**Influence of Implant Diameter and Taper on Virtual Implant Placement in the Maxillary Central Incisor Position: A CBCT Analysis**

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**Purpose:** This study aimed to assess the influence of implant diameter and taper on the proximity of virtually planned maxillary central incisor implants to the nasopalatine canal and adjacent anatomical structures. **Materials and Methods:** Virtual implant planning was performed in the maxillary central incisor position. The distance between the implant and the incisive canal (IC) and the thickness of the surrounding buccal and palatal bone walls were measured. Implants were categorized as having an exposed implant surface, thin bone, or moderate/thick bone. Measurements were repeated for regular-/narrow-diameter and parallel/tapered implants. **Results:** A total of 60 patients were included, and 240 implants (60 of each type: 3.3-bone level [BL], 3.3-bone level tapered [BLT], 4.1-BL, and 4.1-BLT) were planned. The percentages of implants with between 0 and 0.5 mm of remaining bone in the coronal aspect of the IC were 31.6% for 4.1-BL/BLT and 6.6% for 3.3-BL/BLT (P < .001). The frequency of sites that required bone augmentation at the coronal facial aspect (< 1 mm) was 52.6% and 33.9% for 4.1-BL/BLT and 3.3-BL/BLT, respectively. At the apical portion, the percentages of sites requiring bone augmentation at the facial aspect were 59.9%, 49.9%, 31.6%, and 23.3% for 4.1-BL, 3.3-BL, 4.1-BLT, and 3.3-BLT, respectively (P < .001). **Conclusion:** The proximity of the nasopalatine canal is often < 0.5 mm from regular-diameter virtually planned implants at the most coronal aspect in the maxillary central incisor position. In these situations, the selection of narrow-diameter implants significantly lowers the incidence of implant exposure and the need for additional management of the nasopalatine canal and also results in greater residual buccal and lingual bone thicknesses surrounding the implant. As expected, tapered implants reduced the risk of implant exposure through the buccal cortex at the apical aspect. Int J Oral Maxillofac Implants 2022;37:525–532. doi: 10.11607/jomi.9367

**Keywords:** diagnostic procedure, epidemiology, single implant, virtual reality

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When replacing missing maxillary incisors with dental implants, the nasopalatine canal and its incisive foramen are critical anatomical structures that need to be accounted for during implant planning and surgery.¹–³ Fenestration or dehiscence into the nasopalatine canal and incisive foramen is to be avoided, as it can increase risk of implant failure, bleeding, and neurosensory disturbances.⁴,⁵ Lack of circumferential bone from dehiscence or fenestration in this area, with exposure of the implant surface into the neurovascular bundle and zone of supracrestal tissue complex, may result in failure of osseointegration or long-term biologic complications and increase the risk of peri-implantitis.⁶,⁷ The dimensions and location of the nasopalatal canal and its variations have previously been assessed using CBCT and anatomical cadaver studies.²,⁸–²⁰ The canal is located in the midline of the palate just posterior to the maxillary central incisors. It typically begins as two openings in the nasal floor on either side of the nasal septum, which merge and exit into the anterior

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palatal mucosa as one incisive foramen. However, several variations have been reported, such as a single canal, two parallel adjacent canals, variations of the typical Y-shaped canal, and additional supernumerary canals. The canal contains the descending palatine artery and nasopalatine (incisive) nerve. The mean diameter of nasal openings was found to be 3.49 mm, with a wider incisive foramen of 4.45 mm creating a funnel shape, with an average length of the canal being 10.99 mm. The nasopalatine canal may also enlarge following extraction of the adjacent central incisors, with larger canals found on average in patients missing those teeth.

Bone regeneration into the nasopalatine canal has been reported with lateralization of the canal contents at the level of the foramen in situations where the nasopalatine canal encroaches on the implant position or in more invasive approaches, such as severing the neurovascular bundle, removal of the contents, and obliteration of the canal or implant placement directly into the nasopalatine canal. These procedures are technically challenging and significantly increase patient morbidity and risks. Where significant disruption to the nasopalatine canal and its contents are expected, consideration should be given to alternative implant sites or tooth replacement options.

