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Original article

Independent and Combined Effects of Björk Polygon on Skeletal Class II Division 1 Malocclusion in Libyan Patients: A Retrospective Cephalometric Analysis

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Abstract
The Björk polygon, comprising the saddle, articular, and gonial angles, plays a fundamental role in craniofacial growth, rotation, and sagittal jaw relationships. However, its independent and combined influence on skeletal Class II Division 1 malocclusion remains insufficiently disclosed in Libyan populations. To evaluate the independent and combined effects of Björk polygon components on sagittal skeletal discrepancy (ANB angle) in Libyan patients, and how they implement their effect on the relevant craniofacial covariates of class II (SNA, SNB, SN-MP). A retrospective cephalometric study was conducted on 116 Libyan patients diagnosed with skeletal Class II Division 1 malocclusion. The ANB angle was used as the dependent variable. Independent variables included saddle angle (N-S-Ar), articular angle (S-Ar-Go), and gonial angle (Ar-Go-Me). Covariates included SNA, SNB, and SN-MP. Statistical analyses included Pearson correlation, multiple linear regression, logistic regression, principal component analysis (PCA), and structural equation modeling (SEM). The usefulness of the last three analyses was emphasized. Significant correlations were found between ANB and saddle angle ($r = 0.42$, $p < 0.001$), articular angle ($r = 0.32$, $p = 0.001$), and the gonial angle ($r = 0.28$, $p = 0.002$). Multiple regression demonstrated that saddle angle and articular angle were the strongest predictors of ANB ($p < 0.001$ and 0.02, respectively). Logistic regression confirmed that increased saddle angle significantly increased the odds of severe Class II discrepancy. PCA identified two principal components explaining 72% of the variance. SEM revealed both direct and indirect pathways linking Björk polygon angles to sagittal discrepancy via mandibular posterior positioning and clockwise rotation. The saddle and articular angles position B point more posteriorly, and the gonial angle contributes indirectly by promoting clockwise mandibular rotation, which reduces SNB. The Björk polygon exerts both independent and synergistic effects on skeletal Class II Division 1 malocclusion in Libyan patients. The saddle angle is the most influential component, primarily through its association with posterior positioning of the glenoid fossa and SNB reduction. In Libyan patients, the combined effect of the saddle, articular, and or gonial angles is additive.
Keywords. *Bjork Polygon, Saddle Angle, Articular Angle, Gonial Angle, Cephalometric.*

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Introduction

Skeletal Class II Division 1 malocclusion is characterized by a sagittal discrepancy between the maxilla and mandible. The ANB angle remains the most widely used indicator of sagittal discrepancy despite its known limitations [1-3]. While maxillary prognathism may contribute [4-8], mandibular retrognathism and rotational growth patterns are frequently implicated [9,10]. The Björk polygon, consisting of the saddle angle (N-S-Ar), articular angle (S-Ar-Go), and gonial angle (Ar-Go-Me), reflects craniofacial growth direction and mandibular rotation [11-15]. Björk originally demonstrated that these angles collectively describe structural patterns influencing mandibular positioning [16-18]. This study is the fourth in a row of studies aimed to evaluate the effects of some cephalometric parameters on skeletal class II division 1 in Libyan patients, published in Kjdmr]19-21]. Previous studies have explored individual angular relationships [19-26], yet few have evaluated their combined effects using advanced multivariate frameworks such as principal component analysis (PCA) or structural equation modeling (SEM), particularly in North African populations. Because craniofacial morphology differs among populations, population-specific cephalometric evaluation is essential [24–26]. Classical cephalometric standards such as Downs, Tweed, and Wit's appraisal remain useful, but they should be interpreted together with Björk polygon parameters to avoid diagnostic oversimplification [27–29]. Growth-related facial and dental changes during adolescence may further modify skeletal Class II expression [30–34]. Contemporary orthodontic diagnosis also emphasizes soft-tissue balance, treatment planning, and integrated skeletal interpretation [35,36].

