

# Accuracy of Cone Beam Computerized Tomography and a Three-Dimensional Stereolithographic Model in Identifying the Anterior Loop of the Mental Nerve: A Study on Cadavers

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The objective of this ex vivo cadaver study was to determine the accuracy of cone beam computerized tomography (CBCT) and a 3-dimensional stereolithographic (STL) model in identifying and measuring the anterior loop length (ANLL) of the mental nerve. A total of 12 cadavers (24 mental nerve plexus) were used for this study. Standardized CBCT scans of each mandible were obtained both with and without radiographic contrast tracer injected into the mental nerve plexus, and STL models of the two acquired CBCT images were made. The ANLL were measured using CBCT, STL model, and anatomy. The measurements obtained from the CBCT images and STL models were then analyzed and compared with the direct anatomic measurements. A paired sample *t* test was used, and *P* values less than .05 were considered statistically significant. The mean difference between CBCT and anatomic measurement was 0.04 mm and was not statistically significant (*P* = .332), whereas the mean difference between STL models and anatomic measurement was 0.4 mm and was statistically significant (*P* = .042). There was also a statistical significant difference between CBCT and the STL model (*P* = .048) with the mean difference of 0.35 mm. Therefore, CBCT is an accurate and reliable method in determining and measuring the ANLL but the STL model over- or underestimated the ANLL by as much as 1.51 mm and 1.83 mm, respectively.

**Key Words:** cone beam computerized tomography, anterior loop length, stereolithographic model, mental foramen, overestimate, underestimate, safety margin, mental nerve

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## INTRODUCTION

Implant dentistry has evolved over the years and has become a predictable treatment modality.<sup>1</sup> Thorough preoperative planning of implant treatment is a prerequisite for a successful treatment outcome.<sup>2</sup> This requires a comprehensive knowledge of anatomic appearances and variations.<sup>3-5</sup> Treatment concepts for the edentulous mandible using removable implant

overdentures or fixed implant bridges involve placement of 2–5 implants in the interforaminal area.<sup>6</sup> The crucial position of the most distal left and right implants is limited and determined by the position of the mental foramen and its neurovascular bundle, which could involve the anterior loop of the mental nerve.<sup>7,8</sup>

Sensory disturbance and altered sensation resulting from injury or violation of the anterior loop of the mental nerve<sup>9,10</sup> have been observed after placement of endosseous implants in the interforaminal region.<sup>11</sup> Several studies have reported an incidence of transient altered sensation ranging from 8.5% to 24%.<sup>11–14</sup> A 7% incidence of permanent sensory disturbance in the lower lip has also been reported after implant insertion in the interforaminal area.<sup>11</sup> When the anatomic anterior loop is not identified and subsequently injured, surgical complications arise.<sup>15–17</sup> In addition, the incidence of anterior loop varies.<sup>18</sup> In dissected cadavers, Bavitz et al<sup>19</sup> found anterior loop in 11%, while Rosenquist<sup>8</sup> detected it in 24%. Mardinger et al<sup>20</sup> reported anterior loop in 28% of subjects, while Solar et al<sup>7</sup> and Neiva et al<sup>21</sup> reported anterior loop in 60% and 88%, respectively. To avoid injury to the mental nerve, clinicians have advocated varying safety-margin distances from the mental foramen. They recommended placing implants 1 mm,<sup>19</sup> 3 mm,<sup>11</sup> 4 mm,<sup>22</sup> and 6 mm<sup>7</sup> anterior to the foramen.

Because of conflicting reports and diverse recommendations, a variety of diagnostic methods and techniques have been used to detect and measure the anterior loop. These include surgically exposing the mental nerve and probing the mental foramen, using panoramic and periapical radiographs, and most recently, using cone beam computerized tomography (CBCT) and stereolithography. Surgically exposing the mental foramen before implant osteotomy would reduce the incidence of violation of the mental nerve. A blunt probe (Naber's probe) is gently inserted into the foramen to determine the presence of the anterior loop.<sup>21</sup> However, the opening on the mesial aspect of the foramen leading to the incisive region and an anterior loop feel similar, and it is not possible to differentiate between the structures.<sup>23</sup>

