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Original Article

Dentistry Section

Correlation between Skeletal Malocclusion and the Dimensions of Maxillary and Frontal Sinuses using Lateral Cephalograms: A Cross-sectional Study

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ABSTRACT

Introduction: Lateral cephalograms are routinely used in orthodontics for accurate assessment and treatment planning of malocclusion. Paranasal air sinuses, such as the maxillary and frontal sinuses, are visible in the lateral cephalogram. However, a direct correlation between the area of these sinuses and the tendency to develop skeletal discrepancies has not been studied in the literature.

Aim: To determine the cephalometric correlation between different skeletal malocclusions and the dimensions of the frontal and maxillary sinuses.

Materials and Methods: A cross-sectional cephalometric study was conducted at a Tertiary Care Centre in Siliguri district of West Bengal, India. The duration of the study was two years, from August 2019 to September 2021. A total of 150 patients were included and they were divided into three equal groups: skeletal class I (n=50), skeletal class II (n=50), and skeletal class III (n=50). Multiple cephalometric parameters were traced on the radiographs using Dolphin and AutoCAD software, and they were compared among the three groups. The data were analysed using Pearson's correlation test.

Results: The results showed a statistically significant correlation between Maxillary Sinus Area (MSA) and Gonial angle (r=0.468, p=0.001) in skeletal class I malocclusion. In skeletal class II malocclusion, a significant negative correlation was found between Frontal Sinus Area (FSA) and total mandibular length (r=-0.30, p=0.009). However, no significant negative correlation was found between MSA and any cephalometric parameter in skeletal class II malocclusion.

Conclusion: The present study highlights there was an increase in the size of the maxillary and frontal sinuses was observed in skeletal class II and skeletal class III malocclusion. However, no correlation could be found between skeletal class I malocclusion and the areas of the frontal sinus.

Keywords: Functional appliance, Interceptive orthodontics, Northeastern population, Orthognathic surgery, Paranasal air sinus

INTRODUCTION

A cephalometric radiograph is an essential tool in the orthodontic diagnosis and treatment planning of dental malocclusions and underlying skeletal discrepancies, since its introduction by Broadbent in 1931 [1]. Various anatomical landmarks have been used to assess different malocclusions, which can be accurately and precisely depicted on a lateral cephalogram [2]. One of these landmarks is the paranasal sinuses, which can be easily assessed on the cephalometric radiograph. The paranasal sinuses are a group of air-filled anatomical bony chambers embedded in the bones around the nasal cavity and the midfacial structures. They play an important role in the formation of facial contours [3]. They are named according to the bones they develop from, namely the frontal sinus, maxillary sinus, ethmoidal sinus, and sphenoidal sinus. Of these sinuses, the maxillary, sphenoid, and frontal sinuses can be clearly seen on the lateral cephalogram. The development of these sinuses affects different orthodontic malocclusions, as hypothesised in various studies [4-6].

The maxillary sinus is the largest of the four paranasal sinuses and the first to develop. Its development begins at the ethmoidal infundibulum in the third month of foetal life and continues to grow until the age of 12 years. The sinus has a pyramidal shape and is closely related to the pterygomaxillary and infratemporal fossa. Due to its lateral and inferior growth pattern, the maxillary sinus lies in close proximity to the maxillary posterior teeth, which may affect different types of malocclusions [7]. The frontal sinus is a pair of irregularly shaped cavities that surround the nasal cavity in the frontal bone. Unlike the other sinuses, the frontal sinus is not visible at birth. It becomes radiographically visible after the age of eight years as it projects above the orbital rim due to increasing pneumatisation [6]. The height, width, and area of the frontal sinus are altered in skeletal class III malocclusion [6].

Skeletal pattern prediction has been a controversial topic since its advocacy by ricketts. Understanding the skeletal pattern and its changes can help predict developing malocclusions in children. Knowledge of the development and anatomy of the maxillary and frontal sinuses may be crucial in predicting and improving the orthodontic diagnosis, as well as treatment planning for various malocclusions, by correlating maxillary and mandibular growth [5]. The frontal and maxillary sinuses can be observed in the sagittal plane on the lateral cephalogram and in the coronal plane on the posterior-anterior cephalogram.

