Original Article

The Effect of Mandibular Growth Patterns on Sagittal Dysplasia Indicators: A Cephalometric Approach

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KEY WORDS
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Diagnostic performance;
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ABSTRACT

Background: Accurate diagnosis in all three planes of space is essential for developing an appropriate treatment plan. Several cephalometric indicators are used to evaluate sagittal skeletal malocclusions, yet their diagnostic performance is influenced by factors such as mandibular growth pattern.

Purpose: This study aimed to assess how mandibular growth patterns affected the diagnostic accuracy of four sagittal dysplasia indicators: Beta angle, YEN angle, W angle, and Pi angle.

Materials and Method: A retrospective cross-sectional study was conducted using 120 pretreatment lateral cephalograms, evenly distributed based on mandibular growth patterns (mandibular plane angle and facial axis angle). The sagittal malocclusion was diagnosed using A point–Nasion–B point angle, Wits appraisal, molar relation, and patient profile, and compared with the four cephalometric indicators to evaluate their diagnostic performance. Data were analyzed using one-way analysis of variance (ANOVA), Kappa statistics, and intra-class correlation coefficient (ICC), with statistical significance set at p Value < 0.05.

Results: Mandibular growth pattern significantly influenced the performance of sagittal dysplasia indicators. In the normodivergent group, Pi angle was most reliable for class II, while Beta angle was most accurate for class I and class III cases. In the hypodivergent group, Beta angle was the most reliable for all sagittal malocclusion classes. In the hyperdivergent group, YEN and W angles were most accurate for class I cases, and Pi angle for class II. Class III cases were not assessed in the hyperdivergent group.

Conclusion: Mandibular growth pattern has a significant impact on the diagnostic performance of sagittal dysplasia indicators. Consideration of growth pattern alongside sagittal diagnosis may enhance diagnostic accuracy. A hierarchy chart is proposed to aid in selecting the most appropriate sagittal dysplasia indicator based on mandibular growth pattern.

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Introduction

The growth of the craniofacial unit is a complex interplay among three spatial planes, characterized by variations in both extent and timing. The cranium grows in response to the interaction between the cranial functional matrix and the skeletal tissues [1]. A well-balanced face results from the equilibrium between the direction of facial growth and the ratio and timing of that growth-termed static and dynamic growth, respectively. Nature endeavors to restore the facial balance by compensatory mechanisms when disharmony arises from local or environmental factors [1].

Vertical growth of the face significantly impacts the transverse and sagittal development of craniofacial structures [1]. While the amount and timing of growth vary across the three planes of space, vertical growth is typically the most pronounced. Mandibular growth patterns, described by Arne Bjork [2] in 1955, represent a key aspect of vertical development that varies among individuals and influences the growth of adjacent structures.

Traditionally, the anteroposterior relationship between the mandible and maxilla served as a primary diagnostic measure, relying on clinical observation for many years. The introduction of the cephalostat by Broadbent [3] in 1931 marked a pivotal advancement, allowing cephalometry to play a crucial role in establishing sagittal relationships. Several cephalometric parameters, including the A point–Nasion–B point (ANB) angle, Wits appraisal, AF-BF measurement, and the anteroposterior dysplasia indicator (APDI), have been defined and utilized for evaluating apical jaw base relationships.

Wylie's [4] initial efforts to describe anteroposterior jaw relationships laid the groundwork for subsequent cephalometric analyses. The ANB angle remains the most commonly used measurement; however, discrepancies often arise between its interpretation and the actual apical base relationships. Factors contributing to this variation include the position of the nasion, the length and inclination of the cranial base, and anterior facial height [5-6]. Additionally, variables such as patient head positioning and jaw rotation due to growth or orthodontic treatment can further complicate these assessments [7-8].

To address the limitations of existing parameters for sagittal evaluation, several other measurements such as the Beta angle, W angle, YEN angle, and Pi angle have been proposed to enhance diagnostic reliability [7, 9-11]. Nonetheless, these parameters exhibit varying degrees of success and reliability depending on factors such as malocclusion type, population, age, and ethnicity.

Research and growth studies have reported a correlation between sagittal and vertical growth directions in craniofacial structures, indicating that independent evaluations of these growth patterns may yield misleading results [12-13]. Although sagittal diagnostic parameters have been comparatively evaluated, such assessments have largely been conducted without adequate consideration of the growth pattern of the craniofacial skeleton, which significantly influences both the type and severity of malocclusion. Consequently, sagittal indicators have often been analyzed either in isolation or within heterogeneous samples, frequently overlooking the effects of growth pattern and mandibular rotation on sagittal interpretation [14-15]. Research evaluating newer sagittal indicators, such as the MKG angle, have also primarily focused on selected sagittal malocclusion classes without accounting for variations in growth pattern, thereby limiting their diagnostic applicability across diverse growth patterns [16].