Different radiographs have been used to determine the presence and extent of anterior loop.<sup>9,19,20,22–25</sup> However, the dependability of panoramic and periapical radiographs in determin-

ing the anterior loop is unreliable.<sup>20,22,24</sup> It was determined that clinicians should not rely on panoramic and periapical radiographs to identify the anterior loop.<sup>20,22,24</sup> On the other hand, with the emergence of three-dimensional (3D) imaging in the field of dentistry,<sup>26</sup> CBCT seems to be a very promising diagnostic method for determining the anterior loop length (ANLL) of the mental nerve.<sup>27</sup> Stereolithography can also be used to determine the presence and extent of the anterior loop through fabrication of a 3D model, although it is still dependent on the data acquired from the CBCT. In addition, 3D models can be used for treatment planning, communication, guided surgery, identification of anatomic landmarks (ie, mental plexus), and fabrication of prostheses.

Overall, there are diverse recommendations that reflect controversies associated with the prevalence and extent of the anterior loop of the mental nerve. Thus, the purpose of the study was to determine the accuracy of CBCT (i-CAT, Imaging Sciences, Hatfield, Pa) and a 3D stereolithographic (STL) model in identifying and measuring the anterior loop of the mental nerve in comparison to direct anatomic measurements on cadavers.

## MATERIALS AND METHODS

A total of 12 mandibles (24 mental nerve plexus) were used for this study. The specimens came from bodies that had been donated for research and were acquired through the Loma Linda University Department of Anatomy. There were 6 men and 6 women, and the ages ranged from 52 to 69 years old at the time of death. Three of the male and 3 of the female specimens had teeth at least from the premolar to premolar in the mandible (8–15 teeth). The 6 remaining specimens were completely edentulous. Cadavers that had history of trauma, surgical procedures, or disorders in the mandible were excluded from the study. In each specimen, the mandible was surgically detached from the cadaver and completely exposed, with careful emphasis on the mental neurovascular bundle plexus.

### **For CBCT with no tracer**

For the CBCT with no tracer (CBCT[NT]), the inferior margin of each mandible was mounted in a custom-made polyvinylsiloxane (Coltène/Whaledent Inc,

Cuyahoga Falls, Ohio) platform. It was then secured to the imaging base of the i-CAT machine and a scan was obtained. The customized platform ensured that the mandible was positioned the same way for the second CBCT, which was a CBCT with a dye tracer (CBCT(T)).

#### ***For dye tracer (Omnipaque)***

A 15-mm × 10-mm rectangular osteotomy window, at least 15 mm distal to the mental foramen, was created. A round bur, spoon excavator, and piezoelectric machine were used to remove the buccal cortical and spongy bone in order to locate and identify the inferior alveolar nerve. With the use of a 1-mL 28G insulin syringe (Becton Dickinson and Company, Franklin Lakes, NJ), a radiographic iodinated contrast dye tracer (Omnipaque, iohexol 300 mg/mL, GE Healthcare Inc, Princeton, NJ) was injected into the nerve sheath of the inferior alveolar nerve in an anterior direction toward the mental nerve plexus.

#### ***CBCT(T)***

A second CBCT(T) scan of the mandible with the dye tracer was obtained at exactly identical position as the first CBCT(NT) using the same custom-made platform. This was done for all the 12 mandibles (24 mental plexus).

#### ***For the 3D STL model***

The 2 acquired computerized tomographic images of each mandible from the i-CAT unit were stored using Dicom as a medical image file format. It was then sent to the dental imaging company to create anatomic virtual 3D STL augmented models of the mandible with detailed neural pathway of the mental foramina bundle plexus.

### **MEASUREMENTS**

#### ***CBCT(NT) and CBCT(T)***

On the CBCT(NT) image, line A was defined as the plane that is perpendicular to the buccal surface of the mandible as it passes through the anterior-most margin of the mental foramen, and line B was defined as the plane that is perpendicular to the buccal surface of the mandible as it passes through the anterior-most extension of the anterior loop of the mental nerve (Figure 1). The ANLL was defined as the shortest distance from line A to line B. And

for the CBCT(T), the measurements were taken in exactly the same manner and were designated as line A(T), line B(T), and ANLL(T) (Figure 2). All measurements from the CBCT were obtained using the multiplanar reconstruction screen of the i-CAT unit. The acquisition parameters were 120 KV—24 mA at 20-second scan time.

