Research Article

Evaluation of plane-line matching of three-dimensional cephalometric analysis using artificial intelligence assisted software

Husam Majid Hameed[1], **Dheaa H. Al-Groosh**[1*], **Jean-Marc Retrouvey**[3]

1 Ministry of Health, Baghdad, Iraq

2 Department of Orthodontics, College of Dentistry, University of Baghdad, Baghdad, Iraq

3 Baylor College of Medicine, Houston, TX, USA

*Corresponding author: d.al-groosh@codental.uobaghdad.edu.iq

Received date: 02-03-2025

Accepted date: 04-05-2025

Published date: 15-12-2025

Article DOI

Abstract: The introduction of three-dimensional technology has revolutionized the orthodontic digital workflow and facilitated diagnosis and treatment planning. The aims of this study were to evaluate the plane-line matching of conventional lateral cephalometric analysis and three dimensional cone beam computed tomography (CBCT) and to assess the reliability and consistency of linear and angular measurements obtained from the two digital modality. Materials and Methods: Forty five participants with an age range of 18-26 years and Class I skeletal malocclusion were recruited. A standardized cephalometric radiograph and CBCT scans were obtained according to specific indication protocols. The digital images were analyzed using an AI based software, 3D Slicer (version 5.6.2), for enhancement and registration. Anatomical landmarks were allocated and anatomical planes and lines, were aligned for quantitative measurements analysis. Results: The findings indicated an acceptable degree of matching between the two-dimensional cephalometric X-ray analysis and the three-dimensional CBCT analysis. Although linear measurements showed high consistency, some angular measurements presented statistically significant differences between the two modalities. Overall, the paired t-test results indicated that certain measurements, such as ANS-Me and N-Me, exhibited variability, while others, like SN and NB, showed no significant differences. The reliability of measurements was further confirmed using the Intraclass Correlation Coefficient (ICC), which demonstrated strong consistency across most linear measurements. Conclusion: The study concluded that three-dimensional cephalometric analysis using CBCT provides a promising approach for comprehensive and accurate assessment of craniofacial structures, offering significant advantages over traditional two-dimensional methods.

Keywords: Artificial Intelligence, Cephalometric radiograph, Cone-Beam Computed Tomography

Introduction

For years, cephalometric analysis was considered the prime tool for orthodontics and orthognathic surgery (1). It was used for dental and skeletal relationship assessment, formulating treatment planning, assessing growth prediction as well as orthodontic and orthognathic surgery outcome predictions (2). One of the drawbacks of the lateral cephalometric radiographs is the two dimensional representation of a three dimensional subject i.e. the craniofacial structure (3). This results in a 'built in' limitations such as image distortion, variant landmark allocation and superimposition issues. Moreover, the reliability and accuracy of the acquired image dependents on patient positioning. It was claimed that endorsement of artificial intelligence and particularly machine learning logarithms improved the accuracy and the efficiency of cephalometric landmark identification and improve the treatment planning (4).

During recently, cone-beam computed tomography (CBCT) has been introduced to orthodontics to enhance three dimensional assessment of soft tissue and hard tissue dento-facial structures and improve diagnosis via obtaining volumetric data [(1, 5-7)]. The use of three dimensional analysis not only allows craniofacial anatomic relationship but also enables a precise diagnosis of the underlying condition [(8)]. Moreover, obtaining a three dimensional data allows integration with other digital dataset such as face scan and intraoral scan which certainly modernize the digital work flow of the clinic, and improves the treatment outcomes and , hence, patients' care. [(9)].

The current study designed firstly, to evaluate the alignment of a 2D cephalometric lines and plane compared to a 3D cephalometric analysis obtained from CBCT scan. Secondly, it assessed the reliability and consistency of linear and angular measurements obtained from these two digital modality

Materials and Methods

This study was approved by the Ethics Board Committee of the College of Dentistry, University of Baghdad (Ref. 626 in 2/6/2022). A sample of 45 CBCT images of patients attending Al-Shaheed Gazi Al-Harari Specialized Hospital from July 2023 to December 2023 were collected. These patients met the following inclusion criteria [(5, 10)]: participants with an age range of 18-26 years, participants with Class I skeletal malocclusion, and participants with full permanent dentition, including an impacted third molar. Patients with dentofacial abnormalities and those who underwent orthodontic treatment were excluded. All patients underwent a standardized lateral cephalometric radiograph as part of the routine orthodontic treatment procedure, and CBCT scans were planned to remove impacted wisdom teeth before orthodontic treatment.

Image acquisition

1. Lateral cephalometric X-ray

A standardized lateral cephalometric radiograph was obtained using a CBCT unit (3D Pro CBCT; Kavo, Biberach, Germany). The exposure settings were 70-80 kVp and 6 to 8 mAs, depending on patient tissue characteristics, with the exposure time of 0.8 of a second to ensuring sufficient image details according to manufacturer's instructions. A standard field of view (FOV) setting of 15 × 30 cm was chosen for lateral cephalometric radiographs. The patients were positioned in a natural head posture with the Frankfort horizontal plane parallel to the ground, and the teeth were in centric occlusion. Built-up digital magnification correction tools have been used to ensure accurate measurements and compensate for image distortion [(11-13)].

2. Cone beam computed tomography (CBCT)

Cone-beam computed tomography (CBCT) was performed using a full field of view FOV (20 cm × 20 cm × 20 cm). The CBCT machine (3D Pro CBCT; Kavo, Biberach, Germany) was set with scan time of 25 to 30 seconds and the voxel size of 0.25 mm with an exposure setting of 90 kVp and 10 mAs. A high-resolution scan mode was selected, and a slice thickness of 0.5 mm to ensure detailed visualization of anatomical structures. The patient's head was held by head support and a chin rest during the scan with a laser alignment guide to ensure patient head parallelism while the teeth were in centric occlusion. [(14-16)].

