Original Article

A cephalometric evaluation of the effect of glenoid fossa location on craniofacial morphology

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ABSTRACT

Aim: The purpose of this study was to assess the effect of glenoid fossa location in various skeletal malocclusions on craniofacial morphology.**Methods:** Cephalometric data of 84 subjects were analyzed for four linear and two angular variables for assessing glenoid fossa location in cranial base and eight linear and eight angular variables for evaluating the corresponding effect on craniofacial morphology using statistical software STATA 12 for windows. Regression analysis was done to see the effect of glenoid fossa location on the parameters measuring craniofacial morphology.**Results:** Significant association between glenoid fossa location and craniofacial morphology was demonstrated in skeletal class I, class II, and class III malocclusion subjects by the regression analysis.**Conclusions:** Glenoid fossa location varies significantly among skeletal malocclusions and glenoid fossa location has a profound effect on craniofacial morphology of skeletal class I, class II, and class III malocclusions.

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1. Introduction

Managing a developing class II and class III malocclusion has always been the aim of an orthodontist. It is important to understand which area of the craniofacial complex is leading to malocclusion and needs to be corrected or brought under control. For instance, treatment modality for a developing class II malocclusion will differ depending on whether the maxilla is positioned forward, mandible is small sized, or glenoid fossa is retro positioned. It deserves to be highlighted that the distal position of the glenoid fossa, as an anatomical condition predisposing to class II malocclusion, can become a therapeutic target for dentofacial orthopedics. The literature reports significant changes that can be induced in the structural features of the posterior wall of the glenoid fossa following mandibular advancement and mechanical stimulation of condylar cartilage. Hence, the role of glenoid fossa must be recognized in shaping different craniofacial morphologies of skeletal class I, class II, and class III malocclusions and glenoid fossa position must be ascertained

before formulating the treatment plan for these skeletal malocclusions.

The craniofacial region is a complex configuration of multiple bones of the skull and jaws, the proportions of which differ markedly in normal as well as in skeletal malocclusions. Although the dimensions of the individual bones may be within the normal range, an aberrant morphology may still manifest as a result of unfavorable combination of various components. At the same time, compensation by another variable may mask deviant variables.¹

Since the mandible possesses an articulation with the cranial base at the glenoid fossa, it is logical to assume that the position of the mandible relative to the cranium is highly dependent upon the location of the glenoid fossa in the cranium. In addition, skeletal discrepancies of the jaws in both the anteroposterior and vertical direction depend mostly upon the relationship of the mandible to the cranium; so it is likely that glenoid fossa plays an important role in the development of different craniofacial pattern.¹ The determination of the exact location of glenoid fossa can help the orthodontist in diagnosing whether the skeletal aberration is due to faulty jaw position or disproportionate jaw sizes, and hence pave the way for accurate treatment planning.

Some articles in the literature relate the glenoid fossa position to various malocclusions.^{1–4} Hopkin et al.² reported that glenoid

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fossa position anteroposteriorly was related to dental malocclusions. Bjork³ noted that vertical placement of glenoid fossa was a theoretical factor in the rotation of the mandible. Droel et al.¹ and Baccetti et al.⁴ in their research observed a significant difference in the anteroposterior location of glenoid fossa between class II and class III malocclusions. Many experimental and clinical contributions demonstrated the effects of orthodontic/orthopedic therapies on glenoid fossa position and remodeling.^{5–11} On the contrary, the literature provides only limited data about the role of glenoid fossa location as a determining factor in craniofacial morphology.

Thus, this study was conducted in an attempt to appraise whether glenoid fossa location has a role to play in shaping craniofacial morphology of various skeletal malocclusions.

2. Methods

The study was conducted on 84 pretreatment lateral head cephalograms obtained from patient record files, having clarity in the region of temporomandibular joint. The patients in the sample selected for the study were in the age group of 15–21 years with the mean age of 16.77 years, taking into consideration the fact that the facial growth process is in a decelerating phase in this age group and the craniofacial characteristics are not expected to change beyond 11 years of age.^{12–15} The exclusion criteria were cleft lip and palate, craniofacial syndrome, remaining deciduous or missing teeth (except third molars), a previous history of orthodontic treatment, and poor-quality cephalograms. All the cephalograms were scaled to 100% for accuracy of measurements.

The sample was divided according to sagittal skeletal relationship into skeletal class I, class II, and class III on the basis of App-Bpp linear measurement (distance between the projection from point A and point B on the palatal plane)¹⁶ (Fig. 1 and Table 1). Nanda and Merrill¹⁶ found that palatal plane inclination changes little during growth, and App-Bpp linear measurement is the best indicator of sagittal skeletal relationship amongst ANB angle, Wits appraisal, and Nasion perpendicular to FHP.

Table 1

Distribution of sample into skeletal class I, II, and III on the basis of App-Bpp linear measurement.

Skeletal type	App-Bpp (mm)	No. of subjects
Class I	3–7	18
Class II	>7	48
Class III	<3	18

2.1. Cephalometric analysis

Well-detectable contours of the glenoid fossa are not visible on the lateral cephalograms because of interference by the ear rods, so points Articulare (Ar)^{4,9,17–19} and Condylion (Co)²⁰ were used to represent the glenoid fossa cephalometrically.

The glenoid fossa location (Ar and Co) in cranial base was measured in relation to two reference lines using Cartesian coordinate system. The 'X' axis was formed by 'TC line' (Cranial base line) and a vertical reference line (vertical T) passing through point T and at right angles to the TC line served as the 'Y' axis (Fig. 1). The 'TC line' was drawn by joining point T (the most superior point of the anterior wall of the sella turcica at the junction with tuberculum sella)²¹ and point C (the most anterior point of the cribriform plate at the junction with the nasal bone).²¹ The TC line is a stable reference line, because the anterior wall of the sella turcica and the cribriform plate remain unchanged after five years of age.^{22–24} Anteroposterior measurements were recorded parallel to TC line, and the vertical measurements were recorded parallel to vertical T line. Four linear and two angular measurements were used for assessing the glenoid fossa location in the cranial base (Fig. 2) and eight linear and eight angular variables were used to evaluate the corresponding effect on craniofacial morphology (Figs. 3 and 4).

