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Evaluation of two-dimensional lateral cephalogram and three-dimensional cone beam computed tomography superimpositions: a comparative study

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Abstract. Superimposition of radiographic imaging is used to evaluate patient growth and the effects of surgical and/or orthodontic treatment. The purpose of this study was to compare the outcomes of superimposition between two-dimensional (2D) and three-dimensional (3D) superimpositions. 2D lateral cephalograms were generated from the initial and final cone beam computed tomography scans (CBCT) of 18 patients and superimposed. Both 3D CBCT and 2D CBCT generated lateral cephalograms were oriented to the Frankfort horizontal plane and superimposed according to the American Board of Orthodontics recommendations. Changes in landmark position were quantified from the resulting superimposition outcomes via linear measurements made with Dolphin software. Differences between the two methods were analyzed using paired *t*-tests. Measurements were repeated twice for 10 randomly selected scans to assess reliability by intra-class correlation coefficient (ICC) analysis. Intra-examiner reliability was high for all measurements ($ICC > 0.84$). Agreement between 2D and 3D superimposition outcomes, as measured by *P*-values, was low for ANS ($P = 0.026$), B-point ($P < 0.001$), ST Upper lip ($P = 0.019$), U1 tip ($P = 0.010$), and U1 apex ($P = 0.026$). 2D measurements were significantly higher than 3D measurements for ANS, B-point, ST Upper lip, U1 tip, and U1 apex. Findings indicated that both methods of superimposition (2D and 3D) are highly reliable. Statistical differences between 2D and 3D superimposition outcomes were below the threshold of clinical significance.

Key words: cone beam computed tomography; superimposition; reliability; clinical significance.

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Dental clinicians have traditionally used imaging techniques to analyze the facial profile, skeleton, and dentition in planning for orthodontic treatment. For a thorough patient diagnosis and treatment plan, three factors must be considered: the facial soft tissue, facial skeleton, and dentition. Since the 1930s, the 'gold standard' for evaluating and relating the facial skeleton to the dentition has been the lateral cephalogram[1]. One of the challenging aspects of orthodontic and orthognathic treatment is quantifying the interactions of skeletal growth and dental movement that support, inhibit, or are a result of treatment. The superimposition of lateral cephalograms is used to assess these changes due to growth and/or treatment[2].

Over the approximately 80 years during which lateral cephalograms have been used, multiple methods have been advocated to register images for superimposition. In the most recent recommendations of the American Board of Orthodontics (ABO), the following is stated: ''These superimpositions must be performed using the structural method[3], which is based on the use of stable structures described in Melsen's research of cranial base growth[4], Bjork and Skieller's implant research[3,5], as well as Enlow's investigation of remodeling[6]. The structural method has been shown to be reliable and valid[7–9]''. The structural method was used for the superimpositions in the study reported herein.

Conventional lateral cephalograms utilize two-dimensional (2D) technology, which limits the extent of information that can be retrieved from the scan. Previous research has cited limitations of 2D lateral cephalograms, including errors in projection and superimposition, lack of perspective, variations in magnification, imaging artifacts, information voids, and head positioning errors[10]. The potential for any of these errors to lead to suboptimal care has led many practitioners to adopt the use of three-dimensional (3D) imaging for diagnostic scans as well as treatment superimpositions. Since the 1980s, the use of 3D imaging has increased steadily[1]. Through the use of cone beam computed tomography (CBCT), 3D representations of the facial skeleton are possible[11]. With 3D CBCT scans, cross-sectional cuts permit visualization of the internal and external architecture of the dentofacial skeleton[12]. The superimposition of these scans in order to assess growth, as well as orthognathic and orthodontic treatment, has been validated in both growing and non-growing subjects[2,12].

Another advantage of 3D CBCT is the ability to extract conventional 2D images from the CBCT data, including panoramic, lateral cephalogram, and postero-anterior images. Chang et al. determined that overall landmark identification errors on CBCT-derived lateral cephalograms were comparable to those on conventional digital lateral cephalograms, and identification of basion was more reliable on CBCT-derived lateral cephalograms[13].