Several studies have been conducted to correlate paranasal sinuses with class III malocclusions or to predict growth using methods such as dry skull analysis, panoramic radiography [8], Cone Beam Computed Tomography (CBCT) [9-12], Magnetic Resonance Imaging (MRI) [13], and lateral cephalogram [14]. However, in low-resource settings where access to advanced diagnostics is limited, the lateral cephalogram can serve as a tool for interceptive orthodontics by enabling early detection of skeletal malocclusion using the paranasal air sinuses as references. Taking these factors into consideration, present study aimed to determine the cephalometric correlation between different skeletal malocclusions and the dimensions of the frontal and maxillary sinuses.

MATERIALS AND METHODS

A cross-sectional cephalometric study was conducted at a Tertiary Care Centre in Siliguri district of West Bengal, India with a sample size of 150 (75 females, 75 males). The study spanned a period of two years, from August 2019 to September 2021. Clearance from the Institutional Ethical Committee (IEC) was obtained (certificate number - 2018/P/OR/52).

Inclusion criteria: Patients aged between 14-30 years at the start of orthodontic treatment, with no previous history of orthodontic or orthopaedic treatment. Patients with fully erupted permanent dentition, excluding the third molars and good quality radiographs with clear reproduction of frontal and maxillary sinuses were included in the study.

Exclusion criteria: Patients with paranasal sinus pathology and with any systemic or congenital diseases involving the mid-face. Patients with any prosthetic replacement or missing/impacted tooth and those with syndromes involving craniofacial bones or cleft lip and palate. Patients with trauma to the mid-face or nasomaxillary sinus and with any gross facial asymmetry were excluded from the study.

Sample size calculation: The sample size was determined through power analysis based on the formula:

$$\eta = \frac{\{Z1\text{-}\alpha/2\sqrt{P(1\text{-}P\alpha)}+Z1\text{-}\beta\sqrt{P0(1\text{-}P\alpha)}\}2}{(P\alpha\text{-}P0)2}$$

where P0 is the population proportion, Pα is the sample proportion, α is the significance level, and β is the power.

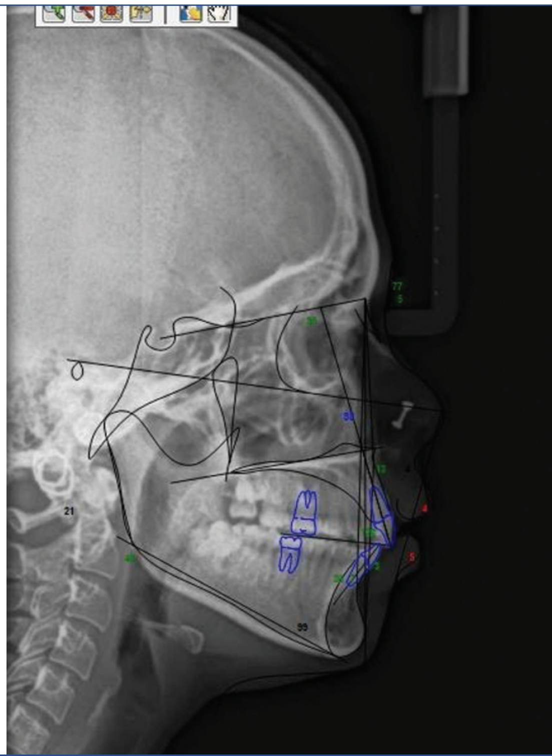
The population proportion was set at 0.04, and the sample proportion was within ±0.06 of the population proportion [11]. The significance level was set at 0.05, and the β value was set at 0.2. With these values, a sample size of 150 (P0) was determined to be sufficient for the study to have 80% power and to be clinically significant in evaluating the association between different skeletal malocclusions and the dimensions of the frontal and maxillary sinuses.

Study Procedure

Based on the ANB Angle obtained from the lateral cephalograms, the sample was divided into three equal groups, each consisting of 50 individuals. An ANB angle between 0°-4° was considered skeletal class I (n=50), an ANB angle greater than 4° was considered skeletal class II (n=50), and an ANB angle less than 0° was considered skeletal class III (n=50). The subjects were randomly selected based on the inclusion and exclusion criteria. The age range of the subjects was 14-30 years. The lateral cephalograms were taken by positioning the patient in such a way that the sagittal plane of the head was vertical to the cephalostat. The teeth were positioned in maximum intercuspation, and the patient's lips were in a relaxed position with the Frankfort horizontal plane parallel to the floor. The natural head position was ensured by using ear rods and forehead positioning knobs. The distance from the tube to the patient was standardised at 5 feet.

