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original article

Validating conventional 2D IMPA against 3D one: is it still a trustworthy angle? A retrospective CBCT-based diagnostic agreement study

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Summary

Aim > This study tested whether conventional 2D incisor mandibular plane angle (IMPA) can be used interchangeably with a rigorously defined 3D one.
Material and methods > This single-centre retrospective study included 169 CBCT scans. Synthetic lateral cephalograms were generated from DICOM data to calculate the conventional 2D IMPA between the Go–Me mandibular plane and the lower central incisor long axis. The 3D IMPA used the axes of teeth 3.1 and 4.1 projected three-dimensionally to the orthogonal plane to GoL-GoR-Me and the higher angle was selected. Normality of paired differences was assessed using the Shapiro-Wilk test. Systematic bias was evaluated with a paired *t*-test. Association between 2D and 3D IMPA was assessed using Pearson's correlation and linear regression. Agreement was quantified by Bland-Altman analysis. Classification agreement within the 85–95° range was evaluated using Cohen's kappa and McNemar's test.
Results > Mean 2D and 3D IMPA were 95.29 ± 8.98° and 95.75 ± 9.42°, respectively, with a mean paired 3D-2D difference of 0.46° (paired *t*-test, $P = 0.084$). Correlation was strong ($r = 0.931$), and linear regression yielded $R^2 = 0.867$. Bland-Altman bias was 0.46° (95%LoA −6.29° to +7.21°). Classification agreement across the 85–95° range was 83.43% ($\kappa = 0.636$; McNemar $P = 0.345$).
Conclusions > 2D and 3D IMPA showed negligible mean bias, excellent association, and substantial diagnostic concordance. Routine cases may rely on 2D IMPA without material loss of information, whereas in torque-critical, anatomically constrained, or borderline cases the observed ±7° dispersion argues for 3D assessment.

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Introduction

The inclination of the mandibular incisors relative to the mandibular basal bone is a mandatory parameter in orthodontic diagnosis, treatment planning, and outcome evaluation [1]. Lower incisor torque influences arch coordination, sagittal compensation of skeletal discrepancies, smile aesthetics, and long-term periodontal health [2]. For decades, clinicians have relied on the incisor mandibular plane angle (IMPA) measured on a lateral cephalogram to quantify this relationship, guide biomechanics, and calibrate expectations for camouflage versus surgical approach in borderline cases [3]. Despite the proliferation of digital technologies, IMPA remains embedded in normative tables, cephalometric analyses, and the everyday language of clinical decision-making among orthodontists [4].

Yet, the conventional 2D lateral cephalogram is intrinsically a planar projection of 3D structures and therefore vulnerable to superimposition, magnification, and posture-dependent distortions [5]. The mandibular plane definition may vary with landmark selection and facial asymmetry. Likewise, the apparent long axis of the incisor may depend on crown–root morphology and projection geometry [6]. These limitations are not merely academic: they can shift a patient across clinically meaningful thresholds and, in turn, alter therapeutic intent, particularly when torque decisions carry biologic costs resulting in an extractive case or not [7].

Cone-beam computed tomography (CBCT) and three-dimensional approaches allow a more precise, vector-based description of lower incisor inclination, in which the tooth axis is represented in 3D relative to the mandibular plane, and its relationship with the anterior bony portion of the mandible can be assessed more realistically [8]. However, with greater geometric fidelity comes a conceptual challenge: IMPA is not a singular construct in 3D. In fact, IMPA becomes definition-dependent rather than a single construct. The mandibular plane definition, the choice of incisor representation, and the projection strategy can produce angles that are not interchangeable. Moreover, considerations of radiation dose, cost, and workflow argue that any putative advantage of 3D must translate into clinically relevant differences, not merely numerical sophistication [9].

Against this background, a direct validation of conventional 2D IMPA against a rigorously defined 3D reference is needed to determine whether traditional measurements remain clinically trustworthy in contemporary orthodontic practice [10]. Interchangeability should be judged against a pre-specified clinically acceptable margin. Likewise, clarifying how closely 2D IMPA follows its 3D counterpart, not only in terms of numerical values but also around clinically relevant thresholds, is essential to decide when conventional measurements are sufficient and when a full 3D evaluation is warranted.

