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RELATIONSHIP BETWEEN CRANIOFACIAL SKELETAL MORPHOLOGY AND FREEWAY SPACE IN ADULTS: A CEPHALOMETRIC AND CLINICAL STUDY

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Abstract

Aim: Freeway space (FWS), the difference between rest vertical dimension and occlusal vertical dimension, is a clinically important component of vertical dimension assessment. Because mandibular rest position reflects a dynamic neuromuscular balance, an objective skeletal indicator that complements clinical measurement may be useful. This study aimed to evaluate the relationships of the saddle, articular and gonial angles, and their cumulative Björk sum, with clinically measured FWS in adults. **Materials and Methods:** Thirty adults with completed growth (20 women and 10 men; mean age 28.06 ± 2.16 years) were included. FWS was calculated using the Niswonger method from repeated measurements between pronasale and soft-tissue pogonion at rest and maximum intercuspation. Manual and digital calipers were used, and measurements were repeated after two weeks by the same clinician. Lateral cephalograms obtained in natural head position, with the jaws in centric relation, were used to measure the saddle (N-S-Ar), articular (S-Ar-Go) and gonial (Ar-Go-Me) angles and their cumulative Björk sum. **Results:** Agreement between manual and digital measurements was excellent (ICC > 0.90, $p < 0.001$). Saddle angle ($r = 0.002$, $p = 0.990$), articular angle ($r = -0.234$, $p = 0.213$) and gonial angle ($r = -0.262$, $p = 0.161$) were not significantly correlated with FWS. In contrast, the Björk sum showed a moderate negative correlation with FWS ($r = -0.419$, $p = 0.021$). FWS did not differ significantly according to sex or sagittal skeletal class. **Conclusion:** Individual craniofacial angles were insufficient as isolated indicators of FWS, whereas the cumulative Björk sum showed a significant moderate negative correlation with FWS. A more vertical cumulative skeletal pattern was associated with a smaller FWS. The Björk sum may therefore provide supportive information alongside clinical assessment of vertical dimension. **Recommendation:** The Björk sum should be considered as a complementary rather than an isolated diagnostic parameter in the clinical assessment of vertical dimension. Further prospective studies with larger and more balanced samples are recommended to confirm its clinical applicability and predictive value.

Keywords: Freeway Space; Vertical Dimension; Cephalometry; Björk Sum; Gonial Angle; Craniofacial Morphology.

INTRODUCTION

Mandibular rest position is a physiologic position in which the maxillary and mandibular teeth are separated and the mandible is maintained by the coordinated activity of the elevator and depressor muscles. The vertical difference between the mandibular rest position and the position of tooth contact is described as the freeway space (FWS). Its

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assessment is relevant to functional balance and to the establishment of vertical dimension in orthodontic and prosthodontic treatment [1-3].

Clinical determination of vertical dimension may rely on phonetic methods [4], rest-position measurements [2,5], and functional or instrumental assessment [6]. However, the mandibular rest position is not a purely static skeletal relationship and can vary according to the method used to induce or record it [7]. This has encouraged the use of cephalometric parameters as objective complementary measures when vertical dimension is evaluated.

Vertical dimension is a central component of stomatognathic function and is clinically relevant when occlusal vertical dimension is evaluated or modified [3]. In clinical practice, the rest position of the mandible has traditionally been used as one reference for establishing an acceptable occlusal vertical dimension [2,5]. The difference between rest vertical dimension and occlusal vertical dimension constitutes FWS [1,2]. Because different clinical and functional methods provide complementary information rather than a single absolute reference, vertical-dimension assessment is best interpreted using more than one observation [3,4,6].

Natural head position is particularly relevant when vertical relationships are assessed. Conventional intracranial reference planes may vary among individuals because of cranial-base morphology, whereas natural head position provides a physiologic orientation that more closely reflects habitual posture. The use of a reproducible natural head position therefore helps connect clinical facial measurements with cephalometric assessment and reduces the risk that apparent vertical differences are created primarily by variation in head orientation [8,9].

Craniofacial morphology is commonly described using angular relationships of the cranial base, mandibular ramus and mandibular plane. The saddle angle (N-S-Ar), articular angle (S-Ar-Go) and gonial angle (Ar-Go-Me) represent different components of this morphology. The gonial angle in particular has been linked to mandibular rotation and vertical facial pattern [10,11]. Nevertheless, the craniofacial complex functions as an integrated biomechanical system, and an isolated angular measurement may not adequately represent the cumulative skeletal pattern.

