Comparison between conventional and cone-beam computed tomography–generated cephalograms

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Introduction: Cone-beam computed tomography (CBCT) is becoming established as an alternative and, in many aspects, superior radiographic technique to conventional radiography in orthodontics. However, cephalometric analysis is still an important tool in relation to treatment planning because 3-dimensional analyses are still not established. The aim of this study was to compare cephalometric measurements performed on conventional cephalograms with those on CBCT-synthesized images. **Methods:** Three observers digitized landmarks used for the Björk analysis on conventional lateral cephalograms and on 2 sets of CBCT-synthesized cephalograms (MIP and RayCast) from 34 patients. **Results:** The calculated measurements did not differ between the 3 image techniques. The RayCast technique proved to be more reproducible than the MIP. **Conclusions:** CBCT-synthesized cephalograms can successfully replace conventional headfilms. (Am J Orthod Dentofacial Orthop 2008;134:798-802)

Diagnosis and treatment planning for orthodontic patients are based on a combination of study casts, intraoral and extraoral pictures, and radiographs traditionally comprising panoramics and cephalograms.

Cephalometric analyses are performed to determine deviations in the skeletal and dentoalveolar relationship by identifying specific landmarks on both hard and soft tissues to consecutively calculate the spatial and angular relationship between them. The reliability of cephalometric analyses depends on projection and identification errors.[1,2]

Computed tomography (CT) has been used successfully to represent the true 3-dimensional (3D) morphology of the skeletal structures of the cranium. Although CT scanning was introduced into medical practice in 1971,[3] its application in dentistry has, because of high levels of radiation and scanning costs, been limited to special patients. Cone-beam CT (CBCT), developed specifically for imaging the structures pertinent to dentistry, was introduced to the dental community in 1998.[4] The cost-benefits of CBCT scanning are superior to the combination of several 2-dimensional (2D) radiographic images with respect to the intrinsic information, and to CT with respect to radiation dose and cost. The replacement of conventional plain radiographs with the 3D-capable devices appears to be an unavoidable trend.[5] To make this transition acceptable by the orthodontic community, it is relevant to evaluate how CBCT-based analyses can fit into the existing databases of lateral conventional cephalograms. Kumar et al[6,7] addressed this problem in a comparative study on dry skulls and an in-vivo study. Our aims in this article were to determine whether (1) cephalometric measurements performed on CBCT-synthesized cephalograms of patients are comparable with measurements on conventional cephalograms, and (2) whether the technique used to synthesize CBCT cephalograms has an impact on the reproducibility of the cephalometric measurements.

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Submitted, March 2008; revised and accepted, July 2008.
0889-5406/$34.00

doi:10.1016/j.ajodo.2008.07.008

MATERIAL AND METHODS

Thirty-seven patients (20 female, 17 male) were originally included in this study. The inclusion criteria were that each patient had both a conventional cephalogram (Cranex Tome cephalostat, Soredex, Tuusula, Finland) (Fig 1, *A*) and a 12-in CBCT scan (NewTom 3G, QR s.r.l., AFP Imaging, Elmsford, NY) available within a 6-month period (average 30 days). From the original 37 patients, only 34 could be included in this study because 2 were not occluding during the CBCT

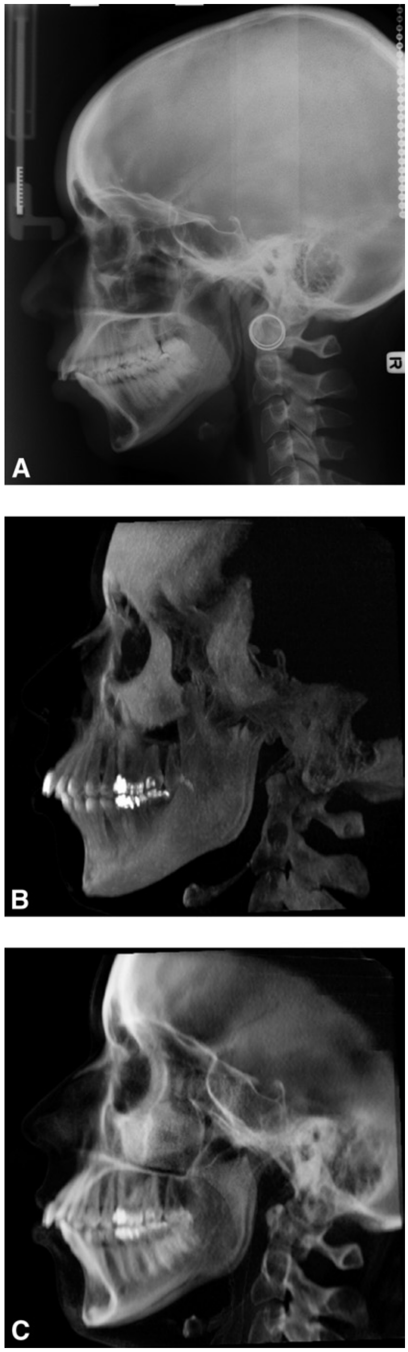

Fig 1. A, Conventional lateral cephalogram. **B** and **C,** CBCT-synthesized lateral cephalograms of the same patient: the MIP technique *(B)* and the RayCast technique *(C)*.

examination, and 1 patient was incorrectly positioned during the CBCT scan.

