RESEARCH

Comparative study between conventional and cone beam CT-synthesized half and total skull cephalograms

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Objectives: The aim of this study was to compare cephalometric measurements obtained from conventional cephalograms with total and half-skull synthesized cone beam CT (CBCT) cephalograms.

Methods: Cephalometric analyses of 30 clinically symmetric patients were conducted by a calibrated examiner on conventional and CBCT-synthesized cephalograms (total, right and left). Reproducibility was investigated using the intraclass correlation coefficient (ICC). The Bland–Altman analysis was used to assess the agreement of the measurements from each factor obtained by conventional, total, right and left CBCT-synthesized cephalograms.

Results: The ICC was above 0.9 for most of the 40 cephalometric factors analysed, revealing similar levels of reproducibility. When the measurements obtained from conventional and CBCT-synthesized cephalograms were compared, the Bland–Altman analysis showed a strong agreement between them.

Conclusions: Half-skull CBCT-synthesized cephalograms offer the same diagnostic performance and equivalent reproducibility in terms of cephalometric analysis as observed in conventional and total CBCT-synthesized cephalograms.

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Introduction

Cephalometry is an important resource in the diagnosis, planning and follow-up of orthodontic, facial orthopaedic or surgical-orthognathic treatments. Therefore, the actual value of cephalometric analysis is directly related to the correct characterization of anatomic landmarks on cephalograms.^{1–5} Some studies have demonstrated the lack of reproducibility in cephalometric analyses conducted by different examiners.^{6,7} This may be explained partly by the occurrence of the phenomenon of superimposition in the radiographic image, owing to the divergent projection of bilateral anatomic structures and to the difference in characterization of each landmark by different examiners.

In a bid to overcome the obstacles imposed by radiographs with regards to the visualization of anatomical structures, some authors have proposed the use of multislice CT scans (MSCT)^{8–10} and, more recently, the cone beam CT (CBCT) technique^{11–15} when conducting craniofacial measurements. CBCT has proved its value in

the dental practice^{16–22} as it displays the characteristics of interaction with data already observed in MSCT^{23–25} but provides significantly lower radiation doses compared with MSCT.^{26–28}

The main advantage in tomographic scans is the possibility to interact with previously stored data, which in turn generates new images and affords the reconstruction of synthesized cephalograms that are comparable with conventional radiographs, based on one single three-dimensional (3D) measurement.²⁹ These new possibilities offered by CBCT pave the way to assessments conducted along the three aspect planes and make a more individualized investigation possible for each patient's condition.

With the intention of further exploring CBCT reconstruction resources, this study has been designed to use the image from half-skull synthesized cephalograms since this is a possibility recently introduced and still lacks further investigation. In order to establish reliable grounds for comparative assessment, the reproducibility and diagnostic performance of this cephalometric image were confronted with findings from conventional and total skull CBCT-synthesized cephalograms using the Bland–Altman analysis.³⁰

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Materials and methods

This study used the images (conventional cephalograms and CBCT) of the first 30 patients who started treatment in the Department of Orthodontics, School of Dentistry, Federal University of Rio Grande do Sul

(UFRGS), Brazil, in 2008 and fulfilled the selection criteria. In order to assess the specific variations related to characteristics of different images in terms of cephalometric measurements, patients who were considered to have significant facial asymmetries based on clinical examinations were not included in the sample. This

Figure 1 Images of one patient from the study. (a) Conventional cephalogram; (b) total skull cone beam CT (CBCT)-synthesized cephalogram; (c) right half-skull CBCT-synthesized cephalogram; (d) left half-skull CBCT-synthesized cephalogram

wariness was adopted to eliminate the bias from asymmetric patients as the purpose of the present study was to evaluate if the reduction of superimposition of structures would influence the outcomes of cephalometric analysis. The sample consisted of 9 males and 21 females with a mean age of 17.5 years. All patients or respective custodians signed an informed consent form. This study was approved by the Ethics Committee of UFRGS.

