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Frequency of Adequate Mesiodistal Space and Faciolingual Alveolar Width for Implant Placement at Human Anterior Tooth Positions

by

James Wilson, DMD

Thesis submitted to the Faculty of the Army Postgraduate Dental School,
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
Masters in Oral Biology

THESIS APPROVAL SHEET

Frequency of Adequate Mesiodistal Space and Faciolingual Alveolar Width for Implant Placement at Human Anterior Tooth Positions

This thesis is submitted by James Wilson and has been examined and approved by an appointed committee of the faculty of the Uniformed Services University of the Health Sciences.

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DEDICATION

To my wife, Katie, without whom nothing is possible.

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08 June 2020

ABSTRACT

"Frequency of Adequate Mesiodistal Space and Faciolingual Alveolar Width for Implant Placement at Human Anterior Tooth Positions"

James Wilson DMD, 2020

Thesis directed by: Thomas M. Johnson, DMD MS, Associate Professor, Department of Periodontics, Army Postgraduate Dental School, Uniformed Services University of the Health Sciences

Background: Investigators have defined a minimum mesiodistal space requirement for dental implant sites, and failure to observe this constraint may adversely impact peri-implant health and esthetics. However, no prior report establishes frequencies at which human anterior tooth positions present favorable mesiodistal space for accommodating a dental implant.

Methods: A single examiner analyzed 205 cone-beam computed tomography images and recorded mesiodistal space available for implant placement at anterior tooth positions. The examiner compared available mesiodistal space with standardized implant platform diameters and evaluated implant-to-tooth distances.

Results: In the esthetic zone, lateral incisor sites most frequently failed to present favorable mesiodistal space. At maxillary lateral incisor positions, 22% to 27% of sites offered < 2 mm between the implant platform and the adjacent teeth. At mandibular incisor sites, 79% to 97% of sites offered < 2 mm and 35% to 76% of sites offered < 1.5 mm between the implant platform and adjacent teeth. Only 3% to 6% of mandibular

central incisor sites presented ≥ 2 mm implant-to-tooth distance, and only 24% of these sites presented ≥ 1.5 mm implant-to-tooth distance.

Conclusions: In the population evaluated, mandibular central incisor positions rarely presented favorable mesiodistal space to accommodate conventional narrow diameter implants. Additionally, the data suggested that many lateral incisor sites may be at risk for compromised esthetics, tissue stability, and peri-implant health when conventional narrow-diameter implants are utilized.

Practical implications: Practitioners should consider specialized narrow-platform implants or alternative tooth replacement methods for many patients missing single mandibular incisors or maxillary lateral incisors.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: BACKGROUND

Dental implants replacing single missing teeth reportedly have five- and ten-year survival rates of 97% and 95%, respectively.[1] However, biologic, esthetic, and technical complications occur frequently,[1] and careful treatment planning is necessary to optimize treatment outcomes. Although additional controlled clinical research is needed, patient- and site-related factors relevant to peri-implant health and tissue stability have become increasingly clarified. These include oral hygiene,[2,3] compliance with supportive implant therapy,[2,3] history of periodontitis,[3] keratinized mucosal width[2-4] and thickness,[3,5] presence of excess cement,[2,3,6] and peri-implant bone dimensions.[7-11] Adequate space and bone volume are fundamental requirements for dental implant therapy, and multiple authors have contributed to the rationale for minimum spacing and bone volume provisions at dental implant sites. After transmucosal abutment placement, typical soft tissue healing around an implant involves formation of a biologic width (connective tissue adhesion and epithelial attachment).[12-14] During biologic width formation limited bone resorption is expected.[4] The vertical component of this physiologic bone modeling extends apically ≈ 1.5 to 2 mm from the platform surface,[15,16] and the horizontal component reportedly measures 1.3 to 1.4 mm on average.[17] Thus, a dental implant platform should encroach no closer than 1.5 mm to a neighboring tooth.[16,17] Otherwise, crestal bone modeling around the implant will extend to adjacent root surfaces. However, this 1.5-mm constraint may be overly permissive. The standard deviation associated with the reported 1.4-mm mean value was 0.6 mm.[17] A patient experiencing horizontal peri-implant bone loss one standard deviation beyond the mean requires at least 2 mm between the implant platform and the tooth. Moreover, the minimum distance required may also depend upon implant platform depth.[16] Since the horizontal dimension of the cone-shaped circumferential peri-implant bone modeling widens crestally, deeper implants require greater inter-implant or implant-to-tooth distances.[16]

