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Three-Dimensional Evaluation of Steiner Analysis and Witt's Appraisal in The Assessment of Sagittal Skeletal Pattern in a Selected Group of Yemeni Adults

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Abstract

Background and Purpose: Precise quantification of the sagittal skeletal relationships between the maxilla and mandible is essential to orthodontic diagnosis and treatment planning. This study aimed to comprehensively evaluate the concordance between WITS appraisal and Steiner analysis across distinct sagittal skeletal patterns (SSPs) and to assess potential sexual dimorphism in these measurements in a Yemeni population utilizing cone-beam computed tomography (CBCT) imaging. **Materials and Methods**: This retrospective cross-sectional study analyzed 120 CBCT scans from a Yemeni population (60 males, 60 females; mean age: 23.39 ± 4.0 years), stratified into three sagittal skeletal pattern groups (n=40 each): Class I, Class II, and Class III, based on the ANB angle. Raw DICOM data were imported into CS 3D Imaging software, where images were oriented to the Frankfort Horizontal plane for three-dimensional reconstruction and segmentation. Cephalometric analysis was performed on standardized sagittal reconstructions to measure the ANB angle and WITS appraisal. These measurements were derived from established skeletal landmarks (including Nasion, Point A, and Point B) and reference planes (specifically the Sella-Nasion plane and the functional Occlusal Plane). Statistical analysis was performed using SPSS, including intergroup comparisons, gender-based comparisons, and Pearson correlation analysis. The level of statistical significance was set at $p < 0.05$. **Results:** Statistically significant differences in both ANB angle and WITS appraisal were demonstrated among the three sagittal skeletal patterns ($p < 0.001$), with Class II subjects demonstrating the highest mean values. No statistically significant sexual dimorphism was detected in either measurement within any skeletal class. A significant positive correlation between WITS appraisal and ANB angle was identified in Class II ($r = 0.517$) and Class III ($r = 0.636$) skeletal patterns; conversely, no statistically significant correlation was observed in Class I ($r = 0.023$). **Conclusion:** While WITS appraisal and ANB angle demonstrate a significant positive association overall, each measurement provides complementary diagnostic information and should be interpreted in conjunction rather than applied interchangeably when evaluating sagittal jaw discrepancies, particularly in borderline skeletal relationships.

Article Info

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Sagittal Skeletal classification, ANB angle, Wits appraisal.

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1. INTRODUCTION

An accurate evaluation of the sagittal skeletal relationships between the maxilla and mandible is essential for precise diagnosis and effective clinical management. Sagittal skeletal patterns (SSPs) play a critical role in determining the treatment modality and prognosis, as they reflect the anteroposterior relationship of the jaws and their influence on facial esthetics and occlusal function [1]. Among the cephalometric parameters for sagittal assessment, Steiner analysis and WITS Appraisal remain the most widely applied indicators of maxillomandibular relationships in routine orthodontic practice [2].

The ANB angle, originally introduced as part of Steiner's analysis, is an angular measurement used to evaluate sagittal jaw relationships [3]. Despite its widespread use, numerous studies have highlighted the limitations affecting its diagnostic reliability. Variations in cranial base length, jaw rotation during growth, vertical facial pattern, and the anteroposterior positioning of landmarks such as the nasion, sella, and subnasale may significantly influence ANB values, potentially leading to misinterpretation of sagittal discrepancies [4, 5]. Longitudinal investigations have also demonstrated that maxillary and mandibular growth can alter ANB values, regardless of the true sagittal skeletal relationships [4].

To overcome these limitations, Jacobson proposed the WITS appraisal as a linear measurement to evaluate sagittal jaw discrepancies with a reduced dependence on cranial base morphology [6]. By projecting points A and B onto the functional occlusal plane, the WITS appraisal provides a more direct assessment of the SSPs. However, several studies have reported that WITS appraisal is also influenced by occlusal plane inclination and dental factors, which may affect its diagnostic consistency [7, 8]. Discrepancies between the Steiner analysis and WITS appraisal have been reported, particularly in cases with altered occlusal plane orientation or borderline skeletal relationships.

Cone-beam computed tomography (CBCT) is an increasingly valuable tool in orthodontics, offering three-dimensional visualization of craniofacial structures and minimizing projection errors and superimposition inherent in conventional two-dimensional lateral cephalograms [9, 10]. Several studies have demonstrated that CBCT-based measurements improve the accuracy and reproducibility of sagittal skeletal assessments and allow for a more comprehensive evaluation of angular and linear relationships [10].

Previous investigations comparing the diagnostic performance of the ANB angle and WITS appraisal across different populations have reported that these parameters are not interchangeable and may yield discrepant classifications of sagittal skeletal relationships [2, 4, 5, 10, 11]. These inconsistencies highlight the importance of understanding the relationship between the two measurements and their potential limitations when applied to different skeletal patterns and populations.

Recently Santiago et. al. [12] introduced a novel three-dimensional bisector–WITS appraisal that was highly correlated with Steiner's analysis and **other three-dimensional sagittal measurements (such as [X], [Y], and [Z])**, emphasizing that linear and angular measurements are closely related but should not be used interchangeably. Their findings highlighted the advantages of CBCT-based analysis in refining sagittal diagnosis and minimizing the geometric distortions inherent in two-dimensional methods.