Previous investigations that specifically examined the influence of growth pattern on sagittal diagnostic parameters have reported variable reliability across different vertical skeletal patterns. Sundareswaran *et al.* [17] found the Beta angle to be a reliable indicator of sagittal dysplasia in normodivergent and hypodivergent growth patterns; however, increased values observed in vertical growth patterns questioned its validity in skeletal class I and class II patients exhibiting vertical growth tendencies. Ajins *et al.* [18] used five sagittal dysplasia parameters for evaluation in different craniofacial growth patterns but sagittal direction included only class I malocclusion cases. Bajjad *et al.* [19] compared ten sagittal discrepancy parameters across three mandibular growth patterns and concluded that a combination of measurements is required for accurate sagittal assessment; however, skeletal class III malocclusion was not included in their analysis. More recently, Krymovskyy *et al.* [20] evaluated the effectiveness of the K-angle across different growth patterns, but the subjects included were of mixed dentition, which may have influenced sagittal interpretation and limited comparability.

Collectively, these studies highlight the influence of mandibular growth patterns on the reliability of sagittal diagnostic parameters while also revealing important methodological limitations, including restricted malocclusion classes, heterogeneous dentition stages, inadequate subgrouping based on growth pattern, and the absence of a standardized reference for true sagittal interpretation. Consequently, there remains a paucity of data regarding the diagnostic performance of sagittal parameters across different mandibular growth patterns. Therefore, the present study aimed to assess the influence of mandibular growth patterns on the diagnostic performance of four sagittal dysplasia indicators, the Beta angle, YEN angle, W angle, and Pi angle, using a standardized true sagittal interpretation as the reference.

Materials and Method

A retrospective cross-sectional study involving lateral cephalograms was designed which were of good diagnostic quality and exposed under the same parameters from the same cephalostat. The radiographs were chosen from the archives from the record room of Department of Orthodontics, after obtaining the ethical committee approval from the institution.

The inclusion criteria for the selection of lateral cephalogram were (1) subjects having permanent dentition with no missing teeth except third molars, (2) subjects without a history of trauma, orthodontic treatment, or orthognathic surgery, and (3) subjects without a history of congenital disabilities or functional mandibular shift.

All the radiographs were traced under proper illumination, using the same instruments and materials.

The study involved three investigators and a key person. The key person collected and coded the radiographs. Each investigator independently performed tracing of the coded radiographs for their respective assigned measurements. The first investigator traced the coded radiographs to classify mandibular growth patterns. The second investigator determined the true sagittal interpretation. The third investigator traced the radiographs to measure the sagittal dysplasia indicators. All measurements were recorded in a coded format and subsequently decoded, compiled, and submitted for statistical analysis by the key person.

The various landmarks used in the study are diagrammatically represented (Figure 1).

The samples were divided into three groups of mandibular growth patterns based on mandibular plane angle (SN-GoGn) and facial axis angle [21-22].

The parameter ranges considered were:

(1) Normodivergent: SN-GoGn: 30˚-34˚; Facial axises angle: 87˚ to 93˚

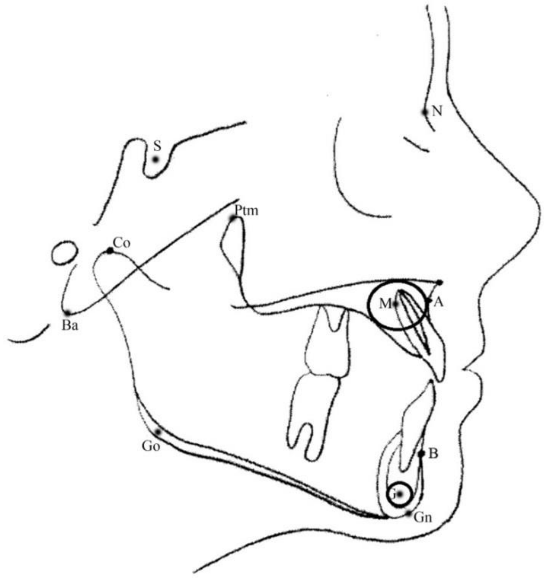

Figure 1: Cephalometric landmarks used in the study

(2) Hypodivergent: SN-GoGn: < 30˚; Facial axis angle: > 93˚

(3) Hyperdivergent: SN-GoGn: > 34˚; Facial axis angle: < 87˚

The sample size was calculated according to a statistical formula based on the results of a previous study where the mean value of Beta angle in class I occlusion in normodivergent patients was found to be 31.0°±2.5° [17]. To detect a change of 2.5° from this mean value with 95% confidence and 80% power, a minimum sample size of 97 lateral cephalograms were required. Hence, 120 lateral cephalograms sufficing the criteria were chosen and divided into 3 groups of 40 radiographs each. All the cephalograms were subjected to calibration for sagittal classes based on four parameters (ANB angle, Wits appraisal, molar relationship profile of the patient) wherein at least three should match to be designated as true sagittal interpretation. On all the cephalograms, values of angular sagittal dysplasia indicators (Beta angle, YEN angle, W angle, Pi angle) were measured and classified into skeletal classes based on the standard values for each sagittal dysplasia indicator.

The influence of each growth pattern was evaluated by matching the diagnosis of a particular investigated parameter to the true sagittal class interpretation and observed as correctly diagnosed if it matched.

The influence and diagnostic performance of all the parameters was according to the total correctly diagnosed cases in the three groups. After a four-week interval, 30 radiographs were arbitrarily selected by the key person. The investigators independently retraced the radiographs and repeated only the measurements initially assigned to them to assess the intra-rater reliability of the sagittal dysplasia indicators.

Statistical evaluation

The data were evaluated for statistical significance using Statistical Package for Social Sciences (SPSS version 23.0) and p Value < 0.05 was considered as the level of significance.

The counts and the respective percentages of the correct and incorrect interpretations for all the investigated angles in the complete sample of 120 subjects were seen. Mean values and standard deviations for each of the four investigated parameters were calculated in all the three growth patterns. The collected data were subjected to Kappa statistics, One-way analysis of variance (ANOVA) and intra-class correlation coefficient (ICC).

Results

Based on the true sagittal interpretation, 30 radiographs were classified as skeletal class I, 82 as skeletal class II, and 8 as skeletal class III cases out of the total 120 radiographs. When the skeletal class interpretation of the investigated angles was compared with the true interpretation, differences in the counts were seen. The mean and standard deviation of each investigated parameter in different growth patterns were calculated and tabulated (Table 1). ANOVA test showed highly significant differences in means of the parameters across skeletal classes in different growth patterns (Table 1). The reliability of sagittal dysplasia indicators showed good intra-rater agreement between four-week time interval observations (Table 2).

On evaluating the normodivergent group based on the true interpretation, 10 class I, 29 class II and 1 class III cases were present (Figure 2). For skeletal class I cases, highest agreement was found for Beta angle and Pi angle followed by W angle and YEN angle. Similarly, for skeletal class II cases, the highest agreement was found for Pi angle followed by Beta angle and YEN angle, followed by W angle. However, for skeletal class III cases, Beta angle, YEN angle and W angle gave the similar agreement while the Pi angle was not able to detect the sagittal class III.

For hypodivergent cases, 13 class I, 20 class II and 7 class III cases were present based on the true interpretation. Skeletal class I cases showed the highest agreement for Beta angle followed by W angle, YEN angle and Pi angle. Similarly, skeletal class II cases had the highest agreement for Beta angle followed by W angle and Pi angle followed by YEN angle. Skeletal class III cases showed the highest agreement for Beta angle and YEN angle followed by W angle, followed by Pi angle.

Analysis of the hyperdivergent group based on the true interpretation showed 7 class I, 33 class II and 0 class III cases. For skeletal class I cases, the highest agreement was found for YEN angle and W angle followed by Pi angle and Beta angle. However, in skeletal class II cases, Pi angle followed by YEN angle, followed by W angle and Beta angle showed the highest agreement. There were no subjects from skeletal class III in the hyperdivergent group.

