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Comparison of the accuracy of 2D and 3D cephalometry: a systematic review and meta-analysis

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Objectives: To compare the measurement of cephalometric parameters using 3D images obtained from CBCT to 2D images obtained from a conventional cephalogram.
Methods: An electronic literature search was conducted using PubMed, Embase, Web of Science, CNKI, CENTRAL, and the grey literature database of SIGLE (up to May 2021). The selection of the eligible studies, data extraction, and an evaluation for possible risk of bias (Quality Assessment of Measurement Accuracy Studies tool) were performed independently by two authors. Inconsistencies were judged by a third author. Statistical pooling, subgroup analysis, a sensitivity analysis and an evaluation of publication bias were performed using Comprehensive Meta-Analysis (version 2.2.064, Biostat, Englewood, NJ).
Results: A total of eight articles were eligible for final meta-analysis. The differences in two of the skeletal measurement parameters [Ar(Co)-Gn, Me-Go] and one of the dental measurement parameters (U1-L1) were found to be statistically significant when using CBCT and conventional cephalograms (P = 0.000, P = 0.004, P = 0.000, respectively).
Conclusions: CBCT can be used as a supplementary option to support conventional cephalometric measurements. In clinical situations in which three-dimensional information is required, patients can benefit from CBCT analysis to improve diagnosis and treatment planning.
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Introduction

Radiographic cephalometry was first proposed by Broadbent and Hofrath in 1931. Soft and hard tissue of craniofacial anatomy was evaluated by measuring X-ray images of the skull, thereby achieving more accurate diagnosis compared with those based on facial anatomy alone.[1] However, traditional X-ray images of the craniofacial complex have inherent deficiencies, including superposition, distortion, and magnification[2] which can compromise diagnostic accuracy. Three-dimensional (3D) imaging can overcome the inherent problems of two-dimensional (2D) imaging and provide more detailed information to ensure accurate diagnosis to enable satisfactory clinical results. Computed tomography (CT) was originally used to obtain 3D images but due to the expense, high radiation dosage and the low resolution of CT, its application has been limited in orthodontic practice.[3]

Cone-beam computed tomography (CBCT) is a 3D imaging technology that has been developed in recent years. CBCT can provide 3D images of the teeth and facial bones and only requires a short scanning time.[4–6] In addition, compared with CT, CBCT has a smaller volume, lower cost and lower radiation exposure and can provide the 3D information needed in clinical practice. While hospitals and private clinics tend to use CBCT because of availability, a conventional cephalogram is still often considered the gold standard for diagnosis. However, it is expected that in the future, CBCT will completely replace conventional cephalograms due to the many advantages.

As 3D and 2D radiographs require different fixed points as well as different methods of measurement, there is doubt regarding whether CBCT can provide comparable accuracy to conventional cephalometric measurements. To date, many articles have compared CBCT 3D cephalometry and conventional cephalograms, but mainly focused on the accuracy and repeatability of the 3D fixed points.[6–8] Unfortunately, the experimental results and conclusions of these studies have been inconsistent. Therefore, in order to draw a comprehensive comparison, a systematic meta-analysis was conducted to evaluate the differences in the cephalometric parameters between 3D images derived from CBCT and 2D images from a conventional cephalogram to determine whether CBCT can replace conventional head films.

Materials and methods

This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines.[9]

Search strategy and study selection

An electronic literature search was conducted using PubMed, Embase, Web of Science CNKI, CENTRAL, and the grey literature database of SIGLE (up to May 2021). The search strategy is displayed in Table I. The related journals and the reference lists of retrieved studies were manually searched to identify relevant publications.

The full texts of all potential studies were obtained to ensure that they were eligible for inclusion. The included studies were independently screened by two reviewers and inconsistencies were judged by a third reviewer. The reasons for exclusion are shown in Figure 1.

Selection criteria

The applied screening criteria were:

1. All samples assessed humans (patients).
2. All patients underwent a conventional cephalogram or a CBCT.
3. The studies compared differences in cephalometric parameters between 2D and 3D images.
4. Raw data could be extracted from the CBCT scans and conventional cephalograms.
5. Clinical trials were considered eligible.

Data extraction

Data were collected by two reviewers and categorised according to country, sample type, sample size, sample information, 2D type, 3D type, CBCT parameters, the number of examiners and measurement times.

Methodologic quality appraisal

The risk of bias was evaluated by two independent researchers using the Quality Assessment of Measurement Accuracy Studies (QUAMAS) tool.[10–13]

The QUAMAS tool which generates a maximum study score of 15 consists of three domains: study design, study measurement, and statistical analysis (shown in Table II). The methodological quality was considered high if the score was over 10, medium if the score ranged between 7.5 and 9.5, and low when the scores were less than 7.5. QUADAS is a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. However, the present review assessed studies that compared the measurement accuracy of CBCT and conventional cephalograms, rather than diagnostic accuracy. Therefore, the QUADAS tool was determined to be unsuitable for the present study and instead, the QUAMAS tool was customised by Li[12] according to previous literature.[10,11,13]

Table I. Search strategies in the study.