Reliability of measurement was tested by doing double determination of 40 cephalograms randomly selected at 15 days interval from the collected sample by the same operator and comparison was drawn between first and second determination.

Fig. 1. Cartesian coordinate system formed by TC line and vertical T line and App-Bpp measurement for division of subjects into skeletal class I, II, and III.

Fig. 2. Linear measurements representing glenoid fossa position in the anteroposterior plane – X_1 (Ar-Vert.T) and X_2 (Co-Vert.T); in the vertical plane – Y_1 (Ar-TC line) and Y_2 (Co-TC line) and angular variables for glenoid fossa position – Co-T-Vert. T and Ar-T-Vert. T.

Fig. 3. Linear measurement for craniofacial morphology, in the anteroposterior plane – maxillary position (A-Vert.T), mandibular position (B-Vert.T, Pog-Vert.T, and Go-Vert.T), and in the vertical plane – upper anterior facial height (N-ANS), lower anterior facial height (ANS-Me), total anterior facial height (N-Me), and ramal height (Co-Go).

On comparing the two sets of values, no statistically significant difference was observed (Table 2). Hence, the measurements were reliable for analysis.

2.2. Statistical analysis

Data were analyzed using statistical software package STATA 12 for windows. A difference between the two values was considered to be significant only if 'p' value was less than 0.05. Regression analysis was done to see the effect of various

parameters estimating the location of glenoid fossa on the parameters measuring craniofacial morphology. β -Coefficients for each of the parameters, corresponding 95% confidence intervals (95% CI) and 'p'-value were reported to make the interpretation for the dependent variables.

3. Results

Regression analysis was carried out for estimating the corresponding change in craniofacial morphology for one unit

Fig. 4. Angular measurements for craniofacial morphology – SN-OP angle, OP-MP angle, SN-MP angle, gonial angle (Ar-Go-Me), SN-PP angle, basal plane angle (PP-MP), and cranial base angle (N-S-Ba and Ba-T-Vert.T).

change in glenoid fossa position in anteroposterior and vertical plane, in skeletal class I, class II, and class III malocclusion subjects.

In skeletal class I malocclusion subjects, the 'p' values from the regression analysis of variables for glenoid fossa location in anteroposterior plane (X_1 , X_2 , Co-T-Vert.T, and Ar-T-Vert.T) on variables for craniofacial morphology indicate that the posterior positioning of glenoid fossa (increase in X_1) significantly influences

and predicts an increase in total anterior facial height (N-Me), lower anterior facial height (ANS-Me), and ramal height (Co-Go), whereas the sagittal position of maxilla (A-Vert.T) and mandible (B-Vert.T, Pog-Vert.T, and Go-Vert.T), and cranial base angle (N-S-Ba and Ba-T-Vert.T) did not vary significantly. The palatal plane angle (PP-MP) also decreases as glenoid fossa moves posteriorly (Table 3a).

Table 2

Double determination of variables for reliability of measurements.

S. No.	Variable	First determination	Second determination	't'	'p'
Variables in anteroposterior plane					
<i>Linear variables (in mm)</i>					
1.	X_1 (Ar-Vert.T)	20.17 ± 3.12	19.83 ± 1.08	0.326	0.75
2.	X_2 (Co-Vert.T)	17.12 ± 5.12	16.90 ± 4.75	0.100	0.92
3.	A-Vert.T	62.81 ± 5.8	66.02 ± 3.06	1.549	0.14
4.	B-Vert.T	56.13 ± 6.5	57.4 ± 5.34	0.477	0.64
5.	Pog-Vert.T	59.38 ± 7.83	58.25 ± 3.79	0.411	0.69
6.	Go-Vert.T	10.71 ± 5.52	9.98 ± 8.92	0.220	0.83
<i>Angular variables (in°)</i>					
1.	Co-T-Vert.T	40.87 ± 6.81	42.27 ± 5.19	0.517	0.61
2.	Ar-T-Vert.T	34.18 ± 3.12	33.89 ± 4.16	0.176	0.86
3.	N-S-Ba	126.51 ± 2.89	128.12 ± 4.12	1.012	0.33
4.	Ba-T-Vert.T	35.19 ± 5.12	36.79 ± 1.79	0.933	0.36
Variables in vertical plane					
<i>Linear variables (in mm)</i>					
1.	N-ANS	50.81 ± 3.22	52.21 ± 1.19	1.289	0.21
2.	N-Me	110.14 ± 5.42	112.82 ± 4.89	1.161	0.26
3.	ANS-Me	60.97 ± 3.47	61.12 ± 5.28	0.075	0.94
4.	Co-Go	56.43 ± 8.12	58.59 ± 6.71	0.648	0.52
<i>Angular variables (in°)</i>					
1.	SN-OP	13.19 ± 3.20	12.9 ± 2.19	0.236	0.82
2.	OP-MP	16.75 ± 5.52	16.87 ± 1.38	0.067	0.95
3.	SN-MP	29.92 ± 1.43	30.47 ± 5.23	0.321	0.75
4.	Ar-Go-Me	125.69 ± 2.30	127.21 ± 5.29	0.833	0.42
5.	SN-PP	6.11 ± 1.00	6.59 ± 0.79	1.191	0.25
6.	PP-MP	21.79 ± 0.82	22.67 ± 1.12	2.008	0.06

Table 3a
Regression analysis of variables for glenoid fossa location in antero-posterior plane on the variables depicting craniofacial morphology in skeletal class I.