The three angular components used in the Björk/Jarabak approach represent anatomically distinct regions. The saddle angle reflects the relationship between the anterior and posterior cranial base, the articular angle describes the relationship between the posterior cranial base and mandibular ramus, and the gonial angle reflects the relationship between the ramus and mandibular body. Changes in these components can accompany different patterns of mandibular rotation and vertical facial development. Their combined interpretation is therefore conceptually attractive when the clinical variable of interest, such as FWS, is also influenced by several interacting skeletal and neuromuscular factors [10,11]. Masticatory muscle size and craniofacial morphology have also been associated with bite-force magnitude [12], underscoring that morphologic and functional variables are related but not interchangeable.

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Previous investigations have frequently examined individual cephalometric variables in relation to vertical facial form. However, an association between an isolated skeletal angle and facial morphology does not necessarily imply a direct association with mandibular rest position. FWS emerges from the difference between two clinically measured vertical positions and is influenced by muscular tone and functional adaptation. Accordingly, the present study was designed not only to test individual angular relationships but also to determine whether their cumulative sum provides a more informative representation of the skeletal background of FWS.

In the Björk/Jarabak framework, the sum of the saddle, articular and gonial angles provides a cumulative representation of skeletal growth direction [10]. A larger sum is associated with a more vertical growth pattern, whereas a smaller sum is associated with a more horizontal pattern. Evaluating this cumulative parameter together with FWS may therefore provide information that cannot be obtained from any one angle alone.

Cephalometric analysis offers a different type of information. Rather than measuring the functional space itself, it describes the skeletal framework within which mandibular posture occurs. This distinction underlies the central question of the study: whether objective skeletal morphology is sufficiently related to FWS to provide useful complementary information. The analysis of both isolated angles and their cumulative sum was chosen specifically to distinguish local anatomic effects from the overall craniofacial pattern.

The Niswonger approach is attractive because it is simple, non-invasive and directly expresses the difference between a rest measurement and an occlusal measurement. Its limitation is that the rest position must first be obtained in a reproducible manner. Small changes in posture or muscular activity can alter the measured distance. In the present study, standardization of head position, repeated measurements and the use of two caliper types were intended to reduce this source of variability while preserving the clinical nature of the measurement [2,7].

From a clinical perspective, the challenge is that the same measured FWS may occur in individuals with different craniofacial configurations. Conversely, individuals with similar cephalometric patterns may not necessarily present identical rest spaces because mandibular rest position is maintained by neuromuscular equilibrium. This variability explains why classical vertical-dimension methods are generally interpreted together rather than in isolation. Rest-position measurements, phonetic evaluation, swallowing, esthetic assessment and instrumental methods each provide a different view of the vertical relationship [2,4-6].

The aim of this study was to investigate the correlations between clinically measured FWS and the saddle, articular and gonial angles, both individually and as the cumulative Björk sum, in adults with completed growth. A secondary aim was to examine whether FWS differed according to sex or sagittal skeletal class.

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METHOD

Study Design and Participants

This retrospective study was based on clinical archive records from patients evaluated in the Department of Orthodontics, Faculty of Dentistry, Istanbul Okan University between 2020 and 2024. Pretreatment lateral cephalometric images from 30 patients were included. The study protocol was approved by the Istanbul Okan University Faculty of Medicine Ethics Committee on 11 September 2024 (Decision No. 36). The inclusion criteria specified in the thesis were age ≥15 years, permanent dentition, systemic health, no missing teeth, and no active or previous orthodontic treatment or temporomandibular joint treatment. The final study group consisted of 20 women and 10 men, with a mean age of 28.06 ± 2.16 years (range, 25-32 years).

Restricting the sample to individuals with completed craniofacial growth was intended to minimize the influence of ongoing developmental change. Vertical facial growth, ramus height and condylar development may continue to alter mandibular relationships during growth; therefore, inclusion of growing patients could confound an analysis focused on the association between established skeletal morphology and FWS. The adult sample allowed the study to examine these relationships after the major growth-related changes in craniofacial form had stabilized.

Clinical Measurement of Freeway Space

Participants were positioned with the head freely balanced and this position was accepted as the natural head position [8,9]. Pronasale (Pn) and the most anterior point of the soft-tissue chin (soft-tissue pogonion, Pog′) were marked. The Pn–Pog′ vertical distance was measured while the mandible was in its physiologic rest position to obtain rest vertical dimension (RVD). The same distance was measured at maximum intercuspation to obtain occlusal vertical dimension (OVD). FWS was calculated as RVD minus OVD according to the Niswonger method [2]. Measurements were first made with a manual caliper and then with a digital caliper. Two weeks later, all measurements were repeated by the same clinician. The clinical measurement procedure is illustrated in Figure 1.

The clinical protocol was selected because mandibular rest position is sensitive to posture and neuromuscular state. A consistent head orientation and clearly defined soft-tissue landmarks were therefore used for all measurements. The same Pn-Pog′ reference distance was recorded at physiologic rest and at maximum intercuspation so that FWS represented the within-subject difference between the two vertical positions rather than a comparison of unrelated facial dimensions.

