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Radioprotection-based cephalometric analysis: validation of AB-ratio for sagittal assessment of malocclusion

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A R T I C L E I N F O

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Wits

A B S T R A C T

Objective: This study aimed to validate the AB-ratio metric, a novel 3D cephalometric tool for assessing skeletal malocclusions, and to evaluate its reliability in comparison to the traditional ANB angle and Wits appraisal, with a focus on minimizing radiation exposure in orthodontic diagnostics.

Methods: A retrospective CBCT analysis was conducted on 352 full-cranium scans. Twelve anatomical landmarks were manually annotated. ANB (°), Wits (mm) and AB-ratio were calculated. Following the assessment of data non-normality using the Shapiro-Wilk test and the removal of outliers via Tukey's fences, statistical analyses were conducted using Spearman's rank correlation coefficient (ρ) and Kendall's tau (τ) to evaluate associations. Additionally, the Siegel non- parametric linear regression estimator was applied to assess the relationships between AB-ratio and ANB, as well as between AB-ratio and Wits. Cohen's kappa coefficient (κ) and percentage of agreement also evaluated the contingency between methods. Significance (p) was set at 0.05.

Results: A strong and significant correlation (ρ=0.787; τ=0.569; $p < 0.001$) was found between the AB-ratio and ANB angle while a moderate correlation was reported between AB-ratio and Wits (ρ=0.733; τ=0.551; $p < 0.001$). Linear regressions provided the following equations: AB-ratio=0.04*ANB+0.76 and AB-ratio=0.03*Wits+0.99. The κ scores of diagnostic concordances between AB-ratio and ANB and Wits were 0.562 and 0.089, respectively, showing different agreements (75.44% vs 31.67%). All tests comparing ANB and Wits showed lower correlations (ρ=0.659; τ=0.484) and agreement (κ =0.042; 29.89%).

Conclusions: The AB-ratio metric might significantly enhance 3D cephalometric analysis by providing reliable assessments of skeletal malocclusions while adhering to radioprotection principles. The AB-ratio classified sagittal discrepancies with norms of 0.84±0.08 for Class I, <0.76 for Class III, and >0.92 for Class II malocclusions.

Clinical significance: The AB-ratio offers a reliable 3D alternative to the ANB angle and Wits appraisal for diagnosing skeletal malocclusions, with strong and moderate correlation and moderate and poor classification agreement, respectively.

1. Introduction

Skeletal malocclusion, a significant concern in orthodontics and maxillofacial surgery, refers to the misalignment of the basal bones, impacting both functional occlusion and facial aesthetics. Traditional methods of assessing skeletal class mainly depend on two-dimensional (2D) cephalometric analysis. This process involves measuring specific angles and linear distances on lateral cephalograms to evaluate the spatial relationship between the maxilla and mandible [1].

However, 2D cephalometry has several inherent limitations as it is prone to errors such as distortion and magnification, which can compromise the accuracy of measurements. Additionally, 2D imaging offers only a limited perspective of the complex three-dimensional (3D) craniofacial structures, often resulting in incomplete assessments. Therefore, a comprehensive evaluation must address both the anteroposterior and the transversal dimensions; 2D projections often fail to

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capture transverse skeletal width, asymmetries, and cross-sectional morphology, risking underdiagnosis or misinterpretation [2]. 3D imaging allows true-size, true-position assessment of sagittal and transverse relationships in the same dataset and thereby strengthens diagnostic precision and treatment planning in complex cases.

With advancements in medical imaging, cone-beam computed tomography (CBCT) has become increasingly popular in orthodontics. CBCT offers detailed volumetric images of craniofacial structures, providing comprehensive views. The 3D nature of CBCT imaging enables more accurate assessments of skeletal relationships and a detailed visualisation of anatomical landmarks, enhancing accuracy during diagnosis [3].

Consequently, developing a 3D ANB angle represents a significant advancement in utilising CBCT technology. The 3D ANB angle is calculated like its 2D counterpart, by identifying points A, B, and Nasion in a 3D space and calculating the angles formed in a 3D plane [4]. By contrast, the Wits appraisal is obtained by orthogonally projecting points A and B onto the functional occlusal plane and measuring the linear AO–BO distance in millimetres; because it is referenced to the occlusal plane, it is strongly influenced by its inclination/cant, dentoalveolar compensations and subjectivity of the definition of a functional occlusal plane. In brief, ANB is chiefly sensitive to cranial-base orientation and Nasion position, whereas Wits is less dependent on the cranial base but more on how the occlusal plane is defined, explaining their only modest concordance during diagnosis [5,6].

Despite the CBCT-based method addressing many limitations of the 2D measurements, this technique involves higher radiation doses than traditional 2D radiographs, as it requires the irradiation of the entire cranium. Therefore, reducing the Field of View (FOV) is a key strategy for minimising radiation exposure during 3D imaging in orthodontics [7].

