ORIGINAL ARTICLE

Intraobserver reliability of landmark identification in cone-beam computed tomography-synthesized two-dimensional cephalograms versus conventional cephalometric radiography: A preliminary study

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Abstract Background/purpose: The aim of the study was to examine the intraobserver reliability of landmark identification in cone-beam computed tomography (CBCT)-synthesized two-dimensional (2D) lateral cephalograms versus conventional digital cephalograms. Materials and methods: Twenty CBCT scans and the corresponding conventional lateral cephalograms were randomly selected. Two-dimensional lateral cephalograms were constructed from the three-dimensional CBCT scans by summing the voxels of the entire volume. All the images were imported into the computer using the analyzing software WinCeph version 8.0. Twenty landmarks in the CBCT-synthesized 2D cephalograms and conventional cephalograms were identified directly on the computer screen by an experienced orthodontist and the operation was repeated 2 weeks later. The x- and y-coordinates of each landmark were examined.

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Introduction

Since Broadbent first introduced cephalometric radiology in 1931,1 this method has been applied in orthodontic diagnosis, treatment planning, and evaluation of treatment results. However, magnification, distortion of the image, and inconsistency in landmark identification cause major errors in conventional cephalometry.2–4

Magnification occurs because the X-ray beams are not parallel at all points of the examined object. Distortion happens due to unequal magnification between different planes. Landmark identification could be influenced by the quality of the image, malposition of the patient, different magnification of bilateral structures, superimposition of craniofacial structures, reproducibility of landmark location, and the experience of the observer.5,6 Despite these problems, conventional cephalography is still widely used for orthodontic monitoring and planning due to its low cost and convenience.7

Computed tomography (CT) was first introduced in 1972 and became increasingly popular in orthodontic diagnosis and treatment. However, traditional CT has the disadvantages of high cost and relatively high radiation dose.8 Cone-beam CT (CBCT), introduced to the dental community in 1998,9 has become an ideal imaging technique for dentistry in recent years.10 Compared to traditional CT, the advantages of CBCT include lower radiation dose,11 lower cost, and higher spatial resolution.9,12 CBCT allows reforming of the three-dimensional (3D) structure into 2D radiographs for conventional cephalometric analysis. By using the ray-sum method, CBCT-synthesized 2D cephalography avoids the anatomic distortion that has been observed in conventional cephalography.13 However, the practicality of replacing conventional cephalometry by CBCT-synthesized 2D cephalography has yet to be established.

Although CBCT can provide 3D morphology, landmark identification in 3D is not simple. The reliability of 3D landmarks in CBCT cephalometry has been evaluated recently but only a few standards have been proposed.14,15 Because 3D cephalometry is still under development, during the transition period of 2D to 3D analysis researchers have proposed the use of CBCT-generated 2D cephalograms. Previous studies showed that angular and linear measurements on CBCT-synthesized cephalograms did not differ from those obtained by conventional cephalometry.16,17 Nevertheless, landmark reliability on CBCT-synthesized cephalograms has not been previously examined. The aims of the present study were to evaluate the intraobserver reliability of landmark identification on CBCT-synthesized 2D lateral cephalograms and to examine whether the reliability is comparable to that in conventional cephalometry.

Materials and methods

Patients

Twenty patients (13 female, 7 male) from the Department of Orthodontics, National Taiwan University Hospital were randomly selected for this study. Each patient had both a pretreatment conventional digital cephalogram and a 22 cm CBCT scan. Informed consent was obtained from all participants.