Software and Extensions

Image processing and analysis were conducted using the 3D Slicer software (version 5.6.2; available at https://www.slicer.org), a widely used open-source platform for medical image analysis. To enhance the capabilities of 3D Slicer for this study, relevant software extensions, specifically SlicerIGT (Image-Guided Therapy) and Elastix, were installed. SlicerIGT was utilized for image-guided interventions, providing modules such as the Fiducial Registration Wizard, which supports both manual and automatic landmark-based registrations of CBCT images and models. This extension allows precise alignment and registration, effectively accommodating the CBCT file format [17].

Elastix was employed as a registration toolkit within 3D Slicer. It offers various registration techniques, including intensity-based and landmark-based registration methods, and supports multiple metrics and transformation models. This flexibility enables the handling of various imaging modalities, particularly CBCT, and facilitates robust image registration workflow [18]. To further enhance the registration process and landmark annotation, MONAILabel, an open-source AI-powered annotation tool, was integrated into the 3D slicer environment. MONAILabel leverages advanced deep learning models, such as UNet and UNETR, for automated and interactive image annotation. The tool is capable of handling DICOM file formats, including CBCT images, and utilizes artificial intelligence (AI) algorithms to assist in fiducial landmark annotation [19].

Importing Images

Conventional lateral cephalometric images in PNG file format and CBCT images in DICOM file format of the same patient were imported into the 3D Slicer software (version 5.6.2; available at https://www.slicer.org) for landmark identification and cephalometric analysis. Subsequently, the importing image was calibrated for the lateral cephalometric image and the CBCT scan, according to the software instructions, to enhance the measurement accuracy and point localization. This was done by adjusting the image parameters, including brightness, contrast, hue, and saturation, depending on AI logarithms of this software to enhance the visibility of the anatomical structures; both manual and automatic options were used for this purpose. The drag-and-drop feature of the software was used to easily curate and edit the images together with the red-eye reduction feature to remove any red-eye effect in the images [20].

Image Registration

Image registration was performed using the Elastix module within the 3D Slicer software environment to align the fiducial markers between the conventional lateral cephalometric X-ray and the three-dimensional CBCT images of the same patient. The registration process utilized both intensity-based and landmark-based algorithms provided by the Elastix module to ensure the precise alignment of anatomical landmarks across the two imaging modalities. To validate the accuracy of the registration, the Transforms module was employed, allowing for the evaluation of alignment by visual inspection and quantitative assessment of the positional accuracy of the fiducial markers. This process ensured that the anatomical structures were accurately superimposed, facilitating reliable measurements for subsequent cephalometric analyses [17, 18].

Measurement and Digitization

The digital workflow involves the followings:

Landmark Identification

Briefly, the first step is to enhance and register images from both modality; then soft tissue and hard tissue landmarks were identified in a triplicate manner and the average coordinates were used for the analysis. In order to align the images, some landmarks, related to the outer border of the cranium, were chosen as a reference points. The image registration is done through identification of the common anatomical landmarks and ,therefore, performs the digitization process for the 2D lateral cephalometric radiograph and the three dimensional scans [17, 21].

Allocation of anatomic landmarks and reference planes

Cephalometric analysis was done using 27 landmarks, including six bilateral points and fifteen midline points, and six planes with nine cephalometric lines [22]. From these, fourteen angular measurement were utilized to evaluate the alignment and comparing the accuracy and consistency of the anatomic landmark allocation and cephalometric analysis of the three dimensional scan representation.

3D Slicer software was employed to measure the linear distances and angular relationships between anatomical landmarks. In two-dimensional images, these measurements correspond to the distance between the points (lines) and the angles formed by the intersecting these lines. In the three-dimensional view, the linear measurements represent distances between border of planes formed by bilateral points and also midline points to form plane in three-dimensional space, as well as the angles measurements that formed by intersection between these planes defined by bilateral anatomical points. This approach allowed for a comprehensive assessment of both linear and angular measurements across both imaging modalities, enhancing the accuracy of landmark identification and ensuring consistent comparative analysis between conventional lateral cephalometric X-rays and 3D CBCT scans as shown in Figure 1 [22].

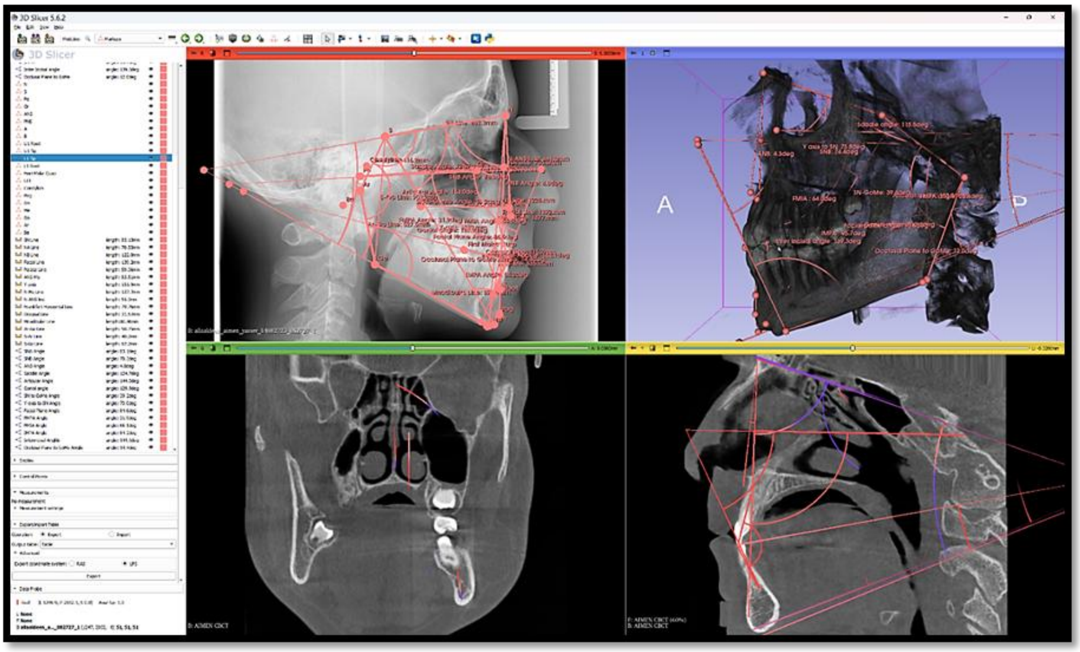

Figure 1: Conventional 2D lateral cephalometric analysis and CBCT 3D Slicer cephalometric analysis by 3D Slicer after registration process

Statistical Analysis

The data were analyzed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY) for data handling and analysis. Descriptive statistics, such as mean, standard deviation, minimum, maximum, and range, were used to provide an overview of both the linear and angular measurements obtained from conventional 2D and CBCT 3D cephalometric analyses. This helped establish baseline characteristics of the data. Comparative Analysis was performed using a paired t-test to determine whether there was a statistically significant difference between the 2D and 3D measurements. This test was used to analyze normally distributed data[23].

