Implications of Virtual CBCT-Based Immediate Implant Planning for Maxillary and Mandibular First Molars

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The purpose of his study was to investigate the projected ridge-implant dimensions derived from virtual superimposition of implants on intact first molars mimicking immediate implantation in the mandible (Md1) and maxilla (Mx1) using cone-beam computed tomography (CBCT). The CBCT records of 41 patients (19 males and 22 females) with Md1 or Mx1 were collected. Ten-millimeter-long cylindrical implants with different diameters were virtually positioned at prosthetically ideal angles into interradicular septum using CBCT software. Radiographic alveolar ridge height (ARH), alveolar ridge width (ARW), gap distance, and vertical distance from the implant platform to the alveolar crest were measured. Twenty Mx1s (48.8%) and 21 Md1s (51.2%) were included. The mean ARH values were 7.13 $\pm$ 4.32 and 15.64 $\pm$ 1.80 mm for Mx1 and Md1, respectively; 87.8% of mesiobuccal sites had gap distance of $>$2 mm when 6-mm-diameter implants were used. Increasing implant diameter from 6 to 9 mm decreased the percentage of sites with ARW $>$ 2 mm from 80.5% to 41.5% buccally and from 86.4% to 26.8% lingually. The mean vertical distance from the implant platform to the alveolar crest was 1.41 $\pm$ 1.09 mm buccally and 1.11 $\pm$ 1.10 mm lingually. Immediate implant placement of first molars, especially in the maxilla, requires stringent presurgical evaluation. Implants no wider than 6 mm placed into the interradicular septum may meet acceptable running room and alveolar plate thickness criteria if the jumping distance is grafted. Further clinical trials are needed to confirm these findings in this virtual study

Key Words: molar, dental implants, cone-beam computed tomography

Introduction

Despite a potential $>$98% survival rate, immediate molar implant placement can be challenging.[1,2] Clinicians have commonly avoided immediate implant placement in molar extraction sockets because of anatomical limitations, such as difficulty in achieving primary stability, maxillary sinus pneumatization, proximity to the inferior alveolar nerve, and mandibular lingual concavity.[3–6] There is no consensus on the ideal implant placement depth,[7–9] implant diameter,[2] or indications for bone grafting of the gap distance between the implant and the socket walls.[10,11]

Cone-beam computed tomography (CBCT) allows for presurgical analysis of vital structures.[12,13] Virtual implant placement using CBCT software helps predict surgical and postsurgical concerns, preventing untoward events, and has become standard practice. This study used CBCT software to superimpose virtual implants on existing maxillary (Mx1) and mandibular (Md1) first molars to (1) mimic immediate implantation when the implant platform is set at the level of the interradicular septal crest and (2) predict the ridge-implant dimensions expected from such treatment.

Materials and Methods

Patient selection

Sixty-five patients presenting for single implant restoration of the first molar between November 2016 and August 2019 were retrospectively screened to meet the following criteria: (1) adults $>$ 20 years old with either Mx1 or Md1, (2) no obvious crowding or spacing in the posterior area, and (3) normally erupted opposite Mx1 or Md1. Scans were excluded if any of the following criteria were present: (1) low-quality CBCT images with artifacts, (2) the opposite first molar presented with periodontitis (furcation involvement) or periapical disease, and (3) absence of CBCT image. This study was approved by the Institutional Review Board of the Peking University School of Stomatology (reference number PKUSSIRB-202054030) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013 (approval number PKUSSIRB-202054032).