Therefore, the aim of this study was to validate conventional 2D IMPA against a rigorously defined 3D reference in a sample of orthodontic patients. Specifically, the study aimed to quantify the mean difference between 2D and 3D IMPA, assess their association, and evaluate classification agreement across clinically relevant IMPA categories. The overarching goal was to determine whether 2D IMPA can still be considered a trustworthy angle for routine orthodontic decision-making, and to delineate the clinical scenarios in which 3D assessment should be preferred.

Material and methods

Study design and patient selection

This retrospective study was conducted in full accordance with the Declaration of Helsinki on medical research involving human subjects. The protocol was reviewed and approved by the Ethics Committee of the University of Milan (approval number: 71/22, dated July 22, 2022). Informed consent was also obtained from all patients and/or their parents at the time of data collection, allowing the use of anonymized records for research.

Patients were eligible if a CBCT scan was available and the permanent dentition included fully erupted mandibular incisors. Two hundred and nine CBCTs were retrieved consecutively from the archives of the Department of Orthodontics (Ospedale Maggiore Policlinico, IRCCS Cà Granda, Milan, Italy), between 2020 and 2024. All examinations had been acquired for specific diagnostic purposes in patients referred for orthodontic assessment and fulfilling the following common diagnostic objectives: assessment of impacted teeth, evaluation of severe skeletal discrepancies or asymmetries, presurgical orthognathic planning, and temporomandibular joint assessment.

Subjects with craniofacial syndromes, previous orthodontic treatment, or a history of maxillofacial trauma or mandibular surgery were excluded. To ensure measurement reliability, cases were included only when CBCT scan quality was adequate, with no significant artifacts or landmark visualization problems. Patients presenting with missing mandibular incisors, extensive restorations that interfered with cephalometric tracing, or incomplete diagnostic records were also excluded.

All CBCT scans were acquired with a voxel size up to 0.4 mm (0.2–0.4 mm) and a field of view sufficient to include all landmarks bilaterally. Exposure parameters and field of view were adjusted according to the ALADA principle.

2D IMPA calculation

Two-dimensional IMPA was measured on synthetic lateral cephalograms reconstructed from the CBCT DICOM volumes using a dedicated software (DRR generator module; 3D Slicer) and analyzed using conventional cephalometric landmarks. These reconstructions reproduce the geometry of conventional lateral cephalograms but share the same volumetric dataset as the 3D measurements.

The mandibular plane (MP) was defined as the line connecting anatomical gonion (Go) to menton (Me). The long axis of the mandibular central incisor was traced from the incisal tip (L1Tip) to the root apex (L1Apex). The IMPA was then calculated as the angle formed between the MP and the incisor axis. All angular values were expressed in degrees to one decimal place and computed by a programming language (Python) after export of landmark coordinates (x, y).

3D IMPA calculation

The same CBCT scans were retrieved and analysed in multiplanar reconstruction mode using the same software (3DSlicer). The MP was defined by left gonion (GoL), right gonion (GoR), and Me. For each mandibular central incisor (3.1 and 4.1), the tooth axis was defined as the Tip–Apex vector. Therefore, each incisor axis was projected onto an orthogonal plane constructed perpendicular to the MP and passing through Me and MidGo (the midpoint of GoL–GoR). 3D IMPA was computed as the angle between the MP and the projected incisor axes on the orthogonal plane. In practical terms, this plane can be visualized as a sagittal-like slice remaining perpendicular to the MP, so that the angle between the projected incisor axis and the projected MP corresponds to IMPA in 3D (*figure 1*).

Both angular measurements between the incisor axes and the MP reference were computed after export of landmark coordinates (x, y, and z). 3D IMPA was defined as the axis of the more proclined lower central incisor, to mimic the outermost incisor landmarked in conventional 2D cephalograms.