The Intraclass Correlation Coefficient (ICC) was used to evaluate the reliability and consistency of the plane-line matching measurements between conventional 2D and CBCT 3D analyses. In addition, Bland-Altman Analysis was used to visually and quantitatively evaluate the agreement between the plane-line matching measurements obtained using the conventional 2D and CBCT 3D measurement methods [24, 25].

Results

The results of the study demonstrated that the overall results showed good agreement between 2D and 3D modalities, and certain landmarks may present more variability when measured in 3D. Table 1. Showed no significant difference in linear measurements between conventional (Conv 2D) analysis and CBCT 3D analysis modalities e.g., SN, NA, NB, Facial Line. However, certain measurements, such as ANS-Me, N-Me, and Occlusal Line exhibited statistically significant differences ($p<0.05$) suggesting some variation between the two methods.

Table 1: Comparison of the linear measurements of 2D conventional cephalometric analysis and 3D CBCT analysis (in mm).

	Linear Measurement	Modality	Mean (mm)	SD (mm)	*t*- value	*p* value
2D conventional cephalometric analysis	**SN**	Conv 2D	81.33	1.99	-1.158	0.253
		CBCT 3D	81.43	1.99		
	NA	Conv 2D	73.51	1.02	0.438	0.663
		CBCT 3D	73.46	0.92		
	NB	Conv 2D	124.07	2.15	0.364	0.718
		CBCT 3D	124.04	2.06		
	Facial Line	Conv 2D	134.1	1.01	-0.340	0.736
		CBCT 3D	134.13	1.05		
	Palatal	Conv 2D	58.12	0.7	1.903	0.064
		CBCT 3D	58	0.67		
	ANS-Me	Conv 2D	83.42	0.87	2.057	0.046
		CBCT 3D	83.21	0.96		
	Y-axis	Conv 2D	154.27	1.17	0.330	0.743
		CBCT 3D	154.23	1.25		
	N-Me	Conv 2D	134.82	1.66	2.179	0.035
		CBCT 3D	134.41	1.55		
	N-ANS	Conv 2D	55.6	0.51	3.011	0.004
		CBCT 3D	55.32	0.65		
	Frankfort Horizontal Line	Conv 2D	80.06	1.4	-1.068	0.291
		CBCT 3D	80.66	3.96		
	Occlusal Line	Conv 2D	30.98	0.73	4.109	0.001
		CBCT 3D	30.7	0.74		
	Mandibular Line	Conv 2D	80.41	0.87	2.690	0.010

		CBCT 3D	79.78	1.63		
	Ar-Go	Conv 2D	48.14	1.28	2.706	0.010
		CBCT 3D	47.7	1.53		
	S-Ar	Conv 2D	39.79	0.35	3.907	0.001
		CBCT 3D	39.53	0.41		
	S-Go	Conv 2D	88.89	0.94	1.582	0.121
		CBCT 3D	88.7	0.77		

	Linear Measurement	**Modality**	**Mean (mm)**	**SD (mm)**	***t*- value**	***p* value**
3D CBCT analysis	**SN**	**Conv 2D**	81.33	1.99	-1.158	0.253
		CBCT 3D	81.43	1.99		
	NA	**Conv 2D**	73.51	1.02	0.438	0.663
		CBCT 3D	73.46	0.92		
	NB	**Conv 2D**	124.07	2.15	0.364	0.718
		CBCT 3D	124.04	2.06		
	Facial Line	**Conv 2D**	134.1	1.01	-0.34	0.736
		CBCT 3D	134.13	1.05		
	Palatal	**Conv 2D**	58.12	0.7	1.903	0.064
		CBCT 3D	58	0.67		
	ANS-Me	**Conv 2D**	83.42	0.87	2.057	0.046
		CBCT 3D	83.21	0.96		
	Y-axis	**Conv 2D**	154.27	1.17	0.33	0.743
		CBCT 3D	154.23	1.25		
	N-Me	**Conv 2D**	134.82	1.66	2.179	0.035
		CBCT 3D	134.41	1.55		
	N-ANS	**Conv 2D**	55.6	0.51	3.011	0.004
		CBCT 3D	55.32	0.65		
	Frankfort Horizontal Line	**Conv 2D**	80.06	1.4	-1.068	0.291
		CBCT 3D	80.66	3.96		
	Occlusal Line	**Conv 2D**	30.98	0.73	4.109	0
		CBCT 3D	30.7	0.74		
	Mandibular Line	**Conv 2D**	80.41	0.87	2.69	0.01
		CBCT 3D	79.78	1.63		
	Ar-Go	**Conv 2D**	48.14	1.28	2.706	0.01
		CBCT 3D	47.7	1.53		
	S-Ar	**Conv 2D**	39.79	0.35	3.907	0
		CBCT 3D	39.53	0.41		
	S-Go	**Conv 2D**	88.89	0.94	1.582	0.121
		CBCT 3D	88.7	0.77		

Table 2 reveals the reliability of linear measurements between 2D and 3D modalities. Measurements such as SN and NB demonstrated an excellent to good reliability, with ICC values above 0.95 for single measurements and 0.98 for average measurements, indicating strong consistency between the methods. Moderate reliability was observed for measurements, such as NA and ANS-Me, with ICC values between 0.65 and 0.72. On the other hand, the Frankfort Horizontal Line and Mandibular Line showed poor reliability, with ICC values below 0.5, indicating greater variability.

Table 2: Interclass correlation coefficient (ICC) analysis of linear measurements of the linear measurements of 2D conventional cephalometric analysis and 3D CBCT analysis.