Importantly, the vertical height of bone on the adjacent root surface is the primary determinant of interproximal papilla height.[16] When an implant is too close to an adjacent tooth, papilla deficiency is thus a common outcome.[11,16,17] Irregular osseous and mucosal architecture can also create areas that are difficult to clean, possibly leading to biologic implant complications.[2,3,11,16-19]
Peri-implant bone modeling following abutment placement occurs three-dimensionally and is not limited to mesial and distal implant surfaces. Accordingly, prior studies have recommended a minimum 2-mm peri-implant bone thickness adjacent to facial and lingual implant surfaces.[7,8,16] Indeed, one expert preferred 4-mm peri-implant facial bone thickness to assure tissue stability.[16] Peri-implant bone thickness < 2 mm has been associated with less stable peri-implant crestal bone levels and advanced mucosal recession.[7,8,16,20]

Cone-beam computed tomography (CBCT) has become an essential tool in dental implant treatment planning. Clinicians commonly measure linear distances on CBCT images in the course of treatment planning, and research has validated the appropriateness of this practice.[21-23] Although acquisition parameters may impact diagnostic performance for some purposes (e.g. fracture detection), investigators have reported acceptable linear measurement accuracy and reliability across a wide range of CBCT scanner settings.[21-23]

Because errors in treatment planning may result in esthetic failure, advanced imaging is particularly important for complementing the clinical examination in assessment of anterior tooth positions as potential implant sites. For example, when considering immediate implant placement in the esthetic zone, CBCT images allow practitioners to confirm the integrity of the facial and lingual cortices and accurately measure the mesiodistal distance between adjacent tooth roots at the intended implant platform level. Likewise, practitioners may use CBCT imaging to quantify the distance between the facial and lingual limits of the alveolar process at the potential implant location. The pre-extraction faciolingual dimension of the alveolar process may represent an upper-limit post-extraction ridge width, since considerable loss of alveolar ridge volume occurs following tooth removal.[24-28] Practitioners can mitigate, but not prevent, post-extraction reduction in FAW using ridge preservation procedures.[25-28]

Although minimum dental implant space and bone requirements have been described, the frequencies at which anterior tooth positions meet these requirements remain undefined. We conducted a retrospective observational study purposed primarily to assess human anterior tooth positions for acceptability as dental implant sites in terms of mesiodistal space (MS) and faciolingual alveolar width (FAW).

CHAPTER 2: METHODS

This protocol involved study of existing patient records, and investigators collected data in such a manner that patients remained unidentifiable directly or through subject identifiers. The research therefore met exemption criteria described in 32CFR§219.101, paragraph b.4. Accordingly, the Dwight David Eisenhower Army Medical Center Human Research Protections Office, Fort Gordon, Georgia, determined this research to be exempt from regulatory requirements of 32CFR§219 (protocol #DDEAMC 17-006, 8978444).

Study Design and Eligibility Criteria

A single examiner (JPW) assessed anterior tooth positions on CBCT images acquired at Fort Gordon, Georgia, from July 1, 2012, to January 18, 2018. Dental specialists acquired all CBCT images using a single scanner (3D Accuitomo 170, J. Morita) in the routine course of patient care. CBCT field of view was ø 40 x height 40 mm (isotropic 80-μm voxel), ø 60 x height 60 mm (isotropic 125-μm voxel), ø 80 x height 80 mm (isotropic 160-μm voxel), or ø 100 x height 100 mm (isotropic 250-μm voxel). All scans utilized a 360-degree arc of rotation and peak tube potential 90 kV. Current ranged from 5 mA to 8 mA, and exposure time ranged from 10.5 to 30.8 seconds. The examiner excluded sites exhibiting crowding (overlap of proximal tooth surfaces) or supereruption (inability to define the vertical level of measurement), sites not bounded by adjacent teeth, edentulous sites, dental implant sites, sites unmeasurable due to poor image quality, and sites exhibiting severe alveolar bone destruction.

Mesiodistal and Faciolingual Measurements

Prior to recording measurements for each potential implant site (tooth position), the examiner oriented the image as described previously,[10,29] using anatomic landmarks such as the occlusal plane, adjacent teeth, and the nasal spine, then aligned the tooth of interest with the vertical. Three millimeters apical to the midfacial cementoenamel junction (CEJ), the examiner horizontally measured the mesiodistal space (MS) between roots of adjacent teeth (Figure 1). Additionally, the examiner measured the faciolingual dimension (FD3) of the alveolus (external aspect) in the mesiodistal center of the site, 3 mm apical to the midfacial CEJ (Figure 2). To confirm linear measurement start and end points, the examiner enlarged images to 400% using CBCT system software (i-Dixel version 2.3.0.3, J. Morita). Additionally, the examiner re-measured all parameters at 40 randomly-selected sites for intra-examiner reliability analysis.

We defined narrow and regular platform diameters as ø 3.4 mm and ø 4.1 mm, respectively. The examiner compared MS and FD3 with narrow platform diameter (mandibular incisor and maxillary lateral incisor sites) or regular platform diameter (cuspid and maxillary central incisor sites) and evaluated implant-to-tooth distances. We considered two thresholds for favorable implant-to-tooth distance (2 mm and 1.5 mm) and two thresholds for favorable faciolingual alveolar width (4 mm > implant diameter and 3 mm > implant diameter).

