Reproducibility of maxillofacial landmark identification on three-dimensional cone-beam computed tomography images of patients with mandibular prognathism
Comparative study of a tentative method and traditional cephalometric analysis

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ABSTRACT

Objective: To clarify the reproducibility of a tentative method for identifying maxillofacial landmarks on three-dimensional (3D) images obtained with cone-beam computed tomography (CBCT) for dental use in patients with mandibular prognathism. Also, the influence of level of experience of dentists applying the method was investigated by dividing them into two groups according to experience.

Materials and Methods: Dentists with less (group A) or more (group B) than 3 years of experience of cephalometry and 3D image manipulation analyzed CBCT data from 10 patients using two different landmark identification methods: method 1 used conventional cephalometric definitions and method 2 used detailed landmark identification definitions developed for each cross-sectional plane. The plotting of nine landmarks was performed twice, and 10 coordinate values were obtained for each landmark. To assess reproducibility, the 95% confidence ellipse method was used.

Results: Comparative analysis showed that method 2 was highly reproducible. Group B subjects attained smaller ellipsoid volumes than group A subjects, regardless of the landmark identification method used. With method 1, except for condyle and coronoid process, all landmarks showed a higher level of reproducibility in group A subjects than in group B subjects. With method 2, however, five landmarks showed no differences between the methods.

Conclusion: The method proposed here may be highly reproducible regardless of the evaluators’ experience. (Angle Orthod. 2014;84:966–973.)

KEY WORDS: CT landmarks; Mandibular prognathism; Cephalometric analysis

INTRODUCTION

Computed tomography (CT) or cone-beam CT (CBCT) for dental use has become more common for diagnosis and treatment planning in dentistry,\textsuperscript{1-4} including orthognathic surgery and orthodontic treatment.\textsuperscript{5-12} The use of these techniques allows for three-dimensional

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(3D) handling of image data, and various methods have been proposed for making 3D measurements.\textsuperscript{11–14} With advances in image-processing technology and marked increases in the capacity of storage devices, it is common to manipulate CT data as 3D volume data.\textsuperscript{7,8,10}

In most of the measurement methods reported to date, the landmarks used in conventional cephalometric analysis are also applied to the 3D images of the maxillofacial skeleton in accordance with the definitions for cephalometry.\textsuperscript{7,8} A two-dimensionally defined cephalometric procedure is applied without modification to 3D measurements. This may cause certain problems.\textsuperscript{11,12} Although landmarks used in the analysis of 3D volume data should be defined three-dimensionally, no definitive 3D methods for identifying landmarks are currently available.

One of the requirements that a landmark identification method should fulfill is reproducibility. Evaluations or measurements should ideally be consistent regardless of experience in cephalometry and 3D image manipulation. Previous studies revealed that 3D measurements of a given distance between two landmarks and an angle formed by three landmarks are sufficiently accurate for clinical applications.\textsuperscript{13–21} However, few studies have investigated the reproducibility of landmarks themselves.\textsuperscript{15,22,23} The lack of sufficiently reliable evaluation methods may partly explain the lack of well-established definitions for 3D landmark identification.

A tentative evaluation method applying the 95\% confidence ellipse method to 3D CT images has been developed to establish a maxillofacial landmark identification method for 3D volume data with high-level reproducibility.\textsuperscript{22,24} The method was shown to have high reproducibility using a phantom.\textsuperscript{24} The aims of the present study were to verify the reproducibility of the tentative method using data from actual patients with mandibular prognathism. In addition, the influence of level of experience was investigated among dentists applying the method, who were divided into two groups based on their years of experience.

MATERIALS AND METHODS

Analyses were performed on CBCT data from patients with mandibular prognathism who underwent preoperative evaluation for orthognathic surgery at our hospital in 2008. Inclusion criteria were as follows: (1) no craniofacial congenital anomaly; (2) fully erupted first molars and central incisors on the left and right sides both in the maxilla and mandible, and with completed skull and jaw development; (3) no definitive cephalometric findings of facial asymmetry; and (4) patient positioning with the occlusal plane horizontally in an intercuspal position during scanning. Consequently, 10 patients (three men, seven women) aged 23.0 ± 4.8 years were enrolled. This study was approved by the ethics committee of our university (approval No.132) and the rights of the subjects were protected.

Acquisition and Analysis of Imaging Data

Patients were positioned with the occlusal plane horizontally in an intercuspal position during scanning. The CBCT examination was performed using an Alphard VEGA (Asahi Roentgen Ind, Co, Kyoto, Japan) with a flat panel detector. The scanned volume was 20 cm in diameter and 18 cm in height; the scan conditions were an 80-kV tube voltage and 5-mA tube current. Voxel size was 0.39 × 0.39 × 0.39 mm.