Linear Measurement	ICC (Single Measurement)	95% Confidence Interval (Single)	ICC (Average Measurement)	95% Confidence Interval (Average)
SN	0.958	0.925-0.977	0.978	0.961-0.988
NA	0.65	0.443-0.792	0.788	0.614-0.884
NB	0.964	0.935-0.980	0.981	0.966-0.990
Facial Line	0.85	0.743-0.915	0.919	0.852-0.955
Palatal	0.78	0.630-0.873	0.876	0.773-0.932
ANS-Me	0.721	0.540-0.837	0.838	0.701-0.911
Y-axis	0.751	0.589-0.855	0.858	0.741-0.922
N-Me	0.671	0.467-0.806	0.803	0.637-0.892
N-ANS	0.395	0.085-0.585	0.529	0.157-0.739
Frankfort Horizontal Line	0.188	-0.559	0.317	-0.862
Occlusal Line	0.764	0.488-0.883	0.866	0.656-0.938
Mandibular Line	0.253	-0.512	0.404	-0.695
Ar-Go	0.676	0.459-0.813	0.807	0.629-0.897
S-Ar	0.276	0.001-0.518	0.433	0.002-0.683
S-Go	0.555	0.319-0.727	0.714	0.484-0.842

The Bland-Altman plot shows a strong agreement and a good consistency between the two modality apart from few outliers, as shown in Figure 2.

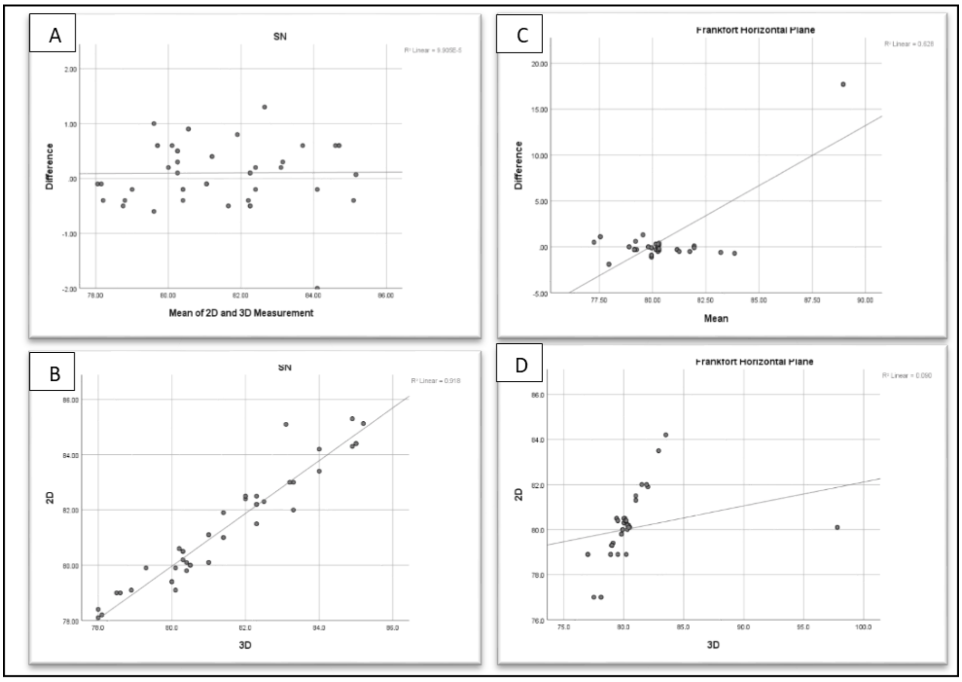

Figure 2: Bland–Altman plots (panels A, C) and scatter plots (panels B, D) between conventional 2D measurements and 3D CBCT measurements. The results are presented for unpaired measurements of SN linear measurements and Frankfort horizontal plane measurements.

Table 3 shows the descriptive statistics for the angular measurements obtained from both the conventional 2D and CBCT 3D modalities. The mean values across both methods showed minimal differences (p>0.05), indicating a good consistency between the two imaging techniques. For example, the mean SNA and the ANB angles was (83.35°, 83.00°) and (2.80°, 2.74°) for the 2D and 3D analysis respectively. However, there was few variability in some regions such as FMPA Angle which showed a significant difference (p = 0.017) indicating some variation between the modalities for these angles.

Table 3: Comparison of the linear measurements of 2D conventional cephalometric analysis and 3D CBCT analysis (in degrees).

Angular Measurement	Modality	Mean (degree)	SD (degree)	t- value	p value
SNA	Conv 2D	83.3	0.58	3.612	0.001
	CBCT 3D	83	0.6		
SNB	Conv 2D	79.1	0.6	0.526	0.602
	CBCT 3D	79.1	0.56		
ANB	Conv 2D	2.8	0.75	1.241	0.222
	CBCT 3D	2.7	0.71		
Saddle	Conv 2D	125	2.57	-1.364	0.179
	CBCT 3D	125.1	2.54		
Articular	Conv 2D	137.8	4.23	0.144	0.886
	CBCT 3D	137.7	4.28		
Gonial	Conv 2D	125.2	2.87	-0.059	0.953
	CBCT 3D	125.2	2.98		
SN to GoMe	Conv 2D	33.8	1.13	-0.289	0.774
	CBCT 3D	33.9	1.06		
Y-axis to SN	Conv 2D	65.6	1.94	-1.624	0.112
	CBCT 3D	65.8	1.72		
Facial plan	Conv 2D	83.3	0.9	1.597	0.118
	CBCT 3D	83.2	1.1		
FMPA	Conv 2D	31.8	1.26	2.475	0.017
	CBCT 3D	31.6	1.46		
FMIA	Conv 2D	70.9	3.46	0.592	0.557
	CBCT 3D	70.8	3.46		
IMPA	Conv 2D	90	3.05	0.000	1.000
	CBCT 3D	90	3.08		
Inter Incisal	Conv 2D	134	1.52	1.495	0.142
	CBCT 3D	133.8	1.52		
Occlusal plane to GoMe	Conv 2D	9.1	0.62	-1.354	0.183
	CBCT 3D	9.1	0.59		

There was an excellent correlation of angular measurements between the two modalities. This was especially true for the ANB, Saddle angle and Gonial angle indicating a reliable data. However, low correlation was found for SNA (Table 4).