Restricting the CBCT field of view (FOV) to the dentomaxillofacial region, rather than acquiring a full-volume scan, enables the use of 3D cephalometric tools such as Bisector-Wits and AB-wise in place of conventional 2D ANB [8,9], while minimizing radiation exposure within 3D imaging. This clarification refers specifically to dose reduction achieved by limiting the CBCT FOV, not to a comparison of radiation dose between 3D and 2D modalities.

Reducing the FOV to include only the necessary anatomical structures minimises the radiation dose while obtaining the required diagnostic information about skeletal assessment, which allows adhering to the ALARA (As Low As Reasonably Achievable) principle. This is particularly important in younger patients, in which reducing a cumulative ionising radiation exposure, which is called stochastic risk, is crucial for long-term health [10,11].

Despite the advantages of CBCT over traditional methods, the orthodontic community still faces challenges in developing and validating robust, reliable metrics to fully exploit the capabilities of 3D imaging while respecting the radiation protection principles of justification, optimisation, and dose limitation. Integrating new 3D assessment methods requires thorough validation to ensure they provide consistent and accurate diagnostic information. This is where the AB-ratio measurement comes into play as a novel metric designed to leverage the detailed imaging capabilities of CBCT for assessing skeletal class. Therefore, this study seeks to validate the AB-ratio measurement by correlating it with established assessments, ultimately contributing to improved diagnostic accuracy and developing a radioprotection-based cephalometry.

2. Materials and methods

The validation study analyzed a dataset of 354 CBCTs from patients treated orthodontically and for maxillofacial purposes at the Department of Orthodontics and Maxillofacial Surgery of the University of Milan. The retrospective collection was approved by the Ethical Committee of the University of Milan (protocol number 71/22, dated July 2022) and adhered to the principles of the World Medical Organization Declaration of Helsinki. Informed consent for scientific use was obtained from all participants before treatment and radiological exams; these image scans were not specifically taken for this study. Moreover, CBCT examinations were obtained only when the anticipated diagnostic yield could not be achieved with conventional 2D imaging, applying always low-dose protocols.

The CBCTs were selected retrospectively based on inclusion criteria: high-quality images, full-cranium FOV encompassing all necessary landmarks, and a slice thickness of 150–300 μm. Patients exhibiting severe asymmetry, prior orthognathic treatments, or systemic diseases or syndromes were excluded.

DICOM images from each patient were processed and imported into dedicated software (3DSlicer, version 5.2.2) to manually annotate twelve landmarks (eight unilateral, two bilateral). Each landmark was identified on 2D axial views, and its position was subsequently verified in the 3D rendered volume image. The list of landmarks and their definitions is presented in Table 1.

Once the reference points were manually marked, the coordinates were exported as a JSON file and processed using a programming platform (Python, version 3.11.4). Subsequently, measurements for ANB, Wits appraisal, and AB-ratio were computed. The ANB angle was calculated as the difference between two angles, as per the following formula:

$$ANB = SNA - SNB$$

The Wits appraisal was calculated after designing the Occlusal Plane (OP) by passing through the points CF16, CF26, and IIP. After that, the distances of projections of A (A') and B (B') on OP from the line connecting CF16 and CF26 (CF16-CF26) were computed and use in the following formula:

$$Wits\ appraisal = (distance\ A'\ to\ CF16 - CF26) - (distance\ B'\ to\ CF16 - CF26)$$

Similarly to Wits, to compute the AB-ratio a preliminary step was necessary: a Mandibular Plane (MP) was defined, using the right and left Gonion, and the Menton landmark; then, the intersection point (IP)

Table 1
Landmarks' list and definitions.

Landmark	Abbreviation	Definition
Nasion	N	The most anterior aspect of the frontonasal suture is observed on the median sagittal plane.
Sella	S	Three-dimensional center of the sella turcica
Anterior Nasal Spine	ANS	The most anterior aspect of the nasal spine is observed on the median sagittal plane.
Posterior Nasal Spine	PNS	The most posterior aspect of the nasal spine is observed on the median sagittal plane.
A point	A	The most posterior aspect of the concavity between the ANS and the alveolar bone of the upper incisors, observed on the median sagittal plane.
B point	B	The most posterior aspect of the concavity between the Pogonion and the alveolar bone of the lower incisors, observed on the median sagittal plane.
Gonion Left	GoL	The most postero-inferior point of the gonial angle, observed on the left side of the mandible.
Gonion Right	GoR	The most postero-inferior point of the gonial angle, observed on the right side of the mandible.
Menton	Me	The lowest aspect of the mandibular symphysis is observed on the median sagittal plane.
Central fossa 1.6	CF16	The deepest point of the central fossa of tooth 1.6.
Central fossa 2.6	CF26	The deepest point of the central fossa of tooth 2.6.
Interincisive point	IIP	The midpoint of the line connecting upper and lower interincisive points.