The CBCT data were saved in the digital imaging and communications in medicine (DICOM) format and transferred to a personal computer. The 3D images were constructed using the 3D imaging software VG Studio MAX 1.1 (Volume Graphics, Heidelberg, Germany), which automatically sets the origin of the coordinate system at a corner point of the volumetric data. The X-axis corresponded to the left-right direction, and the Y- and Z-axes were set parallel to the anterior-posterior and superior-inferior directions, respectively. The left, posterior, and superior sides were defined as positive directions. In this study, the XY plane was defined as the axial plane, and the XZ and YZ planes were the coronal and sagittal planes, respectively (Figure 1). The 3D coordinates (X, Y, and Z) were determined for each voxel and converted to the actual size in millimeters. Using the software, three sectional images in all directions (X, Y, and Z) were simultaneously displayed (Figure 2), from which a cross-sectional image most suitable for landmark
identification could be selected. A landmark plotted on one image was automatically visible on the other two images.

**Landmark Identification Methods**

The landmarks used in this study were menton (Me), pogonion (Po), upper-1 (U1), lower-1 (L1), left upper-6 (U6), left lower-6 (L6), left gonion (Go), left condyle (Cd), and left coronoid process (Cp). These nine landmarks were freely set in accordance with the cephalometric definitions in method 1 (Table 1), while in method 2 they were placed with the detailed definitions tentatively developed for each sectional plane (Table 2).

**Method of Reproducibility Evaluation**

Five dentists with less than 3 years of postgraduate experience were assigned to group A, and another five dentists with more than 3 years of postgraduate experience were assigned to group B.

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**Table 1. Landmark Identification Method Based on Cephalometric Definition (Method 1)**

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Menton (Me)</td>
<td>Most inferior point of the mid-mandibular suture</td>
</tr>
<tr>
<td>Pogonion (Po)</td>
<td>Most anterior point of the bony chin in the midsagittal plane</td>
</tr>
<tr>
<td>Upper-1 (U1)</td>
<td>Midpoint between the mesial angles of maxillary central incisors</td>
</tr>
<tr>
<td>Lower-1 (L1)</td>
<td>Midpoint between the mesial angles of mandibular central incisors</td>
</tr>
<tr>
<td>Left upper-6 (U6)</td>
<td>Most inferior point of the mesial buccal cusp of the maxillary first molar</td>
</tr>
<tr>
<td>Left lower-6 (L6)</td>
<td>Most superior point of the mesial buccal cusp of the mandibular first molar</td>
</tr>
<tr>
<td>Gonion (Go)</td>
<td>Most inferior and posterior point of the mandibular angle</td>
</tr>
<tr>
<td>Condyle (Cd)</td>
<td>Most superior point of the condyle</td>
</tr>
<tr>
<td>Coronoid process (Cp)</td>
<td>Most superior point of the coronoid process</td>
</tr>
</tbody>
</table>
experience were assigned to group B. Group A dentists had limited experience with CT and cephalometric analysis. Both groups identified the nine landmarks a total of four times each based on method 1 (Table 1) and method 2 (Table 2). Each landmark was identified twice with the two methods in random order with a 1-week interval between evaluations; 10 coordinate values were obtained for each landmark. If landmark identification is performed ideally, these 10 coordinate values should be perfectly consistent; thus, reproducibility could be evaluated based on variation in the coordinate values. With statistical software (JMP, SAS Institute Japan, Tokyo, Japan), the variation could be determined as the 95% confidence ellipses on the XY, YZ, and ZX planes (Figure 3). The volume of ellipsoids was then calculated and compared using the Mann-Whitney U test, with significance set at \( P < .05 \).

**RESULTS**

Based on the combined results of groups A and B, all ellipsoids were larger in method 2 than in method 1, and significant differences were clarified in seven landmarks between the two methods (Figure 4). The Cd and Cp showed relatively favorable reproducibility without differences between the two groups.

Based on the combined results using both methods, all ellipsoids were larger in group A than in group B, and significant differences were seen for the same seven landmarks shown in Figure 4 (Figure 5).
Limited to the results of method 1, the ellipsoids were smaller in group B than in group A, similar to the combined results. Significant differences were found for seven landmarks except for Cd and Cp (Figure 6). However, when the results were limited to method 2, the ellipsoids of all landmarks showed markedly smaller volumes compared with those in method 1, except for Go. Moreover, in addition to Cd and Cp, three other landmarks showed no differences between the two groups.