In addition, Paddenberg etal.. Al., and Hosoyama et. Al et al. [13, 14] proposed the concept of regression-based floating norms for both the ANB angle and WITS appraisal. This approach is based on deriving reference values from continuous regression models rather than using fixed cut-off thresholds, allowing normative values to vary along a continuum according to the individual craniofacial characteristics. Their results demonstrated that fixed normative thresholds may not adequately account for individual craniofacial variability and suggested that individualized reference values could improve diagnostic accuracy, particularly in borderline skeletal relationships, where traditional cutoff points may lead to misclassification. In the context of three-dimensional CBCT-based analysis, such a framework is especially relevant as it supports a more precise and individualized interpretation of sagittal skeletal relationships, which underpins the rationale of the present study. Despite these advances, few studies have evaluated the relationship between the traditional ANB angle and WITS appraisal across defined sagittal skeletal patterns using CBCT, and population-specific data remain scarce. Despite these advances, few CBCT-based studies have evaluated the relationship between the traditional ANB angle and WITS appraisal across clearly defined sagittal skeletal patterns, and population-specific data from Arab countries remain scarce. Furthermore, evidence regarding sex-related differences in the association between these parameters is inconsistent, with some studies reporting minimal sexual dimorphism and others suggesting the need for sex-specific norms [15]. To the best of our knowledge, no published studies from neighboring Arab countries have investigated this relationship using methodologies directly comparable to the present research, further emphasizing the novelty and regional relevance of the Yemeni population data.

This study aimed to evaluate the agreement between Steiner analysis and WITS appraisal across different SSPs and the potential sex-related differences in a Yemeni population using CBCT images.

2. MATERIALS AND METHODS

Study design and ethical approval

This retrospective cross-sectional study was conducted to compare and evaluate the agreement between Steiner analysis and WITS appraisal across different SSPs using 120 CBCT scans obtained from a private radiology center. The scans were originally acquired for routine diagnostic purposes and not exclusively for orthodontic treatment planning. This study was approved by the Medical Ethics Committee of the Faculty of Dentistry, Sana'a University, Yemen. Only age and gender information were collected to protect participant confidentiality.

Inclusion and exclusion criteria

The study sample consisted of an equal number of males (n = 60) and females (n = 60), with ages ranging from 15 to 51 years (mean age: 23.39 ± 4.0 y).

The sample was equally subdivided into three sagittal skeletal classes (Class I, II, and III; n = 40 per group).

CBCT scans were included if they met the following criteria: high image quality suitable for cephalometric analysis, presence of complete permanent dentition excluding third molars, maximum intercuspation at the time of image acquisition, and balanced vertical facial proportions (normodivergent growth pattern). The following were excluded: craniofacial anomalies or syndromes, history of facial trauma or fractures, previous temporomandibular joint surgery, extreme vertical facial growth patterns, ongoing orthodontic treatment, or mixed dentition.

CBCT acquisition protocol

The scans were obtained using a PaX-i3D Green CBCT system (Model PHT-60CFO, Vatech Co., Hwaseong, Korea). All CBCT scans were obtained using a standardized imaging protocol, with the participants positioned upright during image acquisition. Each scan was acquired with a 15-second exposure time and a field of view of 15 × 15 cm. The imaging parameters included a tube voltage of 50–99 kV, tube current of 4–16 mA, and voxel size ranging from 0.2 to 0.3 mm.

Raw image data were exported in the Digital Imaging and Communications in Medicine (DICOM) format and analyzed using CS 3D Imaging software (version 3.10.38; Carestream Dental, Carestream Health, USA) for three-dimensional reconstruction and cephalometric measurements.

Image orientation and vertical pattern assessment

All CBCT images were oriented with the Frankfort horizontal plane parallel to the floor before analysis (Figure 1). The vertical growth pattern was assessed using the NL–ML angle, with a normal reference value of 21.36° ± 5.43° for the Yemeni population [16], and the Y-axis angle, with a normal range of 55°–66° [3] (Figures 4 and 5).

Cephalometric landmarks and sagittal skeletal classification

The cephalometric landmarks and reference planes used in the present study are presented in Table (1). All measurements were performed on standardized sagittal reconstructions derived from the CBCT data using the CS 3D Imaging software. The occlusal plane for the WITS appraisal was constructed by connecting the incisal occlusal point (IO) and molar occlusal point (MO). Based on these landmarks, the ANB angle and WITS appraisal were measured on the reconstructed CBCT images.

CBCT images were retrospectively selected from the archive based on predefined inclusion criteria, including a normodivergent facial pattern. After data collection, sagittal cephalometric measurements were taken. The subjects were then classified into sagittal skeletal classes based on the ANB angle (Figure 2), and sagittal skeletal classification was defined as follows: Class I (ANB = 1°–4°), Class II (ANB > 4°), and Class III (ANB < 1°). [8, 16]. As shown in Figure (3), the skeletal classification was determined according to the established criteria: Class I (1 mm to +1 mm), Class II (positive values), and Class III (negative values). [6]

Reliability analysis

To assess the measurement reliability, 10% of the CBCT scans were randomly selected and re-evaluated. Intra-examiner reliability was assessed using repeated measurements performed by the same examiner, yielding an intraclass correlation coefficient (ICC) of 0.995. Inter-examiner reliability was assessed by a second examiner, and an ICC of 0.996 was obtained, indicating excellent agreement.