between MP and bispinal plane, passing through ANS-PNS, was determined as skeletal bite angle (MPˆANS-PNS). The AB line, passing through the A and B points, was therefore calculated. Finally, the subtended angle between the AB line and the MP (ABˆMP) was used to calculate the AB-ratio by the following formula:

$$AB - ratio = \frac{AB^{\wedge}MP}{180 - (MP^{\wedge}ANS - PNS) - (AB^{\wedge}MP)}$$

The denominator represents the geometric subtraction needed to obtain the subtended angle between line AB and the bispinal plane (ABˆANS-PNS). This operation is analytically identical to the direct inter-line angle; the subtraction does not alter measurement precision per se. Fig. 1 offers a graphical representation of the construction methods for AB ratio, ANB, and Wits.

A pilot study was also performed to calculate the sample size (N) according to the expected correlation factor I between ANB and AB-ratio based on 25 CBCTs randomly selected. Considering an α of 0.01 and a β of 99 %, the following formula was applied:

$$N = \left[\frac{Z_\alpha + Z_\beta}{C}\right]^2 + 3$$

Where Z represents the standard normal deviate for (2.58), Z is the normal deviate for (2.33), and C denotes the results from the equation 0.5*ln[(1 + r)/(1-r)] (1.26). A minimum of 18 patients was necessary to statistically demonstrate the robustness of the correlation between ANB and AB-ratio measurements.

To evaluate the errors associated with the method and the intra-observer reliability of the measured variables, Dahlberg's formula was applied:

$$Method\ error = \ Var(d_i) = \Sigma d_i^2 / N$$

Where di represents the difference between the first and second measurements, and N denotes the number of paired observations.

A sample of twenty-five random CBCT scans was selected and annotated twice by the same experienced operator. The results were evaluated to calculate the Dahlberg D. The analysis yielded values ranging from 0.1° to 1.1° for angular measurements (ANB) and from 0.2 mm to 0.6 mm for linear measurements (Wits). These results indicate a very low degree of variability, suggesting that the measurements are robust for further analyses.

Statistical analyses were thus conducted. Initially, data were evaluated for normality using the Shapiro–Wilk test and α error of 0.05 to determine whether parametric or non-parametric correlation analysis was suitable. As the three groups (ANB, Wits, and AB-ratio) exhibited different distribution patterns, non-parametric tests were applied (Fig. 2).

Outliers were identified and removed using Tukey's fences method, which depends on the Interquartile Range (IQR). In this method, data points are flagged as outliers if they fall below the first quartile (Q1) or above the third quartile (Q3) of the data, multiplied by a constant (1.5). The formula was defined as:

$$IRQ = [Q1 - 1.5 * IQR; Q3 + 1.5 * IQR]$$

For the inferential statistical analysis, Spearman's correlation coefficient (ρ) was employed to evaluate the strength and direction of the association between the angular measurement ANB (independent variable) and the proportional measurement AB-ratio (dependent variable) and between Wits and AB-ratio. A significance level of $p < 0.05$ was deemed statistically significant, while correlation coefficients ρ>0.75 were considered strong and clinically relevant. In addition, Kendall's tau (τ) was computed to corroborate monotonic associations while accounting for ties. The Siegel estimator for non-parametric linear regression assesses the relationship between the variables, yielding the transformation equation among them, while R^2 values were used as an indicator of the reliability and goodness-of-fit of the regression models.

To evaluate whether vertical skeletal parameters modify the relationship between AB-ratio and conventional sagittal indices, vertical covariates were entered in a second multivariate regression: SNˆMP was added to the ANB model, and ANS–PNSˆMP was added to the Wits model. The increment in explained variance was assessed by the change in coefficient of determination (R^2) and tested using a partial F-test.

Finally, Cohen's kappa statistic (κ) and the contingency matrix assessed the inter-rater agreement between the classification methods: ANB vs AB-ratio and AB-ratio vs Wits appraisal.

3. Results

The correlations of AB-ratio with ANB angle and with Wits appraisal were evaluated using data from 354 consecutively selected CBCT scans. Outlier analysis identified 2 cases that were excluded from the dataset to ensure consistency in the statistical analysis. Consequently, the correlations and linear regression analyses were performed on 352 cases (212 males, 140 females; mean age 18.48 ± 11.17 years; Range 6.4–48.2 years). To reduce spectrum bias and to stress-test the metric across growth stages, a heterogeneous age distribution was intentionally targeted. The sample had a mean AB-ratio value of 0.92±0.14, a mean ANB value of 3.88±2.78°, and a mean Wits of −1.93±3.6 mm.