3D CBCT superimpositions can be made via three different methods: surface-based, point-landmark-based, and voxel-based registration. Voxel-based registration, the most efficient of the three methods, is not limited by segmentation errors like surface-based superimposition, and does not depend on landmark identification like the point-landmark-based superimposition[14,15]. With the accuracy and reliability associated with voxel-based 3D superimpositions, clinicians have a useful method for evaluating orthodontic treatment changes, as well as growth in patients who require CBCT imaging. The objective of this study was to compare the superimposition outcomes between 2D CBCT generated lateral cephalograms and 3D CBCT voxel-based superimpositions.

Materials and methods

Population and selection criteria

The study was approved by the Institutional Review Board at Indiana University–Purdue University at Indianapolis. The pre- and post-treatment CBCT images of 20 subjects (11 female, nine male; age range 8–15 years) were collected from the same graduate orthodontic clinic and de-identified prior to commencement of the study. The selected subjects were treated with a Herbst appliance. Patients were excluded from the study based on the following criteria: documented or suspected craniofacial abnormalities, history of trauma, systemic diseases, temporomandibular joint disorders, metallic restorations, and low quality CBCT scans with artifacts. Two subjects were excluded from the study due to low quality CBCT scans.

Data collection and measurements

All patients were scanned with the same iCAT 3D imaging system (Imaging Sciences International, Hatfield, PA, USA) with the following scan settings: 120 kV, 20 mA, 17 cm × 23 cm field of view, 0.3 mm voxel size, and a scanning time of 8.9 seconds per section. Dolphin software version 11.8 Premium (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) was used to generate the 2D lateral cephalograms and perform the 2D and 3D superimpositions. The same software was also used to obtain measurements from the 2D and 3D superimpositions in order to assess the superimposition outcomes.

Image orientation

The 3D orientation of all study images was standardized through manual identification and registration of three reference planes of the skull digitally (Fig. 1). The skeletal midline, identified by the plane connecting nasion, anterior nasal spine, and posterior nasal spine (Na–ANS–PNS), was used to define the mid-sagittal plane. The Frankfort horizontal plane (porion–orbitale) was used to define the axial reference plane. A plane connecting the most inferior point of the zygomatic ridge (key ridge) was used to define the coronal reference plane.

Superimpositions

Two-dimensional lateral cephalograms were constructed in Dolphin from the 3D CBCT scans. The corresponding T1 and T2 images were registered by overlaying the anterior portion of sella turcica and the planum sphenoidale for cranial base (overall) superimposition, the anterior surface of the zygomatic process for the maxillary superimposition, and the anterior contour of the chin and internal contour of symphysis of the mandible for the mandibular superimposition (Fig. 2).

For 3D voxel-based cranial base (overall) superimposition, the anterior cranial base area including the anterior wall of sella turcica in the two images was selected in the sub-region box in Dolphin. The program matched the voxels in the defined area and automatically superimposed the two images (Fig. 3). For the 3D voxel-based maxillary superimposition, the zygoma (key ridge) was selected, bilaterally and simultaneously, in the sub-region box in Dolphin (Fig. 4). Finally, for the 3D voxel-based mandibular superimposition, the mandibular symphysis and anterior contour of the chin were selected in the sub-region box in Dolphin (Fig. 5).

