Reproducibility of 3 Different Tracing Methods Based on Cone Beam Computed Tomography in Determining the Anatomical Position of the Mandibular Canal

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Purpose: To investigate the reproducibility of 3 different tracing methods to determine a reliable method to define the proper anatomical position of the mandibular canal based on cone beam computed tomography (CBCT) data.

Materials and Methods: Five dentate and 5 edentate patients were selected at random from the CBCT database. Two independent observers traced both the left and the right mandibular canal using 3-dimensional image-based planning software (Procera System NobelGuide; Nobel Biocare, Göteborg, Sweden). All mandibular canals were traced using 3 different methods. Method I was based on coronal views, also known as cross-sections. Panorama-like reconstructions were the starting point for method II. The third method combined methods I and II.

Results: With respect to interobserver reliability, no significant difference (P = .34) for the various methods was observed. The reproducibility was better in edentate than in dentate jaws (P = .0015). The difference between 2 tracings was the lowest for the combined method: within a range of 1.3 mm in 95% of the course of the canal. The most obvious deviations were mainly seen in the anterior part of the canal.

Conclusions: The best reproducible method for mandibular canal tracing is the combined method III. Between observers, still a mean 95th percentile deviation threshold of 1.3 mm (SD 0.384) is noted, indicating that a safety zone of 1.7 mm should be respected. When planning surgery on CBCT-based data, surgeons should be aware of the obvious deviations located in the region of the anterior loop of the canal.

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Surgical procedures of the mandible, such as osteotomies, bone harvesting procedures, or placement of dental implants, are often involved with a possible unintentional impairment of the inferior alveolar nerve (IAN), causing a broad range in altered sensory perception.\(^1\) This may result in either transient or persistent paresthesia, anesthesia, or even disabling dysesthesia, mostly affecting the lip and chin region.\(^1\)

The mandibular nerve has a complex course. With its origin at the ganglion trigeminale, it branches into the IAN in the infratemporal fossa. At the mandibular foramen this sensitive nerve enters the lower jaw and runs in company with the mandibular vessels in the mandibular canal anteriorly, gradually crossing from a lingual to a more buccal plane. The craniocaudal and buccolingual position and the branching pattern of the neurovascular bundle differ within the mandibular body. At the mental foramen the nerve leaves the corpus mandibula, mostly after a short recurrent intrabony course, creating the so-called anterior loop. The shape, curve, and direction of this terminal segment are quite variable. In addition, the position of the mental foramen itself varies also, although it is mostly situated below the apex of the second premolar.\(^1\)\(^-\)\(^4\) Because of this considerable variation in its course, it is difficult to predict the exact position of the nerve, thus frustrating proper preoperative planning.

Nowadays panoramic radiographs are the most commonly used diagnostic tools despite their shortcomings, such as distortions and 2-dimensional visualization.\(^8\)\(^,\)\(^10\) To overcome misrepresentations of the exact position of the canal, correcting magnification factors as well as safety zones ranging from 2 to 6 mm are recommended.\(^8\)\(^,\)\(^10\)\(^,\)\(^12\) Nevertheless, conventional multislice computed tomography (CT) scans have strongly improved the precision of the preoperative assessment of the mandibular canal since both the height and width of the alveolar ridge can be measured accurately in relation to adjacent anatomical structures. A severe disadvantage of CT, however, is the relatively high radiation dose. Recently, cone beam CT (CBCT) was introduced in the field of oral implant surgery.\(^15\)\(^,\)\(^16\) The radiation dose is significantly less and both multiplanar as well as 3-dimensional reconstructions are provided. Using 3-dimensional (3D) image-based planning software, it is also feasible to mark the course of the mandibular canal at different locations. Subsequently, by interpolating these marks, the canal is visualized by creating a virtual replica. This procedure is called mandibular canal tracing. To perform such a tracing properly, a coronal or a panoramic radiographic slice, as well as the combination of both, can be used. At this moment mandibular canal tracing is a manual procedure and therefore incorporates a certain range of inaccuracy. The purpose of this study is to determine the reproducibility of the mandibular canal tracing for each of these 3 methods.

## Materials and Methods

Five dentate and 5 edentate patients were at random selected from our CBCT database, comprising both orthognathic and preimplant surgery patients. The CBCT scans were acquired using the i-CAT 3D Imaging System (Imaging Sciences International Inc, Hatfield, PA). Data from the CBCT were exported in DICOM format. In the planning software (Procera System NobelGuide; Nobel Biocare, Göteborg, Sweden), the skull and skin surfaces were segmented by thresholding.

After reconstructing the 3D model, 2 observers independently traced both the left and the right mandibular canal using the 3D image-based planning software. All mandibular canals were traced using 3 different methods. Method I was based on coronal views, also known as cross-sections, which depict the mandibular canal exclusively in a buccolingual direction (Figs 1A,B). The tracings of the mandibular canal in method II were based on panoramic-like reconstructions which visualize the mandibular canal only in an anterior-posterior direction (Figs 2A,B). The panoramic reconstruction was generated using the best fitting midline superimposed on the overall contour of the corpus mandibulae. The third method combined methods I and II. First, panoramic reconstructions were used for a quick tracing. In addition, the cross-section images were used for fine-tuning.