Use of both manual and digital calipers provided an additional reliability check for the clinical procedure. Repetition of the measurements after a two-week interval by the same clinician was intended to evaluate reproducibility while avoiding immediate recall of the first measurements. The resulting ICC analysis was used to quantify agreement between the measurement approaches before the clinical values were interpreted in relation to the cephalometric variables.

Figure1: Clinical Measurement of Vertical Facial Dimension Using a Digital Caliper Between Pronasale (Pn) and Soft-Tissue Pogonion (Pog′). Freeway Space Was Calculated as the Difference Between Rest Vertical Dimension and Occlusal Vertical Dimension

Cephalometric Assessment

Lateral cephalograms were obtained with a Planmeca ProMax 3D Mid unit at Istanbul Okan University Faculty of Dentistry. Radiographs were acquired with participants in natural head position and the jaws in centric relation. Exposure parameters were 64 kV, 10 mA and 10 s. One cephalogram from each of the 30 participants was evaluated. The cephalometric landmarks were Sella (S), Nasion (N), Articulare (Ar), Gonion (Go) and Menton (Me).

The reference planes were S-N, S-Ar, Ar-Go and Go-Me. The saddle angle was defined as N-S-Ar, the articular angle as S-Ar-Go, and the gonial angle as Ar-Go-Me. The Björk sum, a standard cephalometric parameter named after Arne Björk, was calculated as the sum of these three angles. The cephalometric reference planes are shown in Figure 2.

Lateral cephalometry was chosen because it permits standardized evaluation of the cranial-base and mandibular angular relationships used in the Björk/Jarabak analysis and remains directly comparable with the historical literature on these parameters. Its two-dimensional nature necessarily introduces limitations such as superimposition and magnification, but the method is suitable for the principal angular measurements investigated here.

Three-dimensional imaging may be advantageous in future studies when condylar morphology, asymmetry or other spatial relationships are primary outcomes. Each angular measurement was interpreted both separately and as part of the cumulative Björk sum. This dual approach was important to the study rationale: an isolated angle may represent only one component of craniofacial morphology, whereas the sum of the saddle, articular and gonial angles provides an integrated indicator of overall skeletal growth direction [10,11].

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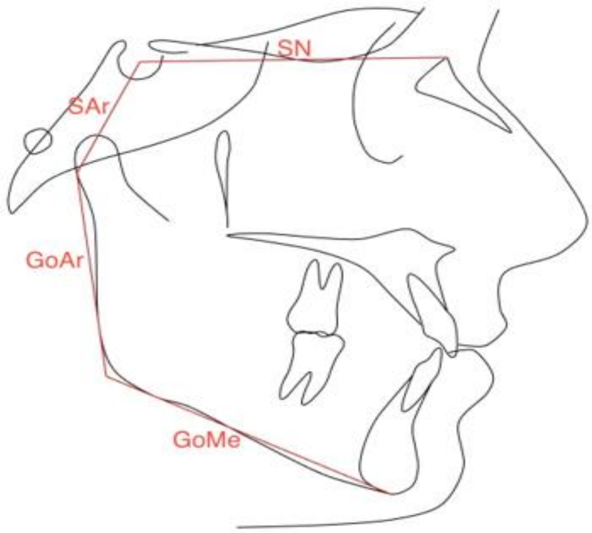

Figure 2: Cephalometric Reference Planes Used to Determine The Saddle (N-S-Ar), Articular (S-Ar-Go) and Gonial (Ar-Go-Me) Angles. the Björk Sum Was Calculated as the Sum of These Three Angles

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 29.0. Distributional characteristics were assessed using the Shapiro-Wilk test. Descriptive statistics were reported as appropriate. Pearson correlation coefficients were used to examine linear relationships between continuous variables. Independent-samples t tests or Mann-Whitney U tests were used for two-group comparisons according to distribution, and Kruskal-Wallis tests were used for comparisons across three skeletal classes, followed where appropriate by Bonferroni-adjusted Mann-Whitney U tests. Categorical variables were compared using the Fisher-Freeman-Halton exact test. Agreement between manual and digital measurements was evaluated using the intraclass correlation coefficient (ICC). Statistical significance was set at $p < 0.05$. The statistical strategy was structured around the type and distribution of each variable. Correlation analysis addressed the primary question concerning linear associations between cephalometric measures and clinical vertical dimensions.