On assessing the agreement between the parameters and true sagittal interpretation, it was found that Beta angle had a substantial agreement for hypodivergent

Table 1: Mean and standard deviation of the investigated parameters under various skeletal classes and growth patterns (Analysis of variance (ANOVA) test to assess the differences in means of the three groups)

Interpretation	Angles	Hyperdivergent Mean (˚)	Hypodivergent Mean (˚)	Normodivergent Mean (˚)	p Value
Class I	Beta	35.9 ± 3.4	30.7 ± 2.9	30.6 ± 4.7	0.00
	Yen	123.1 ± 3.8	122.6 ± 3.3	123.4 ± 3.9	0.00
	W	57.1 ± 1.6	49.3 ± 15.8	55.9 ± 3.4	0.00
	Pi	5.1 ± 6.6	5.3 ± 4.8	4.3 ± 4.0	0.00
Class II	Beta	28.4 ± 4.3	22.7 ± 5.6	23.8 ± 5.7	0.00
	Yen	116.6 ± 4.4	119.3 ± 6.4	116.1 ± 4.4	0.00
	W	53.1 ± 3.4	50.3 ± 7.9	50.5 ± 3.4	0.00
	Pi	9.1 ± 5.3	5.8 ± 5.3	8.7 ± 4.6	0.00
Class III	Beta	-	42.6 ± 3.8	42.0	0.00
	Yen	-	133.0 ± 5.4	129.0	0.00
	W	-	59.6 ± 4.1	60.0	0.00
	Pi	-	-1.9 ± 4.9	6.0	0.35

p < 0.01: Highly significant p < 0.05: Significant p > 0.05: Not significant

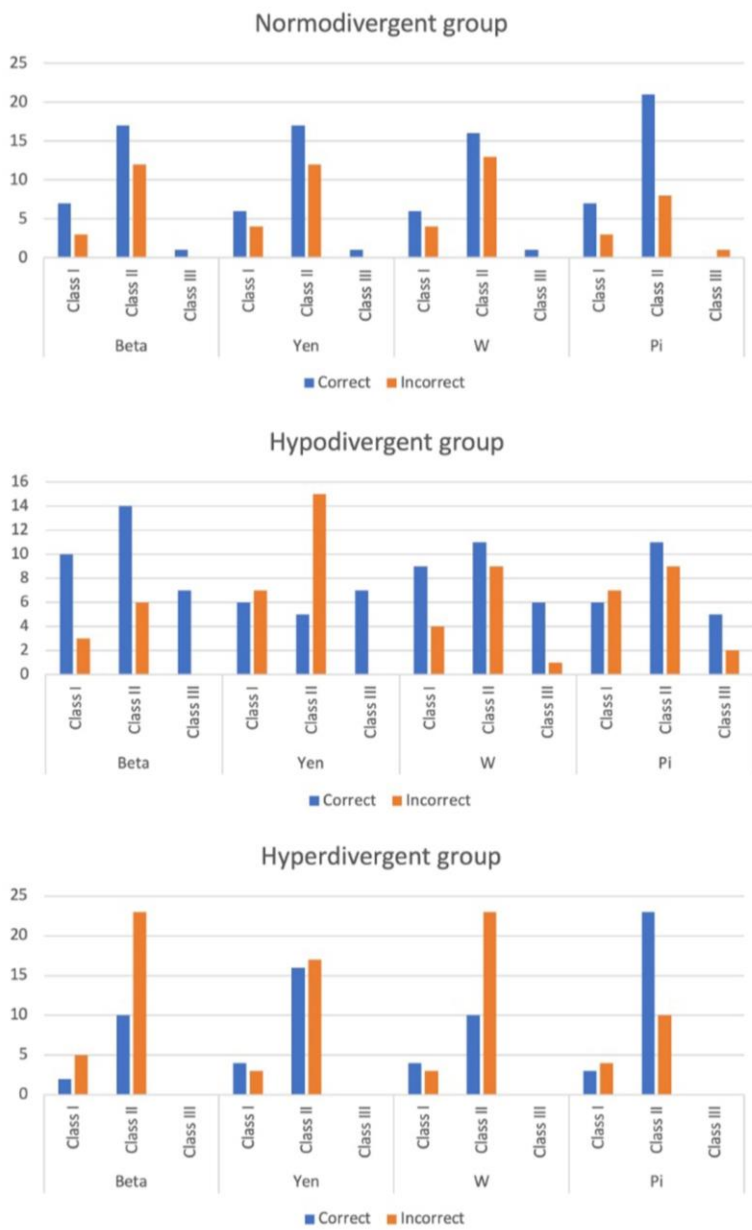

Figure 2: Performance of dysplasia indicators in normo-, hypo-, and hyperdivergent groups

Table 2: Intra-class correlation coefficient (ICC) and Cronbach's alpha (α) to assess the reliability of sagittal dysplasia indicators

Variables	ICC	α value	*p* Value
Beta angle	.965	.982	<0.001
Yen angle	.983	.991	<0.001
W angle	.959	.979	<0.001
Pi angle	.981	.990	<0.001

$p < 0.01$: Highly significant
$p < 0.05$: Significant
$p > 0.05$: Not significant

group, a fair agreement in normodivergent group and no agreement for hyperdivergent group. YEN angle had a fair agreement for both hypodivergent group and normodivergent group and a slight agreement was seen for hyperdivergent group. W angle had a moderate agreement for the hypodivergent group, a fair agreement for the normodivergent group and a slight agreement for the hyperdivergent group was seen. Pi angle had a fair agreement for hypodivergent group and normodivergent group while a slight agreement was seen for hyperdivergent group. The results are tabulated in Table 3.