Methods of evaluation and assessments

A total of 12 landmarks/measurements on the anterior cranial base, maxilla, and

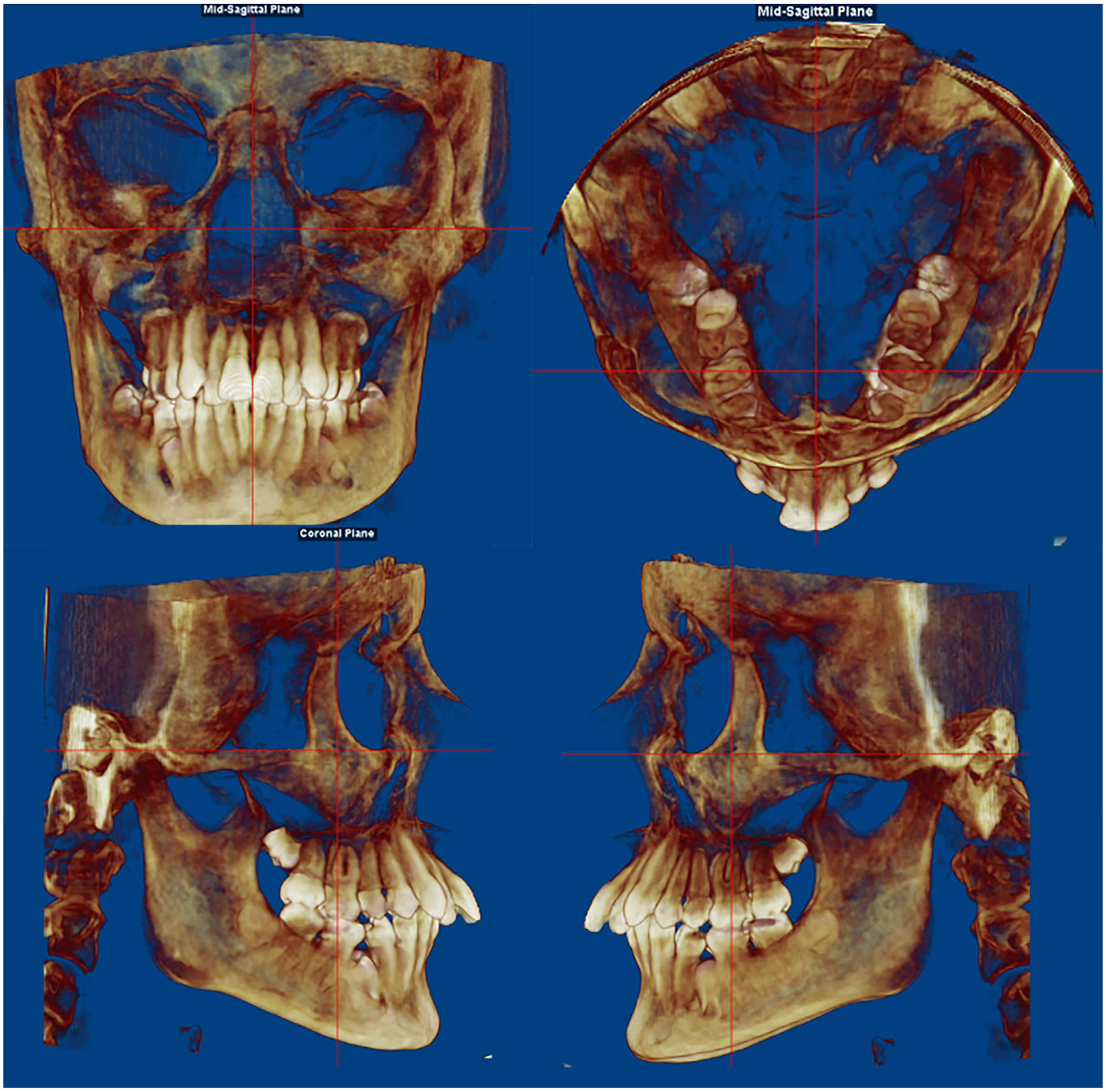

Fig. 1. Orientation in three planes of all CBCT scans.