It is well known that ridge alterations after tooth extraction occur mostly on the labial aspect, with a reduction of ridge width by up to 50% during the first year following tooth extraction. This has led to increased use of reduced-diameter implants and slightly more palatal positioning of implants to minimize the risk of esthetic complications. It is generally recommended that 1 to 2 mm of circumferential bone be required for long-term peri-implant tissue health and stability. The resorption of labial bone, the palatal positioning of implants, and the recommendation for 1 to 2 mm of circumferential bone can make positioning the implant in the central incisor position relative to the nasopalatine canal challenging.

The selection of appropriate implant size and morphology can also play a role in reducing the need for bone augmentation or the risk of entering into adjacent anatomical structures. While many publications have reported on the relationship between tapered implants with increased implant insertion torque and the effects on osseointegration, the benefits of a tapered implant in relation to the avoidance of anatomical structures and reduced need for bone augmentation has not been examined. The use of narrow-diameter implants may also aid in minimizing risks to adjacent anatomical structures while maximizing the remaining peri-implant circumferential bone thickness and its biologic capacity, as well as reducing the need for bone augmentation procedures. Despite the reduced surface area for osseointegration and the mechanical strength of narrow-diameter implants, the clinical outcomes have been reported to be comparable to standard-diameter implants when used in the appropriate indications.

Conventional radiographs do not often accurately represent the size and proximity of the nasopalatine canal to the planned implant site. This requires careful intraoperative assessment by raising a palatal flap to expose the incisive foramen and to probe the inner walls of the canal to determine the shape of the canal and whether it is deemed to be in close proximity. Intraoperative decision-making would then dictate the position, diameter, shape, and length of the implant, as well as the need for any adjunctive procedures such as lateralization or obliteration of the canal with concurrent or staged bone regeneration procedures. However, reducing the number of decisions made intraoperatively can help reduce the risk of medical errors and adverse outcomes associated with decision fatigue.

When indicated, CBCT is used extensively for dental implant treatment planning as an adjunct to a clinical oral examination or in addition to plain film radiography. CBCT provides a 3D overview of the available bone anatomy and adjacent structures. Ideally, this should also be combined with a diagnostic tooth arrangement and comprehensive virtual implant planning to provide the relationship between the ideal prosthetic tooth position, the proposed implant position, its surrounding bone, and any critical anatomical structures. The most appropriate implant shape, diameter, length, and position, as well as any need for adjunctive regenerative procedures, can be determined preoperatively. In situations where the proximity of the nasopalatine canal is of concern, CBCT-guided implant surgery may also be of benefit to minimize the risk of entering into this structure.

Although the anatomy of the nasopalatine canal and adjacent labial bone crest measurements have been previously reported, no previous studies have utilized virtual implant planning to determine its impact on implant placement and treatment planning. The aim of this retrospective cross-sectional CBCT anatomical analysis was to assess the proximity of the incisive canal (IC) and buccal and lingual cortices to the ideal prosthetically planned implant positions and the influence of implant size on reducing the risk of fenestration/dehiscence.

MATERIALS AND METHODS

Following approval from the Harvard Medical School and Harvard School of Dental Medicine Committee on Human Studies (IRB17-0142), CBCTs of patients contemplating implant therapy at the Harvard School of
Dental Medicine were screened to meet the following inclusion criteria:

- Missing single maxillary central incisor
- CBCT taken at least 6 months after tooth extraction
- CBCT field of view included the entire clinical crowns of the adjacent teeth and extended beyond their root apices
- CBCT of sufficient diagnostic quality and free from significant beam hardening or artifacts from adjacent restorations