Group-comparison tests addressed the secondary questions concerning sex and sagittal skeletal class. When a three-group comparison was significant, adjusted pairwise testing was used to identify the groups responsible for the overall difference while controlling for multiple comparisons. Reliability analysis was considered essential because FWS is calculated from two clinical measurements and measurement error in either component could influence the resulting difference. The interpretation of statistical significance was accompanied by consideration of effect direction and clinical meaning. In particular, a statistically significant correlation was not treated as evidence of direct causation or as proof that a cephalometric variable could replace clinical measurement. This distinction

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is important in a study with a relatively small sample, in which the purpose is to identify potentially informative relationships for subsequent validation rather than to establish a definitive predictive model [13].

RESULTS

The study included 30 adults (20 women, 66.7%; 10 men, 33.3%) with a mean age of 28.06 ± 2.16 years (range, 25-32 years). Manual and digital measurements showed excellent agreement. ICC values were 0.937 for RVD, 0.946 for OVD and 0.962 for FWS; all were statistically significant ($p < 0.001$).

Correlation Analysis

No significant correlation was observed between saddle angle and RVD (r = -0.084, p = 0.659), OVD (r = -0.079, p = 0.678), or FWS (r = 0.002, p = 0.990). Similarly, gonial angle was not significantly correlated with RVD (r = 0.094, p = 0.622), OVD (r = 0.121, p = 0.525), or FWS (r = -0.262, p = 0.161). Articular angle showed significant positive correlations with both RVD (r = 0.473, p = 0.008) and OVD (r = 0.472, p = 0.008), whereas its correlation with FWS was not statistically significant (r = -0.234, p = 0.213). The Björk sum was positively correlated with RVD (r = 0.431, p = 0.017) and OVD (r = 0.456, p = 0.011). In contrast, a statistically significant moderate negative correlation was observed between the Björk sum and FWS (r = -0.419, p = 0.021), indicating that higher cumulative angular values were associated with smaller FWS values. This relationship is illustrated in Figure 3. Articular angle and the Björk sum were significantly associated with RVD and OVD; however, among the evaluated angular variables, only the Björk sum showed a statistically significant association with FWS (Table 1).

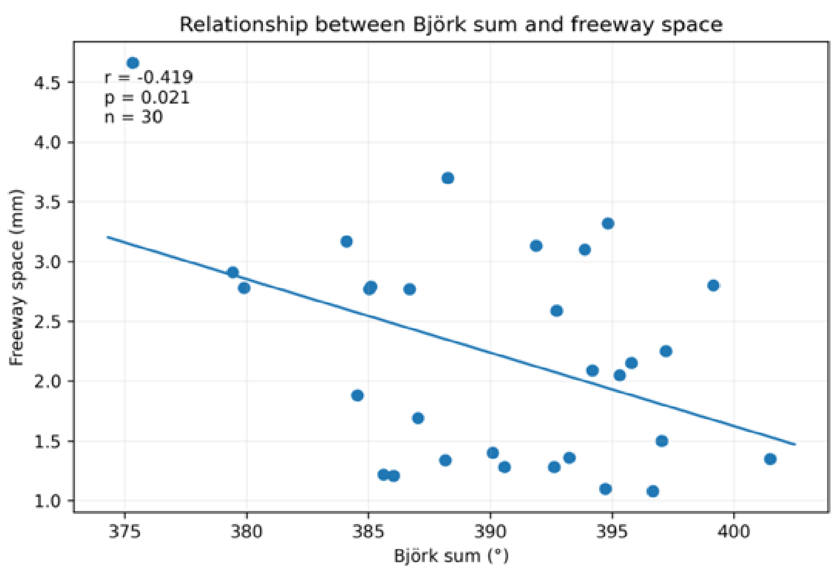

Figure 3: Scatter Plot Showing the Relationship Between the Björk Sum and Digitally Measured Freeway Space. The Fitted Linear Trend Demonstrates a Moderate Negative Correlation (R = -0.419, P = 0.021; N = 30)

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Table 1: Principal Correlation Findings. *P < 0.05. FWS, Freeway Space; RVD, Rest Vertical Dimension; OVD, Occlusal Vertical Dimension

Cephalometric variable	Outcome	Pearson r	p value
Saddle angle	FWS	0.002	0.990
Articular angle	FWS	-0.234	0.213
Gonial angle	FWS	-0.262	0.161
Björk sum	FWS	-0.419	0.021*
Articular angle	RVD	0.473	0.008*
Articular angle	OVD	0.472	0.008*
Björk sum	RVD	0.431	0.017*
Björk sum	OVD	0.456	0.011*

Sex-Based Comparisons

RVD was significantly greater in men than in women (78.1790 ± 8.14281 mm vs. 72.3070 ± 5.31039 mm, p = 0.024). Similarly, OVD was significantly greater in men (76.0760 ± 8.73337 mm) than in women (70.0225 ± 5.72670 mm, p = 0.030). In contrast, FWS did not differ significantly between women (2.2845 ± 0.99973 mm) and men (2.1030 ± 0.75230 mm, p = 0.617).