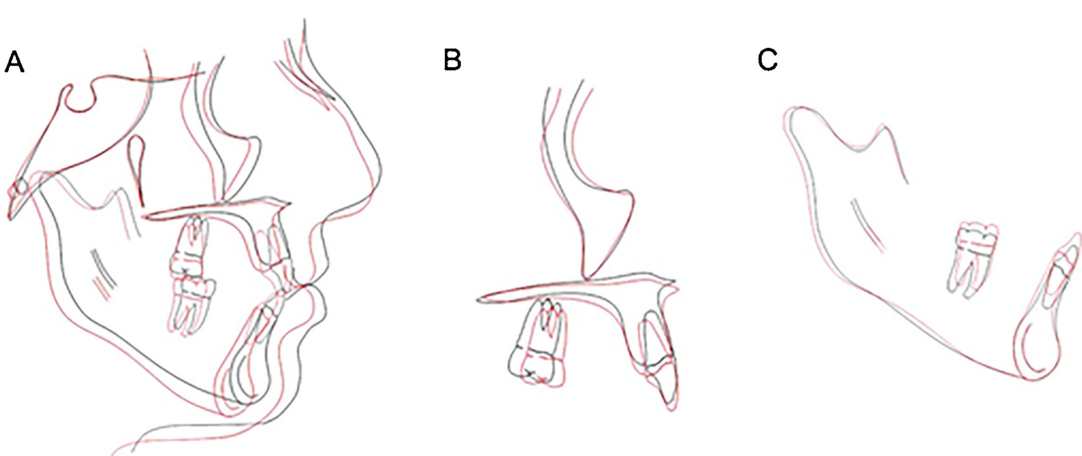

Fig. 2. T1–T2 anterior cranial base 2D superimposition (A), maxillary superimposition (B), and mandibular superimposition (C) using Dolphin imaging software.

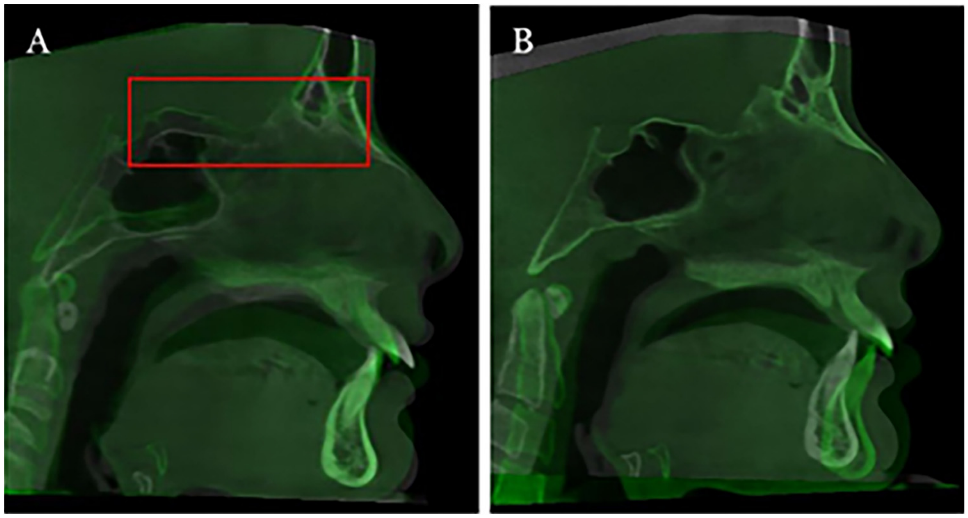

Fig. 3. Before (A) and after (B) anterior cranial base (red box) voxel-based superimposition using Dolphin imaging software. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

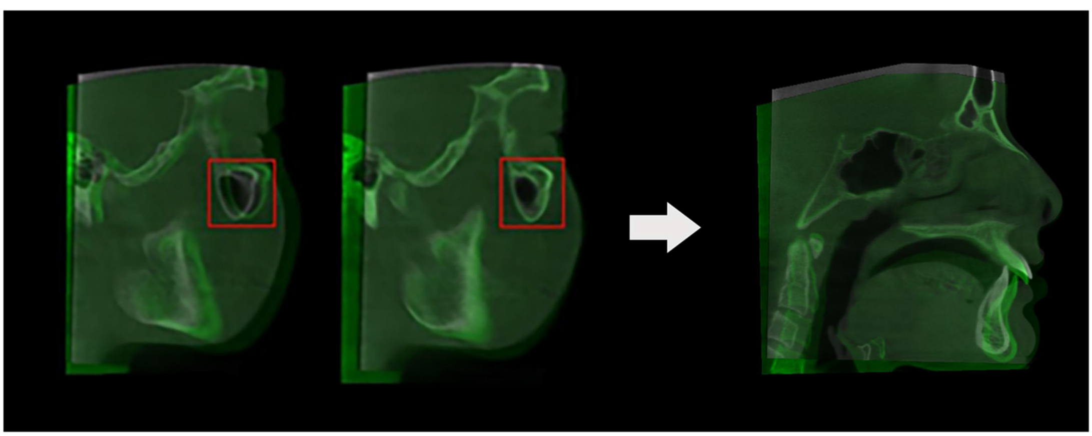

Fig. 4. Maxillary voxel-based superimposition using Dolphin imaging software.