3. STATISTICAL ANALYSIS:

Normality of the data distribution was assessed prior to statistical analysis. All statistical analyses were performed using SPSS Statistics for Windows (version 26; IBM Corp., Armonk, NY, USA). Descriptive statistics, including frequencies and percentages for categorical variables and means and standard deviations for continuous variables, were calculated to summarize the sample characteristics (Table 2). Intergroup comparisons among sagittal skeletal patterns were conducted using one-way analysis of variance (ANOVA). Gender-based comparisons were performed using independent samples *t*-tests. The relationship between WITS appraisal and ANB angle was assessed using Pearson's product–moment correlation coefficient. Correlation analyses were conducted separately within skeletal Class I, Class II, and Class III groups. In addition, Pearson correlation coefficients between WITS appraisal and ANB angle were calculated separately for males and females, and differences between correlation coefficients were evaluated using Fisher's *r*-to-*z* transformation. A significance level of *p*

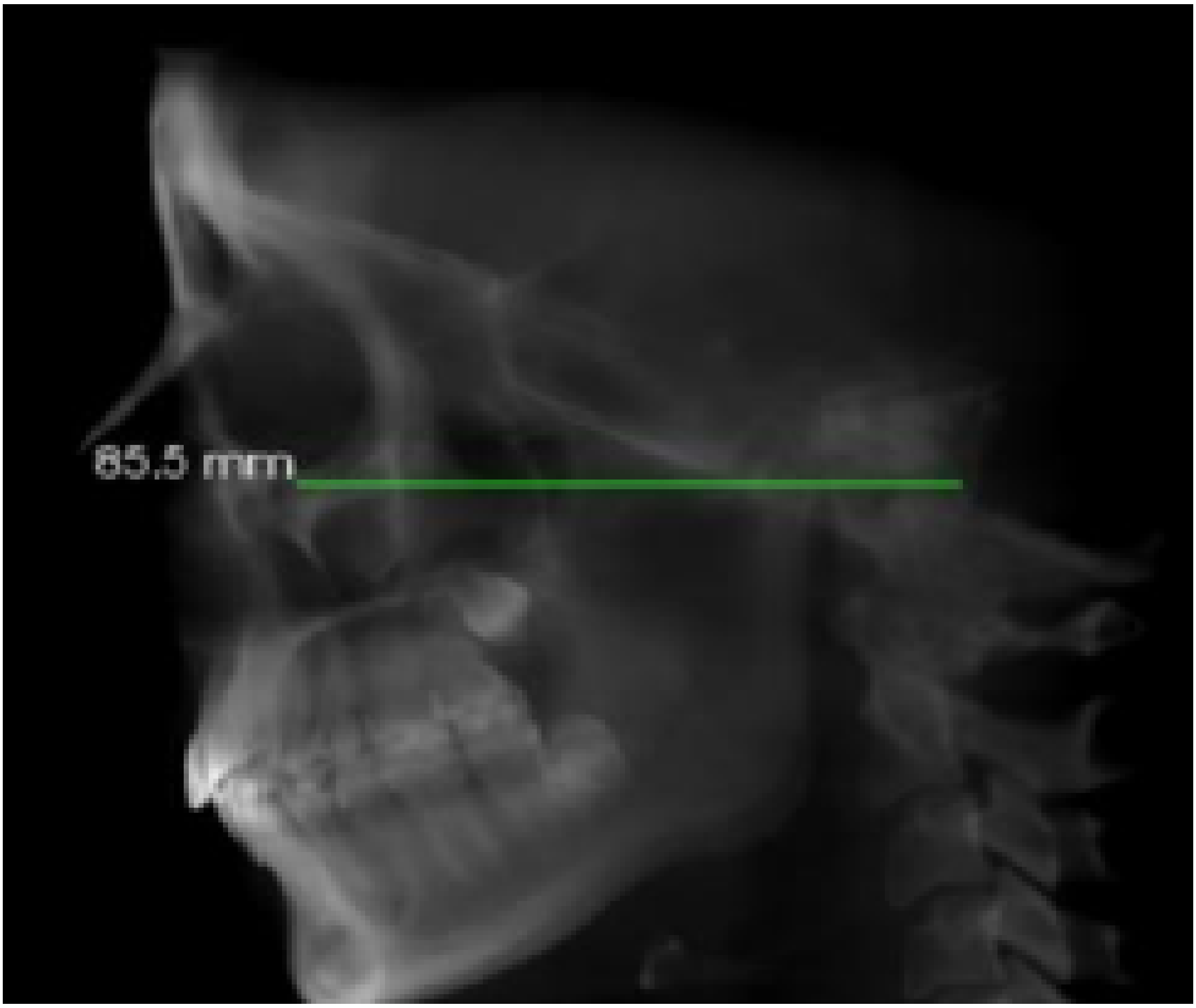

Figure 1. sagittal reconstruction oriented with the Frankfort horizontal (FH) plane parallel to the floor prior to cephalometric analysis

< 0.05 was adopted for all statistical analyses. Subsequently, correlation analysis was performed to evaluate the relationship between the ANB angle and the WITS appraisal within and across the defined skeletal classes.

4. RESULTS:

Comparison of ANB angle and WITS appraisal among skeletal classes

Comparative analysis demonstrated statistically significant differences in both ANB angle and WITS appraisal among skeletal Classes I, II, and III ($p < 0.001$). As shown in Table (2), skeletal Class II subjects exhibited the highest mean ANB angle and WITS appraisal values of 5.75 ± 1.21, whereas skeletal Class III subjects showed negative mean values for both parameters. Skeletal Class I subjects showed intermediate values.