Databases	Steps	Strategies
PubMed	#1	"Cephalometry"[Mesh] OR Craniometry OR cephalometric OR Cephalometry
	#2	"X-Ray Film"[Mesh] OR X Ray Film OR Xray Film OR Film, Xray OR Films, Xray OR Radiographic Film OR Xray Films OR Film, Radiographic OR Films, Radiographic OR Radiographic Films OR Film, X-Ray OR Film, X Ray OR Films, X-Ray OR Films, X-Ray OR radiograph OR roentgenogram OR scotograph OR Lateral cephalometric radiograph
	#3	2d OR two-dimensional OR 2 dimension OR two dimension OR 2 dimensional OR bidimensional OR 2 d
	#4	#2 OR #3
	#5	"Cone-Beam Computed Tomography"[Mesh] OR Cone-Beam CAT Scan OR Computed Tomography, Cone-Beam OR Cone Beam Computed Tomography OR CT Scan, Cone-Beam OR CT Scan, Cone Beam OR CT Scans, Cone Beam OR CT Scans, Cone-Beam OR Cone-Beam CT Scan OR Cone-Beam CT Scans OR Scan, Cone-Beam CT OR Scans, Cone-Beam CT OR Tomography, Cone-Beam Computed OR Tomography, Cone Beam Computed OR Tomography, Volume Computed OR Computed Tomography, Volume OR Volume Computed Tomography OR Volumetric CT OR CT, Volumetric OR Volumetric Computed Tomography OR Computed Tomography, Volumetric OR Tomography, Volumetric Computed OR CAT Scan, Cone-Beam OR CAT Scan, Cone Beam OR CAT Scans, Cone-Beam OR CT, Volume OR Cone-Beam CAT Scan OR Cone-Beam CAT Scans OR Scans, Cone-Beam CAT OR Cone-Beam Computer-Assisted Tomography OR Scan, Cone-Beam CAT OR Computer-Assisted Tomography, Cone-Beam OR Cone Beam Computer Assisted Tomography OR Tomography, Cone-Beam Computer-Assisted OR Cone-Beam Computerized Tomography OR Computerized Tomography, Cone-Beam OR Cone Beam Computerized Tomography OR Tomography, Cone-Beam Computerized OR Cone-Beam CT OR CT, Cone-Beam OR Cone Beam CT OR Volume CT OR CBCT OR Cone Beam Computed Tomography
	#6	#1 AND #4 AND #5
Embase	#1	'Cone-Beam Computed Tomography'/exp OR 'Computed Tomography, Cone-Beam' OR 'Cone Beam Computed Tomography' OR 'CT Scan, Cone-Beam' OR 'CT Scan, Cone Beam' OR 'CT Scans, Cone-Beam' OR 'Cone-Beam CT Scan' OR 'Cone-Beam CT Scans' OR 'Scan, Cone-Beam CT' OR 'Scans, Cone-Beam CT' OR 'Tomography, Cone-Beam Computed' OR 'Tomography, Cone Beam Computed' OR 'Tomography, Volume Computed' OR 'Computed Tomography, Volume' OR 'Volume Computed Tomography' OR 'Volumetric CT' OR 'CT, Volumetric' OR 'Volumetric Computed Tomography' OR 'Computed Tomography, Volumetric' OR 'Tomography, Volumetric Computed' OR 'CAT Scan, Cone-Beam' OR 'CAT Scan, Cone Beam' OR 'CAT Scans, Cone-Beam' OR 'Cone-Beam CAT Scan' OR 'Cone-Beam CAT Scans' OR 'Scan, Cone-Beam CAT' OR 'Scans, Cone-Beam CAT' OR 'Cone-Beam Computer-Assisted Tomography' OR 'Computer-Assisted Tomography, Cone-Beam' OR 'Cone Beam Computer Assisted Tomography' OR 'Tomography, Cone-Beam Computer-Assisted' OR 'Cone-Beam Computerized Tomography' OR 'Computerized Tomography, Cone-Beam' OR 'Cone Beam Computerized Tomography' OR 'Tomography, Cone-Beam Computerized' OR 'Cone-Beam CT' OR 'CT, Cone-Beam' OR 'Cone Beam CT' OR 'Volume CT' OR 'CT, Volume" OR 'CBCT'
	#2	'Cephalometry'/exp OR 'Cephalometry' OR 'Craniometry' OR 'cephalometry'
	#3	'X-Ray Film'/exp OR 'X Ray Film' OR 'Xray Film' OR 'Film, Xray' OR 'Films, Xray' OR 'Radiographic Film' OR 'Xray Films'OR 'Film, Radiographic' OR 'Films, Radiographic' OR 'Radiographic Films' OR 'Film, X-Ray' OR 'Film, X Ray' OR 'Films, X-Ray' OR 'Films, X-Ray' OR 'radiograph' OR 'roentgenogram' OR 'scotograph' OR 'Lateral cephalometric radiograph'

	#4	'2-d' OR 'two-dimensional' OR '2 dimension' OR 'two dimension' OR '2-dimensional' OR 'bidimensional' OR '2 d'
	#5	#3 OR #4
	#6	#1 AND #2 AND #5
CNKI	#1	Cephalometry OR Craniometry
	#2	Lateral cephalometric radiograph OR 2 d
	#3	Cone Beam Computed Tomography OR CBCT
	#4	#1 AND #2 AND #3 AND #4
Web of Science	#1	Cephalometry OR Craniometry OR cephalometric
	#2	X Ray Film OR Xray Film OR Film, Xray OR Films, Xray OR Radiographic Film OR Xray Films OR Film, Radiographic OR Films, Radiographic OR Radiographic Films OR Film, X-Ray OR Film, X Ray OR Films, X-Ray OR Films, X-Ray OR radiograph OR roentgenogram OR scotograph OR Lateral cephalometric radiograph
	#3	2d OR two-dimensional OR 2 dimension OR two dimension OR 2 dimensional OR bidimensional OR 2d
	#4	#2 OR #3
	#5	Cone-Beam CAT Scan OR Computed Tomography, Cone-Beam OR Cone Beam Computed Tomography OR CT Scan, Cone-Beam OR CT Scan, Cone Beam OR CT Scans, Cone Beam OR CT Scans, Cone-Beam OR Cone-Beam CT Scan OR Cone-Beam CT Scans OR Scan, Cone-Beam CT OR Scans, Cone-Beam CT OR Tomography, Cone-Beam Computed OR Tomography, Cone Beam Computed OR Tomography, Volume Computed OR Computed Tomography, Volume OR Volume Computed Tomography OR Volumetric CT OR CT, Volumetric OR Volumetric Computed Tomography OR Computed Tomography, Volumetric OR Tomography, Volumetric Computed OR CAT Scan, Cone-Beam OR CAT Scan, Cone Beam OR CAT Scans, Cone-Beam OR CT, Volume OR Cone-Beam CAT Scan OR Cone-Beam CAT Scans OR Scans, Cone-Beam CAT OR Cone-Beam Computer-Assisted Tomography OR Scan, Cone-Beam CAT OR Computer-Assisted Tomography, Cone-Beam OR Cone Beam Computer Assisted Tomography OR Tomography, Cone-Beam Computer-Assisted OR Cone-Beam Computerized Tomography OR Computerized Tomography, Cone-Beam OR Cone Beam Computerized Tomography OR Tomography, Cone-Beam Computerized OR Cone-Beam CT OR CT, Cone-Beam OR Cone Beam CT OR Volume CT OR CBCT OR Cone Beam Computed Tomography OR CBCT
	#6	#1 AND #4 AND #5
SIGLE	#1	(Craniometry OR cephalometric OR Cephalometry) AND (X Ray Film OR Lateral cephalometric radiograph OR radiograph OR 2-d OR two-dimensional OR 2 dimension OR two dimension OR 2-dimensional OR 2 d) AND (Cone-Beam Computed Tomography OR CBCT OR CT Scan OR Cone-Beam CT)
Cochrane Central Register of Controlled Trials (CENTRAL)	#1	(Craniometry OR cephalometric OR Cephalometry) AND (X Ray Film OR Lateral cephalometric radiograph OR radiograph OR 2-d OR two-dimensional OR 2 dimension OR two dimension OR 2-dimensional OR 2 d) AND (Cone-Beam Computed Tomography OR CBCT OR CT Scan OR Cone-Beam CT)