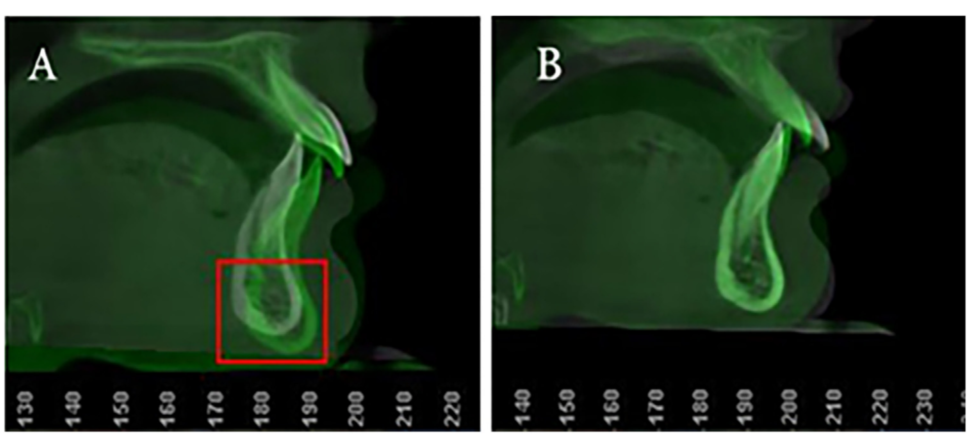

Fig. 5. Before (A) and after (B) mandibular voxel-based superimposition using Dolphin imaging software.

mandible (Table 1) were selected and measured on the superimposed images with the Dolphin measurement tool. These straight-line measurements for 2D and 3D superimpositions were then compared. In order to evaluate the maxillary and mandibular incisor tips and apices, the sagittal plane of reference was adjusted to view the patients' right maxillary and mandibular incisors before performing the linear measurements.

Table 1. Definitions of landmarks.

Structure	Landmarks	Definition
Maxilla	ANS	Anterior tip of the sharp bony process of the maxilla at the lower margin of the anterior nasal opening
	PNS	Posterior spine of the palatine bone constituting the hard palate
	A-point	Most posterior point of the curve of the maxilla, between ANS and the dental alveolus
Mandible	Gn	Midpoint between the most anterior and inferior point on the bony chin
	Pg	Most anterior point on the midsagittal symphysis of the mandible
	B-point	Most posterior point in the concavity along the anterior border of the mandibular symphysis
Dentition	U1 tip	Incisal tip of the upper central incisor
	U1 apex	Tip of the root of the upper central incisor
	L1 tip	Incisal tip of the lower central incisor
	L1 apex	Tip of the root of the lower central incisor
Soft tissue	ST Pg	Most anterior point on the curve of soft tissue chin
	ST Lower lip	Most anterior point on the curve of the lower lip
	ST Upper lip	Most anterior point on the curve of the upper lip

ANS, anterior nasal spine; Gn, gnathion; Pg, pogonion; PNS, posterior nasal spine.

Statistical methods

The repeatability and reliability of the linear measurements was evaluated: the same investigator repeated the measurements on the superimpositions of 10 randomly selected CBCT images with a period of 2 weeks between measurements. Intra-class correlation coefficients (ICCs) and Bland–Altman plots were used to appraise repeatability; measurements were repeated if the ICC was below 0.8.

Bland–Altman plots, ICCs, and measurement error were used to evaluate the agreement between the 2D and 3D superimpositions, and paired *t*-tests were used to compare the 2D and 3D superimpositions. A 5% significance level was used for all tests. With a sample size of 18 subjects, the study had 80% power to detect an effect size of 0.66 between the 2D and 3D superimpositions, assuming two-sided paired *t*-tests each conducted at a 5% significance level.