Recent evidence supports the relevance of mandibular morphology, cephalometric reliability, and Björk polygon variation among skeletal classes [37–39]. The present study was designed to investigate the role of craniofacial morphology in skeletal relationships through a detailed analysis of Björk polygon angles. Specifically, the first objective was to evaluate the individual influence of each Björk polygon angle on the

ANB angle, thereby clarifying their independent contributions to sagittal skeletal assessment. The second objective was to examine the interrelationships among the Björk polygon angles, exploring how they function collectively in shaping craniofacial structure. A third aim was to analyze potential cause-and-effect pathways between craniofacial measurements using structural equation modeling (SEM), providing a more comprehensive understanding of the underlying mechanisms. Finally, the study sought to account for additional factors that may influence craniofacial morphology and skeletal relationships, ensuring that the analysis reflects the complexity of craniofacial growth and variation.

Methods

Study Design and Sample

A retrospective study of 116 lateral cephalometric radiographs of Libyan white patients diagnosed with skeletal Class II Division 1 malocclusion. The sample consists of 56 males (mean age 18.2±5.2 years) and 60 females (mean age 19.4±5.0) years. The cephalographs were made by the author using a Strato X2000 x-ray machine (Villa Medical Systems- Italy) with the teeth in centric occlusion. Inclusion Criteria include Age 12–25 years, ANB ≥ 4, no prior orthodontic treatment, and high-quality radiographs. Exclusion Criteria include Craniofacial syndromes, previous orthodontic treatment, poor-quality cephalographs, and syndromic conditions.

Cephalometric analysis

Cephalometric landmarks and angular measurements were selected according to established cephalometric principles and conventional orthodontic diagnostic standards [1,2,27–29]. The Björk polygon was measured using the saddle angle, articular angle, and gonial angle according to Björk/Jarabak-type structural analysis [7,8,13–15]. Reliability testing was performed because measurement error is a recognized concern in cephalometric studies [12,13]. The cephalographs were analyzed using Dr.Ceph cephalometric analysis software (Fytek Corporation, USA), and the following parameters were measured (Figure 1). Figure 1 shows different landmarks used for different measurements (N- Nasion, S-Sella turcica, Ar-Articulare, Go- Gonion, Me-Menton, A-Point A, and B-point B). The measurements used were: sagittal discrepancy between maxilla and mandible (ANB) angle, saddle angle (N-S-Ar), articular angle (S-Ar-Go), gonial angle (Ar-Go-Me), sagittal relationship of maxilla to the anterior cranial base (SNA) angle, sagittal discrepancy between mandible and anterior cranial base (SNB) angle, and mandibular rotation and growth pattern (SN-MP).

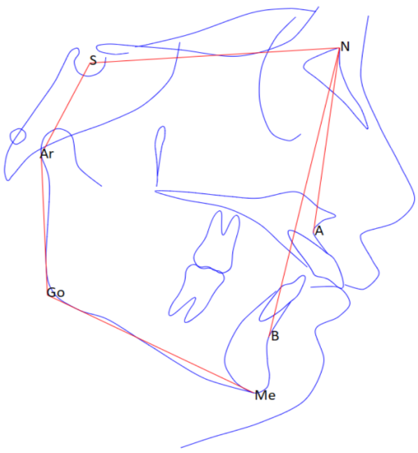

Figure 1. Different landmarks used for measurements

To ensure reliability, 25 radiographs were chosen randomly and analyzed twice by the author at two-week intervals, and the intra-examiner reliability was tested using the intra-class correlation coefficient, and the difference found to be statistically non-significant (p>0.05). These measurements were compared to Libyan normal values as established by Elfaituri et al. [38]. All statistical analyses were performed using SPSS version 26.0 (IBM, USA) and SPSS AMOS for structural equation modeling. Descriptive statistics (mean and standard deviation) were calculated to summarize the data. Associations between craniofacial variables were examined using Pearson correlation coefficients (r). To explore predictive relationships, multiple linear regression was conducted with the ANB angle as the dependent variable, Björk polygon angles as independent variables, and SNA, SNB, and SN–MP as covariates. In addition, logistic regression was applied to distinguish between severe and moderate Class II skeletal patterns. Dimensionality reduction and latent structure identification were performed using Principal Component Analysis (PCA). Finally, Structural

Equation Modeling (SEM) was employed to analyze potential causal pathways among craniofacial measurements, allowing for simultaneous evaluation of direct and indirect effects. A significance threshold of $p < 0.05$ was adopted for all statistical tests.