#### ***Anatomic***

The buccal cortical and spongy bone of the hemimandibles just below the mental foramen was removed using initially a round bur, which was switched to a piezoelectric machine and spoon excavator. This exposed the mental neurovascular bundle plexus, which includes the mental nerve, anterior loop, and incisive branches. Direct measurement of the ANLL was performed. Line A (DM) was defined as the plane that is perpendicular to the inferior border of the mandible (IBM) as it passes through the anterior-most margin of the mental foramen. Line B (DM) was defined as the plane that is perpendicular to the IBM as it passes through the anterior-most extension of the anterior loop. The ANLL (DM) was defined as the shortest horizontal distance from Line A (DM) to Line B (DM) taken at the anterior-most margin of the mental foramen (Figure 3).

#### ***3D STL model***

The buccal surface of the 3D STL was flattened at the area of mental neurovascular bundle plexus to facilitate and ensure accuracy of measurement. We used the same measurement procedure as was used for the anatomic. However, planes were designated as line A (STL), line B (STL), and ANLL (STL) (Figure 4).

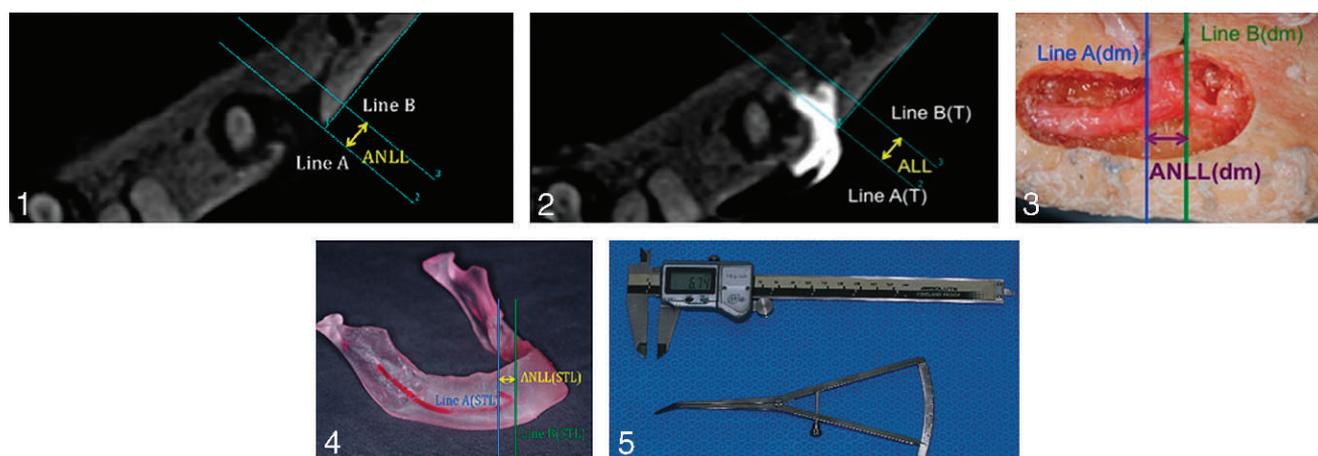
#### ***Measuring devices***

The anatomic and STL model measurements of the ANLL were carried out using Castroviejo 40 mm angled (H & H Co, Ontario, Calif) and Vernier (Mitutoyo, Kawasaki, Japan) measuring calipers (Figure 5).

#### ***Data collection***

All clinical examinations and data collections were performed by one examiner. The presence or absence of anterior loop was also determined.

Measurements of the ANLL were made (in millimeters) from the following (Figures 6 and 7):



**FIGURES 1–5.** **FIGURE 1.** The cone beam computerized tomography with no tracer (CBCT[NT]) measurement of the anterior loop length (ANLL). **FIGURE 2.** The CBCT with a dye tracer (CBCT[T]) measurement of the ANLL. **FIGURE 3.** Anatomic measurement of the ANLL. **FIGURE 4.** The stereolithographic (STL) model measurement of the ANLL. **FIGURE 5.** Vernier and Castroviejo calipers.