Correlation between ANB angle and WITS appraisal by skeletal class

A strong positive correlation was observed between the ANB angle and WITS appraisal in the total sample (r = 0.83, 95% CI: 0.77–0.88; p < 0.001). Pearson's correlation analysis revealed a variation in the strength of the association between the ANB angle and WITS appraisal across skeletal classes (Table 3). No significant correlation was observed in skeletal Class I subjects (r = 0.02). In contrast, a moderate positive correlation was identified in skeletal Class II subjects (r = 0.52), whereas a strong positive correlation was observed in skeletal Class III subjects (r = 0.64).

Correlation analyses performed within skeletal subgroups should be interpreted cautiously, as ANB-based classification may introduce range restriction and partial mathematical dependency.

Gender-based correlation analysis

When analyzed by sex, both males and females demonstrated strong positive correlations between WITS appraisal and ANB angle (Table 4). The correlation coef-

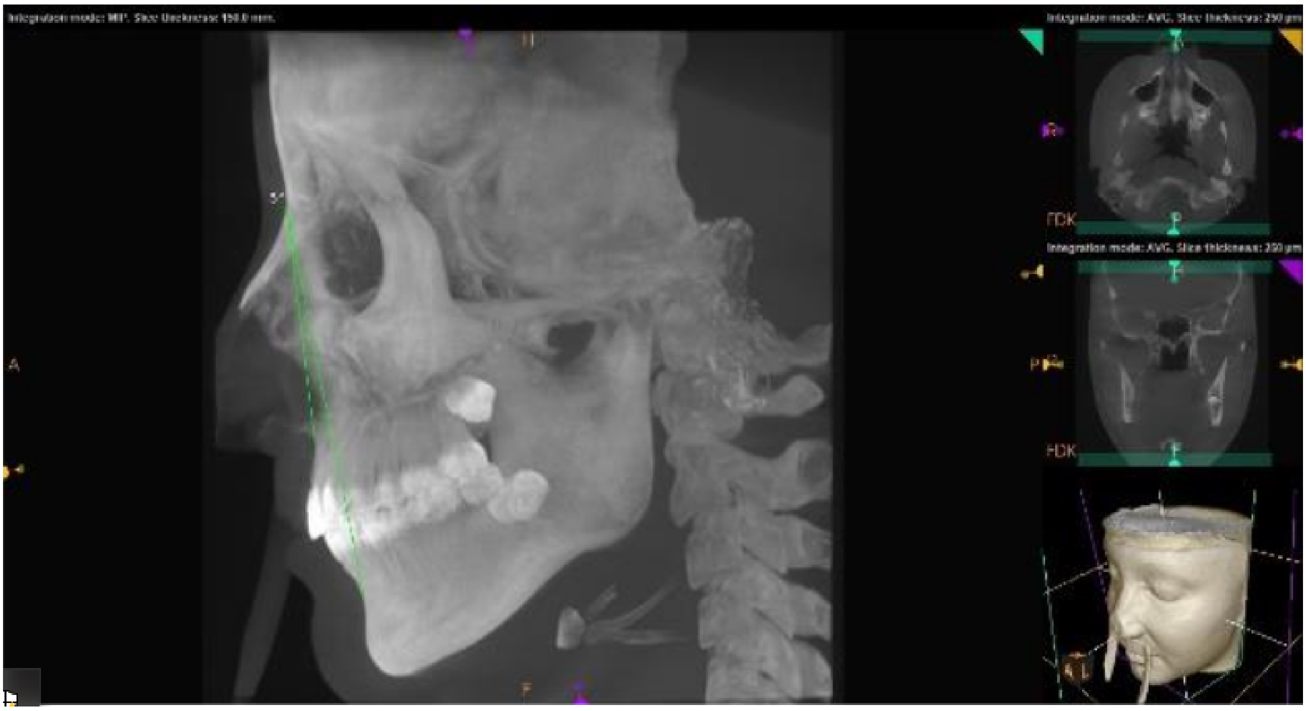

Figure 2. Classification of sagittal skeletal patterns based on the ANB angle

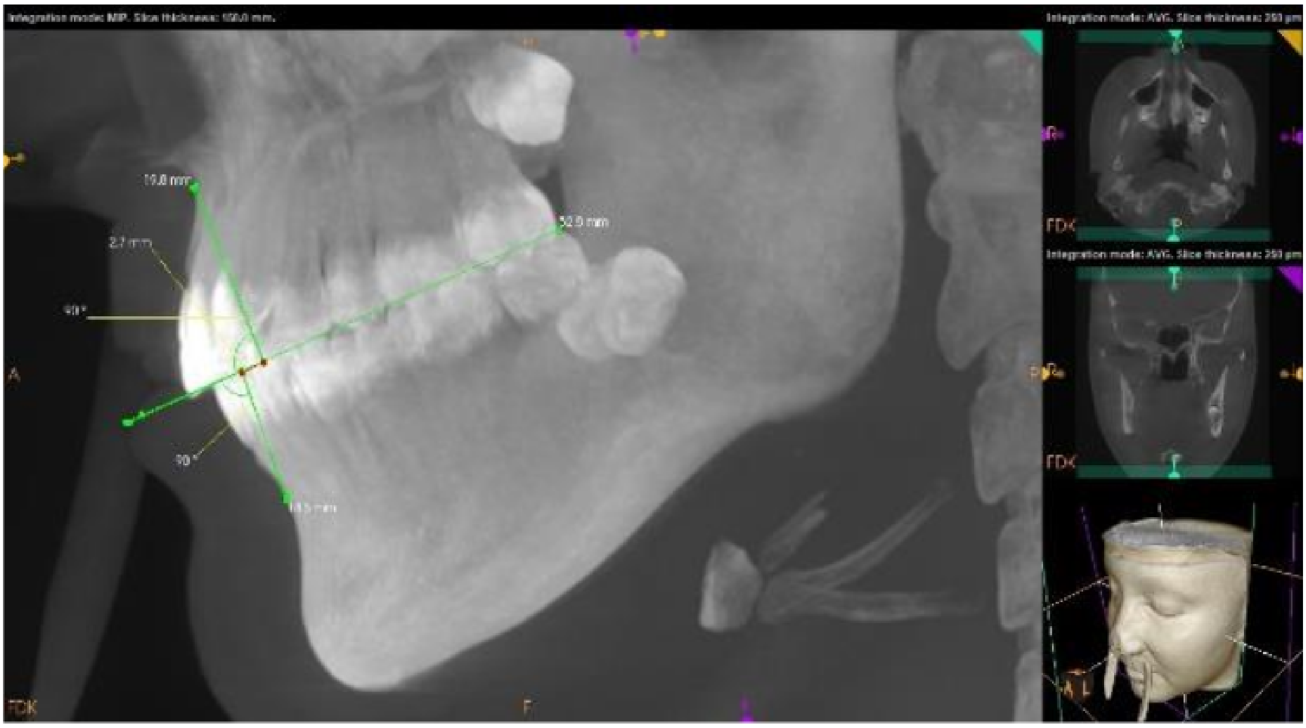

Figure 3. Classification of sagittal skeletal patterns based on WITS appraisal.

ficient was r = 0.85 for males and r = 0.83 for females. Fisher's r-to-z transformation revealed no statistically significant difference between the two correlation coefficients (z = 0.39, $p > 0.05$), indicating a comparable correlation strength between the sexes.

Gender-based comparison of ANB angle and WITS appraisal within skeletal classes

Gender-based comparisons of the ANB angle and WITS appraisal within skeletal Classes I, II, and III are presented in Table (5). No statistically significant differences were observed between males and females for either ANB angle or WITS appraisal in any skeletal class ($p > 0.05$ for all comparisons). No significant sex-related differences were identified in skeletal Class II or Class III.

Table[1]: Cephalometric points, planes, and measurements used in the study

No.	Point / Line / Angle	Abbreviation	Definition
1	Point A (Subspinale)	A	The most inferior point between the anterior nasal spine and the maxillary alveolar crest.[7]
2	Nasion	N	The junction of the nasal and frontal bones at the deepest contour of the nasal bridge, defining the anterior boundary of the frontonasal suture.[7]