By using the frontal scout view, the CBCT scans were reoriented to have the virtual lines tangent to the upper ridges of the orbit horizontal. By using the sagittal view, the occlusal plane was oriented to be horizontal. All CBCT scans were reconstructed to have a voxel dimension of $0.3 \times 0.3 \times 0.36$ mm.

Two rendering algorithms were used to synthesize the lateral cephalograms from the CBCT scans. In the maximum intensity projection (MIP), the 3D images are generated by projecting on the visualization plane the voxel with the highest intensity from the viewpoint to the plane of projection (Fig 1, *B*). With the RayCast, the 3D data are visualized by summing all values of the voxels from the viewpoint to the plane of projection and dividing this number by the number of voxels (Fig 1, *C*). The CBCT-synthesized cephalograms were built by using orthogonal projections (ie, setting the center of projection at an infinite distance from the plane of projection, thus simulating parallel rays). In order for the inner structures of the cranium (eg, sella) to be visible in the MIP cephalograms, the parietal bone had to be virtually excised from the CBCT data sets.

The conventional and the CBCT-synthesized cephalograms were imported into PORDIOS (version 7.00.0002, Institut for Anvendt Datalogi, Middelfart, Denmark). Three examiners (C.B.B., D.C., M.H.), previously calibrated for the Björk analysis,[8] participated in this study. The observers were blinded to subject identity. The relevant landmarks necessary for this analysis were identified on all 3 types of images, and 17 angles were calculated (Table).

Statistical analysis

The statistical analyses were performed by using SPSS (version 13.0, SPSS, Chicago, Ill). A descriptive statistic was made to evaluate the normal distribution of the measurements for the 3 image types. Multivariate analysis of variance (MANOVA) was first applied to assess interobserver differences and then to determine whether there were differences between the 3 imaging modalities. The Student-Newman-Keuls post-hoc test was used to determine which measurements were different.

ANOVA was performed on the average of the absolute differences between the observers for all angular measurements for the 3 imaging modalities. The Student-Newman-Keuls post-hoc was performed.

RESULTS

The absolute differences in degree between the 3 observers were calculated for every angle, and independently for each of the 3 imaging techniques. The Student-Newman-Keuls post-hoc test showed: significant statistical differences between the 3 observers for 3 angular measurements on the conventional cephalo-

Table. Angular measurements (°) from the 3 imaging techniques with *P* values of the MANOVA between them

	Conventional		*CBCT MIP*		*CBCT RayCast*		*MANOVA*
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	P *value*
Pr-N-Ss	2.54	1.10	2.38	1.12	2.40	1.10	0.725
CL-ML	70.24	6.40	70.57	6.25	70.85	6.40	0.920
Ils-NL	111.70	7.15	110.61	6.49	109.02	7.77	0.265
Ili-ML	96.34	7.39	95.51	6.78	95.59	6.46	0.839
Ss-N-Pg	3.00	2.88	2.90	2.84	2.82	2.92	0.964
Ss-N-Sm	4.14	2.23	3.92	2.19	3.83	2.27	0.839
NL-Ols	10.59	3.58	9.48	3.52	10.93	3.27	0.134
Oli-ML	20.69	3.95	19.70	4.22	21.35	3.69	0.158
NL-ML	26.40	5.55	25.66	6.20	27.31	5.15	0.458
S-N-Ss	80.89	3.48	80.45	3.99	80.12	3.86	0.654
S-N-Pg	77.89	3.58	77.55	4.59	77.29	3.43	0.798
NSL-NL	7.27	3.72	8.95	4.78	7.45	3.93	0.141
NSL-ML	33.68	5.18	34.60	6.40	34.77	5.00	0.671
N-S-Ar	122.97	6.07	121.50	9.90	123.87	6.35	0.322
N-S-Ba	131.74	5.93	132.42	9.26	130.69	5.46	0.493
Beta angle	20.42	2.46	20.86	2.34	20.63	2.38	0.726
Jaw angle	122.72	5.17	122.69	5.63	122.84	5.44	0.994

Points: *Ar,* articularis; *Ba,* basion; *N,* nasion; *Pg,* pogonion; *Pr,* prosthion; *S,* sella; *Sm,* supramentale (B-point); *Ss,* subspinale (A-point).
Lines: *CL,* chin Line; *ML,* mandibular line; *NL,* nasal line; *NSL,* nasion-sella line; *Oli,* occlusal line, inferior; *Ols,* occlusal line, superior; *Ils,* axis of maxillary incisor; *Ili,* axis of mandibular incisor.