Conventional cephalograms were acquired by positioning the patients in a cephalostat (Cranex® Tome, Soredex, Milwaukee, WI). After automatic processing, all radiographs were scanned into *.JPG digital format using a UMAX 2400S scanner (Techville Inc, Dallas, TX) (Figure 1a).

The CBCT images were obtained from an i-CAT scanner (Imaging Sciences International, Hatfield, PA). The field of view used was 16 × 13 (diameter × height) and isotropic voxel was defined as 0.25 mm. With i-Cat Vision software, the skull was orientated with the

midsagittal plane perpendicular and the Frankfort plane parallel to the ground, simulating the cephalostat position. A synthesized cephalometric image was then constructed from the 3D CBCT scan by lateral projection of the entire volume. Both half-skull synthesized cephalometric images were constructed under the same standards after tracing a division on the midsagittal plane and excluding all the data from the left or right side of the volume, according to the midfacial projection being considered. Regarding the half-skull images, the midsagittal plane was carefully determined, ensuring that all midsagittal structures which make up the cephalometric landmarks—such as sella, anterior nasal spine, posterior nasal spine, nasion and menton—were included in the image. All images were exported to *.JPG digital format (Figure 1b,c,d).

The cephalometric analyses were conducted on the Radiocef Studio 2 software (Radio Memory Ltda, Belo Horizonte, MG, Brazil). Before the identification of landmarks, a standardized correction of the proportions

Table 1 Description of 40 cephalometric factors analysed on cephalograms*

<i>Cephalometric factor</i>	<i>Description</i>
Linear measurements (mm)	
S–N	Anterior length of cranial base
S–Ar	Extent of lateral cranial base
Go–Ar	Mandibular ramus height
Go–Me	Mandibular body length
S–Go	Posterior facial height
N–Me	Anterior facial height
/I–NPog	Position of lower incisor relative to nasion-pogonion line
A–(V–T)	Position of maxilla relative to V–T line
CD (Vigorito)	Vigorito's cephalometric discrepancy
/I–Orb	Distance from long axis of upper incisor to orbitale
H–Nose	Nose projection relative to Holdaway line
I–NA	Position of upper incisor relative to maxilla
/I–NB	Position of lower incisor relative to mandible
Pog–NB	Distance from pogonion to NB line
Lii–(V–T)	Distance of lower incisor incisal to V–T line
Angular measurements (°)	
(S–N).Ar	Sella angle
(S–Ar).Go	Articular angle
(Ar–Go).Me	Gonial angle
(Ar–Go).N	Upper gonial angle
(Me–Go).N	Lower gonial angle
S–N.A	Position of maxilla relative to anterior cranial base
S–N.B	Position of mandible relative to anterior cranial base
I/.NA	Inclination of upper incisor relative to maxilla
/I.NB	Inclination of lower incisor relative to mandible
I/.NS	Inclination of upper incisor relative to anterior cranial base
S–N.Ocl	Inclination of occlusal plane relative to anterior cranial base
H.(N–B)	Soft-tissue profile of face
(S–N).(Go–Me)	Inclination of mandibular plane relative to anterior cranial base
FMIA	Frankfort mandibular incisor angle
FMA	Frankfort mandibular angle
I/.I	Interincisor angle
IMPA	Incisor mandibular plane angle
(N–Pog).(Po–Orb)	Facial angle
N–A.Pog	Angle of convexity
A–N.B	Relative position of maxilla to mandible
S–N.Gn	Growth axis
(Go–Me).(V–T)	Inclination of mandibular plane relative to V–T line
F.(V–T)	Inclination of Frankfort plane relative to V–T line
(Go–Gn).Ocl	Inclination of occlusal plane relative to mandibular plane
H.(V–T)	Angle formed by Holdaway line and V–T line

Ar, articular; Go, gonion; Me, menton; N, nasion; Pog, pogonion; S, sella.