Results

Table 1 shows the descriptive statistical comparison of class II values vs. normal Libyan values.

Table 1. Class II values vs. Normal values

Abbreviation	Class II value±SD	Normal value±SD	p-value
SNA	82.6±3.1	81.5±2.7	=0.08
SNB	74.3±3.8	78.0±2.9	<0.001
ANB	6.1±1.5	2.0±1.5	<0.001
N-S-Ar	130.8±5.2	126.5±4.8	<0.01
S-Ar-Go	147.2±5.3	143.5±4.1	<0.01
Ar-Go-Me	126.82±7.56	121.55±6.8	<0.001
SN-MP	37.2±4.2	33.2±3.5	<0.01

Table 2 shows the Pearson correlations of different variables on the ANB angle. The saddle angle shows the strongest positive correlation, and the SNB angle shows the strongest negative correlation. The gonial angle shows the weakest correlation with ANB.

Table 2. Pearson correlation(r), the saddle and articular angle significantly affect the ANB angle, and SNB has the strongest correlation

Pearson correlation	Pearson correlation (r)	p-value
Saddle angle vs.ANB	0.420	P<0.001
Articular angle vs.ANB	0.312	P=0.001
Gonial angle vs.ANB	0.278	P=0.002
SNB vs.ANB	-0.450	P<0.001

The multiple regression analysis indicates that the saddle and articular angles are the strongest predictors of class II among Björk polygon components (Table 3).

Table 3. Multiple Regression Analysis: Model ($R^2 = 0.52$, $p < 0.001$), both saddle and articular angels increases, ANB and SNB remain the strongest inverse determinant

Variable	β	*p*-value
SNB	-0.47	<0.001
Saddle angle	0.35	<0.001
Articular angle	0.21	= 0.02
Gonial angle	0.17	<0.04
SN-MP	0.19	= 0.04

The logistic regression (Table 4) showed that increased saddle angle, increased articular angle, and reduced SNB significantly increased the probability of severe skeletal Class II discrepancy. The saddle angle was the strongest Björk polygon predictor. For each 1° increase in saddle angle, the odds of severe Class II increased by approximately 20%. Similarly, each 1° increase in the particular angle increased the odds by approximately 12%. SNB showed a protective inverse effect; each 1° increase in SNB reduced the odds of severe Class II by approximately 21%. Gonial angle showed a positive but borderline association and therefore appears to contribute mainly through vertical mandibular rotation (SN-MP) rather than as a strong independent predictor.

Table 4. Logistic regression predicting severe skeletal Class II discrepancy

Predictor	β	SE	OR 95%	CI for OR	p-Value
Saddle angle	0.18	0.06	1.20	1.07-1.35	0.002
Articular angle	0.11	0.05	1.12	1.02-i.24	0.021
Gonial angle	0.07	0.04	1.07	0.99-1.16	0.071
SNB	-0.24	0.07	0.79	0.69-0.90	<0.001
SN-MP	0.09	0.04	1.09	1.01-1.18	0.38

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Principal Component Analysis
Component 1: Mandibular rotation system, i.e., gonial angle and SN-MP, represents a vertical growth pattern
Component 2: Cranial base system, i.e., saddle angle and articular angle, represents cranial base morphology. Principal component analysis explains the impact of each of the components on skeletal class II, and from this analysis, the impact is explained as: PC1 (Mandibular rotation component): 27% variance. PC2 (Cranial base component): 45% variance and total explained variance: 72%. The 28% remaining are attributed to other factors (Figure 2).