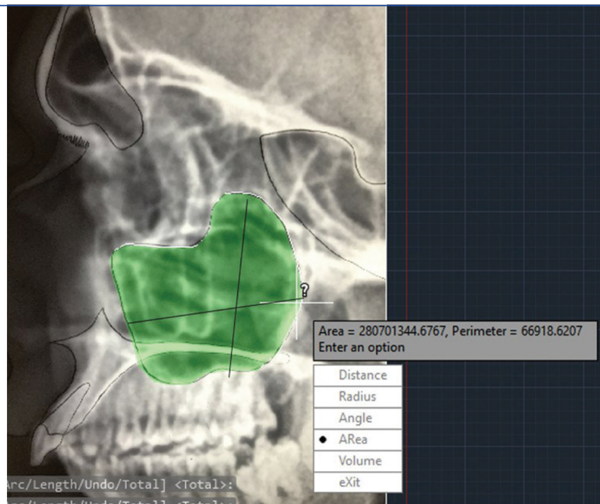
The radiographic apparatus used was X-Mindpan0 D+. The tube voltage was set at 68-72 KvP, with a current of 10 mA, and the scanning time was set at 15 seconds. Digital copies of all subjects were obtained. Cephalometric analysis was performed using Dolphin Imaging Software (Dolphin Imaging Inc., USA). Anatomic landmarks and cephalometric planes were identified on the cephalogram using the software. The dimensions of the sinuses were assessed using AutoCAD software. The collected data was tabulated and analysed [Table/Fig-1].

The digital lateral cephalograms were entered into AutoCAD 2019 Software (Autodesk Inc., USA), and the sinus borders were drawn using the features of the software. The hypothetical line between the outer and inner surfaces of the sinus wall, which appeared opaque, was taken as the sinus border [Table/Fig-2,3].



[Table/Fig-1]: The tracings done in the lateral cephalogram by using the Dolphin software.

[Table/Fig-2]: The tracing of the frontal sinus height, width and area in the lateral cephalogram using the AutoCAD software.



[Table/Fig-3]: The tracing of the total maxillary sinus height, width and area in a lateral cephalogram using the AutoCAD software.

Each radiograph was evaluated twice by the same examiner, with a one-week interval between evaluations, to ensure intraexaminer reliability. The mean of each index was calculated. The measured values are tabulated in [Table/Fig-4-7] [6,7,14].

Reference points and planes	Definitions
Nasion (N)	The most anterior point of the frontonasal suture
Sella turcia (S)-	Midpoint of sella
Articulare-	Intersection of the images of the posterior margin of the ramus and the outer margin of the cranial base
Anterior Nasal Spine (ANS)	The most anterior point of the tip of the anterior nasal spine
Posterior Nasal Spine (PNS)	Intersection of the continuation of the anterior wall of the pterygomaxillary fissure and the nasal floor
Point A (A)	The deepest point on the outer contour of the maxillary alveolar process
Point B (B)	The deepest point on the outer contour of the mandibular alveolar process
Orbitale (Or)	Lower most point of the bony orbit
Menton (Me)	The most inferior point of the outline of the symphysis
Gonion (Go)	Intersection of the lines tangent to of the ramus and the lower border of the mandible
Porion (Po)	Uppermost point of the external auditory meatus
Point Sh-	Highest point on the frontal sinus border
Point Sl-	Lowest point on the frontal sinus border
Point Sa-	Anterior most point on the frontal sinus border
Point Sp	Posterior most point on the frontal sinus border
Point An	Anterior most point on the maxillary sinus border
Point Po	Posterior most point on the maxillary sinus border
Point Su	Superior most point on the maxillary sinus border
Point In	Inferior most point on the maxillary sinus border

[Table/Fig-4]: Reference points and planes used in the AutoCAD and Dolphin softwares for area analysis of the maxillary and frontal sinuses [14].

Linear measurements	Angular measurements
Wits appraisal (WITS)	SNA
Total Length of Mandible (TML)	SNB
Total Length of Maxilla (TMAL)	ANB
Length of the Mandibular Body (MBL)	GA
Length of the Maxillary Body (MAL)	SA
	FA

[Table/Fig-5]: Linear (left) and angular measurements (right) used in the AutoCAD and Dolphin softwares for area analysis of the maxillary and frontal sinuses.
SNA: Sella, nasion, A point; SNB: Sella, nasion, B point; ANB: Anteroposterior position between the maxilla and mandible; GA: Gonial angle; SA: Saddle angle; FA: Facial angle

Frontal sinus indices	Definition
Frontal Sinus Height (FSH)	A line drawn from the superior most point of the sinus to the inferior most point of the sinus.
Frontal Sinus Width (FSW)	A line drawn from the anterior most point of the sinus to the posterior most point of the sinus [3].
Frontal Sinus Area (FSA)	The area of the outlined surface was calculated in mm^2.