Discussion

The hyperdivergent and hypodivergent growth patterns have implications not only in the vertical plane, but also in the antero-posterior plane [23]. Cephalometric analysis is essential for evaluating how vertical changes impact the severity of malocclusion in the anterior-posteri-

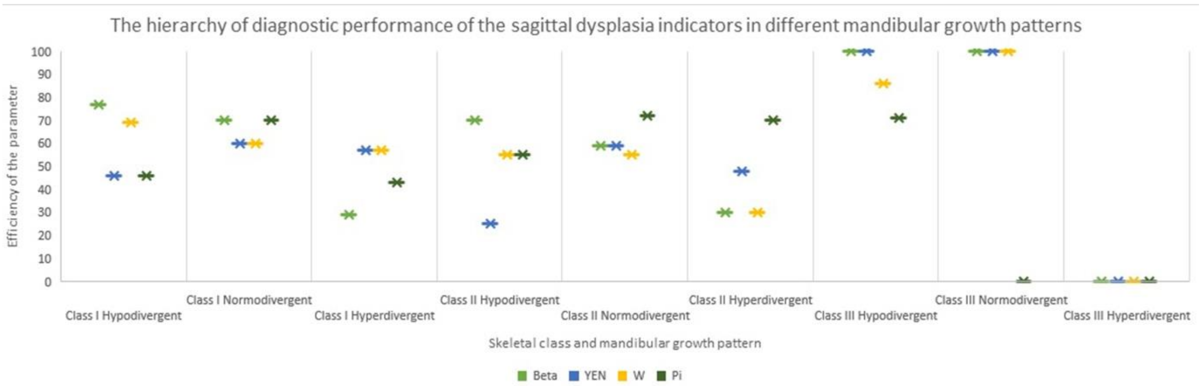

Figure 3: The hierarchy chart of diagnostic performance of the sagittal dysplasia indicators in different mandibular growth patterns

Table 3: Kappa statistics to assess the agreement between the parameters and true sagittal interpretation in different growth patterns

Growth pattern	K Value	*p* Value
Beta angle		
Normodivergent	.300	.017
Hypodivergent	.680	.000
Hyperdivergent	-.004	.961
Yen angle		
Normodivergent	.319	.003
Hypodivergent	.239	.007
Hyperdivergent	.148	.121
W angle		
Normodivergent	.284	.009
Hypodivergent	.466	.000
Hyperdivergent	.068	.348
Pi angle		
Normodivergent	.363	.010
Hypodivergent	.291	.008
Hyperdivergent	.149	.262

$p < 0.01$: Highly significant
$p < 0.05$: Significant
$p > 0.05$: Not significant

or direction. The vertical growth tends to carry the Pogonion downward, while antero-posterior growth carries it forward [12]. These interrelationships between vertical and antero-posterior growth play a significant role in shaping malocclusion, and must be considered when assessing craniofacial balance and malocclusion severity [24].

Given the complexity of this relationship, cephalometric analysis remains a cornerstone for diagnosing and assessing skeletal malocclusions. However, despite its widespread utility, accurately diagnosing the true nature of sagittal dysplasia remains challenging. The errors in obtaining the cephalometric radiographs and conducting head film measurements can be broadly categorized into (i) errors of projection, (ii) errors of landmark reproducibility and (iii) mechanical errors in constructing reference lines and recording the values [25-26]. Previous studies have highlighted the concerns regarding the landmark reproducibility (Landmarks Or, Bo, A, B, Me, ANS, Po), the stability of the reference planes used to construct these parameters and superimposition of 3D structures on a 2D image [27-28]. Angular measurements are susceptible to erroneous readings by changes in facial height, jaw inclination and sagittal variations, while linear measurements can be influenced by inclination of reference lines [29-30]. These inherent limitations result in variations in obtained results, making it difficult for clinicians to rely solely on a single cephalometric indicator for accurate diagnosis and treatment planning.