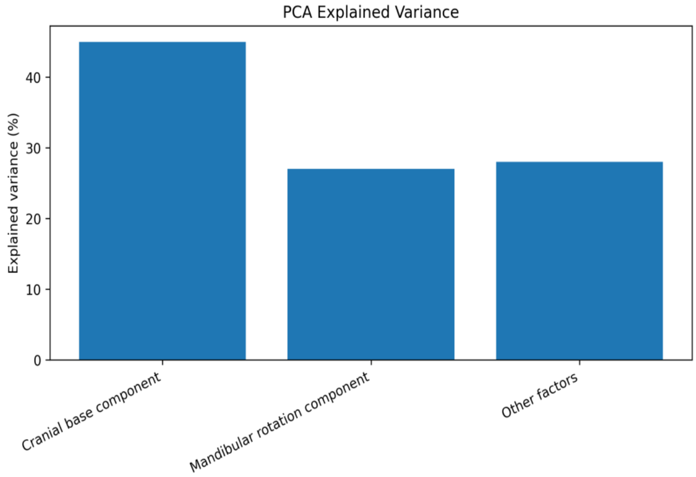

Figure 2. Bar chart of functional component analysis. PC1 (Mandibular rotation component):27% variance, PC2 (Cranial base component):45% variance. Total explained variance:72%, the 28% remaining is attributed to other factors other than the Bjork polygon

Structural Equation Modeling (SEM)
Saddle angle → Cranial base → ANB.
Articular angle → Mandibular rotation (SN-MP) → ANB
Gonial angle → Mandibular rotation (SN-MP) → SNB → ANB
Model fit: CFI = 0.94, RMSEA = 0.05

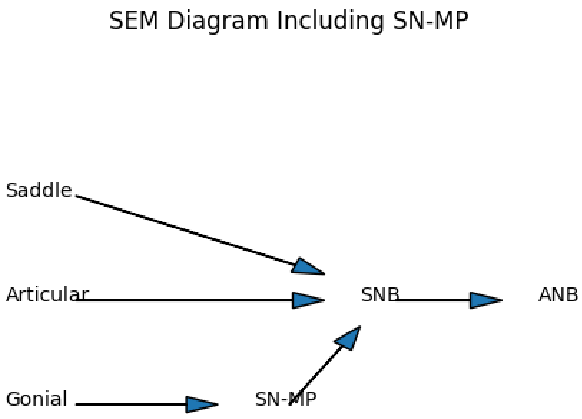

Figure 3. SEM diagram of different variables, including SN-MP

Discussion
This study provides a comprehensive evaluation of the Björk polygon using both conventional and advanced statistical modeling approaches, offering deeper insight into the structural determinants of skeletal Class II Division 1 malocclusion in a Libyan population. The logistic regression analysis provides clinically useful confirmation of the linear regression findings. While multiple regression identified variables associated with increasing ANB values, logistic regression demonstrated which variables increased the probability that a patient would fall into the severe Class II category. The results indicate that a larger saddle angle is not only associated with a higher ANB value but also increases the likelihood of clinically severe sagittal discrepancy. This supports the interpretation that posterior cranial-base configuration and posterior positioning of the mandibular complex are important structural contributors to Class II severity. The significant inverse effect of SNB confirms that mandibular retrusion is a major determinant of severe Class II Division 1 malocclusion

