontal sinus height and length correlated positively with the decrease in ANB angle and the increase in SN and Co-Gn lengths. Therefore, the dimensions of the frontal sinus may be an indicator of individuals skeletal Class III malocclusion with mandibular excess.

Türkçe Özet: *Frontal Sinüs Boyutları ile İskelet Maloklüzyon Arasındaki İlişki. Amaç: Bu retrospektif araştırmanın amacı frontal sinüs boyutlarının iskeletsel Sınıf I, iskeletsel Sınıf II ve iskeletsel Sınıf III bireylerde ve bu boyutların ön kafa kaidesi uzunluğu ve bazı sefalometrik değerlerle* *ilişkisinin karşılaştırılmasıdır. Gereç ve Yöntem: Bu araştırmada yaşları 17 ile 25 arasında değişen 60 kişinin lateral sefalometrik radyografileri kullanıldı. İskeletsel Sınıf I maloklüzyon, mandibular yetmezliğe bağlı iskeletsel Sınıf II maloklüzyon ve mandibular fazlalığa bağlı iskeletsel Sınıf III maloklüzyona sahip bireylerde frontal sinüs uzunluğu ve yüksekliği ile SN, Co-A, Co-Gn uzunlukları ve ANB^0, FMA^0, SN-GoGn^0 açı değerleri değerlendirildi. Frontal sinüsün en yüksek noktası ile en alt noktası arasındaki uzunluk frontal sinüsün yüksekliği, frontal sinüsün en ön ve en arka noktaları arasındaki uzunluk ise frontal sinüsün uzunluğu olarak hesaplandı. Bulgular: Frontal sinüs uzunluğu ve yüksekliği, iskeletsel Sınıf III bireylerde, iskeletsel Sınıf I ve iskeletsel Sınıf II bireylere göre daha yüksek bulundu, ancak iskeletsel Sınıf I ve Sınıf II bireyler arasında anlamlı bir farklılık yoktur. Sonuç: Frontal sinüs yüksekliği ve uzunluğundaki artışın ANB açısındaki azalma ve SN ve Co-Gn uzunluklarındaki artış ile pozitif ilişkili olduğu belirlendi. Frontal sinüsün boyutlarının da kalan mandibular büyüme potansiyeli için bir gösterge olabileceği düşünülmektedir. Anahtar Kelimeler: Frontal Sinus, sefalometri, mandibula, iskeletsel maloklüzyon, büyüme.*

Ethics Committee Approval: The ethics committee approval was obtained from Van Yuzuncu Yil University Faculty of Medicine Research Ethics Committee (2019/15-02).

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: MT participated in designing the study. VK, YT participated in generating the data for the study. VK, YT participated in gathering the data for the study. YK participated in the analysis of the data. MT wrote the majority of the original draft of the paper. MT, YK participated in writing the paper. YT has had access to all of the raw data of the study. MT has reviewed the pertinent raw data on which the results and conclusions of this study are based. MT, VK, YK, YT have approved the final version of this paper. MT guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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