1. CBCT(NT)
2. CBCT(T)
3. STL model with no tracer (STL[NT])
4. STL model with tracer (STL[T])
5. Direct anatomic dissection

The mean value of the ANLLs was then calculated as shown in Figure 8.

### Statistical analysis

Twenty-three anterior loop measurements were made for each group, totaling 115 for the 5 groups. All calculations were processed with SPSS statistical software (version 16.0, SPSS Inc, Chicago, Ill). Means and standard deviations were calculated for all measured values. A paired sample *t* test was used, and *P* values less than .05 were considered statistically significant. The Cronbach alpha test was used for reliability of measurement.

### Measurement reliability

The reliability of measurements obtained was evaluated by randomly selecting specimens used in the study and measuring the ANLL using the methods previously described.

## RESULTS

Surgical dissections of the 12 mandibles were uneventful, except for 1 hemimandible in which the mental nerve was accidentally pulled. It was then excluded from the study, giving a total of 23

mental nerve plexus. The anatomic measurement in this study is considered the control.

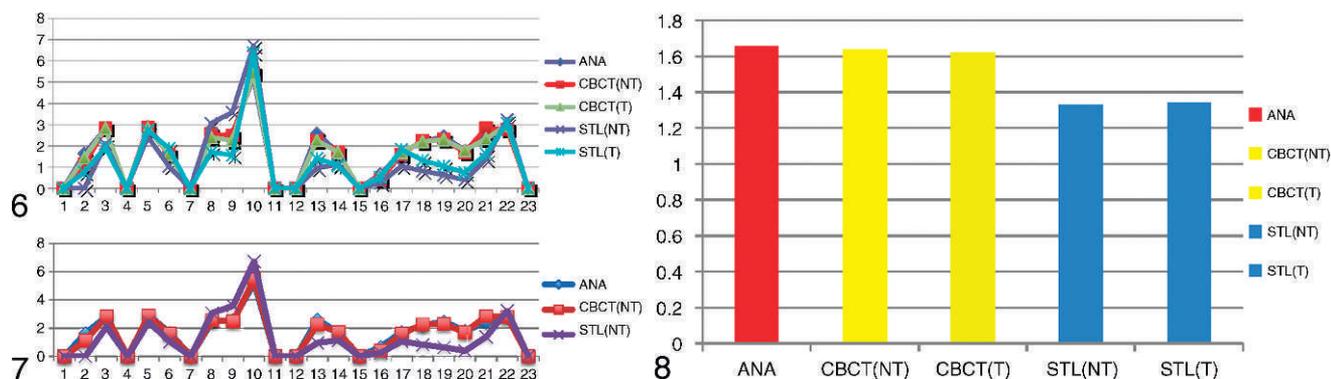
### Comparison between anatomic measurement and CBCT(NT) and CBCT(T)

For the anatomic measurements of the 23 ANLL obtained from 12 mandibles, the mean value and SD were 1.64 mm and 1.37 mm, respectively. For the CBCT(NT) measurements with the same sample, the mean value and SD were 1.60 mm and 1.41 mm, respectively. For the CBCT(T), the mean value and SD were 1.59 mm and 1.38 mm, respectively, as shown on Table 1. There were no statistically significant differences in the ANLL between the CBCT(NT) and anatomic measurements ( $P = .332$ ) and between the CBCT(T) and anatomic measurements ( $P = .102$ ), as shown on Table 2.

For clinical relevance, the mean difference between anatomic measurement and CBCT(NT) was 0.036 mm, as shown on Table 3, and the range of over- and underestimation of the ANLL by CBCT(NT) was only 0.41 mm and 0.51 mm, respectively.