Tracing started with the identification of the mandibular canal. Subsequently, the center of the canal was marked. After all slices were spotted, a virtual canal was reconstructed. To calculate the inraobserver variation, the same procedure was repeated after 1 month and 2 months. Also, the time interval necessary to trace the mandibular canals was registered.

To compare the results of the 3 tracing methods, in-house software was developed using MATrix Laboratory (MATLAB, Natick, MA). This program facilitated the computation of the difference between the center of 2 tracings, using a large number of evenly distributed points (>10,000). The mandibular canal was measured from the mandibular foramen to the mental foramen. This distance was divided in 4 equal parts, representing the first (distal) segment of the mandibular canal, the second and third segment imaging the medial course of the mandibular canal, and finally the most anterior part of the virtually reconstructed tube. To illustrate the difference between the
center of 2 tracings, the 95th percentile threshold was calculated (Figs 3, 4).

Analysis of variance (ANOVA) was used to determine the effect of site (left or right), dentition (dentate or edentate), observer, and tracing method. With respect to the measurement as recorded by the 95th percentile threshold, statistical evaluation was performed using the $\chi^2$ test.

FIGURE 1. A, Example of method I, coronal view, 3D reconstruction. B, Example of method I, coronal view. The mandibular canal is visualized in a buccolingual direction.


Results

The dentate group comprised 2 men and 3 women with a median age of 23 years (range 17 to 33 yrs). The edentate patients, 3 men and 2 women with a median age of 62 yrs (range 54 to 70 yrs) had alveolar resorbtion rates, according to the Cawood and Howell classification, ranging from III to VI in the anterior and posterior part of the mandible.17

No significant difference ($P = .34$) between the 2 observers (the interobserver reliability) for all 3 tracing methods was observed. Also, no differences ($P = .61$) for tracing the left or right mandibular canal were noted (Table 1).

In the dentate jaws, using the combined method (method III), the differences between the center of 2 tracings were within a range of 1.3 mm in 95% of the course of the canal (Fig 5, Table 2). There was a statistically significant difference when method III was compared with both method I (mean 95th percentile deviation threshold: 2.4 mm) and method II (mean 95th percentile deviation threshold: 1.7 mm).

In the edentate jaws, using the combined method (method III), the differences between the center of 2 tracings were within a range of 1.2 mm in 95% of the course of the canal (Fig 5, Table 2). There was a statistically significant difference compared with both method I (mean 95th percentile deviation threshold: 1.5 mm) and method II (mean 95th percentile deviation threshold: 1.4 mm).

For methods II and III for both the dentate and edentate groups, the highest differences between tracings were noted in the fourth segment, meaning the most anterior segment of the canal, comprising the anterior loop (Table 3).

![FIGURE 3. Example of a nerve that was traced twice according to the combined method III.](image1)

![FIGURE 4. Differences between the tracings of both observers are visualized. The plots were split in 4 equal parts. For each segment the 95th percentile threshold was indicated. The most significant differences are localized in the fourth segment.](image2)

<table>
<thead>
<tr>
<th>Variable</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site: left versus right</td>
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</tr>
<tr>
<td>Tracing method (I, II, III)</td>
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<td>Dentate versus edentate</td>
<td>.0015</td>
</tr>
<tr>
<td>Observer</td>
<td>.3404</td>
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</table>

Table 1. ANALYSIS OF VARIANCE RESULTS FOR SITE, METHOD, PATIENT GROUP, AND OBSERVER

Tracing time differed significantly for all three methods ($P < .001$). The panoramic method II had a mean tracing time of 1.5 minutes. Surveying mandibular canals in dentate jaws took significantly more time ($P < .001$), compared with tracing edentate jaws using the combined method (Table 4).

**Discussion**

Many studies are devoted to the unwanted and often avoidable iatrogenic damage to the IAN. Harvesting procedures involving the ramus area may cause sensory deficits in up to 8.3%. In orthognathic procedures this sensory change is reported in up to 65.1% of the cases, and the frequency of sensitivity disturbances after placement of dental implants varies between 0% and 77.8%.

Nowadays, 3D CBCT technology enables the surgeon to determine the position of the mandibular canal more accurately. This so-called mandibular canal tracing technique visualizes the mandibular canal and is helpful as well in preoperative assessment as in surgical planning.

On a coronal slice, as used in method I, the canal is visualized as a tiny circle, discernible from the adjacent trabecular bone marrow by a small radiopaque line, the cortical wall of the mandibular canal. However, it must be realized that this wall is discontinuous, especially toward the mental foramen. As a consequence, the opaque outline in this region is often inexplicit or even absent. This might contribute to the observation that method I is the least reproducible, showing a mean 95th percentile deviation threshold of 2.4 mm for dentate and 1.5 mm for edentate mandibles. The incomplete bony wall in combination with the unpredictable recurrent course of the mandibular canal in the most anterior segment explains why the largest deviations are found in the anterior loop region.