*V–T line indicates long axis of mandibular symphysis.

was performed using a millimetric scale for digital images. The adjustment aimed to correct the magnification effects from cephalometric films and ensure that the proportions of all the images were equal and corresponded to those of the patient. When all the landmarks had been characterized, the software displayed the measurements of the 40 previously chosen cephalometric factors (15 linear and 25 angular measurements) of the patients (Table 1).

Three examiners participated at the calibration stage. Once all of them were considered calibrated (intraclass correlation coefficient (ICC) > 0.8 for all factors analysed in all techniques), the best one was chosen to conduct the research, performing the analyses either on conventional or on CBCT-synthesized cephalograms.

The statistical analyses were performed using SPSS (version 13.0, SPSS, Chicago, IL). In order to assess the reproducibility of exams in each technique, the ICC was

calculated for each cephalometric landmark in each of the techniques investigated. The diagnostic performance of the four images (conventional, total, right and left CBCT-synthesized cephalograms) was evaluated by the Bland–Altman analysis, a scatterplot of the difference between measurements against their average.³⁰

Results

As shown in Table 2, ICC was above 0.9 for most of the 40 cephalometric factors analysed. Although the reproducibility of the total sagittal CBCT-synthesized cephalograms was higher than that of the conventional cephalograms, and reproducibility of the half-skull CBCT-synthesized cephalograms was better than that of the total CBCT-synthesized cephalograms, the

Table 2 Intraclass correlation coefficients to evaluate the reproducibility of linear (mm) and angular measurements (°) from the four imaging techniques

<i>Cephalometric factors</i>	<i>Conventional</i>	<i>CBCT total</i>	<i>CBCT right</i>	<i>CBCT left</i>
Linear measurements				
S–Ar	0.993	0.960	0.993	0.989
Go–Ar	0.967	0.969	0.994	0.993
S–N	0.991	0.993	0.990	0.993
Go–Me	0.990	0.985	0.995	0.994
S–Go	0.991	0.990	0.999	0.997
N–Me	0.995	0.994	0.996	0.990
/I.NPog	0.995	0.998	0.999	0.993
A–(V–T)	0.965	0.979	0.901	0.964
CD (Vigorito)	0.984	0.984	0.966	0.991
/I–Orb	0.971	0.914	0.946	0.895
H–Nose	0.988	0.993	0.988	0.994
I–NA	0.951	0.906	0.754	0.984
/I–NB	0.993	0.995	0.997	0.985
Pog–NB	0.970	0.959	0.966	0.996
Lii–(V–T)	0.960	0.925	0.943	0.914
Angular measurements				
(S–N).Ar	0.971	0.924	0.947	0.965
(S–Ar).Go	0.973	0.958	0.966	0.982
(Ar–Go).Me	0.981	0.982	0.989	0.997
(Ar–Go).N	0.983	0.974	0.981	0.987
(Me–Go).N	0.976	0.990	0.996	0.996
S–N.A	0.972	0.946	0.915	0.969
S–N.B	0.991	0.988	0.985	0.978
I–NA	0.946	0.947	0.963	0.973
/I–NB	0.977	0.936	0.953	0.948
I–NS	0.992	0.968	0.975	0.979
S–N.Ocl	0.995	0.984	0.982	0.971
H.(N–B)	0.986	0.994	0.994	0.992
(S–N).(Go–Me)	0.972	0.982	0.987	0.989
FMIA	0.976	0.953	0.945	0.953
FMA	0.937	0.982	0.984	0.988
I–/I	0.737	0.977	0.970	0.961
IMPA	0.926	0.955	0.955	0.954
(N–Pog). (Po–Orb)	0.993	0.995	0.910	0.987
N–A.Pog	0.980	0.971	0.951	0.996
A–N.B	0.969	0.970	0.949	0.998
S–N.Gn	0.983	0.990	0.978	0.975
(Go–Me).(V–T)	0.978	0.963	0.932	0.916
F.(V–T)	0.988	0.983	0.978	0.971
(Go–Gn).Ocl	0.978	0.980	0.982	0.985
H.(V–T)	0.854	0.898	0.966	0.944

I/, long axis of upper incisor; /I, long axis of lower incisor; A, Point A; Ar, articulare; B, Point B; CBCT, cone beam CT; CD Vigorito, Vigorito's cephalometric discrepancy; FMA, Frankfort mandibular angle; FMIA, Frankfort mandibular incisor angle; Gn, gnathion; Go, gonion; H, Holdaway line; IMPA, incisor mandibular plane angle; Lii, lower incisor incisal; Me, menton; N, nasion; Ocl, occlusal plane; Orb, orbitale; Pog, pogonion; S, sella; and V–T, V–T line.