**DISCUSSION**

A number of previous studies have reported sufficient reliability or reproducibility and sufficient accuracy in 3D measurements using CT or CBCT for clinical use. However, many of them determined accuracy using distances between two landmarks and the angles formed by three landmarks. This means that, if the accuracy of distances and angles is not sufficient, it is difficult to identify the landmark, thereby causing the low-level reproducibility. To address this issue, it is important to investigate the reproducibility of landmarks themselves, as was done in several previous studies. Kragskov et al. used conventional CT images to assess such reproducibility, where two evaluators plotted the same landmarks twice over a few days and assessed the reproducibility as the distance between the two plots.

**Figure 3.** Comparison of ellipsoid volumes between methods 1 and 2 (combined results from subject groups A and B). * Significant difference at $P < .05$.

**Figure 4.** Comparison of ellipsoid volumes between subject groups A and B (combined results from methods 1 and 2). * Significant difference at $P < .05$. 

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Park et al.\textsuperscript{15} also assessed the reproducibility, where one subject identified 19 landmarks five times at 2-week intervals, and the means and standard deviations in the X, Y, and Z directions were compared. Although the use of the interclass correlation coefficient to evaluate intra- and interobserver variability was suggested by de Oliveria et al.,\textsuperscript{16} this coefficient can reveal the approximation of landmarks, but not the extent of variability. The authors addressed this problem by presenting the actual differences, in addition to the values obtained in the analysis of the interclass correlation coefficient.

After developing a method using 95% confidence ellipses to analyze 3D-CT data, Muramatsu et al.\textsuperscript{22} investigated the reproducibility of some landmarks traditionally used in cephalometric analyses. They consequently reported that the basion showed low-level variation in all three directions and high-level reproducibility. In their method, however, landmarks were set solely on the axial image and were not based on a 3D definition. Advancement in computer technology now allows us to manipulate 3D volume data and display three sectional images simultaneously in axial, coronal, and sagittal directions. Almost all CBCT machines now available have such software and enable us to set a landmark on any of the three sectional images. Therefore, a novel landmark identification system should be developed based on 3D definitions. A previous study developed and proposed a tentative method that determined landmarks strictly
on three sectional planes (Table 2), and its reproducibility was tested using an acrylic phantom with an embedded human dried skull. Even though the method showed high-level reproducibility, the results might have been specific to the phantom used. Therefore, the present study was conducted to test the reproducibility of the method—method 2 here—in 10 actual clinical cases and to examine how evaluators’ years of experience influenced the landmark identification.

The ellipsoids in method 2 were smaller than in method 1 for all landmarks in this study. Cp showed stable results with both methods, presumably because of its anatomic location. In method 2, tooth-related landmarks, U1, L1, L6, and especially U6, showed favorable reproducibility, as was also found for Me and Go. Based on the combined results for subject groups A and B, all landmarks showed smaller ellipsoids and superior reproducibility with method 2 (Figure 3), supporting previously published results. This was attributed to the use of detailed definitions for each cross-sectional plane. In method 1, all landmarks had small ellipsoids in group B compared with group A (Figure 5). This suggests that the higher level of experience in group B was the main contributor to the favorable reproducibility. In method 2, differences in the ellipsoid volumes of Me, Pog, and Go were not significant, supporting the highly reproducible nature of method 2, even in group A with less experience (Figure 6). These results suggest that method 2 is reproducible, regardless of experience.

The present study has several limitations. All data were obtained from the results of examinations conducted under the same exposure conditions with the same machine. Image quality, which may be directly related to reproducibility, can be influenced by exposure and reconstruction conditions such as tube voltage, tube current, and voxel size. Moreover, the reduced exposure conditions contributed to the reduced exposure and reconstruction conditions such as tube voltage, tube current, and voxel size. The deteriorated reproducibility in the tooth-related landmarks was likely due to severe metal artifacts caused by dental materials. The use of special software to reduce these artifacts might help to solve this problem.

Taken together, the method proposed here requires no specific software be used and can be applied as a highly reproducible landmark identification system. However, because there is room for improvement, further study is warranted. The key is to develop an effective method to evaluate the reproducibility. Without verification of the reproducibility, data for landmark identification remain unreliable.

CONCLUSION

Based on the results in 10 clinical cases:

- The method tentatively proposed here is potentially a highly reproducible method regardless of the evaluators’ experience for identifying maxillofacial landmarks on 3D CBCT images.

REFERENCES