Craniofacial variables	X_1 (Ar-Vert.T)		X_2 (Co-Vert.T)		Co-T-Vert.T		Ar-T-Vert.T		Constant	
	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value
A-P plane										
<i>Linear variables (in mm)</i>										
A-Vert.T	1.09 (−0.78, 2.98)	0.230	−1.04 (−3.14, 1.06)	0.305	0.07 (−0.61, 0.75)	0.825	−0.85 (−1.73, 0.02)	0.055	82.97 (62.29, 103.64)	0.000***
B-Vert.T	1.04 (−1.34, 3.43)	0.364	−0.99 (−3.66, 1.66)	0.432	−0.08 (−0.95, 0.78)	0.843	−1.00 (−2.12, 0.10)	0.072	88.92 (62.73, 115.10)	0.000***
Pog-Vert.T	1.76 (−0.97, 4.51)	0.187	−1.33 (−4.39, 1.72)	0.362	0.10 (−0.90, 1.10)	0.833	−1.53 (−2.8, −0.25)	0.023*	90.09 (59.99, 120.19)	0.000***
Go-Vert.T	0.30 (−1.27, 1.88)	0.681	1.49 (−0.26, 3.25)	0.089	−0.26 (−0.84, 0.30)	0.331	0.07 (−0.65, 0.81)	0.818	−12.06 (−29.35, 5.23)	0.156
<i>Angular variables (in°)</i>										
N-S-Ba	1.09 (−0.01, 2.20)	0.053	−0.43 (−1.67, 0.79)	0.458	0.10 (−0.32, 0.50)	0.596	−0.04 (−0.56, 0.47)	0.851	110.32 (98.17, 122.47)	0.000***
Ba-T-Vert.T	0.69 (−0.23, 1.61)	0.132	−0.04 (−1.08, 0.98)	0.919	0.00 (−0.33, 0.33)	0.998	0.25 (−0.17, 0.68)	0.228	13.82 (3.64, 24.01)	0.012*
Vertical plane										
<i>Linear variables (in mm)</i>										
N-ANS	0.52 (−0.71, 1.77)	0.378	0.11 (−1.27, 1.50)	0.859	−0.12 (−0.58, 0.32)	0.559	−0.15 (−0.73, 0.42)	0.577	47.51 (33.84, 61.17)	0.000***
N-Me	2.23 (0.27, 4.19)	0.028*	−1.12 (−3.30, 1.06)	0.288	0.08 (−0.63, 0.79)	0.804	−0.83 (−1.74, 0.08)	0.071	107.59 (86.10, 129.08)	0.000***
ANS-Me	1.71 (0.06, 3.35)	0.043*	−1.23 (−3.07, 0.60)	0.169	0.20 (−0.39, 0.81)	0.464	−0.67 (−1.44, 0.09)	0.079	60.08 (42.01, 78.15)	0.000***
Co-Go	2.35 (0.60, 4.10)	0.012*	−1.50 (−3.45, 0.44)	0.120	0.33 (−0.30, 0.97)	0.275	−0.82 (−1.63, −0.00)	0.048*	46.24 (27.05, 65.43)	0.012*
<i>Angular variables (in°)</i>										
SN-OP	−0.72 (−2.21, 0.76)	0.313	0.15 (−1.50, 1.81)	0.845	−0.06 (−0.61, 0.47)	0.793	0.60 (−0.08, 1.30)	0.081	8.56 (−7.77, 24.90)	0.278
OP-MP	−0.84 (−2.13, 0.45)	0.183	−0.03 (−1.47, 1.40)	0.958	0.13 (−0.33, 0.61)	0.533	0.28 (−0.31, 0.88)	0.327	20.38 (6.23, 34.54)	0.008**
SN-MP	−1.56 (−3.64, 0.51)	0.129	0.117 (−2.20, 2.43)	0.915	0.07 (−0.68, 0.83)	0.841	0.89 (−0.07, 1.86)	0.068	28.95 (6.13, 51.77)	0.017*
Ar-Go-Me	−1.02 (−3.21, 1.15)	0.328	−1.2 (−3.63, 1.23)	0.307	0.38 (−0.41, 1.17)	0.320	0.82 (−0.19, 1.84)	0.104	126.90 (102.93, 150.87)	0.000***
SN-PP	0.32 (−0.86, 1.51)	0.563	−0.59 (−1.92, 0.73)	0.350	0.15 (−0.28, 0.58)	0.459	0.15 (−0.40, 0.70)	0.565	−2.19 (15.23, 10.84)	0.722
PP-MP	−1.85 (−3.54, −0.16)	0.034*	0.65 (−1.22, 2.53)	0.466	−0.06 (−0.67, 0.55)	0.830	0.71 (−0.07, 1.49)	0.074	31.54 (13.02, 50.06)	0.003**

* p value < 0.05, significant.

** p value < 0.01, highly significant.

*** p value < 0.001, very highly significant.

In skeletal class I malocclusion subjects, the 'p' values from the regression analysis of variables for glenoid fossa location in vertical plane (Y_1 , Y_2) on variables for craniofacial morphology indicate that inferior positioning of glenoid fossa (increase in Y_1) significantly influences and predicts an increase in the ramal height (Co-Go) accompanied by decrease in SN-MP angle and gonial angle (Ar-Go-Me) (Table 3b).

In skeletal class II malocclusion subjects, the 'p' values from the regression analysis of variables for glenoid fossa location in anteroposterior plane on variables for craniofacial morphology indicate that the posterior location of glenoid fossa influences and predicts a significant decrease in parameters representing sagittal position of maxilla (decrease in A-Vert.T) and mandible (decrease in B-Vert.T, Pog-Vert.T, and increase in Go-Vert.T), and an increase in cranial base angle (Ba-T-Vert.T), anterior facial height (N-ANS, N-Me, and ANS-Me), and ramal height (Co-Go) (Table 4a).