[Table/Fig-6]: Frontal sinus indices and their respective definitions [6].

Maxillary sinus indices	Definition
Maxillary Sinus Height (MSH)	A line drawn from the superior most point of the sinus to the inferior most point of the sinus.
Maxillary Sinus Width (MSW)	A line drawn from the anterior most point of the sinus to the posterior most point of the sinus.
Maxillary Sinus Area (MSA)	The area of the outlined surface was calculated, in mm^2.

[Table/Fig-7]: Maxillary sinus indices and their respective definitions [7].

STATISTICAL ANALYSIS

Pearson's correlation coefficient was used to correlate the variable data in the present study, and Statistical Package for Social Sciences (SPSS) statistics (IBM, version 29.0) was used for statistical analysis. The level of statistical significance was set at 0.05.

RESULTS

The mean values of cephalometric variables and the dimensions of the frontal and maxillary sinuses in class I, class II, and class III patients as shown in [Table/Fig-8]. A statistically significant positive correlation was observed between WITS and MSW (r=+0.388; p-value=0.005), Gonial and FSW (r=+0.478; p-value=0.001), Gonial and MSW (r=+0.288; p-value=0.043), and Gonial and MSA (r=+0.468; p-value=0.001) in skeletal class I malocclusion. On the other hand, a significantly negative correlation was seen between FSH and Gonial (r=-0.417; p-value=0.003), Total Length of Maxilla (TMAL) (r=-0.878; p-value=0.001), Total Length of Mandible (TML) (r=-0.518; p-value=0.001), FSW (r=-0.867; p-value=0.001), Maxillary Sinus Width (MSW) (r=-0.539; p-value=0.001), and Maxillary Sinus Area (MSA) (r=-0.554; p-value=0.001) [Table/Fig-9].

S. No.	Mean value of all the parameters	Class I (n=50)	Class II (n=50)	Class III (n=50)
1.	SNA	81.5±1.5	83.5±1.5	77.5±1.5
2.	SNB	80±0.75	78±2.25	80.1±1.75
3.	ANB	1.5±0.5	4.75±1.75	-2±0.5
4.	WITS	0.98±0.1	4.9±3.75	-3±0.75
5.	Gonial angle	126.5±3.0	127.5±2.0	131±2.0
6.	SA	123±3.0	128±1.0	120.2±2.0
7.	FA	81±2.5	85±1.0	84.7±2.50
8.	TMAL	99.8±1.75	77.8±3.25	77.9±1.75
9.	TML	100±4.3	102.8±2.0	114.8±3.75
10.	MABL	49.5±4.25	49.6±1.50	48.2±1.50
11.	MBL	77.2±3.25	68.2±0.75	78.21±1.50
12.	FSH	35.9±3.75	31.7±3.85	38.94±0.75
13.	FSW	14.6±1.75	14.8±3.75	15.9±1.25
14.	FSA	182.4±4.63	253.5±2.75	389.6±3.50
15.	MSH	36.4±2.50	43.6±1.50	39.2±1.25
16.	MSW	33.5±1.50	36.98±2.50	34.2±1.75
17.	MSA	1236±4.0	1523±3.85	1354±4.25

[Table/Fig-8]: Mean values of cephalometric variables and the dimensions of frontal and maxillary sinus in class I, class II and class III patients (N=150).
SNA: Sella, nasion, A point; SNB: Sella, nasion, B point; ANB: Anteroposterior position between the maxilla and mandible; WITS: University of Witwatersrand; SA: Saddle angle; FA: Facial angle; TMAL: Total length of maxilla; TML: Total length of mandible; MABL: Length of maxillary body; MBL: Length of mandibular body; FSH: Frontal sinus height; FSW: Frontal sinus width; FSA: Frontal sinus area; MSH: Maxillary sinus height; MSW: Maxillary sinus width; MSA: Maxillary sinus area

Pearson's correlation revealed a statistically significant positive correlation between Saddle and MSA (r=+0.28; p-value=0.049), Facial and MSA (r=+0.32; p-value=0.025), and a significant negative correlation between ANB and FSW (r=-0.42; p-value=0.002), Saddle and MSW (r=-0.317; p-value=0.03), TMAL and FSW (r=-0.36; p-value=0.01) in class II malocclusion [Table/Fig-10].