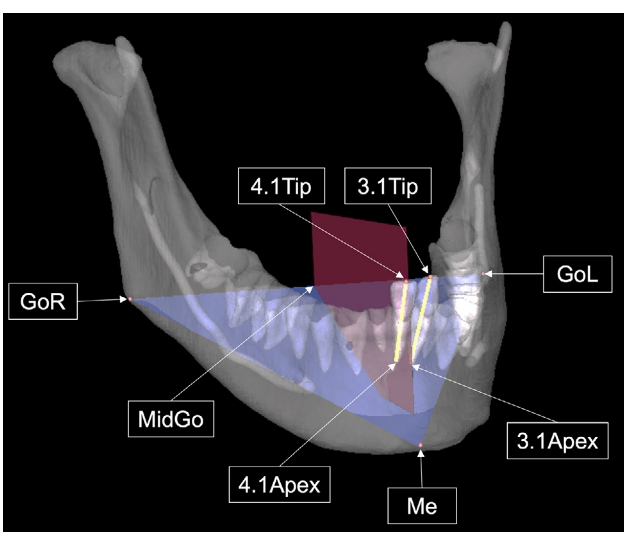

FIGURE 1

3D IMPA

The mandibular plane was defined by Menton (Me) and the right and left gonion landmarks (GoR and GoL). An orthogonal reference plane passing through Me and MidGo (midpoint of GoL–GoR) was constructed to support projection-based computation of 3D IMPA. The long axes of the mandibular central incisors (3.1 and 4.1) are shown as Tip–Apex vectors. For clarity, the mandibular CBCT-derived STL model is displayed with all teeth removed except 3.1 and 4.1, in order to facilitate visualization and interpretation of the reference planes and tooth axes.

Sample size calculation and intra-observer reliability

The required sample size was estimated a priori based on the paired difference between 2D and 3D IMPA values. Assuming a standard deviation (SD) of the paired differences of 3.45°, a two-sided α of 0.05, and a power of 0.80, it was considered a mean 2D–3D difference greater than 1° as clinically relevant. Accordingly, 1° was chosen as a deliberately strict and conservative equivalence margin for the mean bias, so that even small systematic deviations would be detected. Under these assumptions, a minimum of 94 patients was required. This margin was defined for the group-level mean bias only and does not apply to the individual-level variability captured by the Bland-Altman statistic. Intra-observer repeatability was assessed by repeating landmark identification in a subset of 20 random patients after a washout interval of 4 weeks. Intra-observer reliability was quantified for each landmark and for each coordinate separately using the intraclass correlation coefficient (ICC; two-way mixed-effects model), with 95% confidence intervals (95%CIs).

Paired comparisons of mean values

Paired comparisons of mean values between 2D and 3D IMPA were performed using the synthetic lateral cephalograms reconstructed from CBCT DICOM data and the corresponding 3D measurements obtained from the same volume. As both techniques measured the same anatomical parameter on the same sample, analyses were performed using paired statistical methods.

Therefore, for each method, descriptive statistics were calculated, including mean, SD, range (min–max), and standard error of the mean (SEM). The distribution of paired differences (3D–2D) was evaluated with the Shapiro-Wilk test to assess normality.

To test whether systematic differences existed between methods, a paired *t*-test was applied since assumptions of normality were tested.

Association and agreement between methods

Since data were normally distributed, the linear association between 2D and 3D values was quantified by the Pearson correlation coefficient (r). Agreement was further investigated using a simple linear regression of 3D values on 2D values to evaluate potential proportional bias. The coefficient of determination (R^2) was reported as a measure of explained variance. Also, agreement was visually and statistically evaluated with a Bland-Altman approach. The mean difference (bias) and the 95% limits of agreement (LoA) were calculated. To assess proportional bias, the correlation between mean values and differences was examined.

Clinically agreement between methods

Given that a clinically normal IMPA is defined as 85–95°, each measurement was dichotomized into "normal'' (within range) or "abnormal'' (outside range). A 2 $\times$ 2 contingency table was constructed, and the following statistics were derived: overall percent agreement, Cohen's kappa coefficient (κ), and McNemar's test.

Results

After excluding 34 scans (16.3%) that did not meet the inclusion criteria (previous orthodontic treatment, 21 cases; previous orthognathic surgery, 3 cases; syndromic conditions, 2 cases; absence of one or both mandibular central incisors, 6 cases; presence of prosthetic crowns or extensive composite restorations, 2 cases) and 6 scans (2.9%) with poor image quality, the final sample comprised 169 patients (mean age 21.7 ± 7.3 years; 98 females, 71 males). According to the ANB angle, malocclusion distribution was 105 Class I (62.1%), 40 Class II (23.7%), and 24 Class III (14.2%). Relevant prior pathologies included: impacted maxillary/mandibular canines, temporomandibular joint disorders, and pre-surgical orthognathic evaluation.