V–T line indicates long axis of mandibular symphysis.

Table 3 Mean of differences and 95% confidence interval (CI) of linear (mm) and angular (°) measurements from the 4 imaging techniques utilized according Bland–Altman analysis

Cephalometric factors	Conventional↔ CBCT total		Conventional↔ CBCT right		Conventional↔ CBCT left		CBCT right↔ CBCT left	
	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI
Linear measurements								
S–Ar	0.13	–2.31 to 2.57	0.37	–1.73 to 2.46	0.37	–2.04 to 2.77	0.00	–2.39 to 2.40
Go–Ar	–0.72	–4.70 to 3.26	–0.98	–4.46 to 2.49	–0.90	–5.98 to 4.18	–0.08	–4.56 to 4.39
S–N	0.44	–1.89 to 2.78	0.35	–2.61 to 3.31	0.44	–2.19 to 3.06	–0.09	–2.25 to 2.08
Go–Me	0.74	–5.47 to 6.94	0.64	–4.88 to 6.15	0.75	–6.64 to 8.14	–0.11	–5.16 to 4.94
S–Go	–0.99	–6.92 to 4.94	–0.23	–5.00 to 4.54	0.05	–5.75 to 5.86	–0.28	–5.27 to 4.70
N–Me	–0.36	–6.61 to 5.90	–0.53	–6.57 to 5.52	–0.26	–6.97 to 6.46	–0.27	–3.74 to 3.20
/I.NPog	–0.09	–2.41 to 2.23	–0.20	–2.23 to 1.83	–0.16	–2.35 to 2.03	–0.04	–1.10 to 1.02
A–(V–T)	0.43	–3.75 to 4.60	0.69	–4.43 to 5.80	0.78	–6.58 to 8.13	–0.09	–5.16 to 4.94
CD (Vigorito)	0.07	–1.64 to 1.78	0.29	–2.83 to 2.25	–0.07	–3.09 to 2.95	–0.22	–3.31 to 2.86
/I–Orb	–0.46	–7.04 to 6.13	0.86	–8.03 to 9.75	0.33	–6.79 to 7.44	0.54	–8.93 to 10.00
H–Nose	–0.18	–1.59 to 1.24	–0.19	–1.91 to 1.54	–0.31	–1.85 to 1.24	0.12	–0.97 to 1.21
I–NA	–0.34	–5.67 to 5.00	–0.68	–6.35 to 4.98	–0.60	–7.40 to 6.21	–0.09	–6.03 to 5.86
/I–NB	–0.01	–2.26 to 2.24	–0.01	–2.21 to 2.18	0.04	–2.43 to 2.51	–0.06	–1.45 to 1.33
Pog–NB	–0.18	–1.06 to 0.69	–0.08	–1.00 to 0.83	–0.04	–0.84 to 0.76	–0.04	–0.877 to 0.79
Lii–(V–T)	0.08	–2.37 to 2.53	0.20	–2.40 to 2.81	0.53	–3.03 to 4.09	–0.33	–3.57 to 2.90
Angular measurements								
(S–N).Ar	–0.38	–4.38 to 3.62	–0.95	–8.88 to 6.98	–0.20	–7.64 to 7.25	–0.75	–6.93 to 5.43
(S–Ar).Go	1.38	–7.12 to 9.88	2.13	–7.59 to 11.85	1.12	–10.49 to 12.73	1.01	–10.02 to 12.04
(Ar–Go).Me	0.16	–5.89 to 6.21	–0.64	–5.35 to 4.07	0.00	–8.04 to 8.04	–0.65	–8.10 to 6.81
(Ar–Go).N	0.70	–5.52 to 6.92	0.23	–4.35 to 4.81	0.65	–5.94 to 7.23	–0.42	–6.36 to 5.53
(Me–Go).N	–0.54	–4.68 to 3.61	–0.87	–4.66 to 2.92	–0.86	–5.86 to 4.13	–0.01	–3.28 to 3.26