In skeletal class II malocclusion subjects, the 'p' values from the regression analysis of variables for glenoid fossa location in vertical plane on variables for craniofacial morphology indicate that superior or inferior location of glenoid fossa in cranial base may not influence the variables for sagittal position of maxilla, although mandible moves posteriorly with superior location of glenoid fossa (increase in Go-Vert.T). The gonial angle (Ar-Go-Me) also decreases with the superior location of glenoid fossa in cranial base (Table 4b).

In skeletal class III malocclusion subjects, the 'p' values from regression analysis of variables for glenoid fossa location in anteroposterior plane on variables for craniofacial morphology indicate that the anterior location of glenoid fossa may not influence the variable for sagittal position of maxilla significantly, whereas an anterior location of glenoid fossa in cranial base may influence and predict a significant anterior position of mandible (decrease in Go-Vert.T) accompanied by a significant decrease in cranial base angle (N-S-Ba and Ba-T-Vert.T), anterior facial height (N-Me), ramal height (Co-Go), and an increase in the gonial angle (Ar-Go-Me) (Table 5a).

In skeletal class III malocclusion, the regression analysis shows that the vertical location of glenoid fossa may not influence the craniofacial morphology significantly (Table 5b).

4. Discussion

Find out the cause of this effect or rather say, the cause of the defect; for this effect defective comes by cause.

—Shakespeare, Hamlet, II, ii, 101

Some articles in the literature correlate glenoid fossa position with different malocclusions,^{1,4} but the literature provides only limited data about the diagnostic significance of fossa location in shaping craniofacial morphology. In the assessment of orthodontic problems, the determining role of the glenoid fossa location needs to be recognized. The inclusion of the fossa position in the diagnostic assessment brings in, as a major factor, an area of craniofacial complex, which is normally not taken into account in diagnosing a malocclusion.

The results from the study on this sample population showed that the glenoid fossa is located significantly posteriorly in skeletal class II than in class I ($p < 0.05$) and glenoid fossa is located significantly anteriorly in skeletal class III than in class II malocclusion ($p < 0.001$) (Fig. 5).²⁵

4.1. Skeletal class I

It was observed that the posterior location of glenoid fossa in the cranial base resulted in a significant increase in ramal height ($p < 0.01$) with a corresponding but smaller increase in the anterior facial height ($p < 0.05$) and a decrease in the palatal plane angle ($p < 0.05$), indicating a counterclockwise rotation of the mandible, although the sagittal position of the maxilla and mandible and the cranial base angle did not vary significantly (Table 3a).

The inferior location of glenoid fossa in the cranial base influences and predicts an increase in the ramal height, and a corresponding significant decrease in the SN-MP angle and gonial angle (Table 3b). This finding indicates a forward rotation of mandible with inferior location of glenoid fossa in class I malocclusion.

Table 3b

Regression analysis of variables for glenoid fossa location in the vertical plane on the variables depicting craniofacial morphology in skeletal class I.

Craniofacial variables	Y_1 (Ar-TC plane)		Y_2 (Co-TC plane)		Constant	
	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value
A-P plane						
<i>Linear variables (in mm)</i>						
A-Vert.T	0.86 (−0.30, 2.02)	0.136	0.18 (−1.03, 1.41)	0.751	31.95 (0.01, 63.88)	0.050*
B-Vert.T	0.92 (−0.56, 2.42)	0.206	0.70 (−0.86, 2.28)	0.354	13.42 (−27.63, 54.48)	0.496
Pog-Vert.T	1.39 (−0.24, 3.02)	0.089	0.63 (−1.08, 2.35)	0.443	0.85 (−43.99, 45.70)	0.968
Go-Vert.T	0.06 (−1.45, 1.58)	0.929	−0.52 (−2.12, 1.06)	0.493	19.28 (−22.32, 45.70)	0.339
<i>Angular (in°)</i>						
N-S-Ba	−0.04 (−0.92, 0.84)	0.919	−0.29 (−1.24, 0.64)	0.509	136.54 (112.21, 160.86)	0.000***
Ba-T-Vert.T	−0.30 (−1.24, 0.64)	0.505	−0.36 (−1.35, 0.63)	0.451	53.37 (27.44, 79.30)	0.000***
Vertical plane						
<i>Linear variables (in mm)</i>						
N-ANS	0.25 (−0.44, 0.95)	0.446	−0.12 (−0.86, 0.60)	0.718	44.62 (25.46, 63.77)	0.000***
N-Me	0.53 (−0.60, 1.67)	0.331	0.32 (−0.87, 1.52)	0.577	88.86 (57.54, 120.18)	0.000***
ANS-Me	0.28 (−0.60, 1.16)	0.508	0.44 (−0.48, 1.37)	0.321	44.24 (19.96, 68.51)	0.001***
Co-Go	1.03 (0.05, 2.01)	0.039*	−0.62 (−1.65, 0.40)	0.214	37.11 (10.26, 63.96)	0.000***
<i>Angular (in°)</i>						
SN-OP	−0.58 (−1.28, 0.11)	0.096	−0.15 (−0.89, 0.58)	0.667	35.17 (15.92, 54.42)	0.001***
OP-MP	−0.55 (−1.28, 0.17)	0.125	0.52 (−0.24, 1.28)	0.165	24.55 (4.59, 44.51)	0.019**
SN-MP	−1.14 (−2.20, −0.07)	0.037*	0.37 (−0.74, 1.48)	0.488	59.73 (30.60, 88.85)	0.001***
Ar-Go-Me	−1.21 (−2.47, 0.04)	0.050*	0.32 (−1.00, 1.64)	0.610	161.10 (126.53, 195.68)	0.000***
SN-PP	−0.17 (−0.77, 0.43)	0.557	−0.18 (−0.82, 0.45)	0.546	15.58 (−1.00, 32.17)	0.064
PP-MP	−0.93 (−1.90, 0.03)	0.057	0.52 (−0.49, 1.53)	0.291	43.77 (17.25, 70.30)	0.003**

* p value < 0.05, significant.