3	Point B (Supramentale)	B	The deepest point on the anterior curvature of the mandible, located between the alveolar crest and pogonion. It indicates the anterior limit of the mandibular apical base.[7]
5	Molar occlusal point	MO	The bisector point of the overbite of the first molars.[6]
6	Incisal occlusal point	IO	The bisector point of the overbite of the maxillary and mandibular central incisors.[6]
7	Anterior Nasal Spine	ANS	The most anterior point on the inferior border of the nasal cavity, located at the tip of the bony projection formed by the fusion of the maxillary bones. It represents the anterior limit of the maxilla.[16]
8	Posterior Nasal Spine	PNS	The rearmost point of the hard palate at the posterior nasal crest of the palatine bones, marking the posterior limit of the maxilla and the palatal plane.[16]
9	Gonion	Go	A constructed point located midway between the most posterior and inferior points at the angle of the mandible.[16]
10	Menton	Me	The most inferior point on the mandibular symphysis.[16]
11	Gnathion	Gn	The lowest and most forward point of the mandibular symphysis, positioned between Pogonion and Menton.[3]
12	Sella	S	The center of the hypophyseal fossa (sella turcica).[3]
13	Porion	Po	The midpoint of the upper contour of the external auditory meatus.[3]
14	Orbitale	Or	The midpoint between the lowest points on the inferior margins of the right and left orbits.[3]
15	Point A–occlusal plane	AO	The perpendicular projection of Point A onto the occlusal plane.[6]
16	Point B–occlusal plane	BO	The perpendicular projection of Point B onto the occlusal plane.[6]
17	Maxillary Plane	NL	A line extending from ANS to PNS.[16]
18	Mandibular Plane	ML	A line extending from Go to Me.[16]
19	NL–ML angle	NL–ML	The angle formed between NL and ML.[16]
20	Occlusal plane	OP	A functional plane constructed by connecting IO to MO.[6]
21	Frankfort Horizontal Plane	FH	A plane extending from Po to Or.[3]
22	Sella–Gnathion line	S–Gn	A line connecting S to Gn.[3]
23	A–Nasion–B angle	ANB	An angular measurement describing the anteroposterior (sagittal) relationship between the maxilla and mandible.[7]
24	Y-axis angle	Y-axis	The angle between the FH and S–Gn line.[3]

Table[2]: Descriptive statistics of ANB angle and WITS appraisal across skeletal classifications