CBCT imaging and measurements

All images were acquired with a 3DX Accuitomo 170 CBCT (Morita, Japan). All CBCT scans were taken at 90 kV and 5 mA with a duration of 17.5 seconds. The field of view was 6 $\times$ 6 cm

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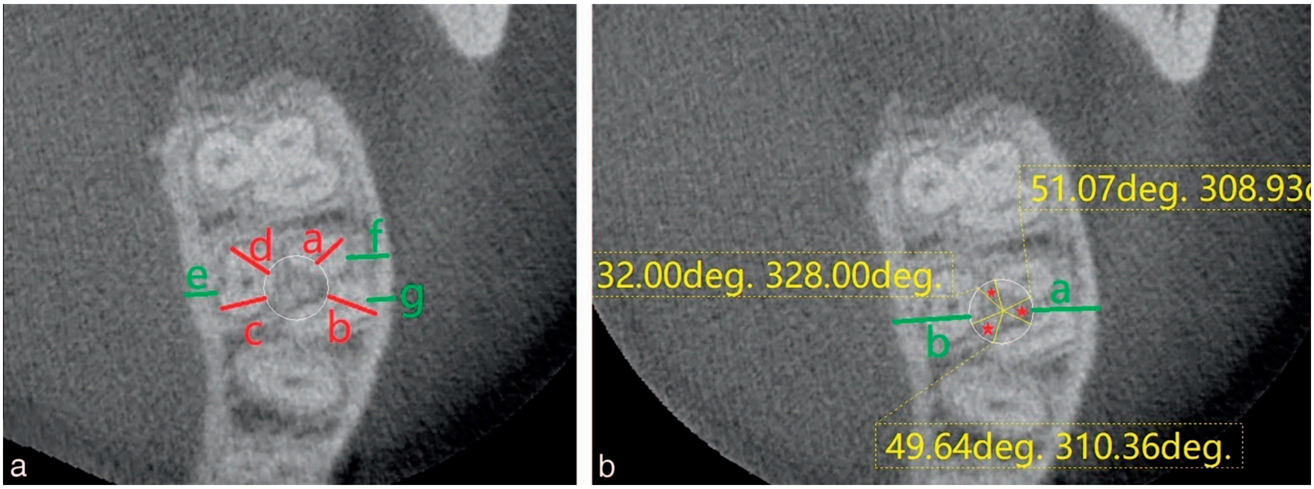

FIGURE 1. Description of CBCT measurements. (a) (a, b, c, d) Gap distance: the maximum distance from the implant surface to the inner aspect of the alveolar plate at the level of the implant platform. (e, f, g) Bone plate thickness (BPT): the thickness of the alveolar plate at the level of the interradicular septal crest. (b) (a, b) Alveolar ridge width (ARW): the distance from the implant surface to the outer surface of the alveolar bone plate at the level of the implant platform. *Area of bone-covered implant surface: the percentage of implant surface covered by alveolar bone expressed as the ratio of the angle corresponding to the arc covered by bone tissue.

with full visibility of either Mx1 or Md1 and a slice thickness of 1 mm.

Ten-millimeter-long nontapered cylindrical implants of various diameters, 4.8, 6, 7, 8, and 9 mm, were virtually placed in each first molar site (superimposed over the existing tooth) using CBCT software (One Volume Viewer version 2.6.0, Morita, Japan) following a restoratively driven approach. The virtual implant platform was positioned at the level of the interradicular septal crest. Implant placement and CBCT measurements were performed separately by 2 investigators (LZ and DD), and mean values were calculated. Interexaminer repeatability was assessed using intraclass correlation coefficients on 10 randomly selected pairs of CBCT data with a repeatability of 0.96. The following parameters were defined and measured (Figure 1):

(1) Alveolar ridge height (ARH): the distance from the crest of the interradicular septum to the maxillary sinus floor for Mx1 or to the superior border of the mandibular canal as measured on the coronal plane for Md1.
(2) Area of bone-covered implant surface: the percentage of implant surface covered by alveolar bone expressed as the ratio of the angle corresponding to the arc covered by bone tissue, which was measured on the transverse plane at the level of the implant platform and at 2, 4, 6, 8, and 10 mm apical to the implant platform.
(3) Bone plate thickness (BPT): the thickness of the alveolar plate at the level of the interradicular septal crest at 3 sites for Mx1 (mesiobuccal, distobuccal, palatal) and 4 sites for Md1 (mesio-buccal, disto-buccal, mesio-oral, disto-oral) as measured on the transverse plane.
(4) Gap distance: the maximum distance from the implant surface to the inner aspect of the alveolar plate at the level of the implant platform measured at mesio-buccal, disto-buccal, mesio-oral, and disto-oral sites on the transverse plane.
(5) Alveolar ridge width (ARW): the distance from the implant surface to the outer surface of the alveolar bone plate at the level of the implant platform as measured at the midbuccal and mid-oral side on the transverse plane.
(6) Vertical distance from the implant platform to the CEJ and the alveolar crest: the vertical distance from the implant platform to the CEJ and the alveolar crest, respectively, at the buccal and lingual side as measured on the coronal plane.