Results

Intra-examiner reliability of repeated measurements, the mean differences, standard deviations, *P*-values, and ICC values for each of the 12 measurements of 2D and 3D CBCT derived lateral cephalograms are shown in Table 2. The ICC values for the reliability assessment were found to be greater than 0.8 for all measurements, prior to data collection.

Agreement between 2D and 3D linear measurements, as measured by ICCs, was high for B-point (ICC = 0.88), Gn (ICC = 0.94), Pg (ICC = 0.87), ST Pg (ICC = 0.87), and ST Lower lip (ICC = 0.92). However, there was a statistically significant difference found for

Table 2. Reliability testing.

Type	Measurement	First measurement, mean (SE)	Second measurement, mean (SE)	Difference			*P*-value[a]	Within-image SD	ICC
				Mean (SE)	Min	Max			
2D	ANS	1.54 (0.21)	1.48 (0.21)	0.06 (0.02)	0	0.2	0.02	0.06	0.99
	A-point	1.44 (0.31)	1.63 (0.31)	−0.19 (0.15)	−1.5	0	0.23	0.34	0.88
	B-point	5.28 (0.57)	5.28 (0.57)	0.00 (0.03)	−0.1	0.1	1.00	0.07	1.00
	Gn	4.45 (0.61)	4.44 (0.61)	0.01 (0.02)	−0.1	0.1	0.68	0.05	1.00
	Pg	4.54 (0.66)	4.56 (0.66)	−0.02 (0.03)	−0.1	0.1	0.56	0.07	1.00
	ST Pg	4.38 (0.59)	4.41 (0.59)	−0.03 (0.03)	−0.2	0.1	0.34	0.07	1.00
	ST Upper lip	2.59 (0.65)	2.59 (0.65)	0.00 (0.03)	−0.1	0.1	1.00	0.05	1.00
	ST Lower lip	5.82 (0.94)	5.80 (0.94)	0.02 (0.03)	−0.1	0.1	0.51	0.06	1.00
	U1 tip	2.90 (0.44)	2.92 (0.44)	−0.02 (0.02)	−0.1	0.1	0.44	0.05	1.00
	U1 apex	1.61 (0.29)	1.56 (0.29)	0.05 (0.03)	−0.1	0.2	0.18	0.08	0.99
	L1 tip	3.49 (0.71)	3.37 (0.71)	0.12 (0.15)	−0.1	1.4	0.43	0.32	0.98
	L1 apex	1.16 (0.24)	1.11 (0.24)	0.05 (0.11)	−0.2	1	0.66	0.24	0.91
3D	ANS	0.75 (0.12)	0.66 (0.12)	0.09 (0.06)	−0.2	0.3	0.17	0.14	0.86
	A-point	0.85 (0.14)	0.81 (0.14)	0.04 (0.07)	−0.3	0.4	0.58	0.15	0.87
	B-point	4.32 (0.49)	4.28 (0.49)	0.04 (0.11)	−0.7	0.6	0.72	0.23	0.98
	Gn	4.18 (0.58)	4.21 (0.58)	−0.03 (0.11)	−0.4	0.6	0.79	0.23	0.98
	Pg	4.47 (0.58)	4.28 (0.58)	0.19 (0.10)	−0.30	0.70	0.09	0.25	0.98
	ST Pg	4.49 (0.59)	4.36 (0.59)	0.13 (0.15)	−0.70	1.00	0.41	0.33	0.97
	ST Upper lip	2.06 (0.33)	1.89 (0.33)	0.17 (0.09)	−0.40	0.60	0.10	0.23	0.95
	ST Lower lip	5.75 (0.78)	5.81 (0.78)	−0.06 (0.08)	−0.50	0.30	0.46	0.17	1.00
	U1 tip	1.64 (0.30)	1.85 (0.30)	−0.21 (0.17)	−0.7	0.8	0.25	0.39	0.84
	U1 apex	1.23 (0.25)	1.15 (0.25)	0.08 (0.14)	−0.7	0.9	0.59	0.31	0.85
	L1 tip	3.21 (0.53)	3.33 (0.53)	−0.12 (0.09)	−0.9	0	0.21	0.21	0.98
	L1 apex	1.04 (0.11)	1.07 (0.11)	−0.03 (0.02)	−0.1	0	0.08	0.04	0.99

ICC, intra-class correlation coefficient; SD, standard deviation; SE, standard error.