### Comparison between anatomic measurement and STL(NT) and STL(T)

For the anatomic measurements of the 23 ANLL from 12 mandibles, the mean value and SD were 1.64 mm and 1.37 mm, respectively. For the STL(NT) measurements with the same sample, the mean value and SD were 1.25 mm and 1.65 mm, respectively, while the STL(T) measurements were



**FIGURES 6–8.** **FIGURE 6.** Linear graph showing the anterior loop length measurement of the 5 groups: anatomic (ANA), cone beam computerized tomography with no tracer (CBCT[NT]), CBCT with tracer (CBCT[T]), stereolithographic model with no tracer (STL[NT]), STL with tracer (STL[T]). **FIGURE 7.** Linear graph showing the anterior loop length of ANA, CBCT(NT), and STL(NT). **FIGURE 8.** Bar graph showing the mean value of the 23 anterior loop lengths from the 5 groups: ANA, CBCT(NT), CBCT(T), STL(NT), STL(T).

1.29 mm and 1.44 mm, respectively, as shown in Table 1. There are statistically significant differences in the ANLL between the STL(NT) and anatomic measurements ( $P = .042$ ) and between the STL(T) and anatomic measurements ( $P = .011$ ), as shown in Table 2.

For clinical relevance, the mean difference between the anatomic measurement and STL(NT) was 0.385 mm, as shown in Table 3. However, the STL(NT) over- and underestimated the ANLL by as much as 1.51 mm and 1.83 mm, respectively.

### Comparison between CBCT(NT) and STL(NT) measurements

The mean difference between CBCT(NT) and STL(NT) was 0.348 mm. The difference is statistically significant at  $P = .048$  (Table 2).

There were no statistically significant differences in the ANLL measurements between CBCT(NT) and CBCT(T) ( $P = .860$ ) and between STL(NT) and STL(T) ( $P = .793$ ) (Table 2).

### DISCUSSION

To the best of our knowledge, no study in the literature has compared the accuracy of CBCT and a 3D STL model in identifying and measuring the ANLL of the mental nerve. Therefore, this article addresses the issue by validation study in human cadavers that were used to mimic the in vivo situation.

In the treatment of mandibular arch in the interforaminal area involving 4–5 implants, the

cantilever length of the fixed complete denture prosthesis is dictated by the position of the most distal implant closest to the mental foramen, with special emphasis on the anterior loop if present.<sup>6</sup> Additionally, in partially dentate patients, in whom implants are placed in the premolar and molar areas, the mental nerve and its neurovascular bundle become a critical surgical reference point during treatment planning.

Studies have been done to identify and measure the anterior loop using surgical cadaver dissection.<sup>7,8,19–22</sup> However, those studies provided divergent results that perhaps could be attributed to the different criteria used to define ANLL, different surgical dissection technique, and diverse anatomic morphology of patients. Most of the studies used round bur and spoon excavator to expose the mental neurovascular bundle. In this study, piezo-electric machine was used to minimize the displacement of the nerve plexus. Furthermore, only one study<sup>27</sup> was found that directly correlated CBCT scans of the ANLL with direct surgical cadaver dissection. They used the mandibular incisive canal (MIC) to determine the most anterior extension of the loop. However, in the cadaver study by Obradovic et al,<sup>28</sup> MIC were detected in only 92% of dentate subjects and 31% of edentulous subjects. In CBCT, Jacobs et al<sup>29</sup> detected MIC in only 93% of subjects, while Pires et al<sup>30</sup> found it only in 83%. In this study, we used the anterior-most extension of the mental nerve in determining the loop, regardless of the position of the incisive nerve.

Several authors<sup>5,7,8,11,19,20,22</sup> have recommended

TABLE 1

Descriptive statistics results for the 5 groups\*

	Minimum	Maximum	Mean	SD
ANA	0.00	5.22	1.6352	1.36639
CBCT(NT)	0.00	5.44	1.5983	1.40590
CBCT(T)	0.00	5.44	1.5926	1.37562
STL(NT)	0.00	6.73	1.2500	1.64822
STL(T)	0.00	6.38	1.2852	1.43823

\* ANA indicates anatomic; CBCT, cone beam computerized tomography; STL, stereolithographic model; NT, no tracer; T, with tracer.