A post hoc power calculation based on the assumed standard deviation of 3.45° and the final sample size of 169 patients indicated that the study had approximately 96% power to detect a true mean 2D–3D difference of 1° at a two-sided α level of 0.05.

Landmark placement showed high intra-observer reliability. In 2D, coordinate-wise ICCs ranged from 0.840 to 0.944, with the highest ICC for Me (x) (0.944; 95% CI 0.748–0.999) and the lowest for Go (y) (0.840; 95% CI 0.670–0.993). In 3D, ICCs ranged from 0.921 to 0.999, with near-ceiling values for x and y coordinates (x: 0.998–0.999; y: 0.991–0.996) and slightly lower values for z (0.921–0.943). Overall, these findings indicate that landmark annotation was highly repeatable, particularly in 3D.

Descriptive statistics

The 2D method produced a mean IMPA of 95.29 ± 8.98° (range: 72.14–118.40°; SEM = 0.69°), while the 3D method produced a mean of 95.75 ± 9.42° (range: 66.86–118.51°; SEM = 0.72°). Both distributions covered a wide clinical spectrum and demonstrated approximate normality (*figure 2*).

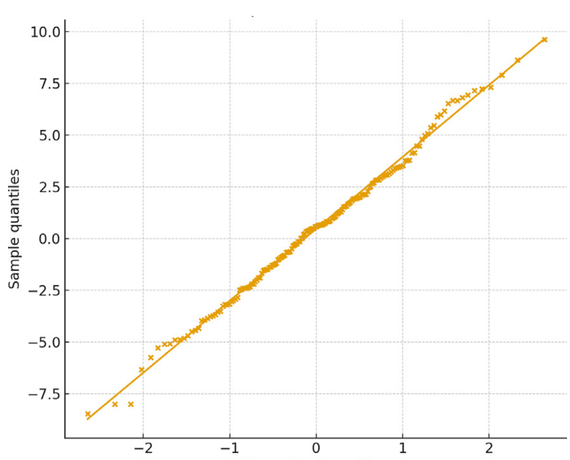

FIGURE 2

QQ-plot of paired differences. Quantile–quantile plot of 3D−2D versus the normal distribution showing near-linear alignment, consistent with normality

Paired comparisons

The distribution of differences (3D–2D) followed normality (Shapiro-Wilk, W = 0.995, *P* = 0.826) (*figure 3*). The mean paired difference was 0.46° (95%CI: −0.06 to 0.98), indicating that 3D values were slightly higher on average. This difference did not reach statistical significance (*t*-test, *P* = 0.084). Thus, there was not significant systematic bias between the two methods.

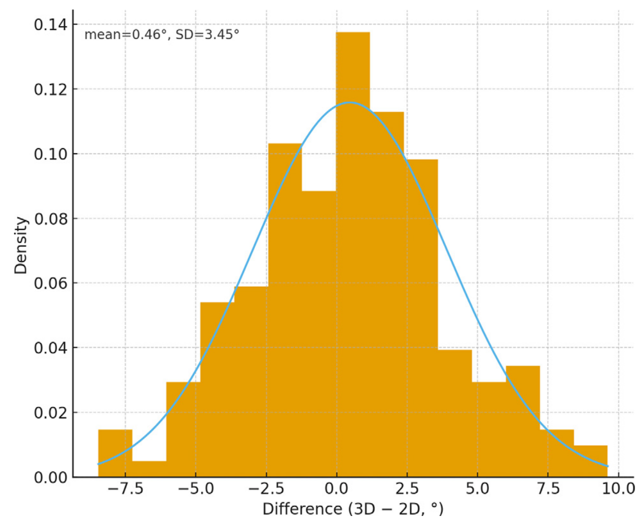

FIGURE 3

Distribution of paired differences. Histogram of 3D−2D with overlaid normal curve

Association and agreement

The correlation between 2D and 3D measurements was very strong (r = 0.931, *P* < 0.001), indicating that cases ranked similarly across methods (*figure 4*). Linear regression analysis