Statistical analyses

The data were analyzed using SPSS version 22.0 (IBM). For continuous variables (dependent variables), independent-sample t test and 1-way analysis of variance (ANOVA) were performed to compare mean differences between groups. For categorical variables (dependent variables), chi-square tests were used to compare frequency between groups. Descriptive statistics including the mean and SD were calculated. The statistical significances were set at $P < .05$.

RESULTS

This study included 41 patients (19 males and 22 females) with a mean age of 36.3 $\pm$ 10.0 years (range: 22–64 years). Of 41 sites, there were 20 Mx1 (48.8%) and 21 Md1 (51.2%).

The mean ARH was 7.13 $\pm$ 4.32 mm (range: 2.23–21.68 mm) for Mx1, which was significantly lower than that for Md1 (15.64 $\pm$ 1.80 mm; $P < .01$). The area of bone-covered implant surface at different levels are shown in Figure 2. Mean area of bone-covered implant surface differed significantly between Mx1 and Md1 at each measurement level (0 mm, $P = .04$; 2 mm, $P = .03$; 8 mm, $P = .02$; 10 mm, $P < .01$). Among the groups of different level below implant platform, 1-way ANOVA statistical analysis showed that the area of bone-covered implant surface of Mx1 was the greatest at 2 mm apical to the platform (56.6%) and the lowest at the implant apex (15.0%; $P = .02$). The area of bone-covered implant surface of Md1 was the lowest at the implant

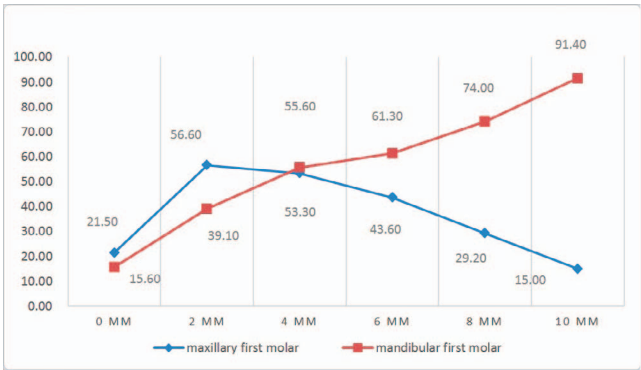

Figure 2. Area of bone-covered implant surface of maxillary and mandibular first molars at different levels around virtual 4.8-mm × 10-mm implants.

platform (15.6%) and the greatest at the implant apex (91.4%; $P < .01$).

The mean mesio- and distal-buccal BPT was significantly thinner at Md1 (0.93 ± 0.57 mm, 0.91 ± 0.73 mm, respectively) than at Mx1 (1.32 ± 0.51 mm, 1.87 ± 1.01 mm, respectively; $P = .02$ and $P < .01$, respectively); 25.1% of mesiobuccal, 25.0% of distobuccal, and 45.0% of palatal Mx1 sites had BPT less than 1 mm, and 76.2% of mesiobuccal, 14.3% of distobuccal, 72.7% of mesio-lingual, and 19.0% of distal Md1 sites had BPT less than 1 mm.