Measured variable	Skeletal class	Mean	SD	p-value
ANB (°)	Class I	3.15	0.86	$< 0.001^b$
	Class II	5.75	1.21	
	Class III	-1.47	1.79	
WITS (mm)	Class I	-0.34	2.24	$< 0.001^a$
	Class II	2.60	2.94	
	Class III	-5.57	2.95	

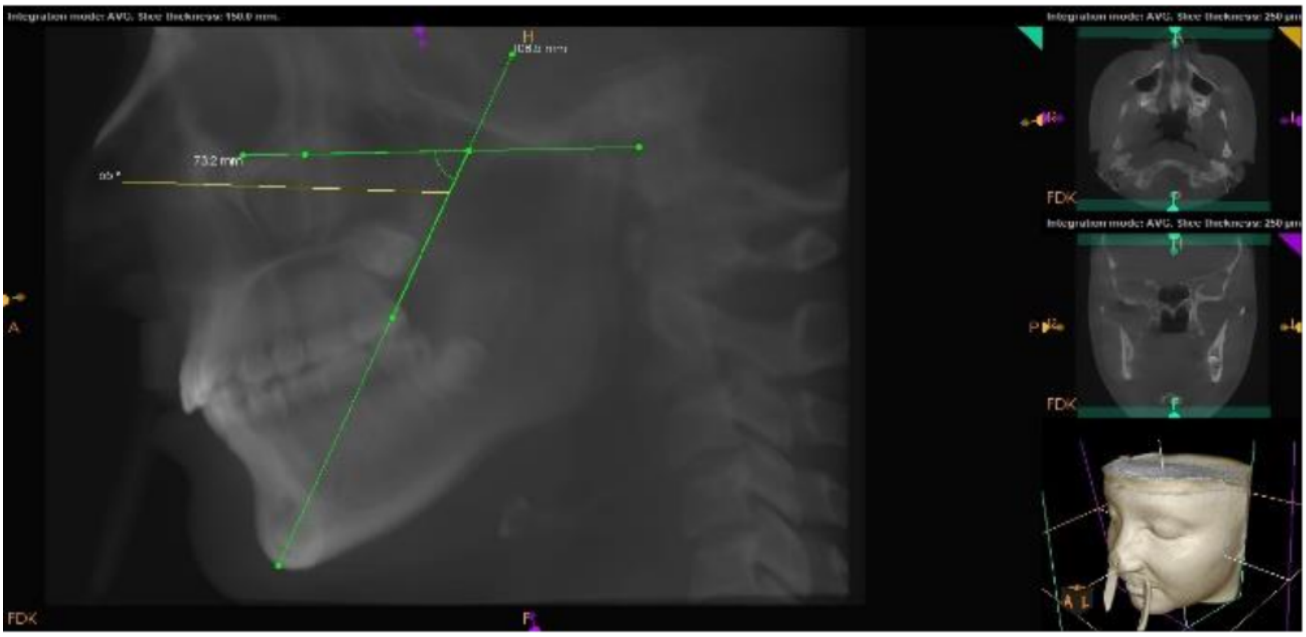

Figure 4. Measurement of the Y-axis angle to assess vertical growth pattern and direction of mandibular growth relative to the cranial base.

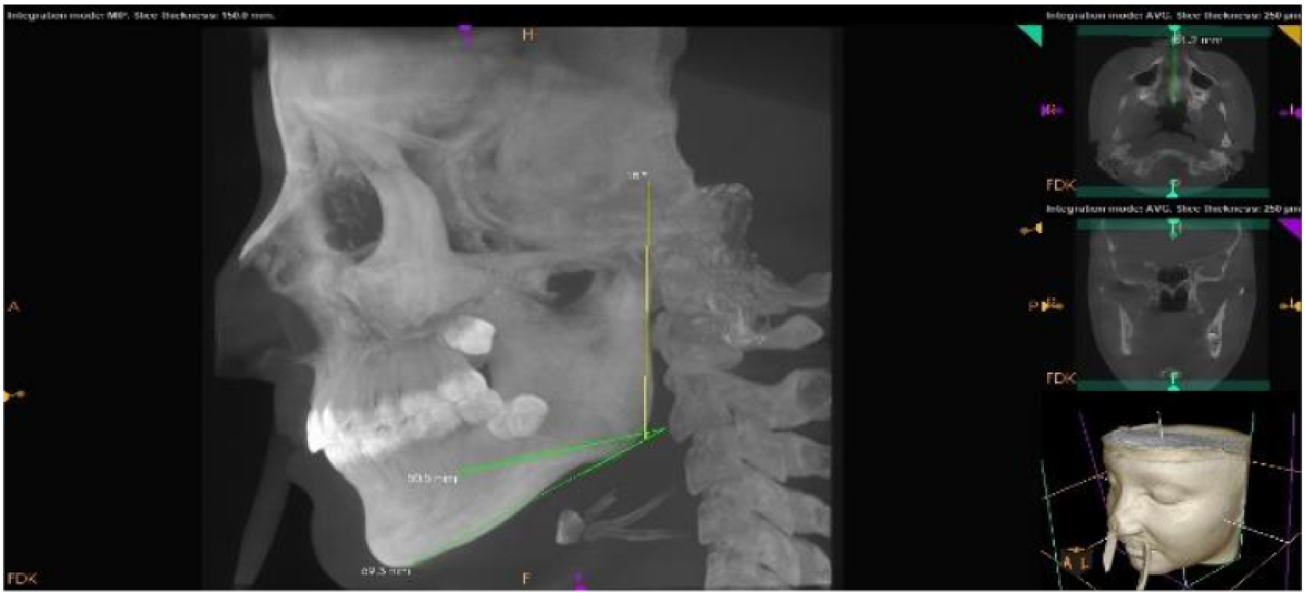

Figure 5. Measurement of the NL–ML angle to determine vertical skeletal growth pattern.