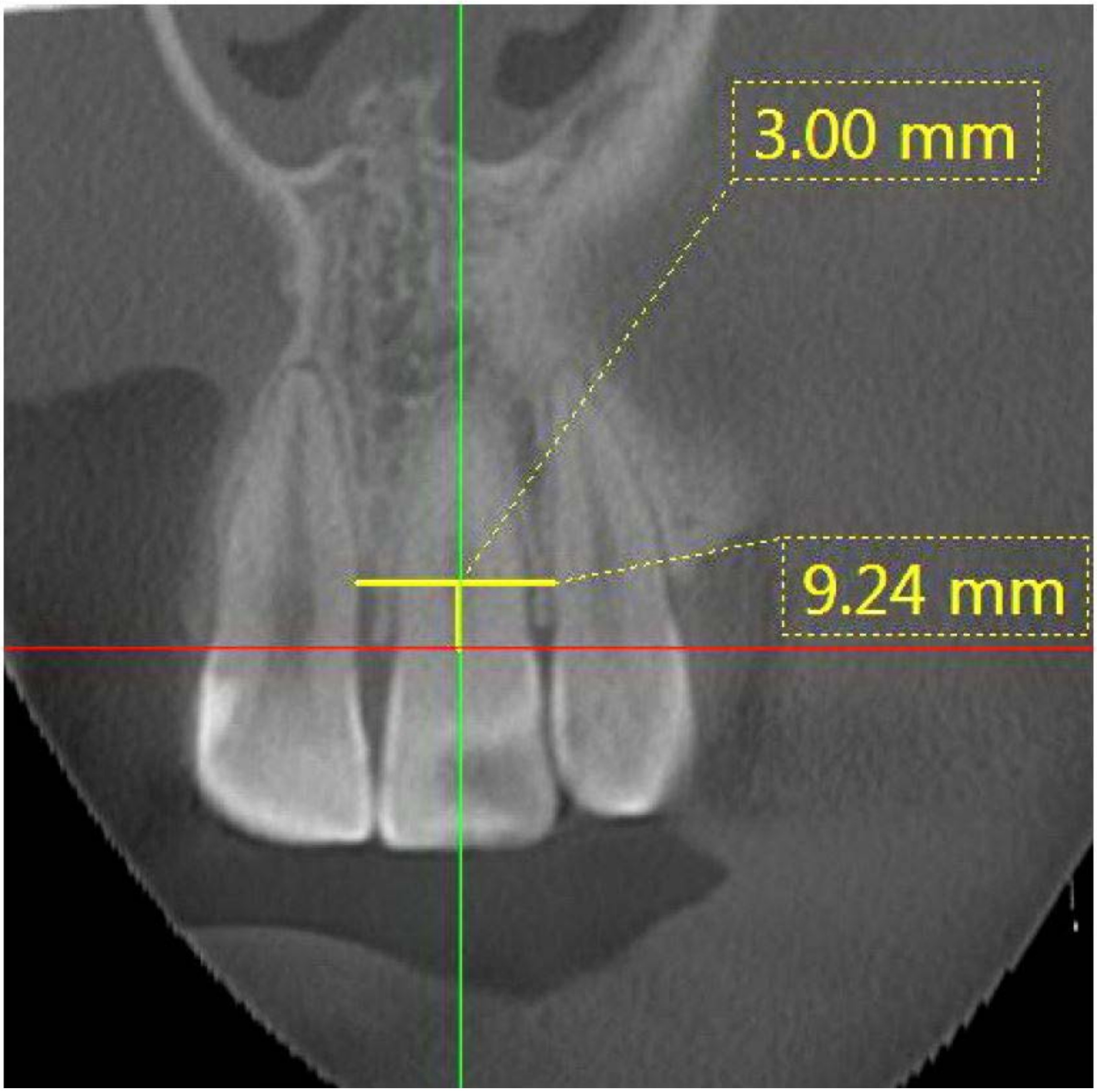

Figure 1: Example mesiodistal space measurement, 3 mm apical to facial cementoenamel junction