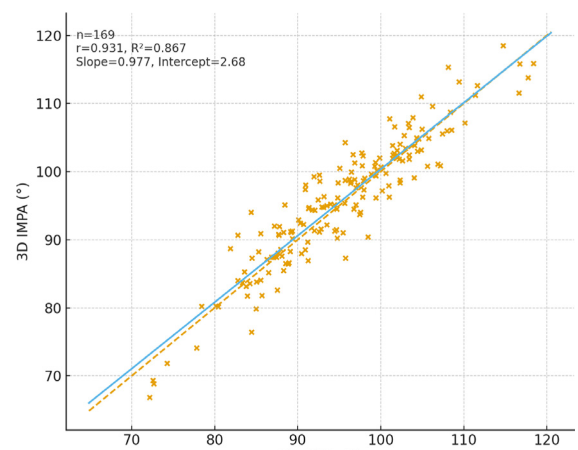

FIGURE 4

Scatter of 2D versus 3D IMPA with identity (dashed) and fitted regression (solid) lines

yielded a slope of 0.98, an intercept of 2.68, and a coefficient of determination of $R^2 = 0.867$ ($P < 0.001$). These findings suggest excellent linear association with no evidence of proportional bias.

Bland-Altman analysis

The mean bias was 0.46°, with 95% LoA ranging from −6.29° to +7.21°. The spread of the LoA indicates that, for most cases, differences between methods were below 7°. No significant correlation between differences and averages was observed ($r = 0.130$, $P = 0.091$), confirming the absence of proportional bias. The Bland-Altman plot visually supported good overall agreement (*figure 5*).

Normality classification

When applying the clinical threshold of 85–95°, the two methods classified most subjects identically. Out of 169 cases: both methods classified 45 subjects as normal (26.6%), both methods classified 96 subjects as abnormal (56.8%), 17 cases were normal in 2D but abnormal in 3D (10.1%), and 11 cases were abnormal in 2D but normal in 3D (6.5%). Notably, no patient showed a complete reversal of inclination, that is, being classified as retroclined by one method and proclined by the other, even among those with an absolute 3D–2D difference ≥ 7°. All large discrepancies occurred between normal and one of the abnormal categories rather than between opposite extremes.

The overall classification agreement was 83.4%, with a Cohen's kappa of 0.636, representing substantial agreement. McNemar's test was not significant ($\chi^2 = 0.893$, $P = 0.345$), indicating no systematic directional misclassification.

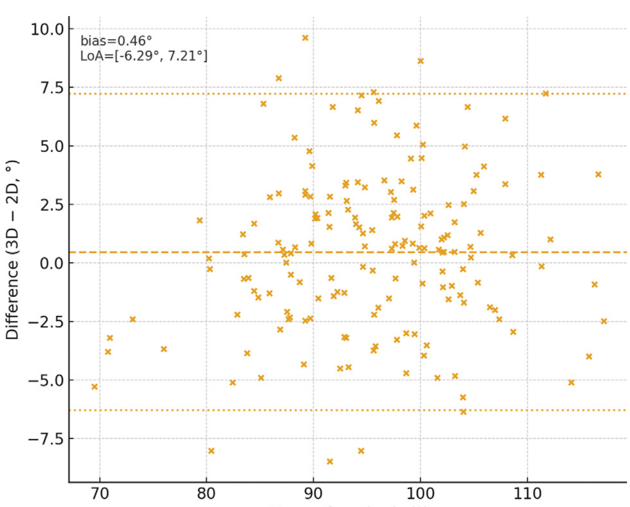

Figure 5

Bland-Altman plot. Difference 3D−2D against the mean of methods with bias (dashed) and 95% LoA (dotted)

Discussion

The present study asked a pragmatic question with immediate clinical consequences: can a conventional 2D IMPA be used interchangeably with its 3D counterpart for everyday decision-making? In a cohort of 169 paired measurements, 2D and 3D IMPA values showed no statistically significant mean difference (*figure 3*), excellent linear association (*figure 4*), and no evidence of proportional bias (*figure 5*). Classification was concordant in most of cases with substantial agreement. Collectively, these findings support the view that, for most patients, 2D IMPA remains a serviceable surrogate for 3D, while caution is warranted near clinical thresholds where a ∼7° dispersion could alter management.