All CBCTs were obtained using the same CBCT machine (i-CAT Platinum, Imaging Sciences) and were taken by a single radiologist (B.F.). The exposure parameters were: kVp = 120, mA = 5, mAs = 18.54, 8.9 seconds, and 0.3 voxels. DICOM (Digital Imaging and Communications in Medicine) files exported from the CBCTs were imported into computer planning software (coDiagnostiX, Dental Wings). Three-dimensional image reconstructions were performed by segmentation according to the relative radiodensity of the bone, dentin, and enamel. Using this 3D reconstruction, a virtual diagnostic tooth arrangement was performed for each patient using the contralateral central incisor and adjacent lateral incisor as references for the size, angulation, and position of the teeth. The position of the proposed mucosal margin in the virtual diagnostic tooth arrangement was established by taking into account the position of the cementoenamel junction (CEJ) and related cervical bone margin of the adjacent central incisor, and esthetic tooth proportions in their respective height-to-width ratios were obtained. Virtual implant planning (Fig 1) was subsequently performed in the site of the missing tooth with a regular-diameter parallel implant (Bone Level Regular Connection 4.1 × 10–mm implant, Straumann) according to the following implant-prosthetic criteria:

- Mesiodistal position: The implant was positioned centrally in the missing tooth site.
- Buccolingual position: The implant was positioned to be directly beneath the cingulum of the planned tooth.
- The implant angulation was established to maintain a restorative screw access hole that exited just palatal of the incisal edge.
- The implant was positioned 3 mm apical to the proposed mucosal margin on the diagnostic tooth arrangement.

All segmentations, diagnostic tooth arrangements, and virtual implant plannings were performed by one prosthodontist (K.V.). Implant positions were then simultaneously refined and modified through agreement by all three examiners (A.D., A.H., and K.V.) to maximize the anatomical bone available and minimize the need for bone regeneration where possible. Once finalized, the following measurements were obtained from axial slices taken at 0, 5, and 10 mm along the implant (Figs 2 and 3):

- Buccal bone thickness
- Palatal bone thickness
- Distance to IC

The implant type was then changed to a tapered design (Bone Level Tapered Regular Connection 4.1 × 10–mm implant, Straumann), and new measurements were taken at the apical end (10 mm). Measurements were also obtained for reduced-diameter implants (Bone Level and Bone Level Tapered Narrow Connection 3.3 × 10–mm implants, Straumann), the position of which was again modified by agreement from all three examiners to maximize the anatomical bone available and to minimize the need for bone regeneration where possible. Schematics of Figs 2 and 3 describe how the measurements were taken.

The results were tabulated and descriptive statistics utilized. The frequency and distribution of various bone thicknesses were reported as percentages. Measurements for remaining buccal and lingual bone thickness around the implants were categorized as implant surface exposed (≤ 0 mm), thin bone (0 to 1 mm), and moderate/thick bone (≥ 1 mm). Measurements of proximity to the IC were categorized as implant surface exposed (≤ 0 mm), thin bone (0 to 0.5 mm), and moderate/thick bone (≥ 0.5 mm). For comparison between the two groups with matched data, Wilcoxon signed-rank test was used. The comparison between more than two groups with matched-data Friedman test was used with Bonferroni correction (.05/6 = .0083.) The significance level was set at α = .05, and 95% CI was also computed. SAS software version 9.4 was used to perform the statistical analyses.
RESULTS

A total of 156 patients were screened. After the inclusion and exclusion criteria were applied, 60 patients missing a single maxillary central incisor for at least 6 months after tooth extraction were included. Patients’ mean age was 56.4 ± 14.5 years. A total of 240 implants (60 of each type: 3.3-BL, 3.3-BLT, 4.1-BL, and 4.1-BLT) were planned on the patients’ CBCTs.

Frequency distributions of the relationship between the IC bone walls and implant surface for each group are described in Table 1. The implant proximity (< 1 mm) in the coronal aspect of the IC area using 4.1-BL/BLT implants was 81.5%, whereas for the 3.3-BL/BLT implants, it was 58.3% ($P < .001$). The percentages of implants with possible exposure (between 0 and 0.5 mm of remaining bone) in the coronal aspect were 31.6% for 4.1-BL/BLT implants and 6.6% for 3.3-BL/BLT implants ($P < .001$).