Conventional cephalometry

Conventional digital cephalography was performed in natural head position. The 24 cm × 30 cm photostimulable storage phosphor (PSP) plate (MD 30; Agfa, Mortsel, Belgium), a phosphor screen with energy storage capability, was used as an X-ray image receptor and placed in the standard carbon-fiber cassette (Agfa). The radiation source was from an X-ray tube (Orthoceph OC 100; Instrumentarium Corporation, Imaging Division, Tuusula, Finland). The exposure was set at 81 kV, 12 mA, and exposure time at 1–1.6 seconds according to the head size of the patient. The source-to-midsagittal plane distance was maintained at 152 cm. The detector was positioned 15.2 cm from the midsagittal plane for all exposures. The patients’ heads were immobilized by two ear rods in the external auditory meati and positioned with the Frankfort plane, which were parallel to the floor. A nasal positioner was also used for head holding in this study. The resolution of the digital cephalograms was 223 dpi.
Three-dimensional images were captured by an i-CAT CBCT scanner (Imaging Science International, Inc., Hatfield, PA, USA) with an isotropic voxel size of 0.4 mm. The scanner was operated with 120 kVp, 3-7 mA, 20 seconds for two rotations, and a total scanning height of 22 cm. A chin holder and self-adhesive bandage were used to stabilize all patients during examination. Each patient’s head was oriented face forward and the midsagittal plane was perpendicular to the floor. Horizontal and vertical laser lines were applied to confirm that the images were within the field of view. Scout view was exposed before each scan to ensure satisfactory position. The image resolution of CBCT was 64 dpi. After the scan, the image was adjusted by orienting both the Frankfort plane in sagittal view and the transporionic line in coronal view to a horizontal position. In order to avoid any loss of 3D information, the ray-sum technique was used to synthesize lateral cephalograms from the CBCT scans.16 The 3D data were 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. The CBCT-synthesized 2D cephalograms were built by setting the center of projection at an infinite distance from the plane of projection, thus simulating parallel rays.

Calibration

The images were saved in JPEG format and imported into the analyzing software WinCeph version 8.0 (Rise Corporation, Sendai, Japan). The conventional digital cephalograms were calibrated by using the computer mouse to click on the points at 0 mm and 45 mm of the radiographic image of an aluminum ruler included at the time of image acquisition in the midsagittal plane, which was at the upper right corner of each image. The dimension for this measured distance was set at 45 mm. The points at 0 mm and 45 mm, named A1 and A2, respectively (Fig. 1), were used as fiducial points. The x- and y-coordinate system was established by connecting the two fiducial points as the y-axis, and the horizontal line arising at A1 perpendicular to y-axis was the x-axis (Fig. 1).

The CBCT constructed images were calibrated by using an internal ruler of the CT image analysis system located at the bottom of each image, the distance between the points of 10 mm and 140 mm was set at 130 mm. The points at 10 mm and 140 mm were named A1 and A2, respectively (Fig. 2), and used as fiducial points. The x- and y-coordinate system was constructed by connecting A1 and A2 as the x-axis, and the vertical line perpendicular to x-axis intersecting at A1 was the y-axis (Fig. 2).

Landmark identification

Twenty commonly used cephalometric landmarks (Table 1) were identified by an experienced orthodontist. Identification of landmarks was performed directly on the same computer and monitor, using a mouse-driven cursor in connection with the computer-aided digital cephalometric analysis system (CADCAS). The operation was repeated by the same examiner after a period of 2 weeks. The positions of landmarks were recorded in the format of x- and y-coordinates. The differences in x- and y-coordinates of each landmark between the two operations were recorded as identification errors.

Statistical analyses

All statistical analyses were conducted using SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). The means and standard deviations of identification errors were calculated for the 20 landmarks. Identification errors of the two modalities

Figure 1  A conventional digital cephalogram and the landmarks used in this study (see Table 1 for abbreviations).

Figure 2  A CBCT-synthesized lateral cephalogram and the landmarks used in this study (see Table 1 for abbreviations).
were compared using the paired Student t test. A P value \(<0.05\) was considered statistically significant. Scatter-plots were used to demonstrate the distribution pattern of landmark identification errors.

### Results

The means and standard deviations of the intraobserver differences in landmark identification by using CBCT-synthesized lateral cephalograms and conventional digital cephalograms are shown in Table 2.