A statistically significant positive correlation was seen between SNA and FSW (r=+0.279; p=0.05), TML and FSH (r=+0.355; p-value=0.011). On the other hand, the correlation displayed a statistically significant negative correlation of TML and FSA (r=-0.282; p-value=0.047) and MSW and MSH (r=-0.327; p-value=0.021). The results show that in all skeletal malocclusions, the frontal sinus dimensions have a positive correlation with the mandibular body and length of the mandible, while the maxillary sinus dimensions have a positive correlation with the total length of the maxilla and maxillary base length (p-value <0.05) [Table/Fig-11].

In the skeletal class I malocclusion group, the MSA was significantly higher (p-value=0.025) in males (1758.08 mm^2) than in females (1286.12 mm^2). In the skeletal class III malocclusion group, the MSA was almost equal among males (1224.92 mm^2) and females

Class I	FSH		FSW		FSA		MSH		MSW		MSA	
	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value
SNA	-0.106	0.464	0.055	0.702	-0.116	0.421	0.052	0.718	-0.08	0.582	-0.092	0.527
SNB	-0.125	0.387	0.128	0.377	-0.178	0.217	0.017	0.907	0.061	0.675	-0.037	0.801
ANB	-0.039	0.79	0.024	0.866	0.017	0.904	-0.074	0.608	-0.278	0.051	-0.037	0.801
WITS	-0.14	0.333	0.03	0.838	-0.013	0.93	-0.156	0.278	0.388	0.005*	0.167	0.247
Gonial angle	-0.417	0.003*	0.478	0.001*	0.14	0.331	-0.203	0.157	0.288	0.043*	0.468	0.001*
SA	0.022	0.881	-0.128	0.377	-0.003	0.985	-0.255	0.074	-0.197	0.17	-0.018	0.904
FA	0.117	0.42	-0.151	0.296	-0.08	0.579	-0.069	0.634	-0.073	0.613	-0.099	0.496
TMAL	-0.878	0.001*	0.837	0.001*	0.13	0.367	0.167	0.247	0.546	0.001*	0.569	0.001*
TML	-0.518	0.001*	0.553	0.001*	0.085	0.557	-0.012	0.934	0.326	0.021*	0.237	0.097
MAL	0.253	0.077	-0.229	0.11	0.138	0.34	0.137	0.344	0.22	0.125	-0.014	0.924
MBL	-0.019	0.893	0.086	0.551	0.145	0.317	-0.105	0.47	0.04	0.784	0.057	0.693
FSH	1		-0.867	0.001*	-0.212	0.14	-0.142	0.327	-0.539	0.001*	-0.554	0.001*
FSW	-0.867	0.001*	1		0.174	0.228	0.176	0.223	0.557	0.001*	0.475	0.001*
FSA	-0.212	0.14	0.174	0.228	1		-0.106	0.464	0.245	0.086	0.15	0.3
MSH	-0.142	0.327	0.176	0.223	-0.106	0.464	1		0.023	0.873	-0.043	0.767
MSW	-0.539	0.001*	0.557	0.001*	0.245	0.086	0.023	0.873	1		0.485	0.001*
MSA	-0.554	0.001*	0.475	0.001*	0.15	0.3	-0.043	0.767	0.485	0.001*	1	

[Table/Fig-9]: Correlation between the cephalometric values and the maxillary and frontal sinuses in skeletal class I Malocclusion.
SNA: Sella, nasion, A point; SNB: Sella, nasion, B point; ANB: Anteroposterior position between the maxilla and mandible; WITS: University of Witwatersrand; SA: Saddle angle; FA: Facial angle; TMAL: Total length of maxilla; TML: Total length of mandible; MABL: Length of maxillary body; MBL: Length of mandibular body; FSH: Frontal sinus height; FSW: Frontal sinus width; FSA: Frontal sinus area; MSH: Maxillary sinus height; MSW: Maxillary sinus width; MSA: Maxillary sinus area