** p value < 0.01, highly significant.

*** p value < 0.001, very highly significant.

Table 4a

Regression analysis of variables for glenoid fossa location in antero-posterior plane on the variables depicting craniofacial morphology in skeletal class II.

Craniofacial variables	X ₁ (Ar-Vert.T) β coefficient (95% CI)	X ₂ (Co-Vert.T) β coefficient (95% CI)	Co-T-Vert.T β coefficient (95% CI)	Ar-T-Vert.T. β coefficient (95% CI)	Constant β coefficient (95% CI)
A-P plane					
<i>Linear variables (in mm)</i>					
A-Vert.T	0.72 (−0.22, 1.68)	−0.20 (−0.97, 0.56)	−0.13 (−0.42, 0.15)	−0.75 (−1.27, −0.22)**	82.45 (73.44, 91.47)***
B-Vert.T	0.39 (−0.99, 1.79)	0.66 (−0.45, 1.78)	−0.46 (−0.89, −0.04)*	−0.83 (−1.59, −0.06)*	79.77 (66.61, 92.93)***
Pog-Vert.T	0.39 (−1.15, 1.94)	0.86 (−0.38, 2.11)	−0.52 (−0.99, −0.04)*	−0.83 (−1.68, 0.02)*	78.87 (64.20, 93.54)***
Go-Vert.T	0.97 (0.31, 1.63)**	−0.41 (−0.94, 0.11)	0.10 (−0.09, 0.30)	0.31 (−0.04, 0.68)	−14.15 (−20.39, −7.91)***
<i>Angular variables (in °)</i>					
N-S-Ba	0.14 (−0.99, 1.16)	−0.43 (−1.25, 0.39)	0.24 (−0.06, 0.56)	0.53 (−0.03, 1.09)	106.89 (97.21, 116.58)***
Ba-T-Vert.T	0.08 (−0.55, 0.71)	−0.27 (−0.78, 0.23)	0.15 (−0.03, 0.35)	0.75 (0.40, 1.10)***	8.31 (2.33, 14.30)**
Vertical plane					
<i>Linear variables (in mm)</i>					
N-ANS	1.14 (0.41, 1.87)**	−0.28 (−0.87, 0.30)	0.009 (−0.22, 0.22)	−0.46 (−0.87, −0.06)*	46.96 (40.02, 53.90)***
N-Me	2.42 (0.81, 4.02)**	−1.19 (−2.49, 0.09)	−0.29 (−0.78, 0.19)	−0.48 (−1.37, 0.40)	111.22 (96.00, 126.44)***
ANS-Me	1.40 (0.11, 2.70)*	−0.95 (−1.99, 0.09)	−0.24 (−0.64, 0.14)	−0.04 (−0.76, 0.66)	60.86 (48.61, 73.11)***
Co-Go	1.51 (0.33, 2.70)**	−0.53 (−1.48, 0.42)	−0.005 (−0.36, 0.35)	−0.56 (−1.21, 0.08)	52.13 (40.94, 63.32)***
<i>Angular variables (in °)</i>					
SN-OP	−0.36 (−1.35, 0.63)	−0.49 (−1.29, 0.30)	0.25 (−0.04, 0.56)	0.23 (−0.30, 0.78)	13.97 (4.56, 23.38)**
OP-MP	−0.43 (−1.49, 0.62)	−0.001 (−0.85, 0.85)	0.05 (−0.27, 0.37)	0.12 (−0.45, 0.71)	19.69 (9.67, 29.72)***
SN-MP	−0.79 (−2.14, 0.56)	−0.49 (−1.58, 0.59)	0.30 (−0.10, 0.72)	0.36 (−0.37, 1.11)	33.67 (20.86, 46.48)***
Ar-Go-Me	−0.79 (−2.23, 0.63)	0.001 (−1.15, 1.15)	0.30 (−0.13, 0.74)	−0.04 (−0.83, 0.74)	133.0 (119.55, 146.62)***
SN-PP	−0.04 (−0.80, 0.71)	−0.009 (−0.62, 0.60)	0.04 (−0.18, 0.27)	0.13 (−0.28, 0.55)	1.89 (−5.30, 9.10)
PP-MP	−0.78 (−2.09, 0.52)	−0.62 (−1.67, 0.43)	0.21 (−0.18, 0.61)	0.33 (−0.38, 1.05)	33.60 (21.22, 45.99)***

* p value < 0.05, significant.** p value < 0.01, highly significant.*** p value < 0.001, very highly significant.

4.2. Skeletal class II

In the skeletal class II malocclusion subjects, posteriorly located glenoid fossa in the cranial base favored a significantly retrognathic maxillary jaw. While certain skeletal class II subjects could be characterized as being deficient in mandibular size, most had mandibles that were well formed but retruded due to a posterior position of glenoid fossa ($p < 0.05$). The cranial base angle became

significantly more obtuse with posterior position of glenoid fossa ($p < 0.001$). The anterior facial height increased significantly ($p < 0.01$) and a corresponding increase in ramal height ($p < 0.01$) was also acknowledged with posterior location of glenoid fossa (Table 4a), which could be nature's compensatory mechanism to maintain the vertical facial proportions.²⁶

The superior location of glenoid fossa tended to increase the anterior facial height ($p < 0.05$) with a corresponding increase in

Table 4b

Regression analysis of variables for glenoid fossa location in the vertical plane on the variables depicting craniofacial morphology in skeletal class II.