No statistically significant sex-based differences were observed for the saddle angle (p = 0.119), articular angle (p = 0.876), gonial angle (p = 0.452), or Björk sum (p = 0.064) (Table 2)

Table 2: Comparison of clinical and cephalometric variables according to sex. *p < 0.05

Variable	Women (n=20), Mean ± SD	Men (n=10), Mean ± SD	p value
RVD (mm)	72.3070 ± 5.31039	78.1790 ± 8.14281	0.024*
OVD (mm)	70.0225 ± 5.72670	76.0760 ± 8.73337	0.030*
FWS (mm)	2.2845 ± 0.99973	2.1030 ± 0.75230	0.617
Saddle angle (°)	127.3715 ± 4.09222	124.7830 ± 4.28891	0.119
Articular angle (°)	144.2895 ± 5.81625	143.9540 ± 4.81253	0.876
Gonial angle (°)	120.0435 ± 5.82465	118.5000 ± 3.65657	0.452
Björk sum (°)	391.7045 ± 6.18138	387.2370 ± 5.50782	0.064

Comparisons According to Sagittal Skeletal Class

FWS did not differ significantly among skeletal Classes I, II, and III (p = 0.076). Mean FWS values were 1.6825 ± 0.65587 mm in Class I, 2.1921 ± 0.80366 mm in Class II, and 2.8213 ± 1.04755 mm in Class III.

In contrast, RVD differed significantly among skeletal classes (p = 0.007), with mean values of 73.2000 ± 3.12723 mm, 78.0264 ± 7.39631 mm, and 68.7450 ± 4.34050 mm for Classes I, II, and III, respectively. Bonferroni-adjusted pairwise comparisons demonstrated a significant difference between Classes II and III (p = 0.006).

OVD also differed significantly among skeletal classes (p = 0.004). Mean OVD was 71.5175 ± 3.27836 mm in Class I, 75.8343 ± 7.83035 mm in Class II, and 65.9238 ±

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5.05015 mm in Class III. Pairwise analysis showed a significant difference between Classes II and III (p = 0.003).

Among the cephalometric variables, saddle and gonial angles did not differ significantly among skeletal classes (p = 0.830 and p = 0.989, respectively). Articular angle differed significantly (p = 0.013), with pairwise analysis demonstrating a significant difference between Classes II and III (p = 0.010). The Björk sum also differed significantly among skeletal classes (p = 0.021), with a significant Class II-Class III difference (p = 0.017).

Sex distribution did not differ significantly among sagittal skeletal classes (Fisher-Freeman-Halton exact test, p = 0.293). The clinical and cephalometric comparisons according to sagittal skeletal class are summarized in Table 3.

Table 3: Comparison of Clinical and Cephalometric Variables According to Sagittal Skeletal Class. Significant Post-Hoc Differences: Class II vs. Class III for RVD (P = 0.006), OVD (P = 0.003), Articular Angle (P = 0.010), and Björk Sum (P = 0.017). *P < 0.05

Variable	Class I (n=8)	Class II (n=14)	Class III (n=8)	p value
FWS (mm)	1.6825±0.65587	2.1921±0.80366	2.8213±1.04755	0.076
RVD (mm)	73.2000±3.12723	78.0264±7.39631	68.7450±4.34050	0.007*
OVD (mm)	71.5175±3.27836	75.8343±7.83035	65.9238±5.05015	0.004*
Saddle angle (°)	126.5775±5.51561	126.9764±3.15950	125.6213±5.01817	0.830
Articular angle (°)	144.2350±4.52988	146.6643±4.88483	139.7688±4.72079	0.013*
Gonial angle (°)	119.5000±4.27969	119.5143±5.02075	119.5838±6.81253	0.989
Björk sum (°)	390.3125±4.20330	393.1550±4.66531	384.9738±7.41224	0.021*

DISCUSSION

The principal finding of the present study was that individual cephalometric angles were not significantly associated with FWS, whereas their cumulative representation, the Björk sum, showed a moderate negative correlation with FWS. This suggests that an integrated assessment of craniofacial morphology may provide more clinically relevant information than reliance on a single angular parameter [10,11].

This distinction is clinically relevant because vertical dimension is not determined by a single skeletal measurement. The stomatognathic system integrates cranial-base configuration, mandibular form, muscular activity and functional adaptation. Although cephalometric parameters can provide objective morphologic information, the clinical rest position remains a physiologic state. The present findings therefore favor a complementary model in which cephalometric analysis supports, rather than substitutes for, direct clinical assessment of vertical dimension.