The results resonate with several prior investigations comparing cephalometric measurements across modalities. Early validation studies showed that CBCT-synthesized lateral cephalograms produce measurements largely comparable to conventional lateral cephalograms, with small, often non-significant differences across common angular variables. Kumar et al. reported close agreement between conventional cephalograms and CBCT-generated lateral views, suggesting either modality can support cephalometric analysis in routine diagnostics [11]. Park et al. likewise found broad compatibility between CBCT-derived and conventional cephalograms [12]. More recently, Chung et al. evaluated conventional versus CBCT-generated lateral cephalograms using an AI analysis pipeline and observed no significant differences across all tested measurements [13]; notably, the largest angular divergence occurred for the IMPA but remained statistically non-significant. Nevertheless, the evidence base is heterogeneous. A 2024 cross-sectional comparison reported statistically significant differences for several angular measures, including IMPA, between conventional and CBCT-synthesized cephalograms, concluding that the CBCT-based reconstructions might yield more accurate dimensional estimates [14]. Of course, methodological differences likely explain the heterogeneity of outcomes in literature.

Moving from projection-based 2D reconstructions to native 3D cephalometry makes explicit the boundary between planar measurements and volumetric morphology. Gribel et al. demonstrated that CBCT measurements are accurate to sub-voxel levels and emphasized that 2D cephalometric norms cannot be naively transferred into 3D frameworks because the constructs and the error structures are not identical [15]. In other words, IMPA in 3D becomes definition-dependent: the chosen mandibular plane, which incisor axis, and whether vectors are projected onto planes or compared in space all influence the resulting angle. This explains why previous studies can reasonably disagree.

From a statistical standpoint, the present study was powered under the assumption that a mean 3D–2D difference greater than 1° would be clinically relevant, and this deliberately strict margin was used only for the group-level mean bias. The observed mean

3D–2D difference in IMPA was small and fell within the predefined threshold, suggesting that, on average, conventional 2D measurements do not systematically overestimate or underestimate IMPA compared with the 3D measurement. However, this equivalence margin cannot be directly extended to individual patients, whose agreement is better captured by the Bland-Altman LoA. In the present sample, the limits indicate that single subjects may exhibit discrepancies of approximately $\pm 7^\circ$ between 2D and 3D IMPA. Such variability is compatible with the known error range of cephalometric angular measurements but clearly exceeds the 1° margin used for sample size planning and precludes full numerical interchangeability at the individual level, particularly for borderline cases. Therefore, in everyday orthodontics where torque prescriptions, camouflage thresholds, and periodontal safeguards may pivot on shifts of 3–5°, a $\pm 7^\circ$ envelope argues for judicious use of 3D when decisions are borderline, the anterior alveolar envelope is thin, skeletal asymmetry is pronounced, or orthognathic surgery is contemplated. These use-cases align with broader guidance on when 3D adds actionable value beyond 2D projections.

This interpretation is corroborated by the pattern observed in the patients with discrepant IMPA classification between 2D and 3D. In all discordant cases, at least one of the two measurements fell within an extended borderline zone, most commonly with one modality placing the patient just inside and the other just outside the conventional neutral range of 85°–95°. Only a small subset of patients showed more marked discrepancies, with absolute 3D–2D differences $\geq 7^\circ$. When these pairs were examined in terms of potential clinical impact, a theoretical change in treatment strategy would have occurred in only 5 patients (3.6%). These findings suggest that, although 2D and 3D IMPA are not numerically interchangeable for every individual, most discrepancies cluster around borderline thresholds and only infrequently translate into a qualitatively different clinical decision.

It is equally important to delineate where 2D methods exhibit systematic limitations. It is well known that bilateral structures, e.g., gonion, are susceptible to superimposition and projection artifacts on lateral cephalograms, whereas CBCT permits bilateral landmarking in true 3D, reducing identification error and geometric distortions [16]. Studies comparing conventional analyses repeatedly attribute inter-study differences to variability in landmark identifiability, magnification, and patient positioning, all factors that CBCT can mitigate via multiplanar reformatting and standardized head orientation [17,18]. The present finding of strong association and acceptable LoA despite these known 2D liabilities suggests that IMPA, as operationalized here, is relatively robust; still, the outliers embedded within the LoA are where 3D earns its keep.