In conventional digital cephalograms, the mean identification errors ranged from 0.26 mm [upper central incisor edge (UIE)] to 1.67 mm [basion (Ba)] in the horizontal direction and from 0.31 mm [lower central incisor edge (LIE)] to 1.56 mm [upper central incisor root apex (UIA)] in the vertical direction. Landmarks with an error \(>1\) mm in the horizontal direction included Ba, posterior nasal spine (PNS), UIA, lower central incisor root apex (LIA), upper molar (UM), and lower molar (LM). By contrast, the vertical errors of pogonion (Pog), gonion (Go), porion (Po), Ba, UIA, and LIA were \(>1\) mm.

For CBCT-synthesized cephalograms, the mean identification errors ranged from 0.18 mm (LIE) to 1.50 mm (PNS) in the horizontal direction and from 0.22 mm (gnathion (Gn)) to 1.16 mm (B point (B)) in the vertical direction. Orbitale (Or), Ba, and PNS had a horizontal error \(>1\) mm, and Or, Ba, and B had a vertical error of \(>1\) mm. Fewer landmarks in CBCT-synthesized cephalograms had significant identification errors.

Significant differences in horizontal errors between the two modalities of cephalometry were noted at menton (Me), LIE, and LIA. In the vertical direction, the differences at Pog, Gn, Me, UIA, LIA, and LM were significant between the two methods.

Scatter-plots of error distribution revealed that each landmark had its own pattern of dispersion of errors. For example, the reliability of points nasion (N), B, and Pog were better in the horizontal than in the vertical direction (Fig. 3A–C). By contrast, points Me, UM, and LM were better in the vertical than in the horizontal direction (Fig. 3D–F). In the cephalograms the first molars (UM and LM) tend to overlap with neighboring teeth in the proximal area, and Me is the most inferior point of mandible, the horizontal locations of these landmarks were harder to identify. By contrast, N, B, and Pog are the deepest or most prominent points along a vertically orientated outline and that made the identification of their vertical positions difficult.

### Discussion

Errors of cephalometric analysis are composed of systematic and random errors. Systematic errors mainly result...
from the errors in projection; random errors include errors of tracing, identification of landmarks and measuring. Image resolution, pixels, and compression formats all influence the quality of digital images. Our study adopted the photostimulable storage phosphor (PSP) imaging system for digital cephalogram. The PSP system is widely known for its wide dynamic latitude, which eliminates any over or under exposure caused by ill-adjusted exposure condition compared to the conventional radiograph. Furthermore, the PSP system significantly decreases radiation dose while the reliability of landmark identification remains unaffected in cephalometry. WinCeph software was used for image storage and analysis in the study. WinCeph does not support conventional digital cephalograms and DICOM.

Table 2  Intraobserver differences in landmark identification (see Table 1 for abbreviations) by using CBCT-synthesized cephalograms and conventional cephalometry.

<table>
<thead>
<tr>
<th>Skeletal landmarks</th>
<th>X-axis</th>
<th>Y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cepholometric</td>
<td>CBCT</td>
</tr>
<tr>
<td>S</td>
<td>0.30 ± 0.25</td>
<td>0.43 ± 0.27</td>
</tr>
<tr>
<td>N</td>
<td>0.27 ± 0.25</td>
<td>0.44 ± 0.42</td>
</tr>
<tr>
<td>Or⁵</td>
<td>0.77 ± 0.64</td>
<td>1.08 ± 1.15</td>
</tr>
<tr>
<td>ANS</td>
<td>0.79 ± 0.81</td>
<td>0.72 ± 0.74</td>
</tr>
<tr>
<td>A</td>
<td>0.74 ± 0.86</td>
<td>0.68 ± 0.74</td>
</tr>
<tr>
<td>B</td>
<td>0.37 ± 0.36</td>
<td>0.43 ± 0.31</td>
</tr>
<tr>
<td>Pog</td>
<td>0.37 ± 0.41</td>
<td>0.23 ± 0.19</td>
</tr>
<tr>
<td>Gp</td>
<td>0.34 ± 0.27</td>
<td>0.30 ± 0.19</td>
</tr>
<tr>
<td>Me</td>
<td>0.70 ± 0.62</td>
<td>0.38 ± 0.27</td>
</tr>
<tr>
<td>Go⁵</td>
<td>0.65 ± 0.68</td>
<td>0.66 ± 0.73</td>
</tr>
<tr>
<td>Ar⁵</td>
<td>0.45 ± 0.67</td>
<td>0.30 ± 0.19</td>
</tr>
<tr>
<td>Po⁵</td>
<td>0.78 ± 0.97</td>
<td>0.81 ± 1.51</td>
</tr>
<tr>
<td>Ba</td>
<td>1.67 ± 1.91</td>
<td>1.25 ± 1.42</td>
</tr>
<tr>
<td>PNS</td>
<td>1.30 ± 1.39</td>
<td>1.50 ± 1.58</td>
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Dental landmarks