The study rationale was based on the possibility that a cumulative skeletal index would capture this integrated morphology more effectively than any one component. The significant Björk sum-FWS relationship is consistent with that rationale. Importantly, the correlation was moderate rather than strong, so the finding should not be interpreted as evidence that the Björk sum alone can predict an individual's FWS. Instead, it identifies a

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measurable skeletal tendency that may be clinically informative when considered together with functional measurements and the overall facial pattern.

The absence of a significant association between gonial angle and FWS deserves consideration. The gonial angle is traditionally associated with mandibular plane inclination, mandibular rotation and vertical facial morphology [10,11]. Previous work has suggested that it may have diagnostic value in relation to vertical facial form [14]. In the present adult sample, however, the correlation with FWS was negative but not statistically significant ($r = -0.262$, $p = 0.161$). This discrepancy may partly reflect differences in sample characteristics and the relatively limited sample size of the present study. In addition, functional or neuromuscular adaptation may contribute to the relative stability of the resting interocclusal space.

Sample size is another plausible explanation. With 30 participants, the study had limited ability to establish statistical significance for weak-to-moderate correlations [13]. The observed negative direction for the gonial angle was therefore not sufficient to support a direct relationship, but it also should not be interpreted as definitive evidence that no relationship exists. Replication in a larger sample is necessary before the diagnostic value of the gonial angle for FWS can be excluded.

The articular angle showed a different pattern. Although it was not significantly correlated with FWS, it was positively correlated with both RVD and OVD. It was also higher in skeletal Class II than Class III participants. These findings are compatible with established relationships between articular morphology, craniofacial growth and mandibular rotational patterns [10,11,15]. The absence of a corresponding FWS association may reflect functional or neuromuscular adaptation, but this mechanism was not directly measured in the present study.

The skeletal-class analysis reinforces this interpretation. Articular angle differed among sagittal skeletal classes, with the principal pairwise difference occurring between Classes II and III. The finding suggests that articular morphology may participate in broader mandibular positional relationships, but the absence of a corresponding significant class effect for FWS indicates that sagittal skeletal classification alone does not determine the physiologic interocclusal space.

The saddle angle was essentially unrelated to FWS in this sample. Although it reflects cranial-base morphology, its influence on the neuromuscularly determined mandibular rest position may be indirect. The result further illustrates the limitation of using an isolated craniofacial angle as a surrogate for a functional measurement.

The significant negative association between the Björk sum and FWS is therefore the most clinically relevant observation. The Björk/Jarabak concept treats the saddle, articular and gonial angles as components of a cumulative growth pattern [10]. In the present data, an increase in this cumulative value—consistent with a more vertical skeletal pattern—was associated with a reduction in FWS. This does not establish causation, but it suggests that the integrated skeletal configuration may carry clinically useful information when interpreted alongside direct functional measurements.

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FWS was not significantly different between women and men despite significantly greater absolute RVD and OVD in men. Rivera-Morales and Mohl discussed the relationship of occlusal vertical dimension to masticatory-system health [16], while sexual dimorphism in craniofacial growth and dimensions has also been documented [17]. Jaw-muscle size has been associated with craniofacial morphology and bite-force magnitude [12]. In the present sample, these sex-related differences in absolute dimensions did not translate into a significant difference in FWS. Likewise, FWS did not differ significantly among skeletal Classes I, II and III, in agreement with Suresh et al. [18].

Methodological reliability was strengthened by the use of repeated manual and digital caliper measurements, with ICC values above 0.90 for all clinical variables. Natural head position was used to provide a physiologic and reproducible orientation, and all repeated clinical measurements were performed by the same clinician. These features reduce measurement variability, although they do not eliminate the biologic variability inherent to mandibular rest position. Natural head position itself is a well-established cephalometric orientation, and its reproducibility has been examined longitudinally [19,20].

At the same time, high measurement reliability does not remove the inherent biologic variability of FWS. Mandibular rest position can vary with stress, fatigue, posture and the timing or conditions of measurement [7]. Consequently, a highly reproducible protocol can reduce technical error but cannot transform FWS into a fixed skeletal measurement. This distinction is important when interpreting the moderate magnitude of the observed Björk sum correlation. The functional relationship between freeway space and muscular activity has also been emphasized in the orthodontic and prosthodontic literature [21].

Interpretation of the Bjork Sum

The Bjork sum should be understood as a cumulative morphologic descriptor rather than a direct functional measurement. Its components reflect the cranial base, the relationship of the ramus to the cranial base, and the relationship of the ramus to the mandibular body. Summing these components produces a broader representation of growth direction than any isolated angle. The present negative correlation with FWS therefore suggests that the overall skeletal configuration may influence the spatial relationship between rest and occlusion even when no single component reaches statistical significance [10,11].