Class II	FSH		FSW		FSA		MSH		MSW		MSA	
	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value
SNA	-0.08	0.58	-0.08	0.58	-0.17	0.23	0.25	0.08	0.12	0.40	-0.05	0.71
SNB	-0.13	0.37	0.21	0.15	-0.09	0.53	0.25	0.08	0.00	1.00	-0.13	0.39
ANB	0.11	0.44	-0.42	0.002*	0.19	0.20	-0.04	0.79	0.10	0.50	-0.01	0.95
WITS	0.14	0.33	0.22	0.12	-0.23	0.11	0.11	0.45	0.02	0.89	0.24	0.10
Gonial angle	-0.06	0.69	-0.13	0.38	0.12	0.40	-0.01	0.95	-0.14	0.35	0.19	0.18
SA	0.18	0.22	0.01	0.95	-0.12	0.41	-0.02	0.90	-.317	0.03*	0.28	0.049*
FA	-0.09	0.53	0.10	0.51	-0.21	0.15	-0.08	0.59	0.08	0.58	0.32	0.025*
TMAL	-0.14	0.34	-0.36	0.01*	0.40	0.004*	0.358	0.01*	.284	0.05*	-0.61	0.001*
TML	0.15	0.30	0.22	0.12	-0.37	0.009*	-0.301	0.03*	-0.05	0.71	0.62	0.001*
MAL	-0.16	0.26	-0.23	0.12	-0.09	0.52	0.04	0.78	.326	0.02*	-0.13	0.38
MBL	0.03	0.86	-0.05	0.74	-0.01	0.93	0.15	0.29	0.08	0.56	-0.26	0.07
FSH	1.00		0.05	0.71	0.08	0.56	-0.05	0.73	-0.01	0.95	0.21	0.15
FSW	0.05	0.71	1.00		-0.06	0.68	0.06	0.70	-0.04	0.76	0.02	0.91
FSA	0.08	0.56	-0.06	0.68	1.00		0.28	0.05	-0.08	0.59	-0.35	0.014*
MSH	-0.05	0.73	0.06	0.70	0.28	0.05	1.00		-0.17	0.24	-0.34	0.016*
MSW	-0.01	0.95	-0.04	0.76	-0.08	0.59	-0.17	0.24	1.00		-0.17	0.23
MSA	0.21	0.15	0.02	0.91	-0.35	0.014*	-0.34	0.016*	-0.17	0.23	1.00	

[Table/Fig-10]: Correlation between the cephalometric values and the maxillary and frontal sinuses in skeletal class II malocclusion.
SNA: Sella, nasion, A point; SNB: Sella, nasion, B point; ANB: Anteroposterior position between the maxilla and mandible; WITS: University of Witwatersrand; SA: Saddle angle; FA: Facial angle; TMAL: Total length of maxilla; TML: Total length of mandible; MABL: Length of maxillary body; MBL: Length of mandibular body; FSH: Frontal sinus height; FSW: Frontal sinus width; FSA: Frontal sinus area; MSH: Maxillary sinus height; MSW: Maxillary sinus width; MSA: Maxillary sinus area

Class III	FSH		FSW		FSA		MSH		MSW		MSA	
	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value
SNA	0.101	0.486	0.279	0.05*	-0.063	0.664	0.01	0.946	-0.041	0.776	0.143	0.322
SNB	0.009	0.951	0.12	0.406	-0.063	0.665	-0.016	0.914	0.201	0.161	-0.014	0.921
ANB	0.082	0.569	0.223	0.119	-0.039	0.787	0.102	0.481	-0.092	0.527	0.092	0.527
WITS	0.154	0.285	-0.158	0.274	-0.102	0.48	-0.019	0.897	0.189	0.188	0.015	0.918
Gonial angle	0.135	0.348	0.104	0.474	-0.205	0.153	0.012	0.932	0.051	0.726	-0.189	0.188
SA	0.056	0.7	0.145	0.317	-0.086	0.553	0.144	0.318	-0.118	0.416	-0.025	0.863
FA	-0.038	0.791	0.053	0.717	-0.059	0.685	-0.068	0.64	-0.077	0.594	0.083	0.568
TMAL	0.116	0.422	0.151	0.294	-0.032	0.826	0.057	0.693	0.087	0.547	-0.063	0.663