Table 4: Interclass correlation coefficient (ICC) analysis of linear measurements from the two imaging modalities (in degree).

Angular Measurement	ICC (Single Measurement)	95% Confidence Interval (Single)	ICC (Average Measurement)	95% Confidence Interval (Average)
SNA	0.324	0.544-0.860	0.740	0.684-0.818
SNB	0.803	0.668-0.886	0.891	0.801-0.940
ANB	0.893	0.814-0.940	0.943	0.898-0.969
Saddle	0.978	0.960-0.988	0.989	0.979-0.994
Articular	0.971	0.948-0.984	0.985	0.973-0.992
Gonial	0.941	0.895-0.967	0.970	0.945-0.983
SN to GoMe	0.647	0.438-0.790	0.786	0.609-0.882
Y-axis to SN	0.895	0.817-0.941	0.945	0.899-0.970
Facial plan	0.757	0.598-0.858	0.862	0.749-0.924
FMPA	0.926	0.860-0.960	0.961	0.925-0.980
FMIA	0.964	0.936-0.980	0.982	0.967-0.990
IMPA	0.931	0.877-0.961	0.964	0.935-0.980
Inter Incisal	0.740	0.574-0.848	0.851	0.729-0.918
Occlusal plane to GoMe	0.962	0.933-0.518	0.979	0.965-0.989

The Bland-Altman plots showed that most data points fell within the 95% limits of agreement, indicating a strong consistency between the two methods for angular measurements. However, a few outliers suggested minor variability at specific angles. Overall, the plots confirm that the two modalities show good agreement with minimal systematic bias, making both techniques reliable for clinical angular assessments in cephalometric analysis, as shown in Figure 3.

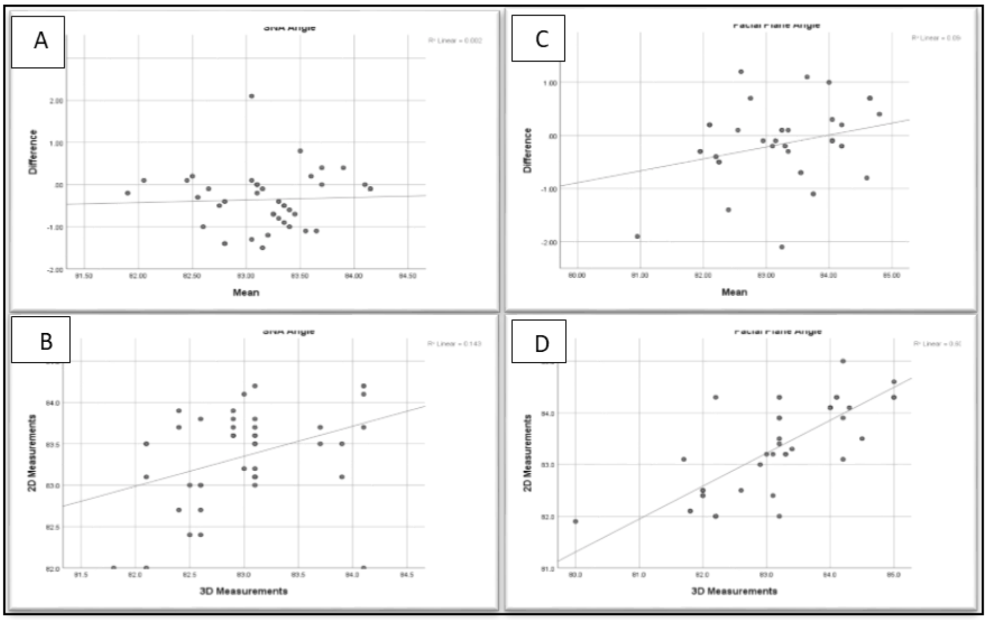

Figure 3: Bland–Altman plots (panels A and C) and scatter plots (panels B and D) between conventional 2D measurements and 3D CBCT measurements. The results are presented for the angular unpaired measurements, SN linear measurements, and Frankfort horizontal plane measurements.

Discussion

Cephalometric analysis is essential for both orthodontic and orthognathic surgery treatment planning. Traditionally, two-dimensional (2D) lateral cephalometric X-ray analysis has been the primary method used to evaluate spatial dental and craniofacial structures. However, recent advances in imaging technology have led to the increasing popularity of three-dimensional (3D) cephalometric analysis using CBCT, which offers a more comprehensive and accurate representation of dental and craniofacial anatomy (26, 27). Additionally, it may help assessment root resorption accurately, after orthodontic treatment in high-risk group patients i.e. vitamin D deficiency (28). Despite these advantages, the reliability of linear and angular measurements derived from 3D CBCT images is still a matter of debate (29). This study aimed to evaluate the reliability of the linear and angular measurements obtained from the 3D cephalometric view of CBCT.

To minimize sources of measurement error, several measures were considered. A strict selection criteria was employed to ensure homogenous sample. Although this improves the internal validity, which is advantageous to test the study hypothesis, the generalization of result may be affected for broader populations with diverse malocclusion types or wider age ranges. Furthermore, best practice protocols were used. Firstly, an experienced orthodontist performed the 2D conventional cephalometric landmark allocation according to a gold standard method (30) and, secondly, an AI-assisted software module was utilized 3D Slicer (version 5.6.2 SlicerIGT, Elastix, and MONAILabel) with an advanced and approved image registration and landmark annotation function. (20). Moreover, landmark identification was carried out in a triplicate and the final value represented the coordiniate average. These measures reduce subjective measurement errors and improve consistency (31).

The implication of an AI based platform, that improves image registration process, provides many advantages. It improves the diagnostic data and helps personalizing the treatment planning through providing a distortion free craniofacial field (32, 34). Hence, reduces variation in landmark allocation between the 2D and 3D analysis (4, 32) and creates a time efficient digital workflow with potential possibility for future 2D/ 3D data representation (35, 36). This comprehensive approach ultimately broadens diagnostic capabilities and sets the stage for better patient outcomes (37).