For clinicians, two practical takeaways emerge. First, in the absence of borderline thresholds, thin labial plate, marked asymmetry, or planned orthognathic movements; a carefully acquired and traced 2D cephalogram will generally place a patient in the same torque tolerance as a 3D analysis. Second, when a few torque degrees carry therapeutic weight (e.g., extraction versus non-extraction torque strategies, or when periodontal risk is a dominant constraint) 3D should be preferred, not to chase decimal precision but to resolve ambiguities inherent to projection, superimposition, and landmark definition. Overall, the present results support maintaining 2D cephalometry as the default approach for assessing IMPA, reserving full 3D analysis for selected patients.

Beyond metrics, torque decisions must respect anatomy. IMPA is a scalar angle; the stable periodontal position of the mandibular incisors is an anatomic state defined by the 3D relationship among the root, the cortical boundaries of the mandibular symphysis, and the soft-tissue phenotype. CBCT uniquely depicts the labial and lingual cortical plates, the sagittal curvature of the symphysis, and root inclination/apex position, allowing clinicians to judge whether a proposed torque would displace the root toward a dehiscence, thin a plate below a biologically safe thickness, or violate an individualized alveolar envelope [19,20]. Multiple CBCT studies demonstrated substantial inter-individual variability in symphyseal form and in anterior alveolar bone thickness at cervical, mid-root, and apical levels-variability that a single 2D angle cannot encode [21,22]. From a clinical point of view, 3D assessment helps reconcile the number (IMPA) with the anatomy (symphysis), ensuring that torque goals remain consonant with a patient's cortical boundaries and long-term periodontal stability.

These biological advantages must be balanced against ionizing radiation. Typical effective doses are approximately 2–5 µSv for lateral cephalograms, whereas CBCT dose varies widely with FOV, voxel size, and protocol [23]. Dose can be reduced by limiting the FOV to the mandibular region when appropriate [24]. Accordingly, consensus statements advise against routine CBCT when 2D imaging is sufficient and support CBCT only when it is likely to change management. In orthodontics, that threshold is typically crossed in retreatment, in multidisciplinary planning with periodontics/implantology or orthognathic surgery, and in borderline cases where a few degrees of torque carry high periodontal risk [25]. In routine patients far from thresholds, a carefully acquired and traced 2D cephalogram usually provides adequate guidance; moreover, this study should not be interpreted as promoting or justifying the use of CBCT in orthodontics, but rather as supporting a selective indication in which 3D imaging is reserved for situations with diagnostic or therapeutic uncertainty.

Limitations

This retrospective, single-center analysis carries several limitations. First, 2D measurement was generated from DICOM rather than acquired on a dedicated cephalostat. While this approach standardizes magnification and head orientation, it may under- or over-represent some real-world 2D projection errors and thus bias toward better agreement with 3D. Second, 3D definition used a Go-Go-Me mandibular plane and outermost axis of the two central incisors projected orthogonally. Alternative planes (e.g., tangent to basal cortical contours) or tooth selection strategies could yield different values. Third, image quality constraints led to the exclusion of 6 scans, introducing potential selection bias toward cleaner datasets. Fourth, only intra-observer repeatability was evaluated while inter-observer reliability was not assessed; data support internal consistency but do not capture the additional variability that might occur when different clinicians apply the protocol. Finally, the LoA ($\pm 6.75°$) exceeds some clinicians' comfort zones for torque-sensitive decisions, cautioning against blanket interchangeability in all cases.

Conclusions

Within the limitations of this retrospective study, 2D and 3D IMPA measurements showed negligible mean bias, strong association, and substantial diagnostic concordance. These findings support a tiered strategy: 2D IMPA should remain the default metric in routine orthodontic care, whereas 3D assessment is preferable when small torque differences are likely to change clinical management.

In these settings, the observed limits of agreement and potential reclassification near the 85–95° IMPA range justify CBCT to resolve landmark ambiguities and to visualize root–cortex clearance. Moreover, when 3D is indicated, the use of limited-FOV protocols targeted to the mandibular region to minimize dose exposure is advocated.

Authors' contribution : Conceptualization, M.S and E.B.; methodology, L.F.; validation, E.B. and A.C.; formal analysis, M.S. and E.B.; investigation, M. S., E.B., and L.F.; data curation, M.S.; writing — original draft preparation, E.B.; writing — review and editing, M.S. and A.C.; visualization, E.B.; supervision, A.C.

Disclosure of interest : The authors declare that they have no competing interest.

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