Statistical analysis

Data analyses were carried out using Comprehensive Meta-Analysis (version 2.2.064, Biostat, Englewood, NJ) and Stata 12.0 (Stata Corp, College Station, TX, USA). The difference in mean (DM) was used in the statistical pooling for continuous data. To further investigate heterogeneity, subgroup analyses were performed using I^2 statistic, and when the I^2 statistic

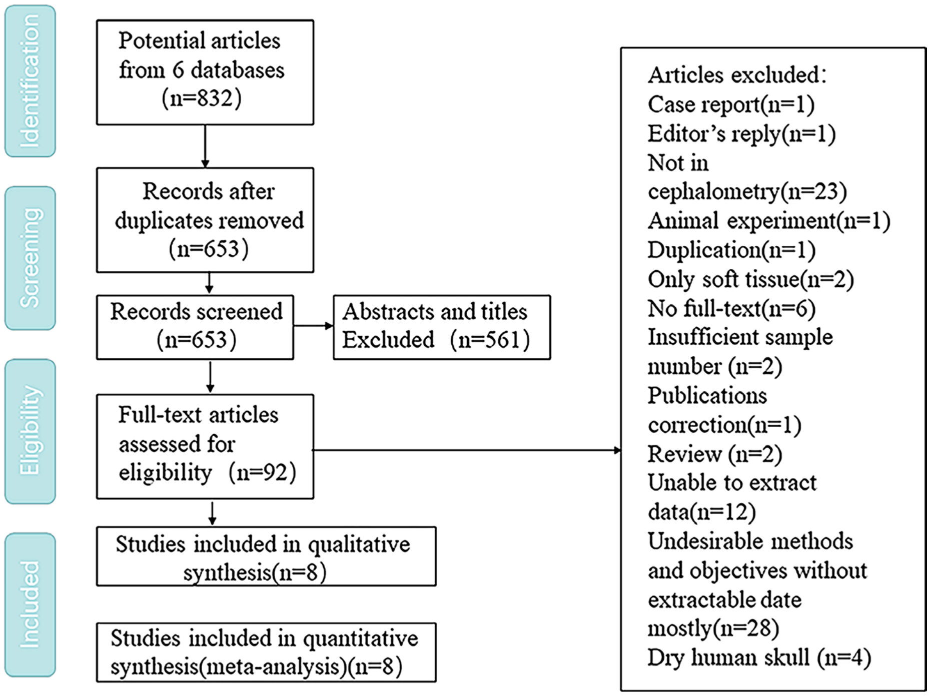

Figure 1. Study flow diagram.

was greater than 50%, it was considered that there was substantial heterogeneity. The random effects model and the fixed effects model can be used when I^2 is lower than 50%, but the random effects model must be used when the I^2 is higher than 50%. Therefore, the random effects model was used to summarise the original outcome data and a sensitivity analysis was conducted to assess the robustness of the pooled results.

Egger's test and Begg's test were applied to assess publication bias. When the result of Egger's test or Begg's test was less than 0.1, publication bias was considered to exist.

Table II. The QUAMAS (Quality Assessment of Measurement Accuracy Studies) tool used in the study.

		Parameter of evaluation	Score
Study design (5√)	A	Objective clearly formulated (√)	1
	B	Randomized sample (√)	1
	C	Sample size: Considered adequate (number≥50)(√)	1
	D	Similar baseline characteristics (√)	1
	E	Selection criteria: Clearly described and adequate (√)	1
Study measurement (5√)	F	Measurement method is appropriate (√)	1
	G	Gold standard is appropriate (√)	1
	H	Adequate examiners and independent measurement (√)	1
	I	Reliability: Described and adequate level of agreement (√)	1
	J	Appropriate examination time interval (√)	1
Statistical analysis (5√)	K	Statistical analysis is appropriate for data (√)	1
	L	Reliability: intra-examiner (√) and inter-examiner (√)	2
	M	Statistical significance level: P value (√) and confidence intervals (√)	2
Total			15

Table III. General information of the included studies.

Studies	Country	Sample type	Sample size	Sample information	2D type	3D type	CBCT parameters	Number of examiners/ measurement times
Jung, 2015	Korea	Patients	50	12 males and 38 females (mean age 19.40 ± 6.40 years)	Conventional lateral cephalograms	CBCT	120 kV, 5 mA, 0.3 mm voxel size	1/3 times
Wen, 2017	China	Patients	60	21 males and 39 females (mean age 21.3 years)	Conventional lateral cephalograms	CBCT	110 kV, 5 mA, 0.25mm voxel size	2/unknown
Zamora, 2011	Spain	Patients	8	4 males and 4 females (mean age 15.55 ± 6.25 years)	Conventional lateral cephalograms	CBCT (NemoCeph 3D and InVivo5)	120 kV, 23.87 mA, 8.9 seconds, 0.4 mm^3 voxel size,	1/twice
Miao, 2016	China	Patients	20	Unknown (age18-35 years)	Conventional frontal cephalograms	CBCT	Unknown	Unknown/twice
Na, 2012	China	Patients	40	18 males and 22 females (age 12-18 years)	Conventional lateral cephalograms	CBCT	120 kV, 5 mA, 4 seconds, 0.4 mm^3 voxel size	1/twice
Zhiyao, 2016	China	Patients	100	50 males and 50 females (age 18-40 years)	Conventional lateral cephalograms	CBCT	120 kV, 5 mA, 0.3 mm voxel size	1/twice
Mingming, 2016	China	Patients	30	14 males and 16 females (age 20-26 years)	Conventional lateral cephalograms	CBCT	120 kV, 5 mA, 4 seconds, 0.25 mm voxel size	Unknown/3 times
Yang, 2012	China	Patients	14	8 males and 6 females (age 15 ± 1.2 years)	Conventional cephalograms	CBCT	Unknown	1/twice

Results

Study selection and characteristics

After removing duplicates, a total of 832 studies were retrieved. The identified studies were evaluated using the inclusion criteria by screening the titles and abstracts. The full texts of 92 articles were further assessed for eligibility. Finally, eight studies were included in the present review. The details of the study selection process are shown in Figure 1.