The evaluation of the craniofacial region in the vertical plane can be accomplished using a variety of well-established parameters. Classic measurements, such as Steiner's mandibular plane angle (SN-GoGn), Down's mandibular plane angle (FMA), Y-axis, facial axis angle, and Jarabak's quotient, are frequently employed in the diagnosis of vertical discrepancies [21-22, 24]. More recent parameters, including the R angle, Dhaval-Rohan (DR) angle, and those utilizing the K plane or the superior border of the zygomatic arch as reference planes, have also been introduced [31-32].

However, these parameters are also not unaffected by the errors of accurate landmark identification and patient head position, which influences the orientation of the reference planes. Low reproducibility and accuracy of landmarks Orbitale and Porion makes Frankfurt Horizontal reference plane less reliable [33]. K plane, dependent on natural head position and superior border of zygomatic arch as a reference plane established using 3D evaluation lacks validation in studies [31-32]. Though the evidential value of both the planes was considered moderate, validation in large sample studies of heterogeneous population remains a concern [34]. Steiner's mandibular plane is represented by the planes SN and GoGn. Landmarks S and N are clearly visible, located and reproduced with ease and accuracy and presence on midsagittal plane makes it to be least deviated in case of head movement of the patient. However, Nasion does move with growth [5]. The other plane, Go-Gn representing the mass of the mandible and not its lower border, is also considered a stable cephalometric plane, though it does get influenced by mandibular rotations and variable positions of gnathion. Thus, the SN-GoGn angle is frequently used to classify growth patterns in orthodontic studies, offering a consistent and reproducible method for assessing vertical discrepancies in craniofacial growth [21]. The Facial Axis Angle, measured between the planes formed by cranial point (Pt) and Gnathion, and Basion and Nasion, is also valuable in analyzing single or serial radiographs. It serves as a central reference axis of the face, with minimal variation (0° ± 1.5° every five years), making it useful for predicting growth patterns [22]. However, the reliability of landmarks such as Basion and Nasion can be questionable. Thus, a combination of Steiner's mandibular plane angle and Ricketts' facial axis angle were considered for classification of growth pattern of the patient.

As growth rotation of the jaws is known to mask the true sagittal dysplasia, the present study aimed to assess the reliability of the parameters under various growth patterns. With only a minor prevalence of orthodontic patients (28.3%) who have completed growth, growth rotation and growth pattern becomes more critical to consider before reaching a diagnosis for the case [35]. This highlights the importance of evaluating growth patterns comprehensively before making a final diagnosis and formulating a treatment plan.

When correlating the data obtained from two investigators on the true sagittal interpretation and sagittal dysplasia indicators, it was observed that the performance of each investigated parameter varied significantly across different growth patterns, in contrast to the findings for the entire sample. The reliability of these parameters fluctuated depending on the specific growth pattern, highlighting the need for a more nuanced, individualized approach in the assessment of sagittal dysplasia. This variability further emphasizes the limitations of relying solely on a single cephalometric measurement in cases where complex growth patterns may be present.

This study involved three independent investigators who measured mandibular growth patterns, evaluated the true sagittal relationship, and assessed the sagittal dysplasia indicators, respectively on all radiographs. This methodology was employed to mitigate inter-rater bias in landmark plotting and to reduce mechanical errors that could arise during measurement recording. To ensure measurement reliability, each investigator repeated the measurements after a four-week interval. A highly significant ICC was observed, indicating strong consistency across repeated measurements and minimal risk of intra-rater bias.

The Beta angle has been reported to be relatively unaffected by growth pattern, with previous studies demonstrating greater diagnostic accuracy in horizontal and average growth patterns [9, 17]. Similar findings were observed in the present study for hypodivergent and normodivergent groups, but the lowest agreement was noted in the hyperdivergent group [14-15, 18].

Although the Beta angle, formed by points A, B, and C, is independent of cranial landmarks or the functional occlusal plane and not thought to be influenced by jaw rotation, its reliability is highly dependent on the reproducibility of these points. Accurate identification of point C (Condylion) may be compromised due to variations in condylar morphology, superimposition of anatomical structures on lateral cephalograms, and tracing inaccuracies, particularly in mouth-closed radiographs [9, 36-37]. Research by Parihar *et al.* [38] demonstrated excellent sensitivity and specificity of the Beta angle in differentiating sagittal skeletal classes; however, the influence of growth pattern was not considered, which may partly explain the variability in diagnostic agreement observed across different growth patterns. In hyperdivergent patients, vertical jaw rotation causes the condylar axis to shift downward and backward, which increases the Beta angle and can lead to misclassifications, such as converting a class II to a class I or a class I to a class III skeletal pattern. Consequently, the Beta angle is less reliable in hyperdivergent jaw bases, and its use in these cases may result in misleading diagnostic interpretations.