Table[3]: Pearson correlation coefficients between WITS appraisal and ANB angle in different skeletal classes.

Skeletal Class	N	r	95% CI	p-value	Strength
Total sample	120	0.83	0.77–0.88	<0.001	Strong
Class I	40	0.023	−0.29 to 0.33	>0.05	No correlation
Class II	40	0.517	0.24 to 0.71	<0.001	Moderate
Class III	40	0.636	0.40 to 0.79	<0.001	Strong

Table[4]: Comparison of Pearson correlation coefficients between WITS appraisal and ANB angle according to gender

Gender	Sample size (n)	Pearson correlation coefficient (r)	Strength of correlation
Males	60	0.85	Strong positive
Females	60	0.83	Strong positive

Table[5]: Gender-based comparison of ANB angle and WITS appraisal within skeletal classes

Variable	Skeletal Class	Gender	Mean	SD	p-value
ANB (°)	Class I	Female	3.40	0.82	0.057
		Male	2.90	0.85	
	Class II	Female	6.00	1.52	0.548
		Male	5.50	0.76	
	Class III	Female	-1.60	1.67	0.648
		Male	-1.35	1.95	
WITS (mm)	Class I	Female	-0.51	2.40	0.642
		Male	-0.17	2.11	
	Class II	Female	3.13	3.56	0.261
		Male	2.08	2.11	
	Class III	Female	-5.56	2.76	0.987
		Male	-5.58	3.21	

5. DISCUSSION

Nevertheless, both Steiner analysis and WITS Appraisal are influenced by different anatomical and geometric factors, including cranial base morphology, jaw rotation, vertical facial pattern, and occlusal plane inclination, which may affect their diagnostic accuracy. Consequently, investigating the association between these two parameters across different SSPs and between sexes is clinically relevant, particularly when using three-dimensional imaging modalities.

Because the sagittal skeletal classification in the present study was based on fixed ANB thresholds, the correlation analyses conducted within individual skeletal classes are subject to range restrictions and partial mathematical dependency. In particular, the narrow distribution of ANB values within skeletal Class I may have attenuated the correlation coefficient, resulting in an apparent lack of association between the ANB angle and WITS appraisal. Therefore, the near-zero correlation observed in Class I should not be interpreted as evidence of true biological independence between the two parameters, but rather as a methodological consequence of classification-dependent variance restriction.

The present study demonstrated statistically significant differences in both ANB angle and WITS appraisal among skeletal Classes I, II, and III. These findings confirm that both parameters are effective in distinguishing sagittal skeletal patterns. Higher mean values observed in skeletal Class II and negative values in skeletal Class III reflect the underlying maxillomandibular discrepancies characteristic of these classifications. Similar observations have been reported in previous studies, supporting the diagnostic validity of both the ANB angle and WITS appraisal for sagittal skeletal assessment [2, 5, 8].

Correlation analysis revealed that the relationship between the ANB angle and WITS appraisal varied according to skeletal classification. No meaningful correlation was observed in skeletal Class I subjects, a finding that is clinically important given the near-zero correlation identified in this group, whereas moderate to strong positive correlations were identified in skeletal Class II and Class III subjects. This suggests that the diagnostic agreement between the two parameters increases as sagittal discrepancies become more pronounced, whereas their relationship appears less consistent in subjects with near-normal skeletal relationships. These findings are consistent with earlier reports indicating that ANB and WITS measurements tend to diverge in borderline or balanced cases but show stronger concordance in marked sagittal discrepancies [3, 7, 8]. Although both parameters demonstrated similar directional trends across sagittal skeletal patterns, their numerical differences indicate that they should not be used interchangeably in clinical practice. The ANB angle is influenced by the cranial base length, facial growth pattern, and mandibular rotation[3, 4], whereas the WITS appraisal is particularly sensitive to the occlusal plane inclination [7]. Consequently, reliance on a single parameter may lead to misinterpretation in certain clinical situations. Therefore, the combined interpretation of the ANB angle and WITS appraisal provides a more comprehensive and reliable assessment of sagittal jaw relationships than the use of either measurement alone [3, 9].

From a clinical perspective, these findings support a structured diagnostic workflow for assessing sagittal skeletal relationships. In cases classified as skeletal Class I based on the ANB angle, systematic evaluation of the WITS appraisal may be particularly useful for identifying occlusal plane–related discrepancies that could conceal subtle sagittal skeletal imbalances. In such situations, a disagreement between the ANB angle and WITS appraisal should prompt a careful assessment of the occlusal plane inclination, dental compensations, and overall facial pattern rather than an immediate reclassification of the skeletal relationship. This complementary approach reduces the risk of misinterpretation in borderline or morphologically balanced cases and supports more individualized treatment planning.