The results of the current study showed that the linear measurement exhibited excellent correlation between the standard 2D conventional lateral cephalometric X-ray analysis and 3D cephalometric analysis. Moreover, the data showed good agreement in the angular measurement between conventional lateral cephalometric X-ray analysis and 3D cephalometric analysis.

The current study disagreed with previous studies that found that the reliability of angular measurement was inconsistent. This was probably due to differences in the interpretation and comparison of plane-line matching between the two techniques, furthermore, an inherited inaccuracy in conventional cephalometric radiography could be encountered, especially in midline point detection (38, 39). This is true when improper orientation of the head is within the cephalostate during X-ray capture, or when there is image distortion due to asymmetry in facial structures (29, 40). Such distortions can obscure or alter the visibility of anatomical landmarks. Moreover, the potential for double images of craniofacial structures in the conventional cephalometric view is higher because of the built-in magnification, which may complicate point determination at midline points (41). Additionally, in conventional cephalometric radiography, projection errors and image display in the software can distort the actual position and orientation of anatomical structures, leading to potential inaccuracies in plane-line matching (38).

In contrast, the CBCT image combat these drawbacks i.e., projection error and analysis through the use of filters which reduces the distortion and provide 'sharp' 3D volumetric representation of the head and face, thus reduce inaccuracy in landmark detection. This was in accordance with many authors, who proposed the superior spatial resolution of 3D over 2D images (1, 13, 42, 43). Furthermore, it is important to note that the measurement and analysis procedure relies on the choice of the registration technique; superimposition, which is affected by the software, tools, and expertise available; and the accuracy of the registration process, which relies on careful landmark identification, proper selection of algorithms, and validation of the results (40). In the current study, 3D Slicer, which is an AI-operated software, relied on improved logarithms that facilitate operator use of the tools, registration, and measurements, without the need for professional expertise. Indeed, it allows for a direct comparison of landmarks, lines, and planes, minimizing the impact of projection errors and facilitating accurate plane-line matching (40).

The results of this study supported the claims that 3D CBCT analysis exhibited a reliable linear measurements which could be used to assess facial proportions, jaw's size, skeletal discrepancies and growth and development studies (44, 45) and could help improving orthodontic treatment plan i.e. extraction vs non-extraction (7, 46).

It is important to note that while 3D CBCT offers advantages in terms of accuracy and visualization, conventional lateral cephalometric X-rays still hold value and are widely used. The choice of imaging modality should be based on the specific diagnostic needs and considerations of each case, considering the challenges and solutions discussed above.

Conclusion

This study showed an excellent agreement between the conventional cephalometric and three-dimensional analyses of linear and angular measurements. However, in conventional cephalometric images, projection errors may affect cephalometric analysis. Hence, the three-dimensional cephalometric image can offer accurate visualization and reliable analysis of dento-craniofacial structures.

Conflict of interest

The authors have no conflicts of interest to declare.

Author contributions

HMH and DA; study conception and design. HMH; data collection. HMH and DA; Methodology. HMH and DA; statistical analysis and interpretation of results. HMH and DA; Writing - review & editing. Supervision; DA. All authors reviewed the results and approved the final version of the manuscript to be published.

Acknowledgement and funding

There was no external support for this study.

Informed consent

Informed consent was obtained from all individuals or their guardians included in this study.

References

1. Singh D. Cone-beam Computed Tomography: A New Era in Clinical Orthodontics. Inter J Health Sci 2021:411-27. https://doi.org/10.53730/ijhs.v5nS1.5677

2. Dai F, Chen S, Feng T, Lu W, Chen G, Jiang J, et al. Accuracy of integration of dental cast and cephalograms compared with cone-beam computed tomography: a comparative study. Odontol. 2023;111(1):238-47. https://doi.org/10.1007/s10266-022-00732-6

3. Durão AR, Bolstad N, Pittayapat P, Lambrichts I, Ferreira AP, Jacobs R. Accuracy and reliability of 2D cephalometric analysis in orthodontics. Revista Portuguesa de Estomatologia, Medicina Dentária e Cirurgia Maxilofacial. 2014;55(3):135-41. https://doi.org/10.1016/j.rpemd.2014.05.003

4. Li C, Teixeira H, Tanna N, Zheng Z, Chen SHY, Zou M, et al. The reliability of two-and three-dimensional cephalometric measurements: A CBCT study. Diagnostics. 2021;11(12):2292. https://doi.org/10.3390/diagnostics11122292

5. Al-Ubaydi AS, Al-Groosh D. The validity and reliability of automatic tooth segmentation generated using artificial intelligence. Sci World J. 2023;2023(1):5933003. https://doi.org/10.1016/j.rpemd.2014.05.003

6. Ali SMAE, Elkhateeb SM. Validity of CBCT for Soft Tissue Examination in the Maxillofacial Area: A Review of the Current Literature. ASDJ. 2024;35(3):134-148. https://doi.org/10.21608/asdj.2024.283922.1252

7. Al-Ubaydi AS, Al-Groosh D. Do the Various Indirect Bonding Techniques Provide the Same Accuracy for Orthodontic Bracket Placement? (Randomized Clinical Trial). International J Dent. 2024;2024:5455197. https://doi.org/10.1155/2024/5455197

8. Lo L-J, Lin H-H. Applications of three-dimensional imaging techniques in craniomaxillofacial surgery: A literature review. biomed J. 2023:100615. https://doi.org/10.1016/j.bj.2023.100615

9. Gupta A. On imaging modalities for cephalometric analysis: a review. Multimedia Tools and Applications. 2023;82(24):36837-58. https://doi.org/10.1007/s11042-023-14971-4

10. Abdaljawwad AA, Al-Groosh DH. Effects of various analgesics on pain perception and rate of tooth movement: a randomized controlled clinical study. J Bagh Coll Dent. 2022;34(2):37-51. https://doi.org/10.26477/jbcd.v34i2.3144