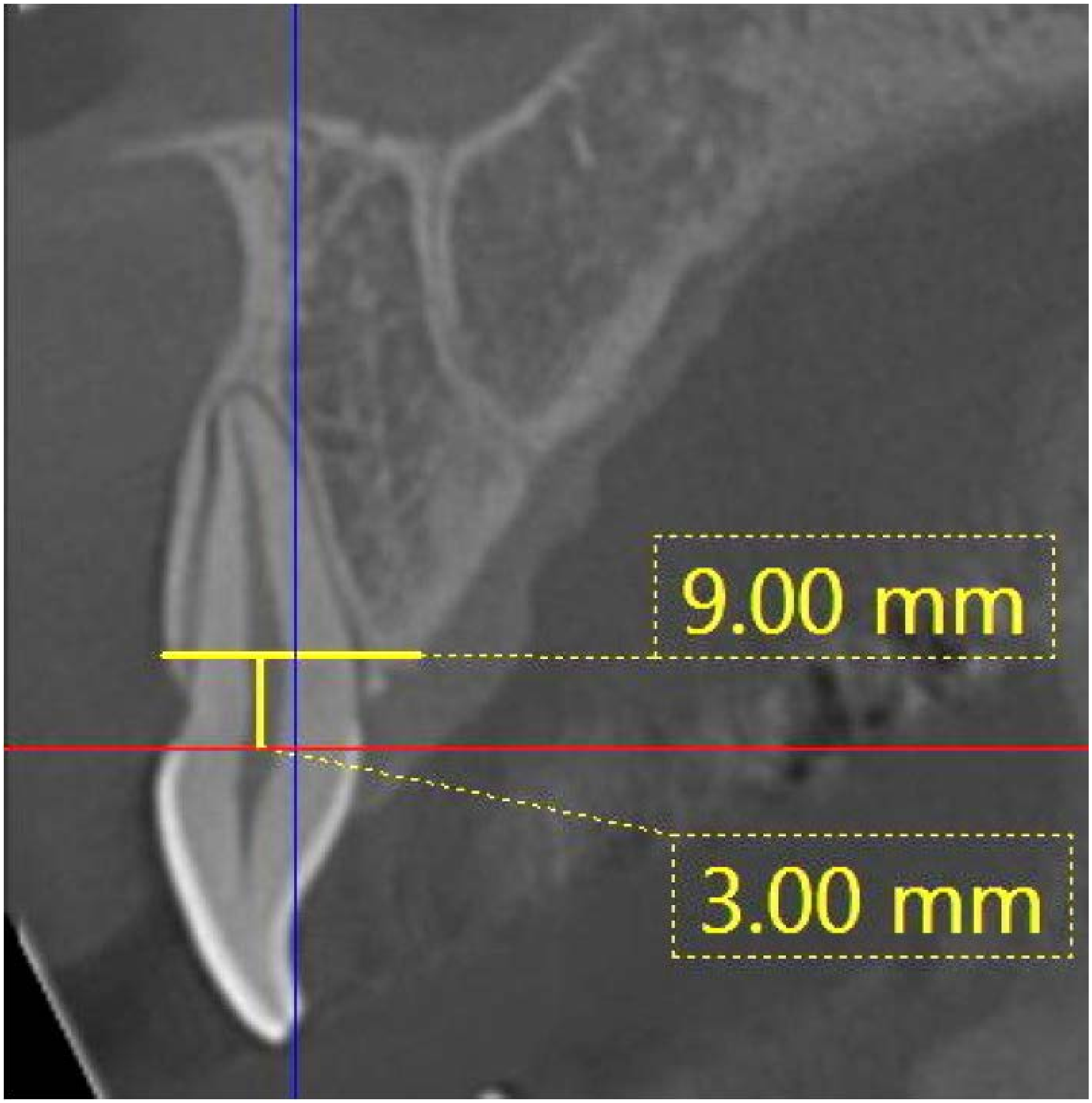

Figure 2: Example faciolingual alveolar width measurement, 3 mm apical to the facial cementoenamel junction

Statistical Analyses

We conducted all analyses using statistical software (SAS 9.4, SAS), with significance level set at 0.05, and calculated descriptive statistics for all qualitative and quantitative variables. We analyzed MS and FD3 using mixed-effects logistic regression. Explanatory variables of interest were age, gender, and tooth position. To account for dependent data, we first performed mixed-effects logistic regression separately for each independent variable, then excluded from final models variables that were not statistically significant predictors of inadequate MS and FD3. To further assess gender-based differences in MS, and FD3, we calculated odds ratios (OR), p-values, and 95% confidence intervals (95% CI) for each positon. Additionally, we calculated intraclass correlation coefficients (ICC) to examine intra-rater reliability.

CHAPTER 3: RESULTS

Two hundred five CBCT images met described criteria and were included in the analysis. One hundred fifty-three patients were male, and 52 patients were female. Mean age was 37.9 ± 12.8 years (range 18 to 70 years). MS at some sites was undefined (e.g. no bordering tooth), yet FD3 remained measureable. Thus, the number of sites included in the study varied among the 12 tooth positions, and the FAW analyses included more sites than the MS analysis (Table 1). The ICC for MS and FD3 were 0.995 and 0.993, respectively, indicating excellent intra-rater reliability.

Mesiodistal space analysis

Table 1 presents results of MS and FAW analyses. Figure 3 reports percentages of sites exhibiting unfavorable MS, assuming 2-mm and 1.5-mm implant-to-tooth thresholds. In the esthetic zone, lateral incisor sites most frequently failed to provide favorable MS for predictable implant placement. Mandibular incisor positions accommodated conventional narrow-diameter implants with strikingly low frequency, particularly in central incisor locations. Cuspid sites accommodated ø 4.1 mm implants with similar frequencies in maxillary and mandibular arches.