The basic characteristics of the included studies are shown in Table III. The studies that were included were published between 2011 to 2017 and consisted of a total of 322 patients. The clinical trials that were considered eligible were those that focused on measurement accuracy. A previously published review that focused on the accuracy of alveolar bone height and thickness measurements measured by CBCT included similar studies.[12] Of the eight eligible studies,[6–8,14–18] the sample size of three studies was greater than or equal to 50 patients[15,17,18] and the sample size of the remaining five studies[6–8,14,16] was less than 50 patients.

In regards to the 2D techniques, conventional lateral cephalograms and conventional frontal cephalograms were used in the identified studies. While six studies[6–8,15,17,18] used only conventional lateral cephalograms, there was one study[16] that relied solely on conventional frontal cephalograms. The remaining study[14] used both conventional frontal and lateral cephalograms.

The voxel size of the CBCT images in the included studies ranged from 0.25 mm to 0.4 mm.

The outcomes were divided into skeletal measurements and dental measurements which included SNA, SNB, ANB, Ar(Co)-Gn, FH-MP, SN-MP, N-S, Me-Go, ANS-PNS, ANS-Me, N-ANS, N-Me, Po-NB, L1-MP, OP-SN, U1-NA (⁰), U1-NA(mm), L1-NB(⁰), L1-NB(mm), U1-L1. Soft tissue measurements were not pooled due to the lack of results. Forest plots and the results of the pooled measurements for the CBCT group versus the conventional cephalogram group are presented in Figures 2–5 and Table IV.

Quality of studies

According to the assessment using the QUAMAS tool, of the eight eligible studies,[6–8,14–18] four studies[8,15,17,18] were found to be of high quality, three studies[7,14,16] were of medium quality, and the remaining study[6] was found to be of low quality (shown in Table V).

Results of meta-analysis

Of the 13 skeletal measurements, the differences in two parameters were found to be statistically

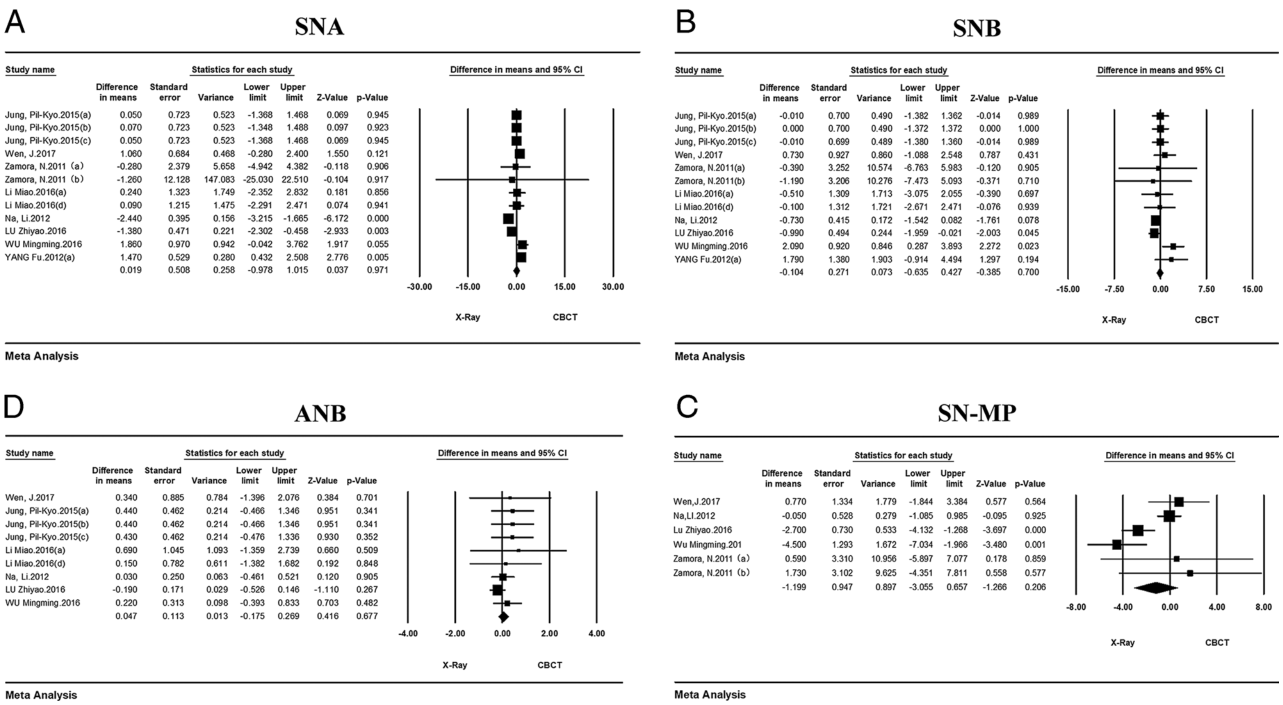

Figure 2. Forest plots of pooled DM for the CBCT group versus the X-ray group (A) SNA, (B) SNB, (C) ANB, (D) SN-MP.