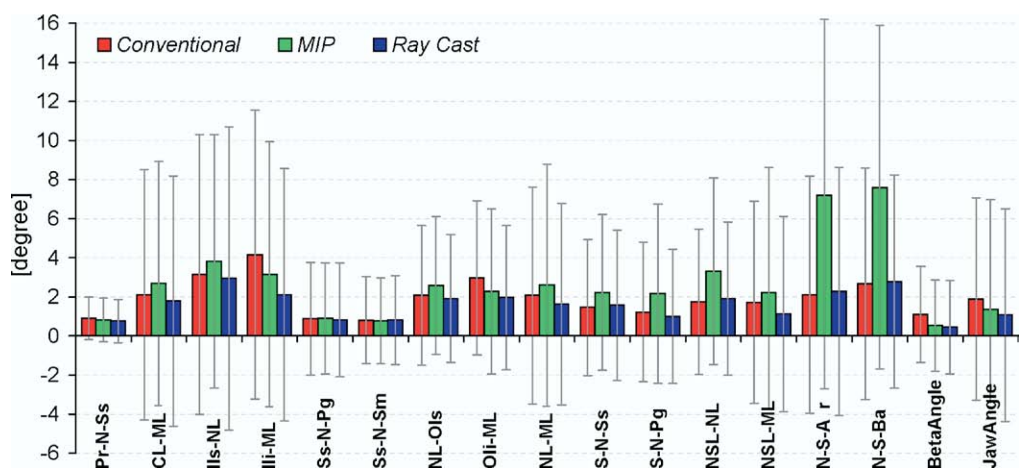

Fig 2. Average of the differences between the maximum and minimum values for specific parameters in the Björk analysis between the 3 observers. The standard deviations are also reported. Note the large range for N-S-Ar and N-S-Ba for the MIP. RayCast measurements showed the least variations.

grams (Ili-ML, $P = 0.026$; NL-Ols, $P = 0.045$; Oli-ML, $P = 0.038$). No angular measurements were statistically different for the MIP technique; 1 angular measurement had a statistical difference for the RayCast technique (N-S-Ba, $P = 0.042$). However, in all cases, the differences were much smaller than the accepted 1 SD for the respective angle according to the Björk analysis.[8] Therefore, it was decided to pool the data and use the averages of the measurements of the 3 examiners. Both the mean and the standard deviation of the angular measurements for the 3 imaging techniques are shown in the Table.

No statistically significant differences were found between the 3 imaging modalities (Table).

The averages of the absolute differences between the observers for all angular measurements for the 3 imaging modalities are reported in Figure 2. It shows that the greatest variation was seen for the MIP technique (especially for the N-S-Ar and N-S-Ba measurements), whereas the results from the conven-