	Tooth Position					
	#6	#7	#8	#9	#10	#11
Mesiodistal Space Analysis						
Sites assessed (n)	91	96	96	94	95	93
Sites offering < 2 mm implant-to-tooth distance	11	26	6	8	21	10
Sites offering < 1.5 mm implant-to-tooth distance	2	4	2	1	2	0
Mean Mesiodistal space available for dental implant placement, assessed 3 mm apical to CEJ* (Mean ± SD)	9.7 ± 1.3 mm	8.1 ± 1.2 mm	9.6 ± 1.1 mm	9.6 ± 1.1 mm	8.1 ± 1.0 mm	9.5 ± 1.2 mm
Faciolingual dimensional analysis						
Sites assessed (n)	113	108	105	105	107	109
Sites with faciolingual alveolar dimension < 4 mm greater than implant diameter (3 mm apical to CEJ)	16	60	69	62	62	18
Sites with faciolingual alveolar dimension < 3 mm greater than implant diameter (3 mm apical to CEJ)	1	20	21	19	23	3
Mean faciolingual dimension of alveolar 3 mm apical to midfacial CEJ (mean ± SD)	9.2 ± 1.1 mm	7.2 ± 0.9 mm	7.7 ± 0.9 mm	7.9 ± 0.9 mm	7.2 ± 0.9 mm	9.0 ± 1.1 mm
	#22	#23	#24	#25	#26	#27
Mesiodistal Space Analysis						
Sites assessed (n)	100	104	102	99	100	99
Sites offering < 2 mm implant-to-tooth distance	10	82	96	96	80	20
Sites offering < 1.5 mm implant-to-tooth distance	1	36	78	75	42	3
Mean Mesiodistal space available for dental implant placement, assessed 3 mm apical to CEJ* (Mean ± SD)	9.3 ± 1.2 mm	6.7 ± 0.9 mm	5.9 ± 0.9 mm	5.9 ± 0.8 mm	6.6 ± 0.9 mm	9.0 ± 1.1 mm
Faciolingual dimensional analysis						
Sites assessed (n)	113	108	104	101	103	106
Sites with faciolingual alveolar dimension < 4 mm greater than implant diameter (3 mm apical to CEJ)	25	84	95	96	82	29
Sites with faciolingual alveolar dimension < 3 mm greater than implant diameter (3 mm apical to CEJ)	3	30	61	61	33	7
Mean faciolingual dimension of alveolar 3 mm apical to midfacial CEJ (mean ± SD)	9.0 ± 1.2 mm	6.8 ± 0.8 mm	6.3 ± 0.7 mm	6.3 ± 0.7 mm	6.8 ± 0.7 mm	8.8 ± 1.2 mm

Table 1: Mesiodistal space and faciolingual dimensional analysis at anterior tooth positions. *CEJ: cementoenamel junction

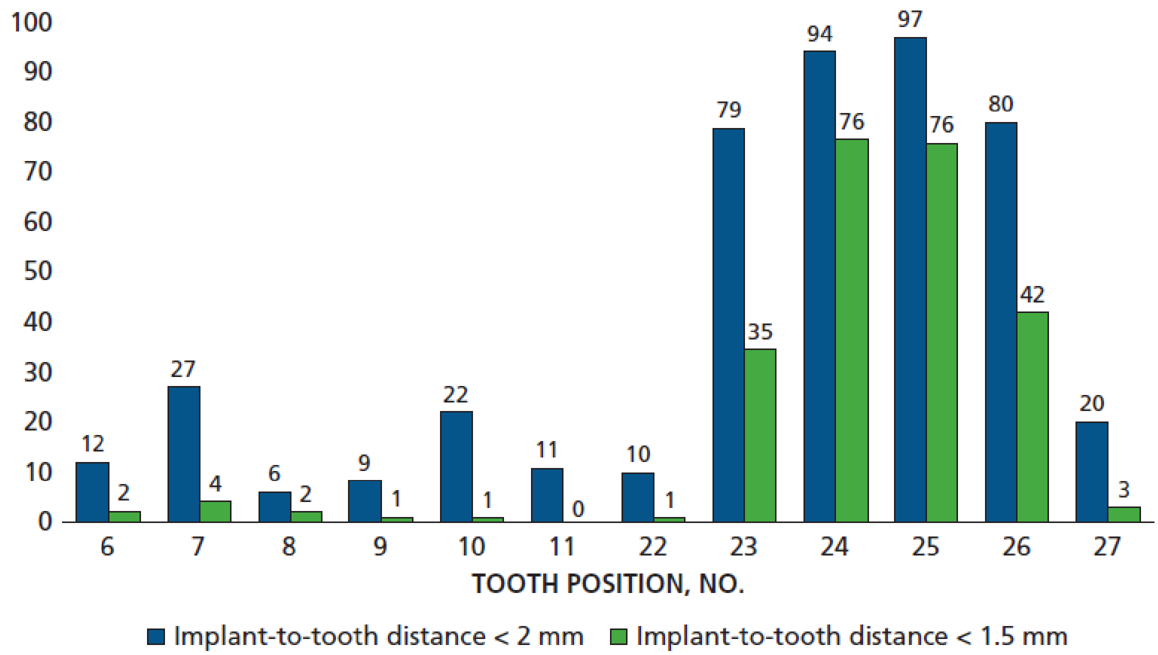

Figure 3: Percentage of sites in inadequate mesiodistal space for dental implant placement