various standard safety margins, ranging from 1 to 6 mm using the anterior-most portion of mental foramen as a reference guide. However, using the mental foramen as a guide without determining the length of the anterior loop would result in either placing the implant too far mesial from the mental foramen or, worse, violating the mental nerve. For instance, in the cadaver study by Uchida et al,<sup>27</sup> they examined 140 hemi-mandibles and found that the ANLL ranged from 0 to 9 mm. Following the 1-mm safety margin recommended by Bavitz et al<sup>19</sup> would definitely violate the mental nerve if the ANLL is more than 1 mm. On the other hand, the 6-mm safety margin recommended by Solar et al<sup>7</sup> could position the implant too far mesial from the mental foramen, especially in the absence of anterior loop. Meanwhile, Neiva et al<sup>21</sup> identified the loop by probing the mesial cortical wall of the mental canal in 22 cadavers. However, Misch<sup>23</sup> cautioned that the opening on the mesial aspect of the mental foramen leading to the incisive canal often feels the same as the anterior loop. Therefore, arbitrarily recommending a standard safety distance from the mental foramen should not be advocated because of the varying length of the anterior loop.

Instead, the most distal implant should be placed at least 2 mm anterior to the anterior-most portion of the loop to allow for surgical error. In this case, the anterior loop becomes the landmark rather than the foramen itself.<sup>23</sup> However, when the size of incisive branch is large, as pointed out by Hirsch and Branemark<sup>31</sup> as well as Kohavi and Bar-Ziv,<sup>32</sup> special consideration should be taken because of the possibility of engaging the incisive branch and stretching the inferior alveolar nerve accompanied by interference with the vascular supply and more or less serious dysfunction. In this

TABLE 2

Significance (*P* value) for the 5 groups†

	ANA	CBCT(NT)	CBCT(T)	STL(NT)	STL(T)
ANA		.332	.102	.042*	.011*
CBCT(NT)	.332		.860	.048*	.017*
CBCT(T)	.102	.860		.055	.011*
STL(NT)	.042*	.048*	.055		.793
STL(T)	.011*	.017*	.011*	.793	

\* Statistically significant.

† ANA indicates anatomic; CBCT, cone beam computerized tomography; STL, stereolithographic model; NT, no tracer; T, with tracer.

case, the safety margin should be increased to at least 4 mm.

### **CBCT and anatomic measurement**

With today's technology, and particularly the emergence of 3D CBCT, it would be irresponsible to rely on panoramic and periapical radiographs in determining the length of the anterior loop of the mental nerve. Several studies<sup>9,19,20,22–25</sup> have shown the unreliability of radiographs because of the high percentage of false-positive and false-negative findings. On the contrary, CBCT has proven its reliability and accuracy<sup>30–36</sup> and was used in this study. We found that the multi-planar reconstruction screen of the i-CAT unit has a high resolution and is a good source to measure the ANLL.

As shown in this study, the mean differences between CBCT and anatomic measurement obtained from 23 hemimandible samples is less than 0.04 mm. It is very similar to the 0.05 mm results found in the study by Uchida et al<sup>27</sup> in 2009, although they used only 7 specimens. This present ex vivo study demonstrates the ability of CBCT imaging to offer a reliability data set for identifying and measuring the ANLL.

### **The 3D STL model and anatomic measurement**

Stereolithography is an additive manufacturing technology for producing models made of curable photopolymer resin in ultraviolet laser to build parts a layer (0.10–0.15 mm) at a time. It is fabricated on the basis of CBCT scan data with a typical accuracy of 0.1 to 0.2 mm.

However, in the study by Barker et al<sup>37</sup> on accuracy of the STL model of human anatomy, they compared the skull measurement with its STL replicas and found an absolute mean difference of

TABLE 3

Paired samples test showing differences between groups\*

Pair No.	Paired Samples	Paired Differences	
		Mean	SD
1	Anatomic measurement – CBCT without tracer	0.03696	0.17857
2	Anatomic measurement – CBCT with tracer	0.04261	0.11970
3	Anatomic measurement – STL model without tracer	0.38522	0.85501
4	Anatomic measurement – STL model with tracer	0.35000	0.60712
5	CBCT without tracer – CBCT with tracer	0.00565	0.15204
6	STL model without tracer – STL model with tracer	-0.03522	0.63699

\* CBCT indicates cone beam computerized tomography; STL, stereolithographic model.