TML	0.355	0.011*	-0.029	0.839	-0.282	0.047*	-0.028	0.846	-0.011	0.938	-0.01	0.947
MAL	0.022	0.881	-0.139	0.335	0.065	0.655	0.056	0.7	0.273	0.055	-0.057	0.694
MBL	-0.093	0.519	0.217	0.13	0.111	0.441	0.228	0.111	0.027	0.852	-0.014	0.922
FSH	1		0.007	0.964	-0.025	0.864	0.151	0.294	-0.132	0.359	-0.053	0.714
FSW	0.007	0.964	1		-0.141	0.328	0.105	0.469	-0.07	0.627	0.158	0.273
FSA	-0.025	0.864	-0.141	0.328	1		0.247	0.084	-0.052	0.722	0.001	0.992
MSH	0.151	0.294	0.105	0.469	0.247	0.084	1		-0.327	0.02*	-0.032	0.824
MSW	-0.132	0.359	-0.07	0.627	-0.052	0.722	-0.327	0.02*	1		0.135	0.349
MSA	-0.053	0.714	0.158	0.273	0.001	0.992	-0.032	0.824	0.135	0.349	1	

[Table/Fig-11]: Correlation between the cephalometric values and the maxillary and frontal sinuses in skeletal class III malocclusion.
SNA: Sella, nasion, A point; SNB: Sella, nasion, B point; ANB: Anteroposterior position between the maxilla and mandible; WITS: University of Witwatersrand; SA: Saddle angle; FA: Facial angle; TMAL: Total length of maxilla; TML: Total length of mandible; MABL: Length of maxillary body; MBL: Length of mandibular body; FSH: Frontal sinus height; FSW: Frontal sinus width; FSA: Frontal sinus area; MSH: Maxillary sinus height; MSW: Maxillary sinus width; MSA: Maxillary sinus area

(1229.76 mm^2), whereas the FSA was marginally higher in males (364.12 mm^2) than in females (384.92 mm^2) [Table/Fig-12].

Parameters	Male	Female	p-value
Class 1- MSA	1758.08 mm^2	1286.12 mm^2	0.025
Class 1 FSA	206.48 mm^2	190.76 mm^2	0.014
Class II- MSA	1343 mm^2	1566.92 mm^2	0.001
Class II FSA	274.4 mm^2	241.32 mm^2	0.016
Class III- MSA	1224.92 mm^2	1229.76 mm^2	0.049
Class III FSA	364.12 mm^2	384.92 mm^2	0.001

[Table/Fig-12]: Comparison between the areas of the maxillary and frontal sinuses in skeletal class I, II and III malocclusion among males and females.

DISCUSSION

Lateral cephalograms have commonly been used for orthodontic diagnosis and are often requested as necessary records. Malocclusion, which refers to unfavourable deviations from the norms, has been extensively studied by analysing lateral cephalograms. Rae TC and Koppe T suggested that paranasal air sinuses, including the frontal sinus, are responsible for respiratory function, thermoregulation, and trauma protection. They also contribute to decreasing skull weight and have other functions [15]. Preuschoft H et al., reported that paranasal sinuses have developed in response to the biomechanical needs of skull architecture [16]. Therefore, the present study aimed to assess the correlation between the frontal sinus and maxillary sinus with other craniofacial patterns in assessing skeletal malocclusion.

Frontal sinus and malocclusion: The development and size of the frontal sinus can be crucial for diagnosing and treating various malocclusions. Tanner JM found that the annual height increment in the frontal sinus among children reaches a plateau at 16 years in boys and 14 years in girls. This suggests that the development of the frontal sinus occurs in close harmony with the occlusion [17]. Therefore, any disturbance in the development of the frontal sinus can directly impact the occlusion [8]. Several finite element studies have demonstrated the distribution of masticatory stress throughout the human skull [17-20]. These high magnitude stresses flow from the dental arches along the medial periphery of the orbits, known as “nasal pillars” as defined by Toldt in 1914. These stresses reach the frontal sinus through the nasal septum [19]. Prado reported a reduction in frontal sinus size after six months of correction of a class II open bite malocclusion using maxilla-mandibular advancement with counterclockwise rotation. The authors concluded that the change in size was an adaptation to the stresses induced by a more favourable occlusion [21]. In the present study, authors found that the area of the frontal sinus was directly proportional to the total mandibular length and mandibular body length. Additionally, the frontal sinus area and width were directly proportional to the length of the mandibular body. This suggests that a rapidly growing frontal sinus will be associated with a rapidly growing mandible, and vice versa. A rapidly growing mandible is associated with skeletal class III malocclusion tendencies. Therefore, analysing the area of the frontal sinus can help clinicians predict class III malocclusion tendencies among growing patients, and appropriate interventions can be done using functional and/or fixed appliances [21].