Faciolingual alveolar dimensions

Figure 4 presents percentages of sites exhibiting unfavorable FAW, considering two different minimum alveolar width thresholds. Over half of maxillary incisor sites and 78% to 95% of mandibular incisor sites exhibited FD3 < 4 mm beyond implant diameter. Twenty-eight percent to 60% of mandibular incisor sites exhibited FD3 < 3 mm beyond diameter. Mean FD3 values at mandibular incisor and maxillary lateral incisor positions were < 4 mm beyond the ø 3.4 mm implant diameter. Mandibular central incisor positions presented mean FD3 values < 3 mm beyond the narrow platform diameter.

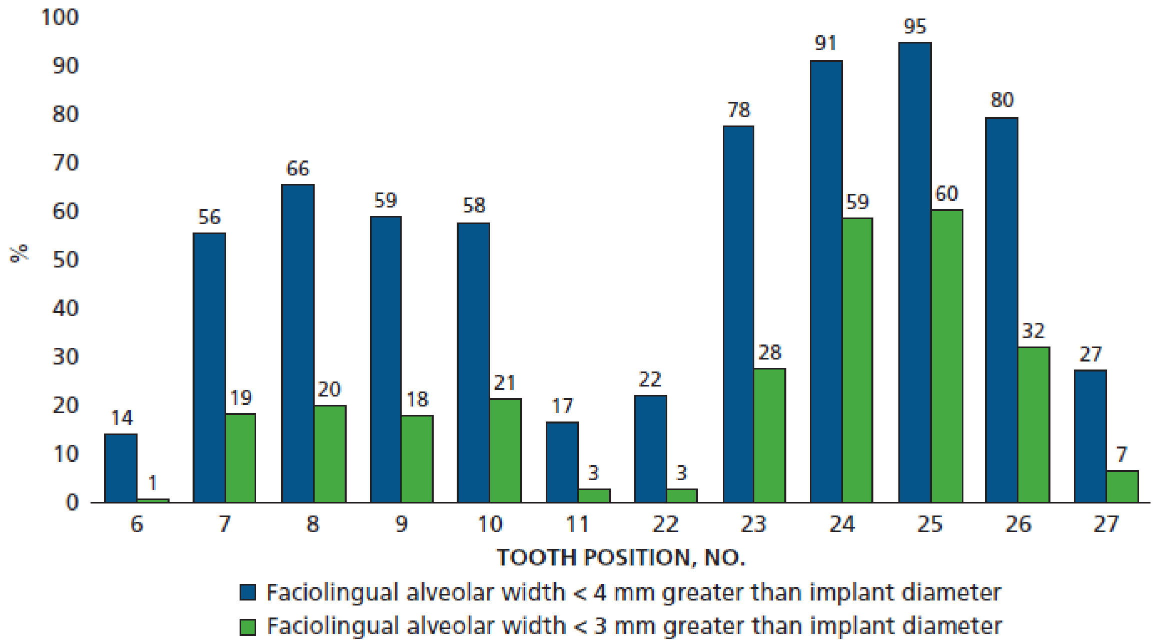

Figure 4: Percentage of sites exhibiting unfavorable faciolingual alveolar width, assessed 3 mm apical to facial cementoenamel junction

Mixed-effects logistic regression

Tables 2 and 3 present mixed-effects logistic regression results. The final model for MS included tooth position and gender for both implant-to-tooth thresholds (2 mm and 1.5 mm). The final model for FD3 included tooth position, gender, and age.

Gender was a statistically significant predictor for MS and FD3 only at less strict thresholds (2 mm and 4 mm, respectively). There were no statistically significant differences between males and females for MS at the 1.5-mm threshold or for FD3 at the 3-mm threshold.

At the tooth #10 position, males were more likely to exhibit adequate MS at the 2-mm threshold (OR, 3.9; 95% CI, 1.4 to 11.2; $p = 0.0125$). Males were also more likely to have favorable FD3 measures (4-mm threshold) at tooth positions #6 (OR, 10.4; 95% CI, 3.2 to 33.7; $p = 0.0001$) and #27 (OR, 5.1; 95% CI, 2.0 to 12.8; $p = 0.0006$).