Table 1 summarizes gap distance at each quadrant for virtual 4.8-mm-wide implants. Mx1 presented significantly wider mean gap distances at each quadrant than Md1. The widest mean gap distance was observed at the mesiobuccal aspect: 3.51 ± 0.43 mm for Mx1 ($P = .04$) and 3.02 ± 0.55 mm for Md1 ($P = .04$). Statistical analysis using a chi-square test showed that the percentages of sites with gap distance exceeding 2 mm were related to implant diameter ($P = .01$) and are presented in Figure 3. Virtual placement of 4.8-mm-wide and 6.0-mm-wide implants resulted in a gap distance exceeding 2 mm in 65.9%–100.0% and 46.3%–87.8% of sites, respectively.

The mean ARWs for virtual 4.8-mm-wide implants were 3.51 ± 1.31 mm (range: 1.89–6.92 mm) at the buccal side and 3.94 ± 0.85 mm (range: 1.61–5.21 mm) at the oral side. There were no significant ARW differences between Mx1 and Md1 at either side ($P = .08$). Figure 4 summarizes the percentage of sites with ARW exceeding 2 mm for virtual implants with different diameters. The chi-square test showed that the percentages of sites with ARW exceeding 2 mm were significantly different when virtual implants with different diameters were used ($P < .01$); there appeared to be an inversely proportional trend. Placing 4.8-mm-diameter fixtures resulted in 97.6% of buccal and 92.7% of lingual sites with ARW exceeding 2 mm; placing 9-mm-diameter fixtures resulted in 41.5% of buccal and 26.8% of lingual sites with ARW exceeding 2 mm.

The vertical positioning of the virtual implants corresponded to the interradicular septal crest. Virtual implant platforms were placed at mean positions 1.41 ± 1.09 and 1.11 ± 1.10 mm apical to the buccal and lingual alveolar crest, respectively. The implant platform was ≤2 mm apical to the alveolar crest in 75.6% of buccal and 80.5% of lingual sites. The mean vertical distance from the implant platform to the CEJ was 3.73 ± 1.21 mm buccally and 3.84 ± 1.00 mm lingually; 68.3% of buccal sites and 85.4% of oral sites had vertical distance from the implant platform to the CEJ ≥ 3 mm.

Discussion

Immediate implant placement into molar sockets is technique sensitive and requires careful presurgical assessment to idealize the prosthetic angle, depth of implant placement, primary stability, jumping distance, and implant diameter. The apical-coronal implant depth dictates the future prosthetic contour. Previous investigations have suggested that the implant platform be placed 3–4 mm apical to the level of the adjacent midbuccal gingival margins to permit adequate running room.[14,15] An implant placed too shallow (<2–3 mm below the level of the adjacent midbuccal gingival margins) or too deep (>3 mm apical to the alveolar crest) may trigger peri-implant tissue inflammation and compromise the subsequent succeed rate.[14,16,17] Several groups recommend positioning implant platforms 1.5–2.0 mm apical to the alveolar crest.[9,18] In our study, the virtual vertical position of the implant platform corresponded to the interradicular septal crest being 1.41 ± 1.09 mm apical to the buccal alveolar crest and 1.11 ± 1.10 mm apical to the lingual crest, and the mean vertical distance between the virtual implant platform and CEJ was 3.73 ± 1.21 mm buccally and 3.84 ± 1.00 mm lingually. Our findings fall in line with existing recommendations for favorable emergence contours, which indicate that the interradicular septal crest may be an ideal landmark for positioning the implant platform.

There are 2 anatomical factors of the interradicular septa relevant to immediate implant primary stability: the distance from the interradicular septa to the sinus floor or mandibular canal and the interradicular septum thickness. If the distance from any molar furcation to the sinus floor is less than 4 mm [12,19] or the minimum interradicular septum width is less than 2.5–3 mm, immediate placement should not be attempted.[3–5] We found the mean available height from the sinus floor to interradicular septum to be 7.13 ± 4.32 mm, which approximated the mean height of 6.51 mm that Matsuda et al[12]