Studies by Ahuja S et al., and Yasseai S et al., showed that frontal sinus dimensions were greater in skeletal class III malocclusion compared to skeletal class I and II [22,23]. Sabharwal A et al., confirmed that a significant difference in the area of the frontal sinus was present in skeletal classes I, II, and III. In the present study, there was a positive correlation between frontal sinus dimensions and cephalometric variables in all skeletal malocclusions [6]. Therefore, the authors can conclude that the frontal sinus plays a significant role in predicting skeletal class III malocclusion tendencies. In severe skeletal class III malocclusion cases, orthognathic surgery is the treatment of choice. However, prior to surgery, once dental anomalies are corrected by fixed appliances, it is desirable to retain the appliance until the age of 18 years. This ensures proper retention and also allows the clinician adequate time to assess the final maxillo-mandibular relationship before planning the surgery.

Herein lies the clinical significance of correlating the development of occlusion with that of the paranasal air sinuses. When the frontal sinus is used as a metric to assess the growth and development of the jaw bones and occlusion, future disharmony in skeletal aspects can be predicted by 14-16 years, enabling clinicians to intercept developing skeletal malocclusions and provide early intervention. This implies that a developing skeletal class III malocclusion can be intercepted by a rapidly developing frontal sinus [21-23].

Among all the paranasal air sinuses, the maxillary sinus is the first to develop in intrauterine life. The maxillary posterior teeth are situated in close proximity to the maxillary sinus, and thus, the dimensions of the maxillary sinus affect orthodontic treatment planning. While Oktay H concluded that maxillary sinus size was not affected by malocclusion and gender [9], Endo T et al., found no significant difference between different skeletal classes in each gender and maxillary sinus measurements [24]. In the present study, a direct correlation was established between the size of the maxillary sinus and the total length of the maxilla and maxillary base length. This implies that volumetric analysis of the maxillary sinus would directly highlight the growth pattern, growth potential, and tendency for skeletal class II malocclusion. This information is critical for clinicians as it helps them predict if the patient exhibits a vertical or horizontal growth pattern.

A developing skeletal class II malocclusion can also be intercepted and treated early with functional appliances, yielding excellent results. The assessment of this specific parameter is relevant because it provides crucial information at an early stage. When intercepted at this stage, the results are long-term, permanent, and stable. Studies by Yassaei S et al., have confirmed that maxillary sinus dimensions are greater in skeletal class II malocclusion [25]. Similar findings were recorded in the present study as well.

Rapidly developing paranasal air sinuses can be assessed by the age of 14 years using lateral cephalograms. A rapidly developing maxillary and/or frontal sinus implies that the patient has above-average growth potential and a greater tendency to develop skeletal class II and/or skeletal class III malocclusion, respectively. Another important outcome of the present study is that volumetric analysis of the paranasal air sinuses helps differentiate between true skeletal class III and pseudo class III malocclusion. In skeletal class III malocclusion, there is a deficient maxilla with a protruded mandible resulting in a true anterior cross bite, whereas in pseudo class III malocclusion, there are proclined lower anteriors and retroclined upper anteriors in normal-sized maxilla and mandible resulting in an anterior cross bite [26]. Furthermore, all this information can be gathered using two-dimensional imaging at lower radiation doses, making it feasible even in low-resource settings.

Limitation(s)

Since the present study was planned with a low or limited resource setting in mind, two-dimensional imaging was used. However, it is worth noting that if the same parameters could have been studied using three-dimensional imaging techniques such as CBCT or non contrast Computed Tomography (CT), it would have provided greater volumetric data, allowing for more precise correlations.

CONCLUSION(S)

The present study highlights that in skeletal class I malocclusion, a significant correlation was found between the MSA and the gonial angle, as well as between MSA and the FA and SA in skeletal malocclusion class II. However, no significant correlation was found between MSA and any cephalometric parameter in skeletal class III malocclusion. When considering the FSA, no significant correlation was found with any cephalometric parameter in skeletal class I malocclusion. Early access to such relevant information, such as the patient's growth pattern and axis, malocclusion tendencies, and probable maxilla-mandibular relationship, through routine diagnostic imaging modalities like lateral cephalograms, can help clinicians intercept such anomalies at an early age and provide necessary treatment with appropriate appliances. This can lead to long-term and stable results, ultimately improving the overall quality of life.

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