0.85 mm, with a maximum of 4.62 mm and a minimum of 1 mm. It has an accuracy of 97.7%–99.12%. Another study by Shahbazian et al,<sup>38</sup> where they compared the accuracy of a 3D computer model and STL replica of a segmented tooth to a real tooth, showed an accuracy of 0.25 mm but a deviation error of up to 2.5 mm in some areas. Van Steenberghe et al,<sup>39</sup> on the other hand, compared the deviation between planned and installed implants using an STL surgical guide and found a maximum linear deviation of 2.7 mm. However, the deviation error could have been influenced by the fixation of the surgical guide rather than the inaccuracy of the STL model itself.

In the current study, the anatomic measurement is considered the control and the basis for all comparisons. Its mean difference with the STL measurements of the ANLL is <0.4 mm. The STL model overestimated and underestimated the ANLL by as much as 1.51 mm and 1.83 mm, respectively. Overestimation of the ANLL would translate into placing the implant too far mesial from the mental foramen, whereas underestimation would potentially result in violating the mental nerve. The accuracy of STL models depends on several factors, namely manufacturing steps, data acquisition and transfer, accuracy and suitability of original data, residual polymerization, operator's interpretation, equipment, and examination parameters to name a few.<sup>40</sup> Any of these factors could have influenced the discrepancy of the STL model found in our study.

The use of radiographic tracer (Omnipaque) enhanced the visibility and identification of the mental nerve plexus. Omnipaque is commonly used in medicine for intrathecal administration and in contrast enhancement for computerized tomogra-

phy. In this study, each specimen with tracer was treated independently from the original specimen without tracer. It gave the 3D modeling company a different perspective of each specimen, which resulted in a slightly more accurate 3D STL model. Although it made identification and measurement of the ANLL easier, there was no statistically significant difference between the measurements of the 2 CBCT groups (with and without tracer) and between the 2 STL groups (with and without tracer). It showed that both measurements were similar, and the use of tracer did not affect the results in the CBCT and STL groups. The STL model with tracer still over- and underestimated the ANLL by as much as 1.16 and 1.42 mm, respectively.

In summary, several clinicians have given guidelines and recommendations on implant placement anterior to the mental foramen from a standard safety margin to probing of the mental foramen. It is the authors' opinion that the CBCT is the best method and a prerequisite in identifying the ANLL. From a radiologic point of view, CBCT is the primary preoperative examination for the presence and extent of the ANLL. It provides an unparallel depiction of the complex anatomic topography of the mental nerve plexus. And, the most accurate way to place an implant anterior to the mental foramen is to determine the ANLL through CBCT, surgically exposing the mental foramen and following a safety margin distance from the anterior most portion of the anterior loop.

### CONCLUSION

Identifying and measuring the anterior loop of the mental nerve is crucial when placing implants in the interforaminal region to prevent complication and injury to the mental neurovascular bundle plexus.

This ex vivo study demonstrates the ability of CBCT images, compared with the control anatomic measurement, to offer an accurate and reliable data set for identifying the ANLL of the mental nerve. On the other hand, the 3D STL model tends to over- and underestimate the ANLL by as much as 1.51 mm and 1.83 mm, respectively. These results lead to the following recommendations:

- 1) CBCT is a prerequisite in identifying and measuring the ANLL.
- 2) A fixed distance from mental foramen is not a safe guideline when placing an implant anterior to the mental foramen. Mental foramen can be used as a reference point only after determining ANLL from CBCT.
- 3) At least a 2-mm safety margin from the anterior-most portion of the loop is recommended.
- 4) A 4-mm safety margin is recommended when a large incisive nerve is present.
- 5) At this point in time, the 3D STL model can be used with caution and awareness that it tends to overestimate or underestimate the ANLL.

#### ABBREVIATIONS

- 3D: three-dimensional  
 ANLL: anterior loop length  
 CBCT: cone beam computerized tomography  
 CBCT(NT): CBCT with no tracer  
 CBCT(T): CBCT with a tracer  
 IBM: inferior border of the mandible  
 STL: 3D stereolithographic image  
 STL(NT): 3D stereolithographic image with no tracer  
 STL(T): 3D stereolithographic image with a tracer

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