Table 1

Gap distance (mean ± SD) around virtual 4.8- mm-diameter implants

	Mesiobuccal Aspect (mm)	Distobuccal Aspect (mm)	Mesio-Oral Aspect (mm)	Disto-Oral Aspect (mm)
Mx1+Md1	3.31 ± 0.42	3.00 ± 0.69	2.51 ± 0.93	2.54 ± 0.77
Mx1	3.51 ± 0.43	3.30 ± 0.70	3.05 ± 0.87	2.97 ± 0.56
Md1	3.02 ± 0.55	2.60 ± 1.09	2.41 ± 0.71	2.07 ± 0.84
P (Mx1 vs Md1)	0.03	0.00	0.01	0.00

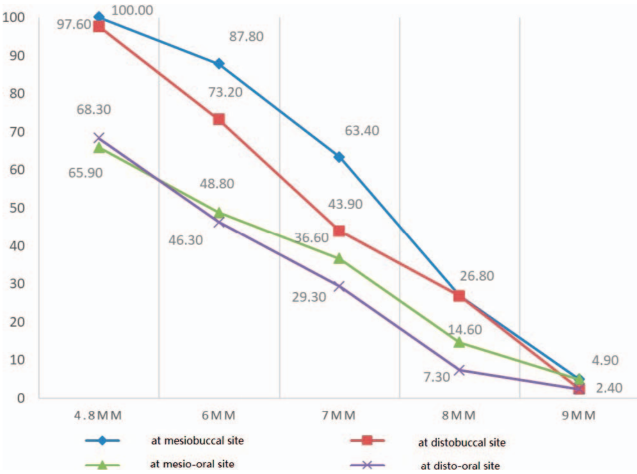

Figure 3. The percentage of sites with gap distance greater than 2 mm around virtual implants with different diameters.

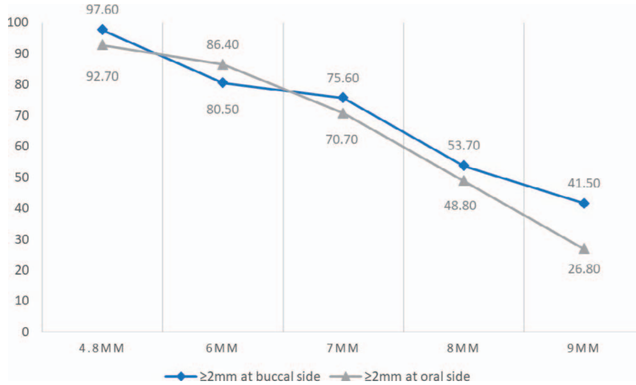

Figure 4. The percentage of sites with ARW greater than 2 mm around virtual implants with different diameters.

reported. The irregular morphology of the maxillary sinus floor also disrupts stability—10% of sites may have sinus recesses lateral to the buccal roots, and 71.7% of sites may demonstrate recesses between the buccal and palatal roots.[13] As such, we found that the proportion of implant surface covered by bone in maxillary sites progressively decreased as the measurement level deepened past 2 mm apical to the platform; area of bone-covered implant surface values in Mx1 sites were 21.5% at the level of implant platform and 56.6%, 53.3%, 43.6%, 29.2%, and 15.0% at 2, 4, 6, 8, and 10 mm apical to the implant platform, respectively. In contrast, the available bone height from the implant platform to the mandibular canal was 15.64 ± 1.80 mm, and the area of bone-covered implant surface progressively increased from 15.6% at the implant platform to 91.4% at 10 mm apical to the implant platform. Based on bone availability and projected alveolar coverage, immediate implant placement favors first molar mandibular rather than maxillary sites. Maxillary first molar sockets must be more stringently evaluated for residual bone morphology and volume when 10 mm long, >4.8-mm-wide immediate implants are considered.