Craniofacial variables	Y ₁ (Ar-TC plane)		Y ₂ (Co-TC plane)		Constant	
	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value
A-P plane						
<i>Linear variables (in mm)</i>						
A-Vert.T	0.39 (−0.19, 0.98)	0.187	0.04 (−0.53, 0.62)	0.887	64.11 (41.64, 86.58)	0.000***
B-Vert.T	0.40 (−0.46, 1.28)	0.350	0.37 (−0.47, 1.23)	0.378	49.02 (15.83, 82.22)	0.005**
Pog-Vert.T	0.39 (−0.59, 1.38)	0.427	0.44 (−0.52, 1.41)	0.361	47.15 (9.49, 84.81)	0.015*
Go-Vert.T	0.59 (0.18, 1.00)	0.006**	−0.24 (−0.64, 0.16)	0.231	−31.56 (−47.24, −15.88)	0.000***
<i>Angular variables (in °)</i>						
N-S-Ba	−0.24 (−0.90, 0.40)	0.447	0.15 (−0.48, 0.79)	0.629	113.16 (88.37, 137.95)	0.000***
Ba-T-Vert.T	−0.06 (−0.46, 0.34)	0.763	0.00 (−0.39, 0.39)	1.000	10.91 (−4.52, 26.35)	0.161
Vertical plane						
<i>Linear variables (in mm)</i>						
N-ANS	0.56 (0.06, 1.05)	0.026*	−0.17 (−0.65, 0.30)	0.472	30.36 (11.71, 49.01)	0.002**
N-Me	0.63 (−0.43, 1.70)	0.240	0.11 (−0.93, 1.16)	0.824	84.19 (43.52, 124.87)	0.000***
ANS-Me	0.14 (−0.69, 0.98)	0.725	0.27 (−0.54, 1.10)	0.501	47.59 (15.61, 79.57)	0.004**
Co-Go	1.11 (0.38, 1.84)	0.004**	−0.61 (−1.33, 0.09)	0.089	25.05 (−2.71, 52.82)	0.076
<i>Angular variables (in °)</i>						
SN-OP	−0.46 (−1.10, 0.17)	0.153	−0.009 (−0.64, 0.62)	0.976	34.37 (9.95, 58.80)	0.007**
OP-MP	−0.26 (−0.93, 0.39)	0.418	−0.04 (−0.70, 0.60)	0.879	32.95 (7.70, 58.19)	0.012*
SN-MP	−0.73 (−1.59, 0.12)	0.094	−0.05 (−0.90, 0.78)	0.889	67.32 (34.60, 100.05)	0.000***
Ar-Go-Me	−0.74 (−1.62, 0.14)	0.100	0.18 (−0.68, 1.05)	0.663	159.57 (125.86, 193.28)	0.000***
SN-PP	−0.28 (−0.75, 0.18)	0.228	0.18 (−0.28, 0.64)	0.437	9.69 (−8.22, 27.61)	0.281
PP-MP	−0.58 (−1.44, 0.27)	0.175	−0.20 (−1.04, 0.63)	0.629	64.64 (32.10, 97.19)	0.000***

* p value < 0.05, significant.** p value < 0.01, highly significant.*** p value < 0.001, very highly significant.

Table 5a

Regression analysis of variables for glenoid fossa location in antero-posterior plane on the variables depicting craniofacial morphology in skeletal class III.

Craniofacial variables	X ₁ (Ar-Vert.T) β coefficient (95% CI)	X ₂ (Co-Vert.T) β coefficient (95% CI)	Co-T-Vert.T β coefficient (95% CI)	Ar-T-Vert.T. β coefficient (95% CI)	Constant β coefficient (95% CI)
A-P plane					
<i>Linear variables (in mm)</i>					
A-Vert.T	0.55 (−0.90, 2.01)	0.03 (−1.77, 1.84)	−0.08 (−0.69, 0.51)	−0.26 (−0.84, 0.31)	63.34 (45.84, 80.83)***
B-Vert.T	0.15 (−1.72, 2.03)	0.43 (−1.89, 2.76)	−0.39 (−1.17, 0.38)	−0.39 (−1.13, 0.35)	80.76 (58.22, 103.29)***
Pog-Vert.T	0.18 (−1.97, 2.34)	0.66 (−2.01, 3.34)	−0.49 (−1.38, 0.40)	−0.49 (−1.35, 0.35)	84.95 (59.06, 110.83)***
Go-Vert.T	1.34 (0.38, 2.31)**	−0.50 (−1.69, 0.68)	0.30 (−0.09, 0.70)	0.03 (−0.034, 0.41)	−21.8 (−33.38, −10.36)***
<i>Angular variables (in°)</i>					
N-S-Ba	0.24 (−0.77, 1.26)	−0.47 (−1.74, 0.79)	0.14 (−0.27, 0.57)	0.59 (0.18, 0.99)**	105.14 (92.90, 117.39)***
Ba-T-Vert.T	1.02 (0.16, 1.87)*	−1.22 (−2.28, −0.17)*	0.27 (−0.08, 0.62)	0.53 (0.19, 0.87)**	5.53 (−4.71, 15.78)
Vertical plane					
<i>Linear variables (in mm)</i>					
N-ANS	1.13 (0.23, 2.03)*	−0.15 (−1.26, 0.95)	0.02 (−0.34, 0.39)	−0.29 (−0.64, 0.06)	38.47 (27.42, 49.21)***
N-Me	2.40 (0.62, 4.18)*	−0.88 (−3.08, 1.31)	0.13 (−0.59, 0.87)	−0.37 (−1.07, 0.33)	81.81 (60.53, 103.10)***
ANS-Me	1.34 (−0.44, 3.13)	−0.70 (−2.98, 1.51)	0.07 (−0.66, 0.81)	−0.11 (−0.82, 0.58)	43.73 (22.31, 65.14)***
Co-Go	2.31 (0.92, 3.69)**	−1.14 (−2.85, 0.57)	−0.25 (−0.83, 0.31)	0.05 (−0.48, 0.60)	35.19 (18.61, 51.77)***
<i>Angular variables (in°)</i>					
SN-OP	−0.90 (−2.12, 0.30)	0.55 (−0.94, 2.05)	0.38 (−0.11, 0.88)	0.12 (−0.35, 0.60)	3.55 (−10.98, 18.10)
OP-MP	−0.45 (−1.74, 0.82)	−0.17 (−1.77, 1.41)	0.13 (−0.39, 0.66)	−0.10 (−0.61, 0.40)	25.43 (10.03, 40.83)**
SN-MP	−1.36 (−3.35, 0.62)	0.37 (−2.08, 2.84)	0.51 (−0.30, 1.34)	0.01 (−0.77, 0.80)	28.99 (5.14, 52.84)*
Ar-Go-Me	−1.65 (−3.29, −0.01)*	0.62 (−1.41, 2.65)	0.27 (−0.40, 0.95)	0.16 (−0.48, 0.81)	133.0 (113.36, 152.67)***
SN-PP	−0.04 (−0.87, 0.77)	−0.09 (−1.11, 0.92)	0.12 (−0.21, 0.46)	0.03 (−0.29, 0.35)	4.24 (−5.64, 14.13)
PP-MP	−1.51 (−3.22, 0.19)	0.73 (−1.37, 2.84)	0.48 (−0.22, 1.19)	−0.06 (−0.74, 0.60)	22.73 (2.29, 43.16)*