Finally, the percentage of implants with exposure in the IC was 13.3% for 4.1-BL/BLT and 6.6% for 3.3-BL/BLT ($P < .001$) implants. There was no statistically significant difference between groups at 5 mm ($P = .317$). The overall average (coronal, mid, and apical aspects) thickness of the bone wall along the implant in proximity to the IC was 1.23 mm, 1.63 mm, 1.56 mm, and 1.99 mm for 4.1-BL, 3.3-BL, 4.1-BLT, and 3.3-BLT implants, respectively. The major difference between bone thicknesses around implants was found to be at the coronal aspect, with 0.55 mm for 4.1-BL/BLT and 0.95 mm for 3.3-BL/BLT (Table 4).

The frequency of sites that required bone augmentation at the coronal facial aspect (< 1 mm) was 52.6% and 33.9% for 4.1-BL/BLT and 3.3-BL/BLT, respectively (Table 2). The percentage of sites with facial implant surface exposure (≤ 0 mm) was 21.6% and 11.6%, respectively, for 4.1-BL/BLT and 3.3-BL/BLT. At the apical portion (10 mm), the percentage of sites requiring bone augmentations at the facial aspect were 59.9%, 49.9%, 31.6%, and 23.3% for 4.1-BL, 3.3-BL, 4.1-BLT, and 3.3-BLT, respectively ($P < .001$). The overall mean values (coronal, mid, and apical aspects) of the facial bone wall were 0.65 mm, 1.05 mm, 0.98 mm, and 1.42 mm for 4.1-BL, 3.3-BL, 4.1-BLT, and 3.3-BLT implants, respectively (Table 4).

At the palatal aspect, the percentages of sites requiring bone augmentation for ideal 3D implant positioning (< 1 mm) were 63.3% and 36.6% for 4.1-BL/BLT and 3.3-BL/BLT implants, respectively (Table 3). At the apical aspect, no implant exposure (< 0 mm) or proximity to the palatal wall (< 1 mm) was noticed in any of the patients. The overall average (coronal, mid, and apical aspects) thickness of the bone wall was 0.55 mm for 4.1-BL/BLT and 0.75 mm for 3.3-BL/BLT (Table 4).
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DISCUSSION

Virtual implant planning is an integral part of modern implant dentistry and can be used to confidently make preoperative decisions regarding the proposed implant positions, diameter, length, and geometry.\(^1,58-60\) It is also beneficial in precisely determining the need for adjunctive regenerative procedures, such as bone augmentation, or potential complications, such as exposure of the implant into adjacent anatomical structures.\(^61-63\) In the present study, the proximity of the IC and its relationship with virtually planned implants was assessed. This required that axial cross sections be viewed at multiple positions along the implant to give a 3D representation of the spatial relationship between the adjacent anatomical structures and proposed implants. This 3D assessment from multiple views around

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**Table 1** Thickness (mm) of the Facial, Palatal, and Incisive Canal Bone Walls at 0, 5, and 10 mm Apical to the Implant Shoulder in Different Implant Diameters and Designs