Results from a finite element analysis and retrospective clinical study demonstrated that 1.8–2 mm of bone thickness may be required for revascularization and alveolar and mucosal maintenance.[20,21] The mean horizontal distances from the implant surface to the lateral aspect of the lingual and buccal plate (ARW) were 3.94 and 3.51, mm, respectively, when a 4.8-mm-diameter implant was virtually placed. Increasing the virtual implant diameter from 6 to 9 mm lowered the percentage of sites with an ARW > 2 mm, which dropped from 80.5% to 41.5% buccally and from 86.4% to 26.8% lingually. In addition, the buccal plate of first molars as measured at the mesiobuccal aspect was thinner than 1 mm in 25.1%–76.2% of sites (BPT). These findings may partly explain the high failure rates of ultra-wide implants (8–9 mm in diameter).[2,10] Per Atieh et al,[10] ultra-wide (8–9 mm in diameter) implants have high failure rates (33.3% in fresh molar extraction sockets, 16.7% in healed sites) after 1 year of function.[10] Similarly, a meta-analysis demonstrated a significant difference in immediate molar implant failure between ultra-wide implants (>6–9 mm, 3.67%) and those with 4- to 6-mm diameters (1.45%).[2] To maintain an ARW exceeding 2 mm and to augment thin alveolar plates, placement of a ≤6 mm-wide implant along with bone regenerative methods may be reasonable.

A space, or gap distance, between the implant body and molar socket walls is to be expected in immediate cases. Botticelli et al[22] showed that a gap distance of 1–2.25 mm could completely spontaneously regenerate with bone after 4 months. Other studies found similar results, demonstrating spontaneous bone regeneration and osseointegration around rough-surfaced implants with gap distance of ≤2 mm.[23–25] In situations where the gap distance is >2 mm or where 1 or more socket walls are missing, concomitant bone augmentation procedures are recommended.[23–25] In our study, placement of virtual 4.8-mm-diameter implants resulted in gap distance > 2 mm at all mesiobuccal sites; 87.8% of mesiobuccal sites around 6-mm-diameter virtual fixtures exhibited gap distance > 2 mm. Our findings indicate that bone augmentation to fill in critical gaps may need to be planned for in immediate molar cases using 4.8- or ≤6-mm-wide implants.

This investigation has several limitations. First, there is the inability to accurately and reliably transfer the exact CBCT based plan to the clinical scenario. For example, the dimensions of alveolar ridge before tooth extraction presented in CBCT were different with theses after tooth extraction in practice. Extraction-related procedures, such as sectioning the tooth or application of excessive tooth elevation forces, may cause alveolar bone loss or alveolar ridge fracture, and subsequently compromise bone healing. Second, the results in present study are based on healthy molars; therefore, its indication was limited to molar site in healthy status. If the implant had been placed at the level of interradicular septum in molar sites with buccal-lingual alveolar crest resorption or periodontal furcation involvement, the implant positioning might have been at an inappropriate depth. Third, tapered virtual implants were not implemented in the current study design. Considering bone flexibility, the tapered implants could achieve greater apical implant bone coverage and subsequently higher insertion torque than nontapered fixtures.[26,27] There would be more clinical implications if a tapered virtual implant was implemented in this current study design. Finally, the sample size is relatively small. We superimposed implant mock-ups over existing molars in a completely digital setting; our findings are not directly applicable to and cannot dictate surgery. However, this virtual study highlights certain parameters, such as gap distance and implant diameters, to consider carefully during real treatment planning of immediate molar placement using CBCT software. Meanwhile, implant placement depth at the level of the interradicular septum and its related vertical distance from implant platform to gingival margin in fresh molar sockets needs to be further study in clinical scenarios.

Conclusion

We recommend stringent presurgical evaluation for immediate implant placement of first molars, particularly those in the maxilla. Evaluation should include CBCT analysis of maxillary sinus morphology with respect to furcation and virtual implant positioning. Our virtual assessment implies (i) implants no wider than 6 mm be placed in an ideal prosthetic manner and (ii) implant cervical margins should be flush with the interradicular septal crest. Following these 2 criteria may meet accepted running room criteria and permit appropriate alveolar plate thickness if bone regeneration is performed to bridge the jumping distance. However, further clinical trials are needed to confirm the findings.

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Note

The authors declare no conflicts of interest.

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