* p value < 0.05, significant.

** p value < 0.01, highly significant.

*** p value < 0.001, very highly significant.

Table 5b

Regression analysis of variables for glenoid fossa location of variables in the vertical plane depicting craniofacial morphology in skeletal class III.

Craniofacial variables	Y ₁ (Ar-TC plane)		Y ₂ (Co-TC plane)		Constant	
	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value	β coefficient (95% CI)	'p' value
A-P plane						
<i>Linear variables (in mm)</i>						
A-Vert.T	−0.18 (−1.60, 1.23)	0.787	0.60 (−0.88, 2.09)	0.399	56.45 (36.44, 76.46)	0.000***
B-Vert.T	−1.13 (−2.92, 0.65)	0.195	1.72 (−0.14, 3.59)	0.068	63.59 (38.38, 88.81)	0.000***
Pog-Vert.T	−1.17 (−3.24, 0.88)	0.243	1.96 (−0.20, 4.12)	0.072	61.36 (32.25, 90.48)	0.000***
Go-Vert.T	0.78 (−1.22, 2.79)	0.416	−0.53 (−2.63, 1.56)	0.597	−3.16 (−31.46, 25.14)	0.815
<i>Angular (in°)</i>						
N-S-Ba	−0.47 (−1.89, 0.94)	0.485	0.04 (−1.43, 1.52)	0.950	142.58 (122.62, 162.55)	0.000***
Ba-T-Vert.T	−0.33 (−1.87, 1.21)	0.654	−0.09 (−1.71, 1.51)	0.898	48.50 (26.71, 70.29)	0.000***
Vertical plane						
<i>Linear variables (in mm)</i>						
N-ANS	0.86 (−0.43, 2.15)	0.176	−0.32 (−1.67, 1.02)	0.615	30.17 (11.95, 48.39)	0.003**
N-Me	0.36 (−2.21, 2.94)	0.768	0.55 (−2.14, 3.25)	0.667	87.61 (51.23, 123.98)	0.000***
ANS-Me	−0.18 (−2.11, 1.75)	0.842	0.63 (−1.38, 2.66)	0.511	52.23 (24.98, 79.49)	0.001***
Co-Go	0.85 (−1.25, 2.97)	0.402	−0.23 (−2.44, 1.97)	0.821	35.88 (6.10, 65.66)	0.021*
<i>Angular (in°)</i>						
SN-OP	−0.73 (−0.55, 2.03)	0.243	−1.17 (−2.53, 0.18)	0.085	12.49 (−5.77, 30.75)	0.166
OP-MP	−0.99 (−2.33, 0.33)	0.131	0.75 (−0.63, 2.15)	0.267	30.31 (11.52, 49.11)	0.004**
SN-MP	−0.26 (−2.34, 1.82)	0.794	−0.41 (−2.60, 1.76)	0.688	42.80 (13.38, 72.23)	0.007**
Ar-Go-Me	−0.49 (−2.33, 1.34)	0.572	−0.20 (−2.12, 1.72)	0.827	143.98 (118.05, 169.91)	0.000***
SN-PP	0.18 (−0.61, 0.97)	0.629	−0.27 (−1.10, 0.55)	0.487	7.37 (−3.82, 18.57)	0.181
PP-MP	0.05 (−1.82, 1.93)	0.952	−0.63 (−2.60, 1.32)	0.499	29.43 (2.95, 55.92)	0.032*

* p value < 0.05, significant.

** p value < 0.01, highly significant.

*** p value < 0.001, very highly significant.

ramal height ($p < 0.005$) (Table 4b). Increase in the anterior facial height could have resulted from clockwise rotation of mandible,^{27,28} and the increase in ramal height was due to a compensatory growth mechanism to maintain the vertical facial dimensions.²⁶ The vertical location of glenoid fossa did not influence the sagittal position of maxilla and mandible and the cranial base angle significantly.

4.3. Skeletal class III

In skeletal class III malocclusion subjects, the characteristic straight line morphology was only partly due to increased length of mandible; the position of glenoid fossa in these cases was further anterior than in average normal occlusion leading to a prognathic mandibular jaw ($p < 0.01$), although the anterior position of

Fig. 5. Mean values of the variables for glenoid fossa location in the sagittal plane in skeletal class I, II, and III malocclusion subjects.

glenoid fossa in the cranial base did not affect the sagittal position of maxilla significantly. It was also found that the anterior location of glenoid fossa in class III subjects resulted in a significant decrease in the cranial base angle ($p < 0.001$). Furthermore, the anterior location of glenoid fossa in the cranial base was accompanied by a decrease in the anterior facial height ($p < 0.01$) (Table 5a), which could have resulted due to counter-clockwise rotation of the mandible²⁷; and an increase in the gonial angle, which could also be nature's compensatory mechanism to maintain the vertical facial proportions.²⁶ The vertical location of the glenoid fossa did not influence the craniofacial morphology of class III malocclusion subjects.