<table>
<thead>
<tr>
<th></th>
<th>Facial</th>
<th>Palatal</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thickness (SD)</td>
<td>Thickness (SD)</td>
<td>Thickness (SD)</td>
</tr>
<tr>
<td>0 mm</td>
<td>0.88 ± 1.17</td>
<td>0.94 ± 0.84</td>
<td>0.55 ± 0.58</td>
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<tr>
<td>5 mm</td>
<td>1.28 ± 1.17</td>
<td>1.34 ± 0.84</td>
<td>0.95 ± 0.58</td>
</tr>
<tr>
<td>10 mm</td>
<td>0.64 ± 1.30</td>
<td>3.33 ± 1.61</td>
<td>1.28 ± 1.01</td>
</tr>
<tr>
<td></td>
<td>0.04 ± 1.22</td>
<td>3.73 ± 1.61</td>
<td>1.86 ± 1.01</td>
</tr>
<tr>
<td></td>
<td>0.55 ± 1.22</td>
<td>6.06 ± 1.97</td>
<td>2.86 ± 1.01</td>
</tr>
<tr>
<td></td>
<td>0.95 ± 1.55</td>
<td>6.46 ± 1.97</td>
<td>2.26 ± 1.01</td>
</tr>
<tr>
<td></td>
<td>1.55 ± 2.05</td>
<td>7.06 ± 1.97</td>
<td>3.36 ± 1.01</td>
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</tbody>
</table>

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**Table 2** Frequency (%) Distribution of the Remaining Facial Bone Walls at 0, 5, and 10 mm Apical to the Implant Shoulder in Different Implant Diameters and Designs

<table>
<thead>
<tr>
<th></th>
<th>Facial</th>
<th>Palatal</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0 mm</td>
<td>21.6</td>
<td>11.6</td>
<td>28.3</td>
</tr>
<tr>
<td>0 &lt; 1 mm</td>
<td>31.6</td>
<td>23.3</td>
<td>23.3</td>
</tr>
<tr>
<td>≥ 1 mm</td>
<td>46.8</td>
<td>65.0</td>
<td>48.4</td>
</tr>
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**Table 3** Frequency (%) Distribution of the Remaining Facial Bone Walls at 0, 5, and 10 mm Apical to the Implant Shoulder in Different Implant Diameters and Designs

<table>
<thead>
<tr>
<th></th>
<th>Facial</th>
<th>Palatal</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0 mm</td>
<td>3.3</td>
<td>1.6</td>
<td>98.3</td>
</tr>
<tr>
<td>0 &lt; 1 mm</td>
<td>60.0</td>
<td>35.0</td>
<td>100</td>
</tr>
<tr>
<td>≥ 1 mm</td>
<td>36.7</td>
<td>63.4</td>
<td>100</td>
</tr>
</tbody>
</table>

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**Table 4** Frequency (%) Distribution of the Remaining Incisive Canal Bone Walls at 0, 5, and 10 mm Apical to the Implant Shoulder in Different Implant Diameters and Designs

<table>
<thead>
<tr>
<th></th>
<th>Facial</th>
<th>Palatal</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0 mm</td>
<td>13.3</td>
<td>6.6</td>
<td>1.6</td>
</tr>
<tr>
<td>0 &lt; 0.5 mm</td>
<td>31.6</td>
<td>6.6</td>
<td>8.3</td>
</tr>
<tr>
<td>≥ 0.5, &lt; 1 mm</td>
<td>36.6</td>
<td>45.1</td>
<td>25.1</td>
</tr>
<tr>
<td>≥ 1 mm</td>
<td>18.3</td>
<td>41.7</td>
<td>65.0</td>
</tr>
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</table>

aspects) bone wall at the IC area was 1.23 mm, 1.63 mm, 1.56 mm, and 1.99 mm for 4.1-BL, 3.3-BL, 4.1-BLT, and 3.3-BLT implants, respectively (Table 4).
a proposed implant is a critical factor in virtual implant planning.

It is generally considered that 2 mm of facial bone thickness is recommended for long-term implant success. In the present study, the majority of implants virtually planned in the maxillary central incisor site had surrounding bone of <1 mm in thickness. Changing to narrow implants significantly increased the thickness of the surrounding bone and may reduce the need for bone augmentation required to achieve osseointegration and complete bone coverage. However, it must be recognized that this increase in surrounding native bone thickness may not reduce the need for contour augmentation with bone and/or soft tissue grafting required for esthetic purposes. The greater thickness of the surrounding native bone preserved with narrower implants reduces the complexity of the bone augmentation required, reducing patient morbidity, and may assist in maintaining biologically successful long-term outcomes.