Notably, research using three-dimensional cone-beam computed tomography–based evaluations have demonstrated that the Beta angle remains independent of cranial base landmarks and is relatively stable irrespective of growth pattern, suggesting improved reliability when assessed using three-dimensional imaging modalities [39].

The authors state YEN angle to be a reliable parameter for assessing anteroposterior sagittal discrepancies, with minimal influence from growth variations, making it applicable in mixed dentition cases [10]. Previous studies have confirmed its high reliability and consistent distribution in evaluating sagittal discrepancies [10, 40-41]. Our findings align with these, showing significant correlations with other sagittal indicators across skeletal classes, with the strongest correlation in class III, followed by class I, and the weakest in class II [40]. However, Katti *et al.* [41] reported the highest accuracy of the YEN angle in class II cases, likely due to ethnic, demographic and methodological variations.

Although the YEN angle is widely regarded as reliable, its accuracy can be affected by growth patterns. In the present study, it was found to be most reliable in the normodivergent group, and reduced applicability in hyperdivergent or hypodivergent cases, consistent with the findings of existing research suggesting reduced reliability in cases with altered vertical dimensions [14, 42-43]. Ajins *et al.* [18] similarly reported lower mean YEN angle values in vertical growth patterns and higher values in horizontal growth patterns, supporting the influence of growth pattern on its diagnostic performance. Bajjad *et al.* [19] observed good consistency of the YEN angle in skeletal class II cases with average and vertical growth patterns; however, its reliability was poor or unacceptable in class I cases, further emphasizing the role of growth-related variability. The YEN angle is influenced by jaw rotations affecting its accuracy in certain clinical scenarios. Vertical rotations shift the MG line downward and backward, decreasing the YEN angle value and potentially misclassifying a class I case as class II. Conversely, horizontal rotations increase the YEN angle, which could lead to misdiagnosing a class I case as class III [7].

These rotational effects highlight the importance of considering craniofacial morphology and growth stage during diagnosing a case. While the YEN angle is valuable for assessing sagittal discrepancies, its use should be carefully considered in relation to growth patterns, skeletal class, and jaw rotations to fully elucidate the limitations and potential applications of the YEN angle in clinical practice.

The W angle is derived from stable points S, M, and G, providing a reliable measure of sagittal discrepancies without relying on variable landmarks or the occlusal plane [7]. The geometrical stability is particularly beneficial during transitional growth phases, where vertical growth can significantly influence skeletal patterns. The line SG rotates with the mandible maintaining its angulation and carrying point M along the same direction, in growth rotations [7]. Previous studies have reported a low coefficient of variance for the W angle, indicating good reliability in sagittal assessment; however, accurate identification of point M and tracing of the premaxilla may be challenging in radiographs with suboptimal diagnostic quality, potentially affecting measurement accuracy [7, 44]. W angle alone cannot diagnose the jaw with skeletal discrepancy in class II or class III cases, necessitating the complementary cephalometric indicators for treatment planning, such as distalization, mesialization, or orthognathic surgery [7].

In the present study, the W angle showed the highest agreement for skeletal class III cases, moderate agreement with hypodivergent group and no statistically significant agreement was seen in the other groups. These findings suggest that the diagnostic reliability of the W angle may be more pronounced in hypodivergent jaw bases and skeletal class III malocclusions. Contrary to earlier reports suggesting uniform reliability across malocclusion types, the present results indicate reduced applicability of the W angle in other skeletal patterns, highlighting the influence of growth pattern on its diagnostic performance [38, 40, 43-45].

The Pi angle is derived from stable points M and G, which are reliable throughout growth and orthodontic tooth movement, though they can be challenging to trace accurately [7, 46]. These points, combined with the extra-cranial reference line (the true horizontal), offer a consistent measurement that does not depend on variable landmarks, such as the occlusal plane. The true horizontal is defined as the line perpendicular to the true vertical at the natural head position, passing through the nasion [46]. While typically stable, the nasion moves forward and upward during growth, which introduces variability in Pi angle measurements, particularly in growing patients [47]. Although jaw rotations are generally considered not to affect Pi angle predictions, the vertical movement of the nasion does impact the angle's value [46].