11. Rozylo-Kalinowska I, Cephalometric Radiograph in Dentistry/Oral Health. In: Imaging Techniques in Dental Radiology. Springer, Cham. 2020:57-64. https://doi.org/10.1007/978-3-030-41372-9_5

12. Wan Y, Chen Q, Lei X, Wang Y, Chen Y, Hu H, et al. A Calibration Method of CBCT Geometric Parameters Based on the Visual Imaging Model. Advances in Natural Computation, Fuzzy Systems and Knowledge Discovery: 2020; (2). Springer. https://doi.org/10.1007/978-3-030-32591-6_81

13. Hassan NA, Al-Jaboori ASK, Al-Radha ASD, Ali MQ, Albayati RM. CBCT Analysis of Edentulous Mandibular Symphysis in Iraqi Patients for Treatment with Implant-Supported Overdentures. Cross-Sectional Single-Center Study. Clinic Cos Investigat Dent. 2023:79-87. https://doi.org/10.2147/CCIDE.S410620

14. Yoon SJ, Wang RF, Na HJ, Palomo JM. Normal range of facial asymmetry in spherical coordinates: a CBCT study. Imaging Sci Dent. 2013;43(1):31-36. https://doi.org/10.5624/isd.2013.43.1.31

15. Al-Mulla AH, Premjani P, Vaid NR, Fadia DF, Ferguson DJ. Evaluating the accuracy of facial models obtained from volume wrapping: 2D images on CBCT versus 3D on CBCT. Semin Orthod. 2018;24(4):443-450. https://doi.org/10.1053/j.sodo.2018.10.008

16. Bhuskute KP, Jadhav V, Sharma M, Reche A. Three-dimensional Computer-aided Design System used in Orthodontics and Orthognathic Surgery for Diagnosis and Treatment Planning-A Narrative Review. J Clinic Diagnos Res. 2023;17(11). https://doi.org/10.7860/JCDR/2023/64570.18710

17. Diaz-Pinto A, Alle S, Nath V, Tang Y, Ihsani A, Asad M, et al. Monai label: A framework for ai-assisted interactive labeling of 3d medical images. Med Image Analys. 2024;95:103207. https://doi.org/10.1016/j.media.2024.103207

18. Klein S, Staring M, Murphy K, Viergever MA, Pluim JP. Elastix: a toolbox for intensity-based medical image registration. IEEE trans med imaging. 2009;29(1):196-205. https://doi.org/10.1109/TMI.2009.2035616

19. Van Griethuysen JJ, Fedorov A, Parmar C, Hosny A, Aucoin N, Narayan V, et al. Computational radiomics system to decode the radiographic phenotype. Cancer res. 2017;77(21):e104-e7. https://doi.org/10.1158/0008-5472.CAN-17-0339

20. Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin J-C, Pujol S, et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magnetic resonance imaging. 2012;30(9):1323-41. https://doi.org/10.1016/j.mri.2012.05.001

21. Ahn J, Nguyen TP, Kim Y-J, Kim T, Yoon J. Automated analysis of three-dimensional CBCT images taken in natural head position that combines facial profile processing and multiple deep-learning models. Comp Meth Prog Biomed. 2022;226:107123. https://doi.org/10.1016/j.cmpb.2022.107123

22. Proffit WR, Fields H, Larson B, Sarver DM. Contemporary Orthodontics-E-Book: Elsevier Health Sciences; 2018.

23. IBM Corp N. IBM SPSS statistics for windows. IBM corp Armonk, NY; 2017. https://doi.org/10.7759/cureus.12639

24. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. International journal of nursing studies. 2010;47(8):931-6. https://doi.org/10.1016/j.ijnurstu.2009.10.001

25. McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. Psycholo meth. 1996;1(1):30. https://doi.org/10.1037/1082-989X.1.1.30

26. Farronato G, Perillo L, Bellincioni F, Briguglio F, Farronato D, Dominici A. Direct 3D cephalometric analysis performed on CBCT. J Inform Tech Soft Engg. 2012;2(107):2. https://doi.org/10.4172/2165-7866.1000107

27. Kotuła J, Kuc AE, Lis J, Kawala B, Sarul M. New sagittal and vertical cephalometric analysis methods: A systematic review. Diagnostics. 2022;12(7):1723. https://doi.org/10.3390/diagnostics12071723

28. Khamees AM, Al-Groosh DH, Al-Rawi NH. Effects of vitamin D deficiency on bone and root resorption post-orthodontic retention in rats. J Bagh Coll Dent. 2023;35(2):54-64. https://doi.org/10.26477/jbcd.v35i2.3403

29. Baldini B, Cavagnetto D, Baselli G, Sforza C, Tartaglia GM. Cephalometric measurements performed on CBCT and reconstructed lateral cephalograms: a cross-sectional study providing a quantitative approach of differences and bias. BMC Oral Health. 2022;22(1):98. https://doi.org/10.1186/s12903-022-02131-3

30. Durão AR, Alqerban A, Ferreira AP, Jacobs R. Influence of lateral cephalometric radiography in orthodontic diagnosis and treatment planning. The Angle Orthodontist. 2015;85(2):206-10. https://doi.org/10.2319/011214-41.1

31. Leonardi R, Giordano D, Maiorana F, Spampinato C. Automatic cephalometric analysis: a systematic review. The Angle Orthodontist. 2008;78(1):145-51. https://doi.org/ 10.2319/120506-491.1

30. Kazimierczak W, Gawin G, Janiszewska-Olszowska J, Dyszkiewicz-Konwińska M, Nowicki P, Kazimierczak N, et al. Comparison of Three Commercially Available, AI-Driven Cephalometric Analysis Tools in Orthodontics. J Clin Med. 2024;13(13):3733. https://doi.org/10.3390/jcm13133733

33. Sahlsten J, Järnstedt J, Jaskari J, Naukkarinen H, Mahasantipiya P, Charuakkra A, et al. Deep learning for 3D cephalometric landmarking with heterogeneous multi-center CBCT dataset. PloS one. 2024;19(6):e0305947. https://doi.org/10.1371/journal.pone.0305947