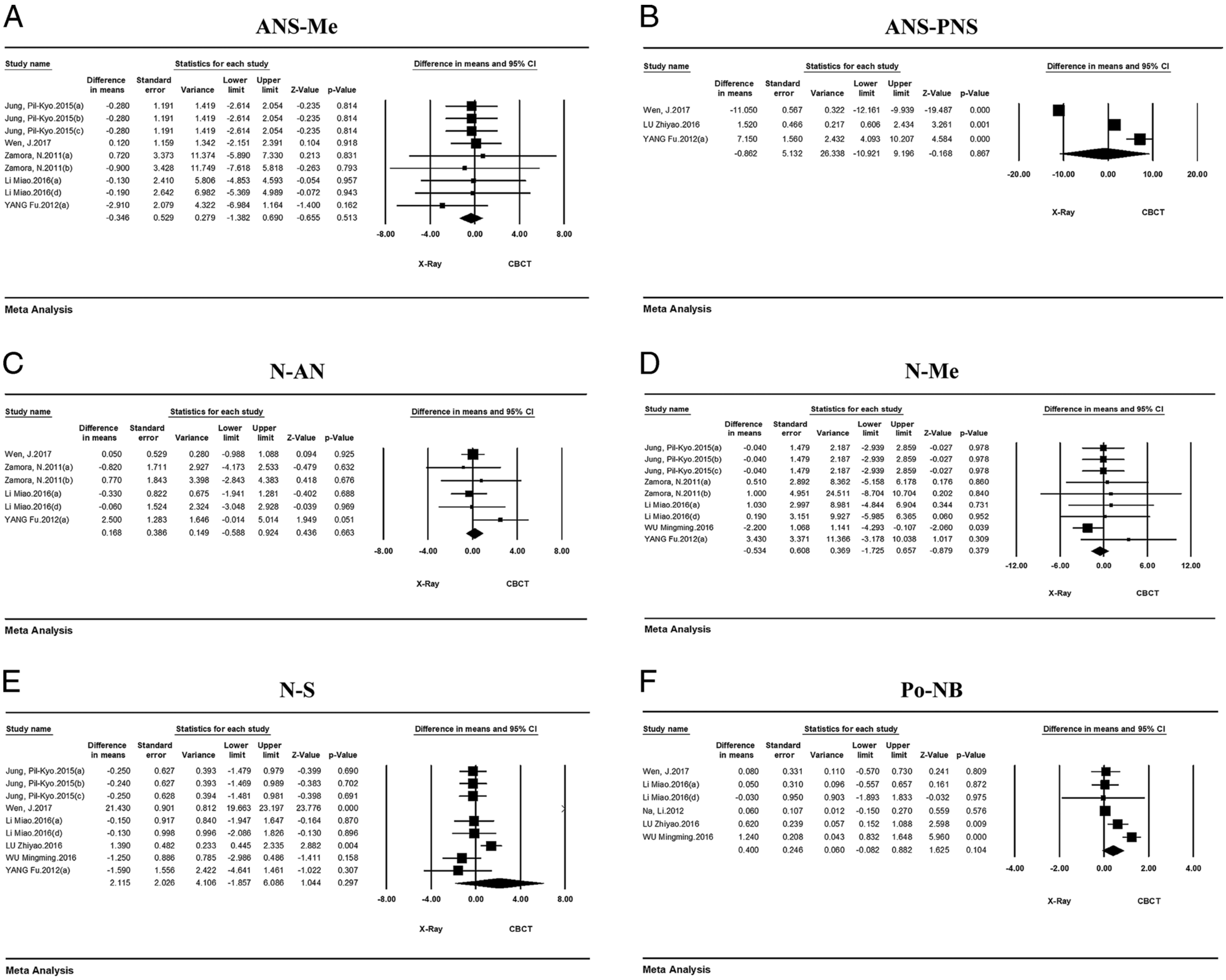

Figure 3. Forest plots of pooled DM for the CBCT group versus the X-ray group (A) ANS-Me, (B) ANS-PNS, (C) N-ANS, (D) N-Me, (E) N-S, (F) Po-NB.

significant. The meta-analysis indicated that the pooled DM was Ar(Co)-Gn (10.76 mm, 95% CI 4.93–16.60, $P = 0.000$), and Me-Go (9.15 mm, 95% CI 2.99–15.31, $P = 0.004$).

Of the seven dental measurements, the differences in one parameter were determined to be statistically significant. The meta-analysis indicated that the pooled DM was U1-L1 (1.55°, 95% CI 1.09-2.00, $P = 0.000$).

No statistical difference was found in the other cephalometric parameters. The results of the meta-analysis are shown in Table IV.

Sensitivity analysis

A sensitivity analysis was performed by excluding low quality studies and one study which used the CBCT system calibration method. The results are shown in Table VI. There was no obvious change in the results, indicating that the present meta-analysis had acceptable stability and low sensitivity.

Publication bias

The results of Egger's test and Begg's test are shown in Table VII. Publication bias was found in the following measurement parameters: ANB, Ar(Co)-Gn, N-Me, Me-Go and OP-SN. There was no publication bias detected in the other measurement parameters.

Discussion

CBCT is a 3D imaging technology applied in craniofacial examination. It can generate high-quality conventional lateral cephalograms, conventional frontal cephalograms, panoramic radiographs and