In our study, the Pi angle showed the lowest reliability for skeletal class I and class III cases but the highest accuracy for skeletal class II, consistent with Khandelwal *et al.* [43]. However, Sanjeniwala *et al.* [48] reported higher accuracy for class I and class III cases. These discrepancies may be due to differences in sample populations, as cephalometric norms can vary significantly across ethnic groups and age cohorts. Our results demonstrated statistically significant agreement for the Pi angle in the normodivergent and hypodivergent groups, contrary to previous research [40, 49]. However, its performance was poorer in hyperdivergent cases, likely due to significant jaw rotations in the sample. This suggests that while the Pi angle is a reliable tool for diagnosing class I and class II cases in normodivergent and hypodivergent patients, its use may be limited in hyperdivergent cases, necessitating the inclusion of additional cephalometric indicators for accurate diagnosis and treatment planning.

The increasing number of studies comparing newer diagnostic parameters with traditional methods highlights the limitations of conventional approaches, particularly landmark reproducibility errors, unstable reference planes, and the effects of bone remodeling and growth. To address these challenges, the current study incorporated four key parameters- ANB, Wits, molar relation, and patient profile for more accurate sagittal classification. A minimum of three matching parameters were required to classify radiographs into a specific skeletal class. This study builds on previous work that highlighted inconsistencies in interpretations of sagittal indicators including ANB, which is considered as gold standard, and emphasizes the need for a more integrated approach, particularly regarding the role of jaw rotations [47, 50-51].

Growth rotation, a critical factor in sagittal dysplasia diagnosis, impacts the relationship between craniofacial structures, leading to variability that complicates diagnosis and treatment planning. To improve diagnostic precision, we prioritized grouping patients by jaw rotations before classifying them into sagittal classes. This approach clarifies how growth patterns influence skeletal structures. Our results suggest that no single parameter can fully address sagittal dysplasia complexities, and clinicians must consider growth patterns when making a diagnosis. This led to the development of a hierarchical chart (Figure 3) that ranks the diagnostic performance of sagittal dysplasia indicators based on mandibular growth patterns. This chart can assist the clinicians to navigate the variability introduced by jaw rotations, offering a more accurate and tailored treatment plan.

A heuristic algorithm using six key cephalometric parameters provided a useful diagnosis but did not account for growth patterns [43]. By integrating the hierarchical chart with this algorithm, diagnostic accuracy can be enhanced. Combining static cephalometric measures with dynamic growth factors offers a more comprehensive tool for assessing sagittal discrepancies, addressing the limitations of reliability of individual parameters and improving the treatment planning precision. Clinicians should assess jaw rotation before making a sagittal diagnosis, improving diagnostic precision and treatment outcomes. The hierarchical chart supports this by integrating multiple diagnostic indicators and growth patterns.

Advancements in radiographic imaging modalities, digital cephalometry, cephalometric automation and artificial intelligence by machine learning and deep learning are expected to complement this approach by offering more accurate, individualized insights into craniofacial development. With these advances, orthodontics can move towards precision medicine, where diagnostic accuracy and treatment planning are personalized to each patient's unique growth patterns, ultimately improving both functional and aesthetic outcomes.

The present study has certain limitations. The retrospective nature of the study and reliance on archived lateral cephalograms limited the availability of complete demographic information; consequently, the influence of age and sex on the diagnostic performance of sagittal dysplasia indicators could not be evaluated. The study could not include class III hyperdivergent cases, limiting the evaluation of sagittal dysplasia indicators in this subgroup, which may affect the generalizability of the findings. The sample lacked ethnic diversity, which could impact the applicability of the results, as craniofacial growth and cephalometric norms vary across populations. A smaller sample size may introduce variability and higher margins of error. Larger studies with more participants would enhance statistical power and improve the reliability of the results. Future studies incorporating prospective designs, ethnically diverse samples, and longitudinal radiographic records may further strengthen the clinical applicability of sagittal dysplasia assessment across different growth patterns.

Conclusion

The mandibular growth pattern can significantly influence the malocclusion in sagittal direction, and thus on the interpretation of the sagittal dysplasia indicators, highlighting that no single cephalometric parameter can be relied upon in isolation. It is therefore crucial for clinicians to evaluate the growth pattern and jaw rotation of the patient when establishing the sagittal diagnosis. We have developed a hierarchical chart that assists clinicians in selecting the most appropriate sagittal dysplasia indicator, tailored to the patient's unique mandibular growth pattern. This approach not only enhances diagnostic accuracy but also improves treatment planning by minimizing the potential masking effects of growth rotations on sagittal interpretation.

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Conflicts of Interest

The authors declare no conflicts of interest.

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