On the panoramic reconstructions in method II, an artificial segment of the mandibular canal is represented. This provides a clear view of the tubular bony structures, which makes it easy to distinguish the canal from the surrounding cancellous bone. The mandibular canal is only partially visualized because the panoramic reconstruction is generated on the best-fitting midline superimposed on the contour of the mandible, thus creating a midline image with additional parallel views. The mandibular canal starts at the mandibular foramen, which is located at the lingual side of the ramus and then proceeds consecutively to the buccally located mental foramen. In this way, the canal shifts gradually from lingual to a more buccal plane, whereas the panoramic slices represent only

| Table 2. MEAN 95TH PERCENTILE DEVIATION THRESHOLD AND STANDARD DEVIATION (SD) |
|---------------------------------|----------|----------|----------|----------|
|                                 | Dentate  | Edentate | Dentate  | Edentate |
| Method I                        | 2.4 0.885| 1.5 0.399| 2.4 0.885| 1.5 0.399|
| Method II                       | 1.7 0.500| 1.4 0.427| 1.7 0.500| 1.4 0.427|
| Method III                      | 1.3 0.384| 1.2 0.399| 1.3 0.384| 1.2 0.399|

Data based on analysis of variance.

<table>
<thead>
<tr>
<th>Table 3. PROBABILITY OF EXCEEDING THE THRESHOLD IN THE ANTERIOR LOOP REGION (FOURTH SEGMENT)</th>
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<tbody>
<tr>
<td>$P$ Value</td>
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<tr>
<td>Edentate</td>
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<tr>
<td>Method II</td>
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Data based on chi-square test.

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<th>Table 4. TRACING TIME (IN MINUTES) PER SESSION FOR DENTATE AND EDENTATE PATIENTS</th>
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<tr>
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<tr>
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<td>Session 2</td>
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Data based on analysis of variance.
those images parallel to the midline. This results in distinct buccolingual steps in the tracings. Visualizing the whole tube in 1 plane would be more accurate. However, this requires an extra step, ie, a reconstruction that precisely follows the course of the canal and therefore passes both the lingula and the mental foramen. The reproducibility of mandibular canal tracing is significantly better for method II compared with method I.

The present study clearly shows that the most reproducible method of the mandibular canal tracing is the combined method III, thus using both cross-sectional images (method I) and the panoramic slices (method II). For a quick overview, tracing of only the panoramic reconstruction is sufficient. However, by also adding information of the cross-sections, optimal fine-tuning is achieved. By contrast, this method also is the most time consuming (~5 minutes).

In contrast to the dentate jaws, the mandibular canal in edentate jaws is free of neighboring teeth, resulting in a more undisturbed reconstruction. This phenomenon might explain the significantly better \( P = .0015 \) reproducibility in edentate jaws compared with dentate jaws.

With respect to the use of orthopantomograms in preventing IAN damage, some guidelines have been proposed. For example, instead of a nerve block or general anesthesia, the use of local infiltration anesthesia is advocated, enabling the patient to sense arising damage to the IAN. Also, the incorporation of a safety zone between the dental implants and the nerve of at least 1 to 2 mm is suggested. In the anterior loop region, even a distance of 6 mm to the mental foramen is promoted. Also, a correct magnification factor is essential to reduce the limitations of 2-dimensional radiographies. Fortunately, CBCT images are true representations, making this implementation unnecessary.

Because the mean 95th percentile deviation threshold is 1.3 mm (SD 0.4 mm) in the dentate and 1.2 mm (SD 0.4 mm) in the edentate mandibles using the combined method, planning a safety zone of 1.7 mm is recommended. At first glance, this equals the range as recommended using orthopantomograms. However, there is a significant difference. In orthopantomograms, only the craniocaudal position of the mandibular canal is defined; in CBCT, the buccolingual location of the canal is also taken into account. Moreover, in the anterior loop region, not the mental foramen but the actual position of the canal is defined.

Obviously, IAN damage cannot only be prevented by optimal radiographic representation of the course of the canal. The surgical skill is the other decisive factor in the risk of nerve damage. Despite perfect information about the exact position of the mandibular canal, a surgeon can nevertheless damage the IAN, eg, by placing implants in the mandibular canal or by drilling into the roof of the canal. To bypass this shortcoming or even to upgrade surgical skills, guided implant surgery is currently advocated. With the support of templates, virtually planned implants can be exactly positioned in the patient, thereby safeguarding the IAN. However, because of the limitations of the different tracing methods, a safety zone of 1.7 mm should be respected in all directions when planning surgery on CBCT-based data. Surgeons should also be aware of the obvious deviations located in the region of the anterior loop of the mandibular canal.

References