S–N.A	–0.27	–5.66 to 5.12	0.40	–5.81 to 6.60	0.13	–5.53 to 5.79	–0.27	–6.23 to 5.69
S–N.B	–0.04	–3.53 to 3.46	0.23	–4.33 to 4.80	0.13	–4.81 to 5.07	0.10	–3.42 to 3.62
I/NA	–1.15	–10.48 to 8.18	–0.18	–9.66 to 9.30	–0.61	–12.52 to 11.30	0.43	–12.65 to 13.51
/I.NB	–0.84	–7.15 to 5.47	–0.86	–5.99 to 4.27	0.03	–6.12 to 6.18	–0.89	–7.58 to 5.81
I/NS	–0.87	–8.09 to 6.36	0.77	–9.64 to 11.19	0.02	–10.89 to 10.93	0.75	–11.25 to 12.75
S–N.Ocl	–0.23	–2.44 to 1.98	0.01	–3.95 to 3.98	–0.85	–6.60 to 4.89	0.86	–3.66 to 5.39
H.(N–B)	–0.66	–5.18 to 3.86	–0.37	–5.17 to 4.43	–0.33	–5.18 to 4.53	–0.04	–0.99 to 0.90
(S–N).(Go–Me)	0.19	–4.88 to 5.27	–0.53	–6.02 to 4.95	–0.60	–6.75 to 5.55	0.07	–4.82 to 4.96
FMIA	0.38	–4.24 to 5.00	1.11	–3.48 to 5.70	0.05	–6.00 to 6.11	1.06	–4.59 to 6.70
FMA	0.14	–1.95 to 2.23	–0.31	–1.91 to 1.30	–0.16	–1.88 to 1.57	0.87	–1.86 to 1.56
I/I	2.88	–9.85 to 15.61	1.68	–9.37 to 12.73	1.19	–11.99 to 14.36	0.49	–12.85 to 13.84
IMPA	–1.25	–9.68 to 7.19	–1.07	–8.81 to 6.67	0.34	–7.67 to 8.35	–1.41	–8.42 to 5.61
(N–Pog). (Po–Orb)	0.01	–1.56 to 1.58	–0.33	–2.00 to 1.34	–0.03	–1.68 to 1.63	–0.30	–1.80 to 1.20
N–A.Pog	–0.41	–9.22 to 8.40	0.08	–9.75 to 9.90	–0.11	–11.33 to 11.12	0.18	–9.30 to 9.67
A–N.B	–0.22	–4.76 to 4.31	0.12	–4.85 to 5.08	0.21	–5.63 to 6.04	–0.09	–5.05 to 4.88
S–N.Gn	–0.22	–4.15 to 3.71	–0.54	–5.36 to 4.28	–0.38	–5.66 to 4.91	–0.16	–3.63 to 3.31
(Go–Me).(V–T)	–0.35	–4.58 to 3.88	–0.37	–6.08 to 5.35	–0.33	–6.06 to 5.40	–0.04	–5.31 to 5.24
F.(V–T)	–0.06	–1.34 to 1.22	0.18	–0.99 to 1.35	0.57	–0.90 to 1.32	0.59	–1.18 to 1.12
(Go–Gn).Ocl	0.07	1.87 to 2.01	–0.21	–3.16 to 2.74	0.32	–1.87 to 2.52	–0.54	–2.90 to 1.82
H.(V–T)	–0.47	–6.63 to 5.69	–0.71	–8.53 to 7.10	–0.17	–8.27 to 7.93	–0.54	–6.24 to 5.15

I/, long axis of upper incisor; /I, long axis of lower incisor; A, Point A; Ar, articulare; B, Point B; CBCT, cone beam CT; CD Vigorito, Vigorito's cephalometric discrepancy; CI, 95% confidence interval; FMA, Frankfort mandibular angle; FMIA, Frankfort mandibular incisor angle; Gn, gnathion; Go, gonion; H, Holdaway line; IMPA, incisor mandibular plane angle; Lii, lower incisor incisal; Me, menton; N, nasion; Ocl, occlusal plane; Orb, orbitale; Pog, pogonion; S, sella; and V–T, V–T line.