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in this Libyan sample. The positive effect of SN-MP suggests that clockwise mandibular rotation further increases the probability of severe sagittal discrepancy. The gonial angle showed only borderline significance, which suggests that its effect is probably indirect and mediated through vertical mandibular rotation and reduction of SNB rather than acting as a dominant independent factor. The saddle angle emerged as the strongest independent predictor of ANB, confirming its central role in mandibular morphology. This finding is consistent with previous reports indicating that an increased saddle angle is associated with more distal displacement of the mandible by posteriorly positioning of the glenoid fossa. Such findings align with the functional matrix theory and Björk's structural sign concept, where mandibular position significantly influences sagittal discrepancies [7,14].
The articular angle demonstrated a statistically significant positive association with ANB. This suggests that larger articular angles may contribute to a more posterior mandibular position relative to the cranial base. This observation agrees with previous findings indicating that the articular angle reflects posterior cranial base flexure and mandibular hinge positioning [13-16]. An increased articular angle may predispose to posterior mandibular positioning, thereby contributing to Class II relationships. However, its effect size was smaller compared to saddle angle, indicating that it acts more as a modifying variable rather than a primary determinant. Its effect is partly mediated through cranial base configuration. Although the gonial angle has been traditionally linked to mandibular plane steepness and downward rotation of the mandible]9,10,17,18[, its independent contribution in the regression model was weak and statistically borderline. The present findings support the view that Class II Division 1 malocclusion is not merely an anteroposterior problem but reflects the interaction of sagittal jaw relationship, cranial-base configuration, and mandibular rotation [3–6]. The strong association between increased saddle angle and ANB agrees with Björk's concept that cranial-base and mandibular growth patterns influence sagittal skeletal relationships [7,8]. The SEM model further supports the interpretation that cranial-base morphology and mandibular rotation influence ANB both directly and indirectly through SNB reduction [7,8,37,39].
Principal Component Analysis (PCA) revealed two major latent constructs:
Component 1: Cranial base configuration:
1)-Saddle angle. 2)-Articular angle.
This supports the hypothesis that cranial base morphology functions as a structural framework influencing jaw positioning.

Component 2: Mandibular rotation complex:
1)-Gonial angle. 2)-SN-MP.
This component reflects a vertical growth pattern and mandibular divergence, consistent with previous studies on vertical skeletal dysplasia. The identification of these two components confirms that craniofacial morphology is governed by interacting anatomical systems rather than isolated variables]16-18[
SEM analysis provides a more biologically meaningful interpretation of craniofacial relationships. It further supports the interpretation that cranial-base morphology and mandibular rotation influence ANB both directly and indirectly through SNB reduction [7,8,37,39].

Key findings of SEM analysis

1. Moderate indirect effect: Saddle angle → cranial base → ANB
2. Moderate direct effect: Articular angle → ANB
3. Week indirect effect: Gonial angle → SNB → ANB

This shows that all the variables work together directly and indirectly in skeletal class II in Libyan patients, and there is no clear dominant factor. The results have direct orthodontic relevance, which is important for Libyan orthodontists to understand. This relevance can be summarized as:

1. Saddle angle can serve as a predictive marker for mandibular retrusion.
2. Patients with increased gonial angle may require:
   a. Vertical control strategies
   b. Growth modification appliances
3. Articular angle assessment may refine the diagnosis of cranial base influence

Moreover, reliance solely on ANB without considering the Björk polygon may lead to diagnostic oversimplification. This study provides valuable data for Libyan patients, a population underrepresented in orthodontic literature. Recent studies evaluating Björk polygon variations among different skeletal classes further support the present findings, confirming the structural relevance of these angles in Class II malocclusion [39].

Conclusion

This study demonstrates that the Björk polygon plays a fundamental role in determining sagittal skeletal relationships in Class II Division 1 malocclusion**.** Binary logistic regression confirmed that increased saddle angle, increased articular angle, and reduced SNB significantly increased the probability of severe skeletal Class II discrepancy**,** with the saddle angle being the strongest Björk polygon predictor of severity. The Saddle angle is the most significant predictor of ANB and skeletal Class II severity in this study sample, while the articular angle contributes independently, reflecting cranial base–mandibular interaction. The gonial angle has a secondary indirect role. Its effect is mediated primarily through mandibular rotation and reduction in SNB. Craniofacial relationships are best understood through multivariate and structural modeling approaches. Clinically, these findings emphasize that class II malocclusion is not purely sagittal; it is also influenced by vertical and rotational growth patterns. Therefore, a comprehensive cephalometric evaluation should include Björk polygon analysis alongside conventional sagittal parameters. Craniofacial morphology varies across ethnic groups, and the observed relationships highlight the importance of developing population-specific cephalometric norms, refining existing data, and avoiding extrapolation from Caucasian standards.

Conflict of interest. Nil

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