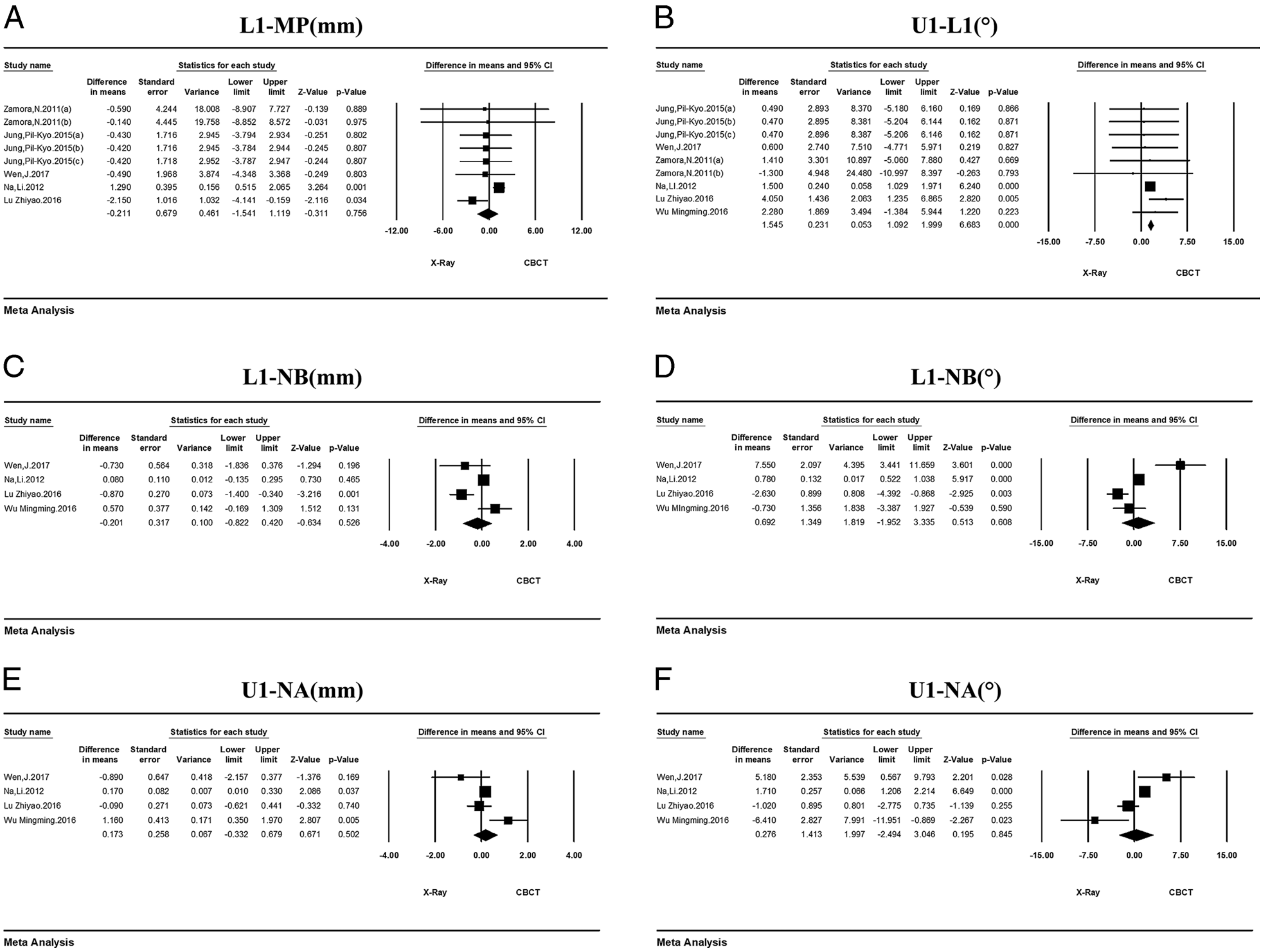

Figure 4. Forest plots of pooled DM for the CBCT group versus the X-ray group (A) L1-MP, (B) U1-L1(°), (C) L1-NB(mm), (D) L1-NB (°), (E) U1-NA(mm), (F) U1-NA(°).

anteroposterior radiographs. Therefore, it is able to show the spatial position of the bones of the craniofacial skeleton as well as the dental roots, which therefore facilitates the examination of morphology, symmetry, and the craniofacial relationships. However, as CBCT and conventional cephalograms have different measurement requirements and involve fixed points in two dimensions and three dimensions, variation between the techniques requires consideration. The present study is the first to systematically evaluate the differences between 3D images from CBCT and 2D images from a conventional cephalogram in the measurement of cephalometric parameters.

The quality evaluation method applied in the present study required specific characteristics which necessitated the evaluation of the suitability, accuracy and reliability of measurement methods adopted in the included articles. The current review assessed studies on the measurement accuracy of cephalometric parameters using 3D images obtained from CBCT to those of 2D images obtained from conventional cephalograms rather than the diagnostic accuracy of orthodontic-related disease. Therefore, the QUADAS tool which is usually used as a quality assessment tool to study diagnostic accuracy and to further analyse parameters of specificity and sensitivity was finally considered unsuitable because the present study mainly compared the differences between the two groups of measurement data. According to the characteristics of the measurement studies, scholars had designed the QUAMAS tool to focus on three domains: study design, study measurement, and statistical analysis. The QUAMAS tool was specially designed for the quality evaluation of measurement accuracy but required some accommodating changes, such as an added P value and confidence interval in the domain of statistical analysis.

The results of the meta-analysis showed that there were no significant statistical differences in most

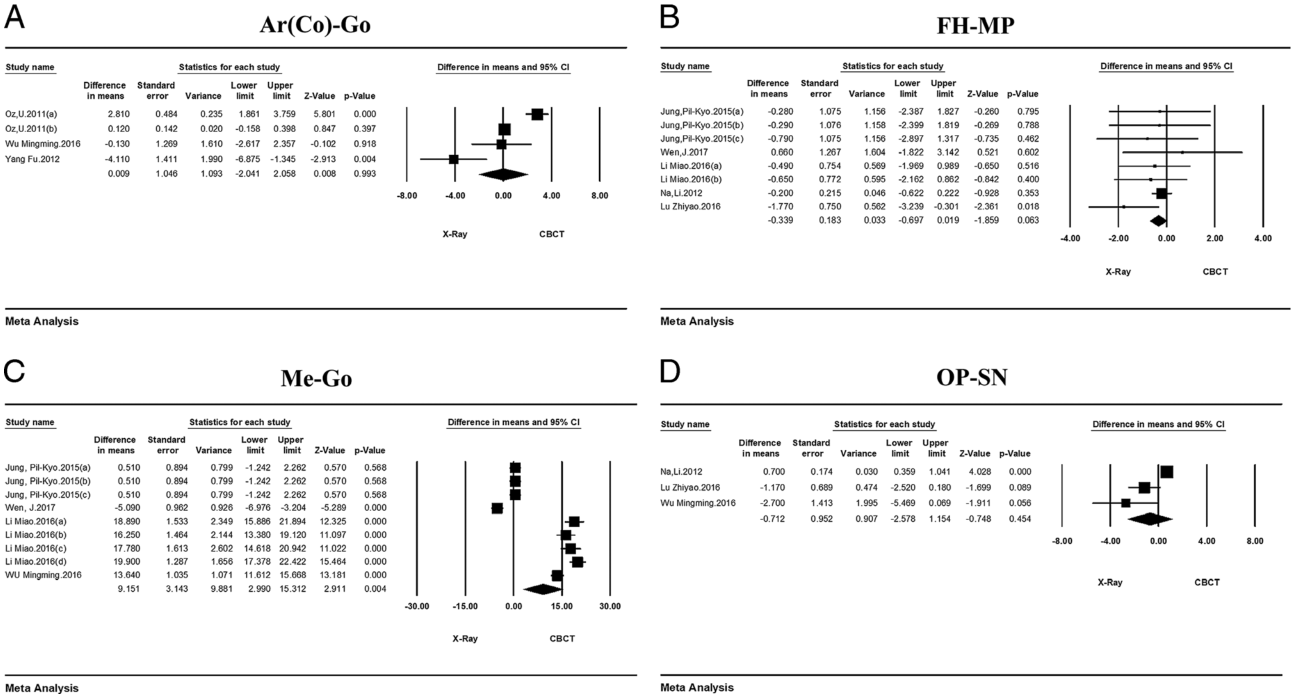

Figure 5. Forest plots of pooled DM for the CBCT group versus the X-ray group (A) Ar(Co)-Go, (B) FH-MP, (C) Me-Go, (D) OP-SN.

Table IV. Original result.