Table 2: Mixed-effects logistic regression analysis, mesiodistal space

Outcome	Factor	Estimate	SE	p-value	Regression Equation
Inadequate mesiodistal space (Implant-to-tooth distance < 2 mm)	Intercept	-3.19	0.21	>.0001	Mesiodistal space = - 3.19 + 0.45*Gender + 0.15*Tooth Position
	Female Gender	0.45	0.22	0.0383	
	Tooth Position	0.15	0.01	<.0001	
Inadequate mesiodistal space (Implant-to-tooth distance < 1.5 mm)	Intercept	-5.40	0.40	<.0001	Mesiodistal space = -5.4 + 0.35*Gender + 0.2*Tooth Position
	Female	0.35	0.21	0.0928	
	Tooth Position	0.20	0.02	<.0001	

Table 3: Mixed-effects logistic regression analysis, faciolingual alveolar width

Outcome	Factor	Estimate	SE	p-value	Regression Equation
FD3 < 4 mm greater than implant diameter	Intercept	-1.41	0.30	<.0001	FD3 = -1.41 + 0.41*Gender + 0.02*Age + 0.5*Tooth position
	Female Gender	0.41	0.20	0.045	
	Age	0.02	0.01	0.0116	
	Tooth Position	0.05	0.01	<.0001	
FD3 < # mm greater than implant diameter	Intercept	-3.41	0.40	<.0001	FD3 = 3.41+0.42*Gender + 0.20*Age + .06*Tooth Position
	Female Gender	0.43	0.24	0.0807	
	Age	0.02	0.01	0.0223	
	Tooth Position	0.06	0.01	<.0001	

*FD3: Faciolingual dimension of the alveolus (external aspect), measured 3 mm apical to the facial cementoenamel junction.

CHAPTER 4: DISCUSSION

Although space deficiency can occur at any tooth position, the present study suggests mandibular central incisor sites rarely provide favorable MS for conventional dental implant placement, and lateral incisor positons in both arches also commonly present spacing concerns. Mandibular incisor anatomy may amplify the risk of violating minimum implant space requirements. Mandibular incisors exhibit the smallest mesiodistal dimensions of any teeth in the permanent dentition.[30] These teeth exhibit highly scalloped CEJ and accentuated arcuate gingival architecture.[30-32] In a mandibular incisor position, placement of a conventional implant platform 3 mm apical to the intended midfacial mucosal position, which is the recommended depth for ideal abutment emergence,[11,33] results in a zone of thin supporting bone on adjoining root surfaces. Physiologic crestal bone modeling following abutment placement can easily involve this supporting bone.

Unfortunately, non-implant tooth replacement strategies for single missing anterior teeth also carry decided disadvantages. Orthodontic therapy can, in some cases, close the edentulous space. However, this alternative often requires fixed appliances, an extended treatment duration, and considerable cost for the patient. Additionally, orthodontic closure of the space could, for some patients, result in unfavorable occlusal relationships or deviation of the dental midline. Practitioners can use preliminary orthodontic therapy, on the other hand, to create proper space for implant placement in some situations. Resin-bonded fixed dental prostheses

(RBFDP) represent another option for replacing single missing anterior teeth. A long-term study of RBFDP clinical performance reported survival rates of 76% and 60% at five and ten years, respectively.[34] Updated materials and techniques may impact the longevity of these prostheses. A more recent long-term study reported ten-year survival rates of 74% for two-retainer RBFDP and 94% for single-retainer RBFDP.35 Clinicians may also replace a single missing anterior tooth using a two-unit (cantilever) or three-unit conventional FDP. This treatment alternative may necessitate preparation of virgin or minimally restored adjacent teeth. Additionally, lack of dentin bulk can render mandibular incisor FDP preparation challenging.[30-32] When root canal therapy and post and core placement are required, minimal residual dentin thickness can increase risk of catastrophic root fracture and adversely impact tooth prognosis.[31,32] Finally, for some anterior edentulous sites, some patients may consider not replacing a single missing anterior tooth. Beyond esthetic considerations, this option could result in drifting or tilting of adjacent teeth unless an orthodontic retainer is employed.

Specific implant designs may increase the number of sites acceptable for implant therapy. The past thirteen years has witnessed the emergence of platform switching as a strategy for preserving crestal peri-implant bone.[36] Investigators have shown that shifting the implant-abutment interface inward, away from the outer margin of the implant platform, reduces the vertical change in crestal bone height around functioning dental implants.[36-39] Some evidence also suggests implants with conical abutment connections may experience less crestal bone loss than implants with nonconical abutment connections.[40] Practitioners have hypothesized that platform switching may allow placement of dental implants closer than 1.5 mm to adjacent teeth without negatively impacting the outcome.[38] However, this practice has not been validated through controlled clinical research.[38] Moreover, platform switching may have limited applicability in mandibular incisor and maxillary lateral incisor regions, since crestal bone preservation appears related to the degree of platform-abutment mismatch.[37,38] Only a small inward shift of the abutment interface is typically possible in these areas.