The results of the present study, apart from substantiating certain known facts regarding glenoid fossa position in cranial base, in different craniofacial patterns, have demonstrated that this location has a profound effect on the craniofacial morphology. The detection of glenoid fossa location can guide the orthodontist to the crux of the malocclusion, which could either be due to abnormal jaw size or variation in the position of glenoid fossa, and this can be the decisive factor in framing the treatment plan. A three-dimensional analysis using CBCT can probably access the location of glenoid fossa more accurately as compared to two-dimensional cephalometric analysis and can be a future possibility of research.

5. Conclusion

The glenoid fossa position should be made an essential part of cephalometric analysis for diagnosing craniofacial aberrations, as its position has a significant influence on the craniofacial morphology of skeletal class I, class II, and class III malocclusions.

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Conflicts of interest

The authors have none to declare.

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References

1. Droel R, Isaacson RJ. Some relationships between the glenoid fossa position and various skeletal discrepancies. *Am J Orthod.* 1972;61:64–78.
2. Hopkin GB, Houston WJB, James GA. The cranial base as an aetiological factor in malocclusion. *Angle Orthod.* 1968;38:250–255.
3. Bjork A. Prediction of mandibular growth rotation. *Am J Orthod.* 1969;55:585–599.
4. Baccetti T, Antonini A, Franchi L, Tollaro I. Glenoid fossa position in different facial types: a cephalometric study. *Br J Orthod.* 1997;24:55–59.
5. Stockli PW, Willert HG. Tissue reactions in the temporomandibular joint resulting from anterior displacement of the mandible in the monkey. *Am J Orthod.* 1971;60:142–155.
6. Elgoyhen JC, Moyers RE, McNamara Jr JA, Riolo ML. Craniofacial adaptation to protrusive function in young rhesus monkeys. *Am J Orthod.* 1972;62:469–480.
7. Pancherz H. Treatment in class II malocclusions by jumping the bite with the Herbst appliance. *Am J Orthod.* 1979;76:423–441.
8. Birkebeck L, Melsen B, Trep SA. Laminographic study of the alterations in the temporomandibular joint following activator treatment. *Eur J Orthod.* 1984;6:257–266.
9. Agronin KJ, Kokich VG. Displacement of glenoid fossa. *Am J Orthod.* 1987;91:42–48.
10. Woodside DG, Metaxas A, Altuna G. The influence of functional appliance therapy on glenoid fossa remodeling. *Am J Orthod.* 1987;92:181–198.
11. Paulsen HU, Karle A, Bakke M, Herskind A. CT scanning and radiographic analysis of temporomandibular joints and cephalometric analysis in a case of Herbst treatment in late puberty. *Eur J Orthod.* 1995;17:165–175.
12. Buschang PH, Tanguay R, Demirjian A, LaPalme L, Turkewicz J. Mathematical models of longitudinal mandibular growth for children with normal and untreated Class II, division 1 malocclusion. *Eur J Orthod.* 1988;10:227–234.
13. Mitani H. Occlusal and craniofacial growth changes during puberty. *Am J Orthod.* 1977;72:76–84.
14. Mitani H. Prepubertal growth of mandibular prognathism. *Am J Orthod.* 1981;80:546–553.
15. Mitani H. Growth of mandibular prognathism after pubertal growth peak. *Am J Orthod.* 1993;104:330–336.
16. Nanda RS, Merrill RM. Cephalometric assessment of sagittal relationship between maxilla and mandible. *Am J Orthod.* 1994;105:328–344.
17. Buschang PH, Santos-Pinto A. Condylar growth and glenoid fossa displacement during childhood and adolescence. *Am J Orthod.* 1998;113:437–442.
18. Bjork A. Cranial base development. *Am J Orthod.* 1955;41:198–225.
19. Popovich F, Thompson G. Craniofacial templates for orthodontic case analysis. *Am J Orthod.* 1997;71:406–420.
20. Baumrind S, Korn EL, Isaacson RJ. Superimpositional assessment of treatment-associated changes in the temporomandibular joint and the mandibular symphysis. *Am J Orthod.* 1983;84:443–465.
21. Viazis AD. The cranial base triangle. *J Clin Orthod.* 1991;15:565–570.
22. Melsen B. The cranial base: the postnatal development of the cranial base studied histologically on human autopsy material. *Acta Odont Scand.* 1974;32:62.
23. Roche AF, Lewis AB. Late growth changes in the cranial base. In: Bosma JF, ed. *Development of the Basicranium*. Bethesda, MD: DHEW Publications; 1976:221–239.
24. Bjork A, Skieller V. Normal and abnormal growth of the mandible: a synthesis of longitudinal cephalometric implant studies over a period of 25 years. *Eur J Orthod.* 1983;5:1–46.
25. Mengi A, Sharma VP, Tandon P, Agarwal A. The glenoid fossa location in cranial base: in various skeletal malocclusions. *J Dent Herald.* 2015;2(2):6–10.
26. Enlow DH. *Handbook of Facial Growth*. Philadelphia: WB Saunders; 1975:56–57.
27. Laverne J, Gasson N. A metal implant study of mandibular rotation. *Angle Orthod.* 1976;46:144–150.
28. Laverne J, Gasson N. Operational definitions of mandibular morphometric and positional rotations. *Scand J Dent Res.* 1977;85:185–192.