In agreement with Serafin et al. [17], who reported a strong and statistically significant correlation between the ANB angle and the three-dimensional bisector–WITS appraisal in a CBCT dataset, the present study also demonstrated significant associations between ANB and WITS measurements across sagittal skeletal patterns. While Serafin et al. focused on developing regression-based norms using a novel three-dimensional approach, the present study extends these findings by evaluating the relationship between traditional WITS appraisal and ANB angle within defined skeletal classes and assessing sex-related differences. Both studies support the concept that angular and linear sagittal indicators are closely related but not interchangeable, emphasizing the importance of a combined diagnostic interpretation. Similarly, the findings of this study are consistent with those of Almaqrami et al. [9], who reported statistically significant correlations between the ANB angle and several sagittal indicators, including WITS appraisal, using CBCT data. Their results highlighted the reliability and diagnostic value of three-dimensional assessment in sagittal plane analysis. In line with these observations, the present study demonstrated significant positive correlations between the ANB angle and WITS appraisal, particularly in skeletal Class II and Class III subjects, further supporting the integration of multiple parameters for accurate sagittal evaluation.

The lack of a meaningful correlation between the ANB angle and WITS appraisal in skeletal Class I subjects observed in the present study is also supported by previous literature [13], which emphasized that fixed normative thresholds may be insufficient for borderline cases and advocated for individualized or pattern-based interpretation of sagittal parameters. Furthermore,[14] highlighted that reliance on WITS appraisal alone in Class I subjects may lead to overinterpretation of minor numerical deviations that do not necessarily correspond to clinically relevant skeletal discrepancies. Similarly, Santiago et al. [12] reported less consistent associations between ANB and WITS measurements in morphologically balanced individuals, attributing this to compensatory growth and individual variability rather than to true sagittal disharmony.

Gender-based analysis in the present study revealed no statistically significant differences in the ANB angle or WITS appraisal within any skeletal class. Although minor numerical variations were observed between men and women, these differences were neither statistically nor clinically meaningful. This suggests that sagittal skeletal relationships, as assessed by the ANB angle and WITS appraisal, are comparable between the sexes in the Yemeni population. These findings are consistent with those of previous studies reporting minimal sexual dimorphism in sagittal cephalometric parameters [10, 14, 15]. In agreement with [15], the current findings indicate that differentiating normative WITS values by gender is unnecessary. The absence of significant sexual dimorphism supports the use of common reference standards for both men and women without compromising diagnostic accuracy. Clinically, reliance on a single sagittal indicator may lead to diagnostic misclassification, particularly in borderline cases.

Although the upper age limit of the sample was 51 years, which may be associated with alveolar bone remodeling or periodontal changes that could potentially influence the identification of skeletal landmarks such as Point A or Point B, the present study focused exclusively on sagittal skeletal classification rather than dental or periodontal conditions. To minimize potential confounding effects, only CBCT images with clearly identifiable skeletal landmarks were included in the study. Therefore, the inclusion of older participants is unlikely to have compromised the validity of the sagittal skeletal assessments performed in this study.

6. LIMITATION:

The present study has several limitations. First, the sample was obtained from a single center and had a relatively limited size, which may limit the generalizability of our findings. Second, only individuals with balanced vertical facial patterns were included to minimize the confounding effects of vertical growth, thereby restricting the applicability of the results to hyper-and hypodivergent growth patterns. Additionally, sagittal skeletal classification was based on traditional fixed normative thresholds; recently proposed individualized or regression-based floating norms were not applied and may provide a more refined assessment of sagittal discrepancies, particularly in borderline cases. Future studies using larger multicenter samples and incorporating advanced three-dimensional analytical approaches are recommended.

Classification based on ANB thresholds may have introduced range restrictions and partial mathematical dependency in class-specific correlation analyses, particularly in Class I; therefore, these correlations should be interpreted with caution. Future studies should use independent or combined classification criteria.

Although only CBCT images with clearly identifiable skeletal landmarks were included, age-related biological variations in craniofacial and occlusal characteristics cannot be completely excluded, particularly in older individuals within the sample.

As sagittal skeletal classification was based on ANB thresholds, correlation analyses performed within skeletal classes should be interpreted with caution because of potential range restriction and mathematical dependency between the classification variable and the analyzed parameter

7. CONCLUSION

The ANB angle and WITS appraisal are not interchangeable diagnostic parameters, as each may yield different outcomes when used independently. However, both measurements provide complementary information for the assessment of sagittal skeletal relationships. Their combined interpretation allows for a more accurate and reliable evaluation of sagittal jaw discrepancies in different skeletal patterns. The degree of association between the ANB angle and WITS appraisal varied according to the sagittal skeletal pattern, showing stronger agreement in skeletal Class II and Class III and weaker association in Class I, further supporting their complementary rather than interchangeable use in orthodontic diagnosis and treatment planning.

Additionally, the absence of significant sex-based differences suggests that common reference values may be applicable to both male and female patients in the Yemeni population, simplifying clinical assessment.

As the present study was limited to subjects with normodivergent vertical growth patterns, the findings should be interpreted within this context and cannot be generalized to hyperdivergent or hypodivergent individuals, in whom vertical skeletal characteristics may substantially affect ANB and WITS measurements.

Future research should expand these findings to include diverse populations and vertical growth patterns and further explore individualized reference values, particularly for borderline skeletal relationships. The integration of advanced imaging techniques, such as CBCT, with traditional cephalometric measurements may further enhance orthodontic diagnosis and treatment planning.

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