<table>
<thead>
<tr>
<th></th>
<th>X-axis</th>
<th>Y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cepholometric</td>
<td>CBCT</td>
</tr>
<tr>
<td>UIE</td>
<td>0.26 ± 0.20</td>
<td>0.30 ± 0.24</td>
</tr>
<tr>
<td>UIA</td>
<td>1.29 ± 1.00</td>
<td>0.95 ± 0.59</td>
</tr>
<tr>
<td>LIE</td>
<td>0.42 ± 0.40</td>
<td>0.18 ± 0.17</td>
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<tr>
<td>LIA</td>
<td>1.21 ± 1.04</td>
<td>0.43 ± 0.35</td>
</tr>
<tr>
<td>UM⁵</td>
<td>1.52 ± 1.95</td>
<td>0.93 ± 1.30</td>
</tr>
<tr>
<td>LM⁵</td>
<td>1.04 ± 1.13</td>
<td>0.64 ± 0.85</td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation.

⁵ Bilateral landmarks.

* The difference between the two modalities is significant as revealed by Student t test (P < 0.05).

Figure 3  Scatter-plots showing the distribution of intraobserver errors in landmark identification. (A) Nasion; (B) B point; (C) pogonion; (D) menton; (E) upper molar; (F) lower molar.
Another study reported that landmark identification errors that a mean error within 1 mm is acceptable clinically. Radiographic diagnosis.

Identification, save time, and reduce random errors in tracing, CADCAS could increase the reliability of landmark identification, save time, and reduce random errors in radiographic diagnosis.

In a study on cephalometric uncertainty, Cohen stated that a mean error within 1 mm is acceptable clinically. Another study reported that landmark identification errors <1 mm are clinically acceptable, and errors of 1–2 mm are also useful in most analyses. However, landmarks with identification errors >2 mm must be applied with care. In our study, the errors of landmark identification by the two modalities of cephalometry were 0.18–1.67 mm, implying that both methods are clinically acceptable. In conventional digital cephalograms, six landmarks (Ba, PNS, UIA, LIA, LM, and LM) in the horizontal direction and seven landmarks (Pog, Go, Po, Ba, UIA, LIE, and LIA) in the vertical direction showed errors >1 mm. By contrast, in CBCT-synthesized lateral cephalograms only three landmarks (Or, Ba, and PNS) in the horizontal direction and three landmarks (Or, B, and Ba) in the vertical direction showed errors >1 mm. Our findings indicate that CBCT-synthesized cephalograms have a higher reliability in landmark identification than conventional digital cephalograms.