[a] *P*-value for the difference between the first and second measurements.

Table 3. 2D vs. 3D linear superimposition measurements.

Measurement	Number	2D Mean (SD)	3D Mean (SD)	Difference (2D–3D)					P-value[a]	Measurement error
				Mean	SD	SE	Min	Max		
ANS	18	1.44 (0.66)	1.01 (0.73)	0.43	0.75	0.18	−1.6	1.6	0.026*	0.53
A-point	18	1.37 (1.07)	1.09 (0.60)	0.28	1.01	0.24	−1.3	2.1	0.261	0.72
B-point	18	5.12 (2.16)	4.29 (2.00)	0.83	0.70	0.17	−0.7	2.2	<0.001*	0.50
Gn	18	4.63 (2.23)	4.46 (1.99)	0.18	0.76	0.18	−1.9	1.4	0.337	0.54
Pg	18	4.67 (2.31)	4.67 (2.03)	−0.01	1.15	0.27	−3.1	1.3	0.984	0.79
ST Pg	18	4.76 (2.02)	4.62 (1.95)	0.14	1.05	0.25	−1.9	1.6	0.580	0.73
ST Upper lip	18	2.95 (1.87)	2.20 (1.28)	0.75	1.22	0.29	−1.1	2.8	0.019*	0.86
ST Lower lip	18	6.14 (2.54)	5.79 (2.08)	0.34	0.91	0.21	−1.2	1.7	0.128	0.64
U1 tip	18	2.79 (1.18)	1.88 (1.12)	0.92	1.35	0.32	−2.5	4.2	0.010*	0.95
U1 apex	18	1.78 (0.93)	1.37 (0.74)	0.41	0.72	0.17	−1.2	1.3	0.026*	0.51
L1 tip	18	3.46 (1.83)	3.52 (1.31)	−0.06	1.10	0.26	−2.2	2.4	0.817	0.76
L1 apex	18	1.22 (0.81)	1.18 (0.60)	0.04	0.73	0.17	−1.2	1.3	0.799	0.50

[a] P-value for the difference between 2D and 3D measurements.
* significant, $P < 0.05$.

B-point, as measured by a P-value of <0.001.

Agreement between 2D and 3D linear measurements, as measured by P-values, was low for ANS ($P = 0.026$), B-point ($P < 0.001$), ST Upper lip ($P = 0.019$), U1 tip ($P = 0.010$), and U1 apex ($P = 0.026$). In general, 2D measurements were significantly higher than 3D measurements and they were statistically significant for ANS, B-point, ST Upper lip, U1 tip, and U1 apex, as show in Table 3.

Discussion

This study compared the reproducibility of linear measurements on superimpositions produced from 2D and 3D lateral cephalograms. Harrell et al. previously reported that due to the confines of traditional 2D lateral cephalograms, superimpositions based upon 2D data may not be accurate[10]. Although 3D CBCT cephalometry is considered highly accurate and reliable[16,17], no recent studies have examined whether superimposition outcomes from 2D and 3D lateral cephalograms are analogous.

In order to limit potential variables that could have skewed the data, the 2D and 3D superimpositions were performed for the same sample of patients, using the same software and same workstation, under consistent environmental conditions. Additionally, the 2D cephalograms were derived from the 3D CBCT scans rather than using a separate machine for the scan. Furthermore, to exclude potential orientation errors, all CBCT images were oriented to axial, coronal, and sagittal planes before conducting the tracings. Thus, if certain measurements on both 2D and 3D superimposition outcomes agree and others do not, then the differences noted for those points could be due to landmark identification error, which has been reported previously in the literature[18]. Certain dry skull linear measurements have been shown to be more reliable with 3D CBCT scans versus conventional 2D digital radiography[19], which leads to the possibility of other linear measurements, based upon superimposition outcomes, being different as well.