The direction of the association is also noteworthy. Higher cumulative angular values, representing a more vertical skeletal tendency within the Björk/Jarabak framework, were associated with smaller FWS values. This finding does not mean that all vertically patterned individuals will have a small rest space. The moderate coefficient indicates substantial individual variability. Rather, the result identifies a group-level tendency that may help explain why functional vertical relationships cannot always be inferred from one local skeletal feature. The finding also illustrates a statistical and biologic principle relevant to craniofacial research: several modest component effects can become more apparent when considered collectively. Saddle, articular and gonial angles describe connected parts of the same craniofacial system. A cumulative parameter may therefore capture coordinated variation that is not detectable when each component is tested

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independently. Validation in an independent and larger cohort would be required to determine whether this advantage is reproducible.

Relationship to Clinical Vertical-Dimension Assessment

Clinical vertical-dimension assessment often requires the integration of several observations because no single method provides an absolute physiologic reference in every patient. The present study supports that multidimensional approach. The Niswonger measurement directly quantifies the rest-to-occlusion difference, whereas cephalometric analysis provides information about the skeletal framework. Their roles are therefore complementary: one is primarily functional and clinical, and the other primarily morphologic and radiographic [1-6]. Electromyographic changes associated with variations in vertical dimension and established prosthodontic approaches to vertical-dimension assessment further support the need for a multimodal clinical interpretation [22, 23]. For patients in whom vertical dimension is being evaluated before orthodontic, restorative or prosthodontic intervention, a cumulative cephalometric pattern may help the clinician interpret an unusual clinical measurement. However, the moderate strength of the Björk sum association and the variability of mandibular rest position argue against using the cephalometric value to calculate a target FWS. The safer interpretation is that skeletal morphology can provide context while the final assessment remains grounded in clinical function, esthetics and patient-specific adaptation.

This study has limitations. The sample comprised only 30 adults and the sex distribution was unequal. These factors restrict generalizability and may have limited statistical power, particularly for weak-to-moderate correlations. Two-dimensional cephalometric assessment also limits detailed evaluation of condylar morphology or asymmetry. In addition, FWS is a dynamic neuromuscular variable that can be affected by stress, fatigue, posture and time of day [7]. Larger prospective studies with balanced samples, standardized measurement timing and, where clinically justified, three-dimensional imaging would help determine the reproducibility and clinical predictive value of the observed association. The limitation of two-dimensional assessment is particularly relevant when more detailed three-dimensional facial soft-tissue morphology is of interest [24].

Clinical Implications

Within these limitations, cephalometric analysis should not replace direct clinical assessment of FWS. Instead, the Björk sum may be considered a complementary skeletal parameter. Its potential value lies in adding a cumulative morphologic perspective to functional vertical-dimension assessment rather than serving as an isolated diagnostic determinant. For orthodontic and prosthodontic planning, FWS should continue to be measured clinically. The Björk sum may add context when the clinician evaluates a patient's vertical skeletal pattern, especially when considering changes in occlusal vertical dimension. The present data do not support calculating a target FWS from the Björk sum or using a universal cephalometric threshold to prescribe vertical dimension.

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Directions for Future Research

Future work should first replicate the Björk sum-FWS association in a larger cohort with a balanced sex distribution. A larger sample would improve the precision of correlation estimates, increase power for subgroup comparisons and allow multivariable models to assess whether the cumulative skeletal parameter remains informative after accounting for age, sex and sagittal skeletal class. Such analyses would be necessary before any predictive application could be considered. Prospective standardization of FWS measurement would also be valuable. Because rest position can be affected by posture, fatigue, stress and time of day, future protocols could standardize the measurement session and repeat observations on separate days. This would help distinguish short-term physiologic variability from stable individual differences and provide a more rigorous estimate of the relationship between skeletal morphology and habitual mandibular rest position [7].

Finally, three-dimensional imaging could extend the present two-dimensional angular analysis. Detailed assessment of condylar position, joint morphology, mandibular asymmetry and volumetric facial characteristics may identify additional morphologic factors associated with vertical dimensions. These approaches should be evaluated against their additional radiation exposure and clinical benefit, but they may be particularly useful for clarifying the articular findings observed in the present study. Future morphologic work may also benefit from interpreting such imaging within established concepts of facial growth and contemporary orthodontic diagnosis [25,26].

CONCLUSION

In adults with completed growth, the saddle, articular and gonial angles were not individually associated with freeway space. The cumulative Björk sum showed a moderate, statistically significant negative correlation with freeway space, indicating that a more vertical cumulative skeletal pattern was associated with a smaller interocclusal rest space. Freeway space did not differ significantly by sex or sagittal skeletal class, and repeated manual and digital clinical measurements demonstrated excellent reliability. The Björk sum may therefore be considered a complementary morphologic parameter during vertical-dimension assessment, but larger prospective studies are needed before predictive clinical use can be recommended.