To establish new clinical reference ranges for the measurements obtained from the AB-ratio, the strength and direction of the relationship were first assessed using the non-parametric Spearman correlation coefficient. The analysis revealed a strong (ρ=0.787) and statistically significant ($p < 0.001$) correlation with ANB angle. Since ρ>0.75, it was considered clinically relevant. Also, Kendall's correlation analysis showed significant associations among ANB and AB-ratio (τ=0.569; $p <$ 0.001) The positive sign indicated a positive monotonic association.

A post-hoc analysis was then conducted using the Siegel estimator for non-parametric linear regression to model the relationship between the

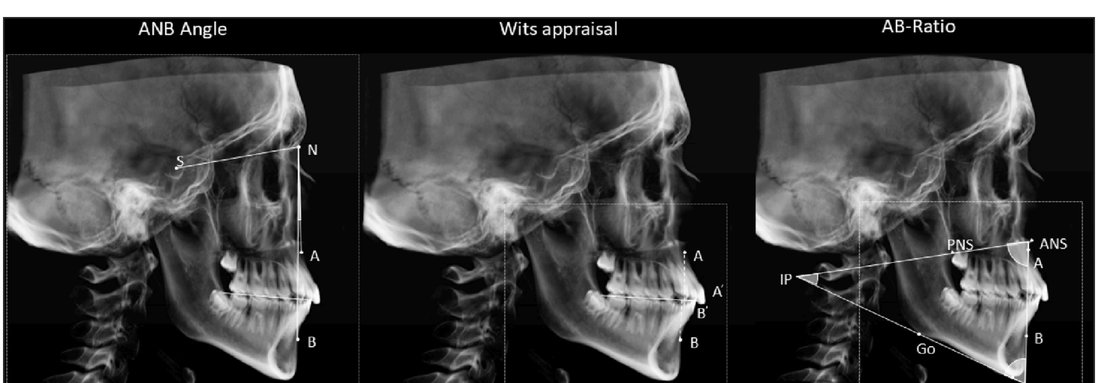

Fig. 1. Construction methods for ANB, Wits, and AB-ratio.

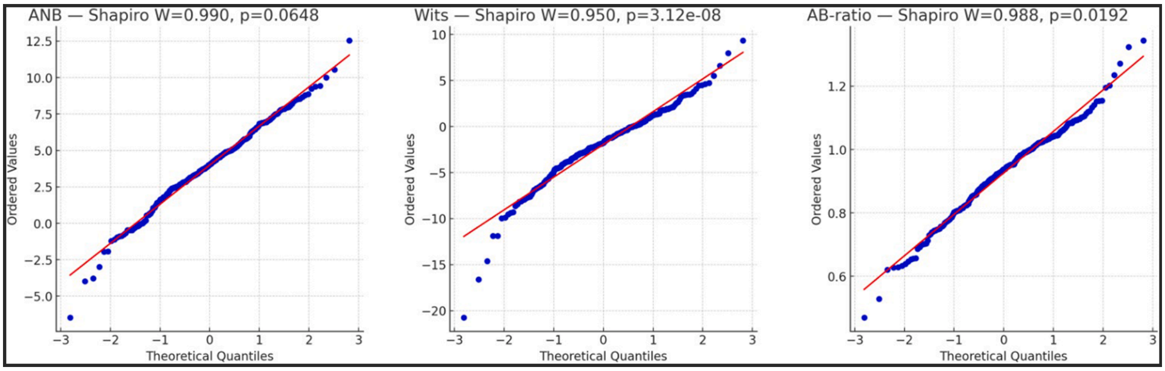

Fig. 2. QQ-plots against the standard normal distribution with Shapiro–Wilk statistics.

two sets of measurements. The resulting equation was as follows:

$$AB - ratio \ = \ 0.04 * ANB + 0.76$$

Consequently, the rounded corresponding norm of the AB-ratio to ANB ($2 \pm 2^{\circ}$) assessment was 0.84±0.08, suggesting that the sagittal discrepancy should be classified as Class I. An AB-ratio lower than 0.76 indicated a Class III relationship, while values above 0.92 were associated with a Class II relationship.

Moreover, when SNˆMP was added to the regression of AB-ratio on ANB, the explained variance significantly increased ($\Delta R^2 = 0.078$; $R^2 =$ 0.691 vs. 0.613), with a partial F-test confirming the added value of the vertical component ($F = 60.5$; $p < 0.001$). These results, despite statistically significant, were clinically not relevant since coefficient of SNˆMP was quite equal to zero ($\beta = -0.0058$). Therefore, the simpler linear regression model remained a robust predictor of AB-ratio without including the additional parameter.