This study demonstrated a significantly lower probability of fenestration or dehiscence into the canal by selecting a reduced-diameter implant. However, despite the use of a reduced-diameter implant, without augmentation procedures on the mesiopalatal aspect to distalize the contents of the canal at the level of the crest or augmentation with complete obliteration of the canal, it appears that a target of 2 mm of bone between the implant and IC is unrealistic. Although studies have shown that when facial bone is <2 mm thick there is an association with greater bone loss following implant placement and esthetic complications, there are no reports on whether the same association is found with palatal bone thickness or the bone between the implant and IC. It is possible that due to the high density of the palatal cortical bone and generally thick overlying soft tissue, a reduced bone thickness between 0.5 and 2 mm may be adequate.

Narrow-diameter implants have been shown to have comparable survival rates to regular-diameter implants. The concerns with using narrow-diameter implants for all clinical situations relates to their reduced mechanical strength and a reduced surface area for osseointegration. Hence, patient factors such as functional and parafunctional demands, occlusion, prosthetic characteristics, and site-specific local anatomy should be carefully considered when making such a decision. When utilizing narrow-diameter implants, alternative implant materials such as titanium-zirconium alloys or cold-worked commercially pure titanium, which have increased mechanical strength, can be utilized.

In the present study, all the implants were prosthetically planned to provide direct screw access through the cingulum of the diagnostic tooth arrangement. This provides an ideal prosthetically driven plan and allows for a predictable restorative approach with ease of retrievability. With this position, the apex of the implant is often close to or protruding through the buccal plate due to the labial concavity under the anterior nasal spine. In the majority of implant sites assessed in this study, it was possible to avoid fenestration of the implant at the apex of the site by selecting a tapered implant design and to almost completely avoid this in every site planned with a combination of tapered and narrow-diameter implants. It must also be recognized that it may be possible to avoid complications associated with implant placement in contact with the IC or to minimize the need for bone grafting in certain situations by modifying the implant position to accommodate a cement-retained or angulated screw channel restoration.

When performing flapless implant surgery, it is generally recommended that at least 2 mm of buccal bone on virtual implant planning be present to accommodate for the deviation in implant placement that can occur with static computer-assisted guided surgery. In this study, there were no sites that presented with sufficient bone volume to consider flapless implant placement in the maxillary central incisor area. Although the ideal conditions for flapless implant placement were not found, these cases did not have socket grafting performed, which may provide the bone volume required for such a procedure.

The results of this retrospective CBCT analysis should be confirmed with further clinical trials to validate the digital measurements made and their effects on intraoperative treatment decisions. A limitation of this study is the lack of information on the specific timing after extraction that the CBCTs were taken. Given the anticipated changes in the overall alveolar ridge dimensions following tooth extraction, further research should be conducted to assess the dimensions of residual bone and the characteristics of virtual implant treatment planning with regard to specific timings of implant placement.

**CONCLUSIONS**

The use of comprehensive implant-prosthodontic virtual implant planning is an effective measure for preoperative implant assessment and aids in surgical decision-making. Ideally, this should include a diagnostic tooth arrangement to aid in correct 3D positioning of the implant. Cross-sectional and axial reformatted images from CBCT data should be viewed in all three dimensions surrounding the proposed implant.

The CBCTs viewed in this study showed that the proximity of the nasopalatine foramen to virtually planned implants in the maxillary central incisor location is often
< 0.5 mm. The need for augmentation of thin bone in this area is yet to be determined; however, in light of the current evidence, efforts should be made to maximize surrounding bone thickness where feasible. Exposure of the implant surface into the canal should be avoided unless augmentation procedures are being undertaken. The use of narrow-diameter and tapered implants had a significant effect on the amount of residual native bone present and significantly reduced the risk of bone fenestration and dehiscence.

ACKNOWLEDGMENTS


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REFERENCES