In theory, the PSP system inherits a higher accuracy because it proceeds in 223 dpi, better than the 64 dpi for CBCT-synthesized cephalograms. However, our results showed that the errors of landmark identification tended to be smaller in CBCT-synthesized cephalograms as compared with the digital cephalograms obtained from the PSP system. Our results are similar to those reported by Moshiri et al. Because the X-rays in conventional cephalometry are not parallel, objects closer to the X-ray source have larger magnification in the image. When the 3D structures of the skull are laterally projected to a 2D receptor by conventional X-rays, their different distances from the X-ray source result in different image sizes. The overlapped images are indistinct, which makes the identification of landmark position difficult. By contrast, the CBCT-synthesized lateral cephalograms are built by setting the center of projection at an infinite distance, thus simulating parallel rays and avoiding the problem of different magnification. Therefore, the reliability of landmark identification is enhanced.

Further evaluation of the landmark identification errors between the two methods demonstrated that CBCT-synthesized cephalograms had significantly better results on seven landmarks (Pog, Gn, Me, UIA, LIE, LIA, and LM). The seven landmarks can be divided into two groups, those located in the midsagittal chin area (Pog, Gn, Me) and the dental landmarks (UIA, LIE, LIA, LM). Landmarks in the midsagittal plane are usually easier to identify in conventional lateral cephalograms due to less anatomical overlapping. However, in conventional cephalometry projection errors resulting from incorrect positioning of the head may occur, even when cephalostat and other positioning devises are used. When the central X-ray beam is not perfectly perpendicular to the sagittal plane, the midline image may be blurred, which makes landmark identification difficult. This is especially true for landmarks in the chin area (Pog, Gn, Me) because these are on a gradual curve without sharply demarcated intersection. By contrast, while constructing the 2D cephalogram from CBCT scan, images are adjusted by orienting both the Frankfort plane in sagittal view and the transporionic line in coronal view to a horizontal position. After image reconstruction and fine-tuning, better anatomic clearance is obtained than that in conventional cephalometry, resulting in higher reliability in the identification of chin landmarks. As for the dental landmarks, UIA and LIA are not easy to identify in conventional cephalometry because they are housed in the jaws, which makes the images obscure. For LIE and LM, the images are often overshadowed by the upper teeth with the jaws in centric occlusion. The overlapping of bilateral images with different magnifications further worsens these situations. Obviously, using CBCT-synthesized cephalograms effectively circumvented the difficulties in identification of dental landmarks.

Our results are consistent with those from previous studies that showed that CBCT-synthesized cephalogram is comparable or better to conventional cephalometry for landmark identification. Clinically, patients undergoing orthodontic treatments may take temporomandibular joint images, lateral cephalogram, posteroanterior cephalogram, panoramic film, full-mouth periapical films, and bite-wing radiographs to evaluate dental and skeletal problems for making treatment decisions. Because CBCT records volumetric data, multiplanar information is acquired. By adjusting the ray-sum slice thickness of the section, the aforementioned 2D conventional images can be simulated. In ICRP103 report, the combination dose of the three most widely used images in orthodontic routine examination—lateral cephalogram, posteroanterior cephalogram, and panoramic radiograph—is 25–35 μSv, whereas a full-mouth periapical series using PSP system or F-speed film is about 170 μSv. The effective dose of the i-CAT CBCT used in this study (with an extended field of view of 22 cm height, 2 × 20 seconds exposure and 0.4 mm voxel size) is about 82 μSv, which is 2–3 times more than the combination dose of lateral cephalogram, posteroanterior cephalogram, and panoramic radiograph, but half the dose used in a full-mouth periapical series. CBCT is an ideal option when the ALARA (as low as reasonably achievable) principle is followed. Furthermore, it supplies much more information for clinical practice, such as the temporomandibular joint condition and 3D structures for surgery.

In conclusion, our study found no significant differences in intraobserver reliability between CBCT-synthesized cephalograms and conventional digital cephalograms for the identification of most of the commonly used landmarks. For some landmarks, CBCT-synthesized cephalograms yield even better results. Our results support the view that CBCT-synthesized cephalograms can successfully replace conventional cephalograms for orthodontic diagnosis. Further
investigations need to be performed to evaluate the interobserver reliability of landmark identification and the precision of angular and linear measurements for this new mode of cephalometry.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

References