Regarding the correlation between AB-ratio and Wits appraisal, the Spearman's rank correlation revealed a moderate positive association ($\rho = 0.733$; $p < 0.001$), supporting a significant correspondence between the two indices; similarly, Kendall's test reported significant and positive association ($\tau = 0.551$; $p < 0.001$). As for the ANB analysis, the Siegel estimator for non-parametric linear regression was applied to derive the transformation equation between AB-ratio and Wits. The resulting regression equation was:

$$AB - ratio \ = \ 0.03 * Wits + 0.99$$

Based on this equation, an AB-ratio of approximately 0.99 corresponded to a Wits value of 0 mm, considered within the Class I range. Values lower than 0.76, corresponding to negative Wits values, were indicative of a Class III skeletal pattern, whereas values greater than 0.92, associated with positive Wits values, reflected a Class II relationship. This confirms that the AB-ratio demonstrates consistent performance across different sagittal reference standards, maintaining clear thresholds for the classification of skeletal discrepancies. The coefficient of determination (R-squared=0.625) indicated that approximately 62.5 % of the variability in AB-ratio values could be explained by changes in the Wits appraisal, confirming a moderate strength of association between the two indices but slightly higher than the model explaining the relation between AB-ratio and ANB (R-squared=0.613).

By contrast to previous multivariate regression including cranial divergence to AB-ratio/ANB relation, when adding ANS–PNSˆMP to the regression between AB-ratio and Wits, the increase in explained variance was negligible ($\Delta R^2 = 0.002$; $R^2 =$ 0.627 vs. 0.625), with a non-significant effect of ANS–PNSˆMP ($\beta = 0.0008$; $F = 1.16$; $p = 0.281$).

A κ coefficient of 0.562 ($p < 0.001$) was observed between the ANB and AB-ratio classifications, indicating moderate agreement (75.44 %) between the two methods. This suggests that some inconsistencies remain, although the classifications yield similar results. On the contrary, a κ coefficient of 0.089 ($p = 0.001$) was observed between the AB-ratio and Wits classifications, indicating very poor agreement (31.67 %) between the two methods. This suggests that the AB-ratio provides inconsistent performance when compared with the Wits appraisal.

The highest concordance was found between AB-ratio and ANB, with Class II and Class I cases showing the greatest consistency and no misclassifications between Class II and III, resulting in a moderate κ score. In contrast, the comparison with Wits revealed scattered misclassifications across Class II and III cases, which accounted for the final very poor agreement.

When ANB and Wits have been compared, the association was only modest. Spearman's and Kendall's tests were both statistically significant showing values of 0.659 and 0.484, respectively ($p < 0.001$). The linear regression of Wits on ANB yielded a R-squared of 0.515, indicating limited explanatory power. Despite a good correlation between data, categorical agreement was poor (29.89 %), with a Cohen's κ of only 0.042. The cross-classification between ANB and Wits showed the majority of consistent diagnoses limited to Class II and III cases. Misclassifications were frequent, while direct swaps occurred between Class II and III. This distribution explains the very low κ score and the limited diagnostic reliability of these conventional assessments.

Overall, the ANB–Wits pairing performed worse than the

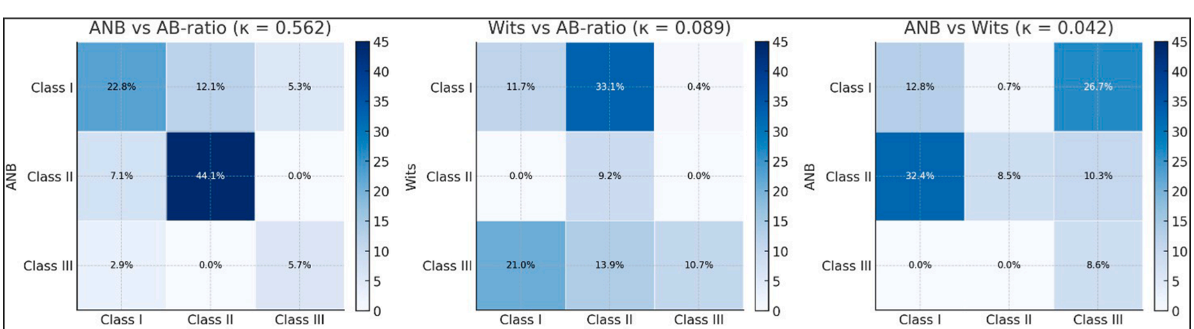

Fig. 3. Heatmaps. Cells show the percentage of the total sample; darker shading indicates higher frequency. Cohen's κ is shown in each panel title.

comparisons involving AB-ratio, reinforcing the superior behaviour of the AB-ratio-based method. Graphic representations of linear regressions and agreements were also presented in Figs. 3 and 4, while Fig. 5 shows pairwise alluvial plots.