34. Alessandri-Bonetti A, Sangalli L, Salerno M, Gallenzi P. Reliability of artificial Intelligence-Assisted cephalometric analysis. A Pilot Study. Biomedinformatics. 2023;3(1):44-53. https://doi.org/10.1371/journal.pone.0305947

35. Darzi F, Bocklitz T. A Review of Medical Image Registration for Different Modalities. Bioengineering. 2024;11(8):786. https://doi.org/10.3390/bioengineering11080786

36. Unberath M, Gao C, Hu Y, Judish M, Taylor RH, Armand M, et al. The impact of machine learning on 2d/3d registration for image-guided interventions: A systematic review and perspective. Frontiers in Robotics and AI. 2021;8:716007. https://doi.org/10.3389/frobt.2021.716007

37. Pinto-Coelho L. How artificial intelligence is shaping medical imaging technology: A survey of innovations and applications. Bioengineering. 2023;10(12):1435. https://doi.org/10.3390/bioengineering10121435

38. Stamatakis HC, Steegman R, Dusseldorp J, Ren Y. Head positioning in a cone beam computed tomography unit and the effect on accuracy of the three-dimensional surface mode. European J oral Sci. 2019;127(1):72-80. https://doi.org/10.1111/eos.12582

39. Olszewski R, Tanesy O, Cosnard G, Zech F, Reychler H. Reproducibility of osseous landmarks used for computed tomography based three-dimensional cephalometric analyses. J Cranio-Maxillo Surg. 2010;38(3):214-21. https://doi.org/10.1016/j.jcms.2009.05.005

40. Muenzing SE, van Ginneken B, Murphy K, Pluim JP. Supervised quality assessment of medical image registration: Application to intra-patient CT lung registration. Medical image analysis. 2012;16(8):1521-31. https://doi.org/10.1016/j.media.2012.06.010

41. Malkoc S, Sari Z, Usumez S, Koyuturk AE. The effect of head rotation on cephalometric radiographs. The European J Ortho. 2005;27(3):315-21. https://doi.org/10.1093/ejo/cjh098

42. Mahmood RR, Jassim IS, Yassir YA. Influential Effect of Digital Smile Design on Orthodontic Treatment Decision. Sci J Med Res. 2022;6(22):1-5. https://doi.org/10.37623/sjomr.v06i22.01

43. Raz E, Nossek E, Sahlein DH, Sharashidze V, Narayan V, Ali A, et al. Principles, techniques and applications of high resolution cone beam CT angiography in the neuroangio suite. J Neurointerven Sur. 2023;15(6):600-7. https://doi.org/10.1136/jnis-2022-018722

44. Dagan M, Kolben Y, Goldstein N, Ben Ishay A, Fons M, Merin R, et al. Advanced hemodynamic monitoring allows recognition of early response patterns to diuresis in congestive heart failure patients. J Clin Med. 2022;12(1):45. https://doi.org/10.3390/jcm12010045

45. Millett DT, Benson PE, Cunningham SJ, McIntyre GT, Fleming PS, Naini FB, et al. Systematic reviews in orthodontics: a fresh look to promote renewal and reduce redundancy. American J Ortho Dentofaci Orthoped. 2022;162(1):1-2. https://doi.org/10.1016/j.ajodo.2022.03.012

46. Xiang B, Lu J, Yu J. Evaluating Tooth Segmentation Accuracy and Time Efficiency in CBCT Images using Artificial Intelligence: A Systematic Review and Meta-analysis. J Dent. 2024:105064. https://doi.org/10.1016/j.jdent.2024.105064

مقارنه التطابق للسطوح و الخطوط بين التحليل السيفالومتري ثلاثي الأبعاد وتحليل السيفالومتري الجانبي ثنائي الأبعاد التقليدي باستخدام برامج مساعدة تعتمد على الذكاء الاصطناعي:

حسام ماجد حميد, ضياء حسين عبد , جين ماك

المستخلص:

أحدث اختراع تقنية التصوير ثلاثي الأبعاد ثورة في تشخيص و تحديد خطط العلاج لحالات تقويم الأسنان من خلال تمكين تحليل العلاقات التشريحيه المعقدة باستخدام صور ثلاثيه الابعاد. تهدف هذة الدراسه الى تقييم دقه التطابق بين التحليل التقليدي المستند الى الأشعه الجانبيه للرأس ثنائيه البعد التقليديه والتحليل ثلاثي الأبعاد للقياسات الرأسية باستخدام التصوير المقطعي المحوسب بالأشعة المخروطية. المواد و الطرق : شملت الدراسه الحصول على الأشعه الجانبيه للرأس ثنائيه البعد التقليديه و تصوير المقطعي المحوسب بالأشعة المخروطية ل 45 مشارك تترواح اعمارهم بين 18و 26 عاماً لمراجعين يعانون ممن سوء اطباق ذو نوع الدرجه الاولى لسوء الأطباق. تم تحليل جميع الصور الحاصل عليها للدراسه باستخدام برنامج ثري دي سلايزر الإصدار 5.6.2 المجهز بلمحقات متخصصه لتحسين معالجه الصور و تسجيلها, تضمن تسجيل الصور التطابق الدقيق للمستويات والخطوط التشريحية تم تحديد النقاط التشريحية المرجعية ومحاذاتها بين طريقتي التصوير متبوعًا بقياسات كمية للتحليل المقارن. النتائج: أشارت النتائج إلى درجة مقبولة من التطابق بين تحليل الأشعة السينية ثنائية الأبعاد وتحليل ثلاثي الابعاد حيث اظهرت القياسات الخطية أظهرت اتساقًا عاليًا ، إلا أن بعض القياسات الزاوية أظهرت اختلافات ذات دلالة إحصائية بين طريقتي التصوير. كما اظهر التحليل الاحصائي لمعامل الأرتباط داخل الصف اتساقا قويا عبر معظم القياسات. الخلاصه: خلصت الدراسه الى أن التحليل ثلاثي الأبعاد للأشعه المخروطيه يوفر نهجا واعدا لتقييم شمل و دقيق لهيكل الجمجمه و الوجه, مما يوفر مزايا كبيرة مقارنة بالطرق التقليدية التي تعتمد على صور شعاعيه ثنائية الأبعاد.