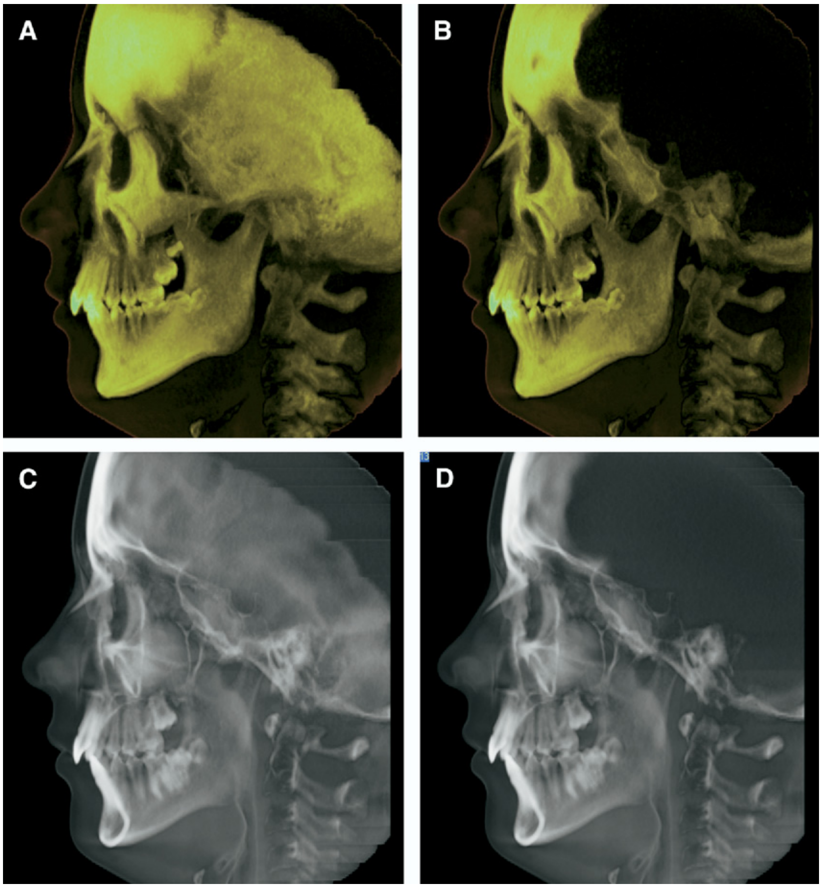

Fig 3. CBCT-synthesized lateral cephalograms: **A** and **B,** the MIP technique; **C** and **D,** the RayCast technique. In *B* and *D*, the left part of the skull and the right parietal bone are virtually excised, and only the right part of the skull is represented.

tional and the RayCast cephalograms were generally comparable. This was confirmed by the post-hoc analysis of the ANOVA. The RayCast presented the least differences for 11 of the 17 angles; the conventional cephalogram for 5, while the MIP for only 1 angle.

DISCUSSION

One problem in this study was that none of the 3 imaging methods can be taken as the gold standard. For this reason, our focus was on the reproducibility of the parameters obtained on the 3 types of cephalograms. The Björk analysis[8] was chosen to be independent from linear calibration errors, to keep the source of external errors as low as possible. The results of the analyses showed that the measurements performed were independent of the type of image used (conventional, RayCast, or MIP). The method used to generate the CBCT cephalogram was also of importance. The cephalometric analyses performed on RayCast cephalograms were more reproducible (ie, the average of the differences was smaller) than the measurements taken on both the conventional and the MIP cephalograms. The first issue might be because errors of projection present in the conventional cephalograms, and therefore the identification of landmarks of bilateral structures (eg, the mandibular line) presents some inaccuracy.[9] The MIP technique is useful in displaying 3D structures in a solid-like way, and it is valuable to represent the overall morphology of tissues. However, the MIP has the drawback that dense structures tend to occult less dense structures along the line from the viewpoint to the plane of projection. This might have prejudiced the recognition of specific anatomic landmarks (eg, articularis and basion) and could explain why the Björk analysis[8] on the MIP cephalograms showed the lowest reproducibility. This is also the reason why the MIP data sets must be preventively prepared to be able to clearly see the internal structures.

However, independently from the image type, due to the dynamic nature of CBCT-generated images, it is of the utmost importance to apply the best histogram function to each image type to fully exploit the information of a CBCT scan.

Although errors in identification of the 3D craniofacial structures with a 2D approach have been addressed,[1] cephalometry has been and still is a valuable method to diagnose and evaluate the treatment outcomes of orthodontic patients.[10]

CBCT data sets can provide undistorted 3D morphology, making it possible to identify craniofacial structures more naturally. However, landmark identification in 3D is not simple. Recently, the reliability of 3D landmarks and the possibility of using anatomic features have been discussed, yet no standards have been proposed or accepted.[11,12] Kumar et al[6] stressed that, because assessment of anatomic landmarks in 3D is still under development, the transition from the 2D to the 3D analysis could be achieved by using CBCT synthesized cephalograms. In both an in-vitro study,[6] performed on dry skulls, and an in-vivo study,[7] it was demonstrated that cephalometric measurements performed on CBCT-synthesized cephalograms are not different from conventional cephalometric analyses. Our results show no statistical differences between cephalometric analyses performed on conventional and CBCT-generated cephalograms of patients. This corroborates and completes clinically what was found by Kumar etal,[6,7] that landmarks used in cephalometry can be identified on CBCT-synthesized cephalograms.

In contrast to conventional cephalograms, the errors due to malposition of the patient during image acquisition could be corrected in CBCT data sets by iterative adjustment. The innate 3D characteristics of the CBCT data set allow for the generation of virtually an infinite number of reformatted images[13] and orthogonal cephalograms (parallel x-rays). In addition, it is possible to represent the right and left parts of the skull separately, avoiding superimposition of the bilateral structures; the position of the teeth in the 2 sides can be determined, and all nonpertinent structures can be virtually excised (Fig 3).[14] However, as clearly stated by Farman,[15] CBCT scanners are valuable when 3D morphology is needed and therefore should be used only when the inherent 3D information could improve the outcome of the treatment.[15]

Similar to cephalograms, CBCT scans taken at different times can be superimposed. Whereas with lateral headfilms it is only possible to illustrate the sagittal and vertical changes of the midsagittal structures of the facial skeleton, by using CBCT data sets, it is possible to quantify changes in all planes of space simultaneously.[14]

CONCLUSIONS

CBCT-synthesized cephalograms can be successfully used to perform cephalometric analyses. The RayCast technique is superior to the MIP because the measurements are not as spread out, and no preliminary preparation of the images is needed to visualize the structures for the cephalometric analyses.

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