V–T line indicates long axis of mandibular symphysis.

differences in reproducibility between these techniques were not statistically significant.

Table 3 shows the mean difference and the 95% confidence intervals for each of the 40 cephalometric factors analysed. The Bland–Altman analysis showed a strong agreement between the measurements obtained from conventional and CBCT-synthesized cephalograms.

Discussion

Reproducibility of measurements is a crucial element in cephalometric analyses because it is proof of satisfactory performance of the examiner in the identification

of anatomical landmarks. The aim of the present study was to analyse the performance of different imaging techniques as assessed by the results provided by a trained and calibrated examiner. The experimental aspects such as image acquisition (same equipment and protocol) and measurement (same software) were controlled.

Some authors have suggested that CBCT-synthesized cephalograms afford the easy characterization of anatomical landmarks in comparison with conventional radiographs, which may be due to a higher level of contrast in that image form.³¹ In the present study the reproducibility of exams obtained from conventional cephalograms and CBCT-synthesized cephalograms

were similar. This demonstrates that the reproducibility of a cephalometric analysis is more likely to be linked to the examiner calibration than to the kind of image chosen for the realization of the exam, which is in agreement with Delamare *et al*.³²

Kumar *et al*¹⁵ compared conventional and CBCT-synthesized cephalograms and observed statistically significant differences in the Frankfort mandibular angle plane, imputing these discrepancies to the difficulty sensed in characterizing the porion in some conventional cephalograms and, in those cases, to the use of the ear rods as a surrogate. Nevertheless, although the authors recognize the presence of difficulties within some cephalometric landmark identification, the present study did not observe any differences regarding the measurements obtained. Additionally, the statistical method utilized by Kumar *et al*¹⁵ did not take into consideration the clinical relevance of the observed differences which might not have appeared if the Bland–Altman method had been chosen.

CBCT data set allows the generation of an almost infinite number of reformatted images, including thin-section slices, multiplanar reconstruction and 3D models.²⁴ Despite some studies assessing the reliability of landmark identification³³ and the accuracy of linear measurements³⁴ in 3D volumetric images, the main objective in orthodontics still is the development of a cephalometric analysis based on 3D models. This study showed that half-skull cephalograms undeniably allow a representation of the right and left sides of the skull separately, avoiding superimposition of bilateral structures and therefore determining their real position.

Based on the Bland–Altman analysis, the diagnostic performance of right and left CBCT-synthesized

cephalograms were similar to conventional and total CBCT-synthesized cephalograms. This finding demonstrates that all images offer the same diagnostic performance and thus can be used interchangeably for cephalometric analyses in clinically symmetric patients.

The patient exposure to radiation should be a constant concern to health professionals so the imaging technique chosen may follow the basic principles of justification, optimization and limitation of radiation dose exposure. Thus, for the majority of cases, the cephalometric diagnosis should still be done as usual with conventional cephalograms. However, when additional information is necessary, such as for patients with impacted teeth, dental resorption or surgical planning, where a CBCT scan is required, the cephalometric analysis can be performed on CBCT-synthesized cephalograms. Similarly, the other radiographic projections required in the characterization of differential diagnosis may be obtained based on reconstructions of CBCT, thus avoiding repeated exams.

In conclusion, the results showed no differences amongst conventional cephalograms and total and half-skull CBCT-synthesized cephalograms in terms of diagnostic performance and reproducibility of measurements in clinically symmetric patients.

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