Index	X̄	95%CI	*P* value
SNA	0.02	(-0.98, 1.02)	*P* = 0.971
SNB	-0.10	(-0.64, 0.43)	*P* = 0.700
ANB	0.05	(-0.18, 0.27)	*P* = 0.677
Ar(Co)-Gn	10.76	(4.93, 16.60)	*P* = 0.000
ANS-PNS	-0.86	(-10.92, 9.20)	*P* = 0.867
ANS-Me	-0.35	(-1.38, 0.69)	*P* = 0.513
N-ANS	0.17	(-0.59, 0.92)	*P* = 0.663
N-Me	-0.53	(-1.73, 0.66)	*P* = 0.379
FH-MP	-0.34	(-0.70, 0.02)	*P* = 0.063
SN-MP	-1.20	(-3.06, 0.66)	*P* = 0.206
Me-Go	9.15	(2.99, 15.31)	*P* = 0.004
N-S	2.12	(-1.86, 6.09)	*P* = 0.297
Po-NB	0.40	(-0.08, 0.89)	*P* = 0.104
L1-MP	0.21	(-1.54, 1.12)	*P* = 0.756
OP-SN	-0.71	(-2.58, 1.15)	*P* = 0.454
L1-NB(mm)	-0.20	(-0.82, 0.42)	*P* = 0.526
L1-NB(°)	0.69	(-1.95, 3.34)	*P* = 0.608
U1-L1	1.55	(1.09, 2.00)	*P* = 0.000
U1-NA(mm)	0.17	(-0.33, 0.68)	*P* = 0.502
U1-NA(°)	0.28	(-2.49, 3.05)	*P* = 0.845

cephalometric parameters except Ar(Co)-Gn, Me-Go and U1-L1 between the CBCT measurement and the conventional cephalometric measurement. By considering that images obtained from the two measurement methods would have similar accuracy, CBCT can be recommended as a supplementary option to conventional cephalometric measurements as it overcomes conventional cephalometric shortcomings related to structure magnification, overlap and distortion.[2,19] A published study found that when comparing the physical measurements of human dry skulls, digital 2D images presented variations in the measurements, while CBCT showed almost perfect diagnostic results.[20] In addition, the conventional lateral head film uses exposure technology, which is affected by the distance between the structure projected to the recording medium, and so images may have different magnifications. In CBCT, the gantry rotates 360 degrees around the head, so the generated image is 1:1 without magnification.[21]

The advantage of CBCT is that it reflects the true distance and angle between measurement points and provides greater information for clinical diagnosis and treatment compared with 2D images. Because the fixed point of a conventional cephalogram is 2D, while the human head is 3D, inherent variations are produced between 2D and 3D measurements.

Table V. Quality assessment of the included studies using the QUAMAS tool.

	Study design					Study measurement				Statistical Analysis			
Studies	A	B	C	D	E	F	G	H	I	J	K	L	M	Total
Jung, 2015	1	1	1	1	1	1	1	0	1	1	1	1	1	12
Wen, 2017	1	0	1	0.5	1	1	1	0.5	1	0	1	2	1	11
Zamora, 2011	1	0	0	0	0	0.5	1	0	1	0	1	1	1	6.5
Miao, 2016	1	0	0	1	1	1	1	0	0	1	1	0	1	8
Na, 2012	1	0	0	1	1	1	1	0	1	1	1	0	2	10
Zhiyao, 2016	1	0	1	0.5	1	1	1	0	1	1	1	1	1	10.5
Mingming, 2016	1	0	0	0.5	1	1	1	0	1	1	1	1	1	9.5
Yang, 2012	1	0	0	1	0	1	1	0.5	0	1	1	0	1	7.5

Specifically, the 2D angle is larger than the 3D angle, and the 2D linear distance is smaller than the 3D linear distance. The capture and measurement methods of CBCT can eliminate errors likely caused by 2D images which better reflect the true distance and angle between the craniofacial landmarks. In addition, the accuracy of conventional lateral cephalograms to determine the mandibular plane also varies due to artifacts, while CBCT can effectively avoid this issue.

In clinical situations that require 3D information to assist in diagnosis and treatment planning, related to TMJ disorders, tooth impactions, and respiratory issues involving the sinuses and airways, root resorption, implant surgery, and complex orthodontic and dentofacial orthopaedic problems,[22–24] conventional 2D imaging methods find difficulty in providing the required information. The CBCT advantage is the provision of more detailed 3D information to enhance diagnosis and treatment considerations.[25,26] Compared to 2D radiographs, CBCT better facilitates the accurate determination of tooth and root length, the detailed assessment of root resorption, the determination of available bone width, the assessment of tooth inclination, the calculation of torque and the appreciation of soft tissue relationships. CBCT further provides detailed information regarding craniofacial morphology and maxillary and mandibular changes resulting from rapid maxillary expansion.[27]

Data obtained from three-dimensions is greater than that acquired in two dimensions. Only one measured value can be obtained by comparing 2D overlapping images, while two measurements can be acquired from both sides of the 3D images. The comparison of these two measurements in three dimensions may be helpful in diagnosing patients with mandibular asymmetry. Moreover, a systematic review also showed that CBCT was more useful in cases that were difficult to diagnose by conventional radiography.[28] Therefore, in specific clinical situations, the use of CBCT should be considered to enhance the diagnosis and treatment plan.

The radiation dose of CBCT is routinely higher than conventional 2D radiography, and so its application is limited due to health concerns. When comparing effective doses arising from CBCT scans to that reported for 2D extra-oral radiography in dentistry, a minimal value for a CBCT (11 μSv) is 0.2–2.0 times greater than a dental panoramic film, or 1.0–5.5 times greater than a cephalometric image.[29] Whereas, low-dose protocols have been proposed and usually achieved by milli-amperage reduction, scan time reduction, the use of partial rotations, a reduced number of projections and a larger voxel size.[29] A prospective study compared the radiation dose of CBCT with a low-dose regimen and cranial imaging. The results indicated that the effective dose of CBCT with a low-dose regimen was 35.4 μSv, which was comparable to the effective dose of 2D cephalometry while the image quality was satisfactory.[30] A recent study used Frankfort Horizontal (FH) instead of the traditional reference plane (SN) to reduce the FOV, and thereby reduced the radiation dose of CBCT. The research results showed that this method could be used for paediatric orthodontic patients in specific

Table VI. Result of sensitivity analysis.