4. Discussion

The results of this study provide significant insights into the novel application of the AB-ratio metric for 3D cephalometric analysis, emphasizing its potential to offers a reliable 3D auxiliary metric the assessment of skeletal malocclusions in orthodontics. The validation of the AB-ratio underscores its utility in clinical practice and highlights its importance in advancing radioprotection-based cephalometry, particularly when utilizing an ultra-reduced FOV limited to the maxillary complex.

Traditional 2D cephalometric analyses, such as the ANB angle and Wits appraisal, have been widely used for decades but suffer from inherent limitations, including distortion, magnification errors, and an inability to capture the complex spatial relationships of craniofacial structures, along with dependence on several factors like the rotation of the SN plane and the degree of facial prognathism [12,13].

In contrast, the AB-ratio metric offers a more nuanced and accurate assessment by integrating 3D data. The ANB angle has long been utilized to assess sagittal jaw relationships, distinguishing between Class I, II, and III malocclusions. Despite its widespread use, the accuracy of the ANB angle can be influenced by cranial base tilting and the vertical cranial height, potentially leading to misinterpretations [14,15].

On the other hand, the Wits appraisal provides a direct assessment of jaw relationships without the influence of cranial base variations; however, it can be particularly problematic in cases with significant vertical discrepancies, where the occlusal plane might be altered due to dental compensations [5,16]. In contrast, the AB-ratio method mitigates the influence of cranial base, vertical jaw position, and occlusal plane variations, leading to a more consistent assessment of skeletal discrepancies. In fact, geometrically, AB-ratio partitions the angular span from the MP to the ANS-PNS by locating the AB line between them; because both reference planes are intra-jaw and often co-vary with vertical growth rotations, first-order pitch effects largely cancel in the proportion, attenuating sensitivity to vertical jaw position. Empirically, adding vertical covariates (SNˆMP and ANS–PNSˆMP) confirmed only negligible influence; thus, AB-ratio attenuates but does not eliminate vertical effects while preserving classification at the extremes.

Over the years, other several alternative methods have been proposed to overcome the limitations of ANB and Wits. The AF-BF appraisal represented one of the earliest attempts to reduce dependence on the occlusal plane [17], followed by more recent 3D-based approaches such as the ABwise and Bisector-Wits analyses [8,9], which were specifically designed to limit cranial base bias and improve reproducibility in CBCT datasets. In parallel, previous indices including the Beta angle [18], ODI angle [19], and APDI angle provided a composite sagittal evaluation limiting the effect of cranial base landmarks [20]. More recently, innovative constructs such as Zeta angle and the sagittal G-triangle analysis have been also introduced [21,22]. Collectively, these methods underline the persistent need to refine sagittal skeletal assessments, but also emphasize that no single approach has yet achieved universal acceptance, thereby justifying the exploration and validation of novel indices such as the AB-ratio. Moreover, unlike prior indices, the AB-ratio expresses AB as a normalized proportion between MP and ANS–PNS, avoiding cranial-base/occlusal-plane anchors and dampening vertical co-rotation.

In this cohort, AB-ratio correlated strongly with ANB ($\rho=0.787$) with a robust regression fit ($R^2=0.613$), and only moderately with Wits ($\rho\approx0.63$; $R^2=0.625$). Categorical agreement mirrored this pattern: $\kappa=0.562$ with ANB (observed agreement 75.44 %), but $\kappa=0.076$ with Wits (agreement 30.25 %). Notably, no Class II-III swaps occurred; most discrepancies involved Class I drifting to adjacent classes. These findings indicate that AB-ratio aligns more closely with ANB than with Wits while preserving separation between clinically critical extremes.

The divergence from Wits is not a failure of the AB-ratio; it reflects substantive construct differences. As previously mentioned, Wits is anchored to the occlusal plane, which is susceptible to dental compensations and vertical pattern effects, whereas AB-ratio, as a proportion of angular relationships, inherently normalizes the relationship between the structures being measured [14]. This means that variations in individual anatomy, which might distort a single angle or linear distance, have a reduced impact on the overall assessment.

Accordingly, modest association and poor categorical agreement versus Wits are anticipated and consistent with the long-known modest concordance of ANB and Wits themselves [4,23]. By contrast, AB-ratio attenuates reference-plane and scaling effects, does not depend on the occlusal plane, and preserved separation of clinically critical extremes: against ANB it achieved moderate agreement with no Class II-III swaps, and displayed stronger association and model fit than the Wits pairing. These results support AB-ratio as a more stable and clinically reliable measurement, particularly for maintaining correct classification at the extremes while limiting artefacts introduced by cranial-base, vertical, and occlusal-plane variability.