Recommendations

1) Future studies should evaluate the relationship between freeway space and cumulative craniofacial morphology in larger and more balanced samples.

2) Three-dimensional imaging may be used to investigate condylar morphology and other skeletal details that cannot be fully assessed on two-dimensional lateral cephalograms.

3) Standardized prospective protocols should be considered to reduce the effects of posture, fatigue, stress and time of day on clinical freeway-space measurements.

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References

1) Potgieter PJ, Monteith BD, Kemp PL. The determination of free-way space in edentulous patients: a cephalometric approach. J Oral Rehabil. 1983;10(4):283-293.

2) Niswonger ME. The rest position of the mandible and the centric relation. J Am Dent Assoc. 1934;21(9):1572-1582.

3) Abduo J, Lyons K. Clinical considerations for increasing occlusal vertical dimension: a review. Aust Dent J. 2012;57(1):2-10.

4) Silverman MM. The speaking method in measuring vertical dimension. J Prosthet Dent. 1956;6(4):465-471.

5) Atwood DA. A cephalometric study of the clinical rest position of the mandible. Part I. J Prosthet Dent. 1956;6(4):504-519.

6) Slavicek R. Clinical and instrumental functional analysis for diagnosis and treatment planning in orthodontics. Part I. J Clin Orthod. 1983;17(8):513-521.

7) Wessberg GA, Epker BN, Elliott AC. Comparison of mandibular rest positions induced by phonetics, transcutaneous electrical stimulation, and masticatory electromyography. J Prosthet Dent. 1983;49(1):100-105.

8) Showfety KJ, Vig PS, Matteson S. A simple method for taking natural-head-position cephalograms. Am J Orthod. 1983;83(6):495-500.

9) Solow B, Tallgren A. Natural head position in standing subjects. Acta Odontol Scand. 1971;29(5):591-607.

10) Jarabak JR, Fizzell JA. Technique and treatment with light-wire edgewise appliances. 2nd ed. St. Louis: Mosby; 1972.

11) Schudy FF. Vertical growth versus anteroposterior growth as related to function and treatment. Angle Orthod. 1964;34(2):75-93.

12) Raadsheer MC, van Eijden TMGJ, van Ginkel FC, Prahl-Andersen B. Contribution of jaw muscle size and craniofacial morphology to human bite force magnitude. J Dent Res. 1999;78(1):31-42.

13) Altman DG. Practical statistics for medical research. London: Chapman & Hall; 1991.

14) Bhad WA, Nayak S, Doshi UH. A study of the correlation between gonial angle and vertical facial morphology in adults. Angle Orthod. 2013;83(4):715-722.

15) Katsavrias EG. Changes in articular eminence inclination during the craniofacial growth period. Angle Orthod. 2002;72(3):258-264.

16) Rivera-Morales WC, Mohl ND. Relationship of occlusal vertical dimension to the health of the masticatory system. J Prosthet Dent. 1991;65(4):547-553.

17) Ursi WJ, Trotman CA, McNamara JA, Behrents RG. Sexual dimorphism in normal craniofacial growth. Angle Orthod. 1993;63(1):47-56.

18) Suresh S, Chaitra P, Chandrashekar N. Comparative evaluation of interocclusal rest space in subjects with Class I, Class II & Class III skeletal malocclusion. Int J Pharm Bio Sci. 2015;6(3):189-195.

19) Moorrees CFA, Kean MR. Natural head position, a basic consideration in the interpretation of cephalometric radiographs. Am J Phys Anthropol. 1958;16(2):213-234.

20) Peng L, Cooke MS. Fifteen-year reproducibility of natural head posture: a longitudinal study. Am J Orthod Dentofacial Orthop. 1999;116(1):82-85.

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21) Mongini F. Freeway space and muscular function in orthodontics and prosthodontics. J Prosthet Dent. 1977; 38(5):523-530.

22) Manns A, Miralles R, Palazzi C. EMG, bite force and elongation of the masseter muscle under isometric voluntary contractions and variations of vertical dimension. J Prosthet Dent. 1979;42(6):674-682.

23) Zarb GA, Hobkirk JA, Eckert SE, Jacob RF. Prosthodontic treatment for edentulous patients. 13th ed. St. Louis: Mosby; 2013.

24) Hassan B, Nijkamp P, Verheij H, Tairie J, van der Stelt P, Blowalda S. Precision of three-dimensional imaging for facial soft tissue analysis: a systematic review. Orthod Craniofac Res. 2013; 16(1):31-42.

25) Enlow DH, Hans MG. Essentials of facial growth. Philadelphia: WB Saunders; 1996.

26) Proffit WR, Fields HW, Sarver DM. Contemporary orthodontics. 6th ed. St. Louis: Elsevier; 2019.