Index	Original result	Exclusion of Zamora, N 2011 and Jung, Pil-Kyo 2015	Exclusion of Zamora, N 2011	Exclusion of and Jung, Pil-Kyo 2015
SNA	0.02 (-0.98, 1.02) *P* = 0.971	0.05 (-1.40, 1.51) *P* = 0.942	0.04 (-1.00, 1.07) *P* = 0.948	0.03 (-1.35, 1.40) *P* = 0.970
SNB	-0.10 (-0.64, 0.43) *P* = 0.700	0.09 (-0.83, 1.00) *P* = 0.855	-0.05 (-0.63, 0.54) *P* = 0.881	0.01 (-0.82, 0.83) *P* = 0.987
ANB	0.05 (-0.18,0.27) *P* = 0.677	–	–	-0.04 (-0.28, 0.21) *P* = 0.760
Ar(Co)-Gn	10.76 (4.93, 16.60) *P* = 0.000	–	–	10.76 (12.94, 20.39) *P* = 0.000
ANS-PNS	-0.86 (-10.92, 9.20) *P* = 0.867	–	–	–
ANS-Me	-0.35 (-1.38, 0.69) *P* = 0.513	-0.49 (-2.22, 1.23) *P* = 0.577	-0.36 (-1.42, 0.70) *P* = 0.507	-0.44 (-2.06, 1.18) *P* = 0.593
N-ANS	0.17 (-0.59, 0.92) *P* = 0.663	–	0.07 (-0.19, 0.33) *P* = 0.599	–
N-Me	-0.53 (-1.73, 0.66) *P* = 0.379	-0.85 (-3.13, 1.44) *P* = 0.468	-0.61 (-1.84, 0.62) *P* = 0.332	-1.04 (-2.74, 0.65) *P* = 0.229
FH-MP	-0.34 (-0.70, 0.02) *P* = 0.063	–	–	-0.44 (-0.99, 0.11) *P* = 0.119
SN-MP	-1.20 (-3.06, 0.66) *P* = 0.206	–	-1.57 (-3.67, 0.53) *P* = 0.142	–
Me-Go	9.15 (2.99, 15.31) *P* = 0.004	–	–	13.53 (4.60, 22.47) *P* = 0.003
N-S	2.12 (-1.86, 6.09) *P* = 0.297	–	–	3.30 (-3.43, 10.03) *P* = 0.337
Po-NB	0.40 (-0.08, 0.89) *P* = 0.104	–	–	–
L1-MP	-0.21 (-1.54, 1.12) *P* = 0.756	-0.32 (-2.91, 2.28) *P* = 0.812	-0.27 (-1.79, 1.24) *P* = 0.726	-0.28 (-2.43, 1.87) *P* = 0.799
OP-SN	-0.71 (-2.58, 1.15) *P* = 0.454	–	–	–
L1-NB(mm)	-0.20 (-0.82, 0.42) *P* = 0.526	–	–	–
L1-NB(°)	0.69 (-1.95, 3.34) *P* = 0.608	–	–	–
U1-L1	1.55 (1.09, 2.00) *P* = 0.000	1.75 (0.86, 2.64) *P* = 0.000	1.55 (1.10, 2.01) *P* = 0.000	1.5 (1.11, 2.02) *P* = 0.000
U1-NA(mm)	0.20 (-0.34, 0.73) *P* = 0.465	–	–	–
U1-NA(°)	0.28 (-2.49, 3.05) *P* = 0.845	–	–	–

Table VII. Results of publication bias.

Index	Begg's test	Egger's test
SNA	0.49289	0.20611
SNB	0.68075	0.14336
ANB	0.29715	0.00829
Ar(Co)-Gn	0.11785	0.00061
ANS-PNS	1.00000	0.89425
ANS-Me	0.40425	0.54673
N-ANS	0.70711	0.61827
N-Me	0.29715	0.02517
FH-MP	0.62069	0.38980
SN-MP	0.70711	0.94893
Me-Go	0.14440	0.00522
N-S	0.83483	0.67174
Po-NB	1.00000	0.66028
L1-MP	0.13765	0.10617
OP-SN	1.00000	0.09144
L1-NB(mm)	0.73410	0.59868
L1-NB(°)	0.73410	0.85952
U1-L1	0.34808	0.95074
U1-NA(mm)	0.73410	0.95712
U1-NA(°)	0.73410	0.48943

circumstances.[31] Continuous research efforts and attempts to improve low-dose CBCT are expected to make CBCT more widely used.

The results of the meta-analysis showed that Ar(Co)-Gn, Me-Go and U1-L1 differed greatly between orthodontic CBCT measurements and measurements from conventional cephalograms ($P < 0.05$). Ar(Co)-Gn and Me-Go were the two measurements that had significant statistical differences between the 13 skeletal measurements, the former represents the length of mandibular ramus and the latter represents the length of mandibular body. In the actual 3D structure, both of these structures have an angle with a horizontal or sagittal plane, which can affect the accuracy of 2D measurement. Clinically, patients with mandibular retrusion might see a change in the shape of the mandibular body and ramus, as well as a change in mandibular length. Because CBCT can eliminate the anglular deviation in 2D measurements, the accuracy of diagnosis may be improved by measuring from three dimensions using the two parameters. Of 7 dental measurements used the present study, U1-L1 was one parameter determined to be statistically significant. The reason for the difference may be due to the 2D images confusing the mesial-distal inclination of adjacent teeth or the 2D images were too unclear because of the radiographic magnification. However, in general, this parameter has no great clinical application.

There was publication bias in Ar(Co)-Gn and Me-Go measurements identified in the present study, and it was considered that a possible reason might be that previous research was more inclined to publish cephalograms with poor left-right overlap in order to highlight the advantages of CBCT. It is common that an upper measurement overlap occurs, and so it is considered that publication bias cannot overcome the significance of the conclusion. Although the publication bias of Ar(Co)-Gn and Me-Go may affect the accuracy of the results, combined with the rigorous retrieval and selection process of the present study, and the practical clinical significance of the two parameters, it is suggested that statistical significance can provide reference for the differences between parameters in 2D and 3D cephalometry.

It is acknowledged that the present study has limitations. The heterogeneity of some parameters was found to be high. Additionally, as some of the studies had small sample sizes, the power of the analysis may have been affected. It is considered that further clinical research with larger sample sizes is indicated. Moreover, with the continuous development of current computer-aided design and computer-aided production (CAD/CAM) technology, dental treatment is becoming simplified, personalised and scholarly. Compared with 2D images, CBCT has obvious advantages in oral digital treatment planning. By combining related software, CBCT can quickly obtain 3D scan data of oral and maxillofacial hard tissues and establish virtual patients to achieve effective digital design and treatment[32,33] which is considered more refined and certainly more advanced than traditional methods. As the current trend of dental treatment is continually shifting to digitalisation, CBCT will become a greater and valuable tool.

Conclusions

The images obtained from CBCT scans have similar accuracy to conventional cephalometric measurements. CBCT is recommended as a supplementary option when current circumstances require improved diagnosis and treatment planning.

Conflict of interest

The authors declare that there is no conflict of interest.

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