Another strategy for managing a space-deficient site involves selecting a smaller diameter implant. However, below a minimum implant diameter, fatigue fracture becomes a concern. In laboratory testing, implants with diameters < 3 mm, also called mini implants, achieved maximum load values well below values attained with conventional narrow diameter implants.[41] The maximum load achieved with mini implants fell below the value representing high risk for clinical fracture.[41] In fact, many implants < 3 mm in diameter are manufactured using a titanium alloy (titanium-aluminum-vanadium or titanium-zirconium) rather than commercially pure titanium.[41-43] Titanium alloys improve material strength but may adversely impact biocompatibility.[42,44] Separate from increased risk of fatigue fracture with small diameter implants, finite element analysis also suggests that crestal bone stress may be inversely related to implant diameter.[44] Thus, very small diameter implants may produce excessive stress in the adjacent crestal bone.[44] Standardized terminology for small diameter implants remains unestablished. However, one systematic review placed implants ≤ 3.5 mm into one of three categories based on platform diameter: 3.3 to 3.5 mm (category 1), 3.0 to 3.25 mm (category 2), or < 3.0

mm (category 3).[45] This study reported that category 1 implants are well documented for all indications in both anterior and posterior areas, whereas existing data supports category 2 implants for replacement of single teeth in non-load-bearing regions only.[45] Success rates and long-term data were not available for category 3 implants.[45]

Generally, the ideal faciolingual position of a single anterior dental implant is achieved when the long axis of the fixture emerges between the incisal edge and the cingulum of the implant-supported crown.[11,16] However, in practical terms, anterior implant treatment planning involves consideration of multiple factors including the patient's occlusion and the morphology of palatal or lingual bone in the ideal implant position. A patient may present a wide alveolus that is positioned too far to the facial or lingual to support ideal implant position. Therefore, simply measuring faciolingual dimensions of the alveolus provides an incomplete picture of the clinical situation. Furthermore, faciolingual alveolar dimensions at dentate sites are virtually always greater than faciolingual alveolar ridge dimensions following tooth extraction.[16,20,24-28,46] Even so, pre-extraction alveolar measurements provide some information regarding site favorability for dental implant placement. In this study population, implant placement in mandibular incisor and maxillary lateral incisor positions would often require alveolar ridge augmentation if 2-mm peri-implant bone thickness is a clinical goal. One report estimated that over half of dental implant sites may require a bone augmentation procedure as a component of the treatment plan.[47] Data presented here suggest that when observations are limited to incisor regions, percentages of sites benefitting from ridge augmentation may be considerably higher, particularly in the mandibular arch.

CHAPTER 5: CONCLUSIONS

Results of the present observational study suggest clinicians replacing single missing teeth in mandibular incisor and maxillary lateral incisor sites may frequently need to consider a specialized dental implant (≤ 3-mm diameter) or an alternative to implant therapy. Additionally, alveolar ridge augmentation procedures may be necessary at these sites in a large proportion of patients if facial/lingual peri-implant bone thickness ≥ 2 mm is intended.

APPENDIX 1: MEASUREMENT TECHNIQUE

Step 1. Evaluate CBCT scans that contain tooth-bounded anterior teeth (#6 through 11 or #22 through 27).

Step 2. Sequentially consider each tooth position. Align the long axis of the root and crown with the vertical reference lines in the sagittal and coronal panels. The positioning cursors should be through the center of the tooth.

Step 3. Align the tooth in the axial view, so that the positioning cursors are through the adjacent teeth.

Step 4. In the sagittal panel, place the axial positioning cursor at the mid-facial CEJ. This should be the most apical point of the facial CEJ.

Step 5. Expand the coronal panel to 400x magnification and use the measure tool to draw a line that is exactly 3.0 mm. The positioning cursors will not be visible in the expanded window. Using the expanded window, move the measured 3.0 mm line to the axial positioning cursor, aligned with the facial CEJ, which will be visible in the full screen image.

Step 6. At a vertical level 3.0 mm apical to the facial CEJ, measure the distance between the roots of the adjacent teeth. Use the expanded 400 x magnification window to align the measurements and make the measured line as straight as possible (Figure 1).

Step 7. Expand the sagittal panel to 400x magnification and use the measure tool to draw a line that is exactly 3.0 mm. The positioning cursors will not be visible in the expanded window. Using the expanded window, move the measured 3.0 mm line to the axial positioning cursor, aligned with the facial CEJ, which will be visible in the full screen image.

Step 8. In the expanded window, measure a new line from the apical point of the 3.0 mm line to the buccal and lingual limits of the alveolus. Use the expanded 400 x magnification window to align the measurements and make the measured line as straight as possible (Figure 2).

Step 9. Repeat steps 2 through 8 for all remaining anterior teeth that meet inclusion criteria.

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