The differential impact of vertical skeletal relationships on sagittal indices was also explored. The statistically significant but clinically negligible contribution of SNˆMP (cranial divergence) in the ANB–AB-ratio model reflects the well-known sensitivity of ANB to MP inclination: as the mandible rotates downward and backward, ANB may artificially increase, whereas AB-ratio adjusts for this effect. In contrast, the Wits appraisal relies on linear projections along the occlusal plane and is less influenced by vertical maxillary inclination, explaining why ANS–PNSˆMP (skeletal bite) failed to improve the Wits–AB-ratio model. Overall, this suggests that vertical skeletal correction can contribute when interpreting ANB but not when considering Wits in relation to AB-ratio.

Another critical aspect of this study is the emphasis on radioprotection. Integrating the AB-ratio metric within CBCT imaging protocols with ultra-reduced FOVs is particularly noteworthy. A previous attempt

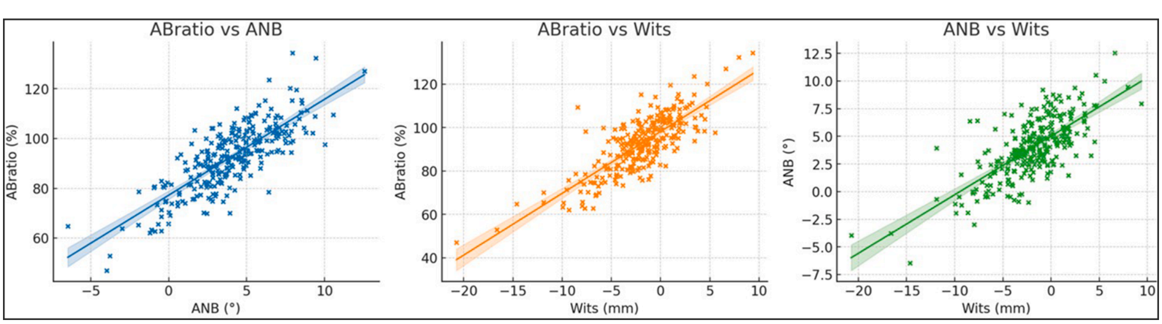

Fig. 4. Robust regressions among sagittal indices. Points are individual cases; solid lines are Siegel (non-parametric) regressions with bootstrapped 95 % confidence bands.

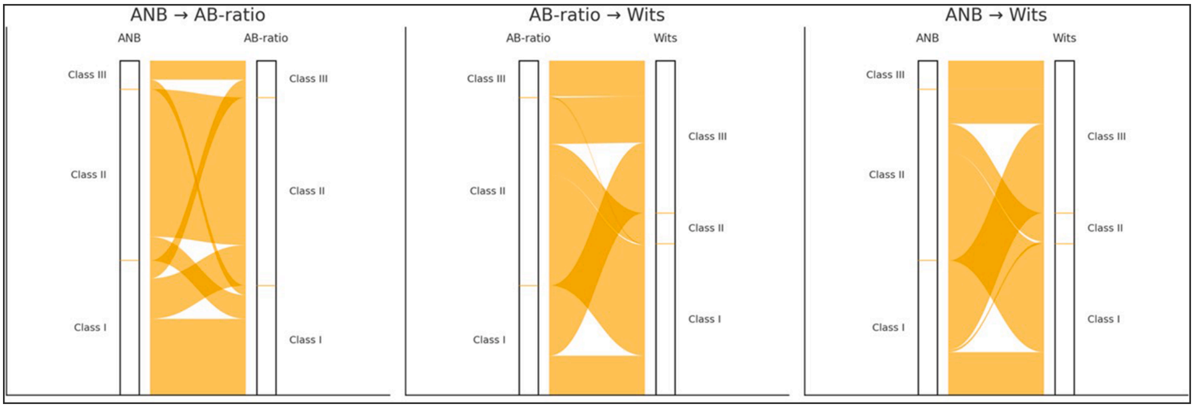

Fig. 5. Pairwise alluvial plots (ANB-AB-ratio, AB-ratio-Wits, ANB-Wits). Ribbon width is proportional to the number of cases moving between Class I–III; side bars show marginal class totals.