The current data showed high agreement between 2D and 3D points on lateral cephalogram superimpositions for A-point, Gn, Pg, ST Pg, ST Lower lip, L1 tip, and L1 apex, which may indicate that the superimpositions of 2D and 3D lateral cephalograms are similar. However, statistically significant differences were observed between several 2D and 3D landmarks including ANS, B-point, ST Upper lip, U1 tip, and U1 apex. Baumrind and Frantz described the identification of landmarks as estimating the position of a point on an edge, and the precision of that selection as a function of how sharp the edge folds on the region of the point being estimated[20]. Accordingly, landmarks such as ANS, U1 tip, and L1 tip should be more reliably located than points such as A-point, B-point, and Pg, which are located along a gradual curve rather than a sharp edge. Assuming the superimpositions are similar, the current data do not follow the same trend for all points except for L1 tip. However, there is agreement with the work by McClure et al., which showed statistically significant differences in landmark identification for ANS[21].

Another potential source of disagreement in U1 tip and U1 apex measurements could be a result of the methodology used to locate these points in 3D images. As a consequence of the accuracy of the 3D CBCT superimpositions, the co-investigator was not able to evaluate maxillary and mandibular incisor tips and apices in the midsagittal plane. This would have led to a view that would be between the incisors, which would not show the incisor apex and tip. Rather, the investigator chose a midsagittal slice that was through the right upper and lower central incisors. This eliminated projection error and allowed a more accurate depiction of the respective tips/apices.

Baumrind and Frantz also described difficulty in identifying points located inside the bones of the skull rather than on the surface due to the 'noise' from adjacent and superimposed structures[20]. In the current study, it was possible to utilize slices of the 3D CBCT image to precisely select both maxillary and mandibular incisor tips and apices, which could account for the differences noted in the linear measurements obtained in the superimpositions of the U1 tips and apices. However, L1 tips and apices were shown to be statistically similar, which could mean that the 2D and 3D superimpositions themselves were similar for the mandibular superimpositions but not for the maxillary ones.

In line with previous findings[22], there was a statistically significant trend showing higher 2D linear measurements than 3D measurements for five of the 12 denoted measurements. However, since the 2D cephalograms were derived from 3D scans, this was likely not due to projection error. A general trend like this could be an indication that the superimpositions themselves were yielding slightly different results. Along with landmark identification error, bilateral anatomic landmarks could be leading to differences in 2D and 3D superimpositions, which would produce increased measurement errors. Although no current evidence has shown that 2D and 3D cephalogram superimpositions are dissimilar, the 3D superimposition algorithm could account for measurement differences.

Although there were statistically significant differences noted between the 2D and 3D measurements, no mean difference was greater than 1 mm. Previous studies have suggested the threshold for a clinically significant difference to be around ±2 mm[23,24]. Thus, the differences noted in this study are likely not clinically relevant.

Interestingly, the point Upper lip demonstrated poor agreement in this study, which has not been shown to be unreliable previously in the literature. It is postulated that the lack of agreement seen for Upper lip could have resulted from the method used to produce the 2D images. The midsagittal slice taken through the philtrum on the 3D CBCT could have shown up as a different point than would be shown on a 2D lateral cephalogram. A conventional 2D lateral cephalogram shows the superimposed lateral borders of the philtrum, which are located more superior and anterior to the midline area of the philtrum. This difference could have led to inconsistencies in linear measurements made from T1 to T2 time points.

Of further note, no points showed agreement based upon the individual maxillary superimposition. This could be due to the inherent difficulty in locating incisor tips and apices, as discussed previously, or could possibly be due to differences in maxillary superimposition by the two methods.

In conclusion, no differences were recorded between linear measurements made from 2D and 3D superimpositions for A-point, gnathion, pogonion, soft tissue pogonion, lower lip, and mandibular central incisor tip/apex, while differences were found for ANS, B-point, upper lip, and maxillary central incisor tip/apex, although these are considered below the threshold of clinical significance. Superimposition outcomes from 2D and 3D CBCT cephalometry are considered reliable and reproducible.

Funding

None.

Competing interests

All authors declare no conflict of interest.

Ethical approval

The study was exempted by the Institutional Review Board at Indiana University–Purdue University at Indianapolis (IRB #1703554830).

Patient consent

Not required.

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