to overcome the limitations of conventional two-dimensional analyses, like the ANB angle and Wits appraisal, was made by Ertty and colleagues in 2023 [24]. They introduced a new linear distance between points A and B, aimed at improving sagittal assessment, particularly for orthognathic patients, using true vertical and horizontal planes with the patient in natural head position. Yet, given their focus on orthognathic diagnostics, they utilised an extended FOV and relied on extracranial references. While this approach enhances reproducibility, it inherently involves higher radiation doses. By contrast, the AB-ratio metric is particularly well-suited for use with reduced FOVs, as it does not require the entire cranial structure to be imaged, unlike the ANB angle or the new measurement by Ertty et al. [24]. This adaptability not only reduces the patient's exposure to ionizing radiation but also aligns with the growing emphasis on developing diagnostic tools that are both effective and safe [25]. CBCT, while offering superior imaging capabilities compared to traditional 2D radiographs, typically involves higher radiation doses. Therefore, optimizing the FOV to include only the necessary anatomical structures is essential for adhering to the principles of radioprotection: justification, optimization, and dose limitation [26]. In fact, this supports radioprotection aims without sacrificing diagnostic discrimination, provided that clinicians adopt the reported normative band (Class $I \approx 0.84 \pm 0.08$; <0.76 Class III; >0.92 Class II) and apply it as an auxiliary metric rather than a wholesale replacement.

Clinically, the absence of Class II-III mismatches and the concentration of disagreements around Class I suggest that AB-ratio is robust for identifying clear extremes while borderline cases remain sensitive to the chosen reference. This pattern is coherent with the construct logic above and argues for using AB-ratio alongside ANB in equivocal cases. From a clinical point of view, one of the practical advantages of the AB-ratio method is the ease of reference identification and subsequent calculation through simple computational software. In 2D cephalometry, the accurate identification of landmarks can be challenging due to overlapping anatomical structures and projection errors, as well as the identification of a proper occlusal plane when Wits appraisal is evaluated for the skeletal assessment [5,6,27–30]. Conventional cephalometry points are located on a hypothetical sagittal midline, leading to inaccuracies, especially in maxillary and mandibular asymmetries. In contrast, 3D imaging allows each landmark to be identified in its true anatomical position by moving through CBCT slices, offering a more precise and accurate skeletal assessment independently of the diagnostic technique used [28,31].

In 3D imaging these points can be more easily and accurately identified, reducing the operator-dependent errors in landmarking [32]. The AB-ratio method can also be utilized in 2D cephalometric analysis, adopting the same norm values. However, its application in 2D is subject to limitations that may affect the precision of skeletal assessment.

From a critical perspective, it is important to highlight the mismatch observed in skeletal classification when using this method, as shown by the moderate inter-rater agreement between the two classification methods included in the present study. Class I cases are often misidentified as either Class II or III, similarly to what has been reported with other indices such as the Wits appraisal. However, it is essential to note that no mismatch occurs between Class II and III cases, supporting the diagnostic accuracy of the AB-ratio. Clearly, the AB-ratio should be considered an additional tool for identifying the correct basal skeletal class, integrating the conventional 3D measurements in modern cephalometry.

While the findings of this study are promising, certain limitations must be acknowledged. Although practical, the retrospective nature of the research and the use of pre-existing CBCT scans may introduce selection bias. Furthermore, excluding patients with severe asymmetry, previous orthognathic treatments, or systemic diseases limits the generalizability of the results to these populations. Other limitations include manual landmarking and the fact that the present dataset was acquired with full-cranium FOV. The reduced-FOV advantage is therefore inferential from the geometry of the metric; a prospective external validation using ultra-reduced FOV CBCT would directly test non-inferiority and strengthen the radioprotection claim.

Future studies should aim to validate the AB-ratio metric in a more diverse patient cohort, including those with complex craniofacial conditions and from heterogeneous ethnicities.

5. Conclusions

AB-ratio metric represents a significant advancement in 3D cephalometric analysis, offering a novel and reliable assessments while minimising CBCT dose via limited-FOV protocols when CBCT is clinically indicated. Its validation in this study, particularly within the context of ultra-reduced FOV CBCT imaging, underscores its potential to become an auxiliary metric in orthodontic diagnostics. The AB-ratio value of 0.84 ± 0.08 classifies the sagittal discrepancy as Class I; values lower than 0.76 and higher than 0.92 classify Class III and Class II malocclusion, respectively. The results also confirm that AB-ratio provides a sagittal assessment less biased by vertical discrepancies than ANB, while preserving comparability with Wits. Clinically, this supports the use of AB-ratio as a more robust index for diagnosis and treatment planning in patients with variable vertical skeletal patterns. Further studies are needed to confirm these data and to validate this method on extended datasets.

Ethical approval and informed consent statements

This retrospective data collection received the approval from the Ethical Committee of the University of Milan (protocol number 71/22, dated July 2022) and adhered to the World Medical Organization Declaration of Helsinki principles. Informed consent for scientific use was obtained from all participants before any treatment and radiological exams.

Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author.

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CRediT authorship contribution statement

Marco Serafin: Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Benedetta Baldini:** Writing – review & editing, Software, Data curation. **Elisa Boccalari:** Writing – review & editing, Visualization, Data curation. **Piero Antonio Zecca:** Writing – review & editing, Data curation. **Alberto Caprioglio:** Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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