Original Article

Bone and cortical bone thickness of mandibular buccal shelf for mini-screw insertion in adults

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ABSTRACT

Objective: To analyze the buccal bone thickness, bone depth, and cortical bone depth of the mandibular buccal shelf (MBS) to determine the most suitable sites of the MBS for mini-screw insertion.

Materials and Methods: The sample included cone-beam computed tomographic (CBCT) records of 30 adult subjects (mean age 30.9 $\pm$ 7.0 years) evaluated retrospectively. All CBCT examinations were performed with the i-CAT CBCT scanner. Each exam was converted into DICOM format and processed with OsiriX Medical Imaging software. Proper view sections of the MBS were obtained for quantitative and qualitative evaluation of bone characteristics.

Results: Mesial and distal second molar root scan sections showed enough buccal bone for mini-screw insertion. The evaluation of bone depth was performed at 4 and 6 mm buccally to the cementoenamel junction. The mesial root of the mandibular second molar at 4 and 6 mm showed average bone depths of 18.51 mm and 14.14 mm, respectively. The distal root of the mandibular second molar showed average bone depths of 19.91 mm and 16.5 mm, respectively. All sites showed cortical bone depth thickness greater than 2 mm.

Conclusions: Specific sites of the MBS offer enough bone quantity and adequate bone quality for mini-screw insertion. The insertion site with the optimal anatomic characteristics is the buccal bone corresponding to the distal root of second molar, with screw insertion 4 mm buccal to the cementoenamel junction. Considering the cortical bone thickness of optimal insertion sites, predrilling is always recommended in order to avoid high insertion torque. (*Angle Orthod.* 2017;87:745–751.)

KEY WORDS: Mandibular buccal shelf; Mini-screw; Mini-implants; Skeletal anchorage; Extra-alveolar orthodontic anchorage; Temporary anchorage devices

INTRODUCTION

Orthodontic mini-screws have attained widespread use recently, providing skeletal anchorage to improve orthodontic mechanics.[1–3] Mini-screws have demonstrated good patient acceptance[4] and relatively low failure rates, reported at around 13.5%.[5,6] Primary stability is a key factor for successful mini-screw placement.[7] Anatomical factors affecting the stability of mini-screws are bone characteristics (bone density,

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bone depth, cortical bone thickness), soft tissue characteristics (mucosa vs attached gingiva, tissue thickness, mobility and proximity to the frenum), and the proximity of specific anatomical structures (roots, nerves, vessels, sinus/nasal cavities).

Different sites have been used for mini-screw insertion: palatal bone,[7,8] the palatal side of the maxillary alveolar process,[9] the mandibular retromolar area,[10] the infrazygomatic crest,[11] the maxillary and mandibular bucco alveolar cortical plate,[12] and the posterior palatal alveolar process.[7] Recently, the mandibular buccal shelf (MBS) has been proposed[13] as a suitable extra-alveolar mini-screw insertion site. The MBS is located bilaterally in the posterior part of the mandibular body, buccal to the roots of the first and second molars and anterior to the oblique line of the mandibular ramus.

To date, no quantitative and qualitative bone assessment of the MBS has been performed for mini-screw insertion. The aim of this study was to analyze the buccal bone thickness, bone depth, and cortical bone depth of the MBS to determine the most suitable sites of the MBS for mini-screw insertion.

MATERIALS AND METHODS

The sample of this retrospective study included cone-beam computed tomographic (CBCT) records of 30 subjects (mean age 30.9 $\pm$ 7.0 years), including 15 males (mean age 31.2 $\pm$ 7.7 years) and 15 females (30.7 $\pm$ 5.2 years) selected from the digital archive of a private practice. The CBCT exams were performed between June 2012 to November 2015 and were pre-selected if the examined subjects fulfilled the following selection criteria: Caucasian subjects, aged between 20 and 41 years, with an absence of periodontal disease, no metallic restorations in the first or second permanent mandibular premolars and molars, no missing teeth except for third molars, no genetic syndromes or craniofacial dysmorphism, no history of facial trauma, and no previous orthognathic surgery treatment.

Seventy-six patients fulfilled the selection criteria (35 male and 41 female). The patients were divided according to sex, and each of the two samples was ordered by age from the youngest to the oldest patient. These two lists of patients were used to assign a number to each patient from 1 to 35 for the male list and from 1 to 41 for the female list. A random sequence generator (http://www.randomizer.org) was used to generate two lists of randomized numbers of 35 and 41 numbers, respectively. The first 15 numbers of both random lists were selected and the corresponding CBCT exams were included in the study. According to this method, a balanced block randomization based on patients' sex was applied to select the included CBCT exams. The protocol of this study was approved by the human research ethical committee (Approval No. 102/16). All CBCT examinations were performed with the i-CAT CBCT scanner (Imaging Sciences International, Hatfield, Pa) after setting the acquisition parameters as follows: 120 kV, 5 mA, and 4- to 6-second exposure time. Each exam was converted to digital imaging and communications in medicine (DICOM) format. DICOM files were processed using the OsiriX Medical Imaging 32-bit software (Pixmeo, Geneva, Switzerland; www.osirix-viewer.com).

The following procedure was used to obtain proper view sections of the MBS for quantitative and qualitative evaluation of bone characteristics. Three preliminary reference lines were considered, as shown by the software interface, corresponding to the three conventional scan planes (sagittal: yellow line; axial: violet line; and coronal: blue line). These view scan planes were reoriented according to the following method: the furcation point of the right and left first molar and the furcation point of the right second molar were identified and the axial view scan plane was reoriented in order to pass through these three furcation points. In this reoriented axial scan plane, two points were identified at the center of the dento-alveolar process at the level of the mesial root of the mandibular first molar and the distal root of the second molar. These points were used as references to reorientate the sagittal view scan plane section in order to identify the mesio-distal direction of the mandibular alveolar process in the molar segment. Finally, the coronal view scan plane was reoriented in order to best fit the direction of the two-thirds coronal long axes of these four roots (Figure 1): mesial and distal first molar roots, mesial and distal second molar roots. This procedure identified four coronal view sections used to investigate the MBS bone characteristics. It was repeated for both the right and left sides.

A modified version of the method reported in previous publications[14,15] was performed to identify specific parameters evaluating bone quantity and quality on each coronal view section.

This methodology included the following steps:

- Identification of the vestibular cementoenamel junction (CEJ) on each scan view root section;
- Evaluation of the buccal total bone thickness on two horizontal reference lines located apically at 6 mm (TotThick-at-6) and 11 mm (TotTick-at-11) from the CEJ (Figure 2); and
- Apico-coronal total bone depth (cortical + medullary bone) and cortical coronal bone depth were measured on two vertical reference lines buccally located

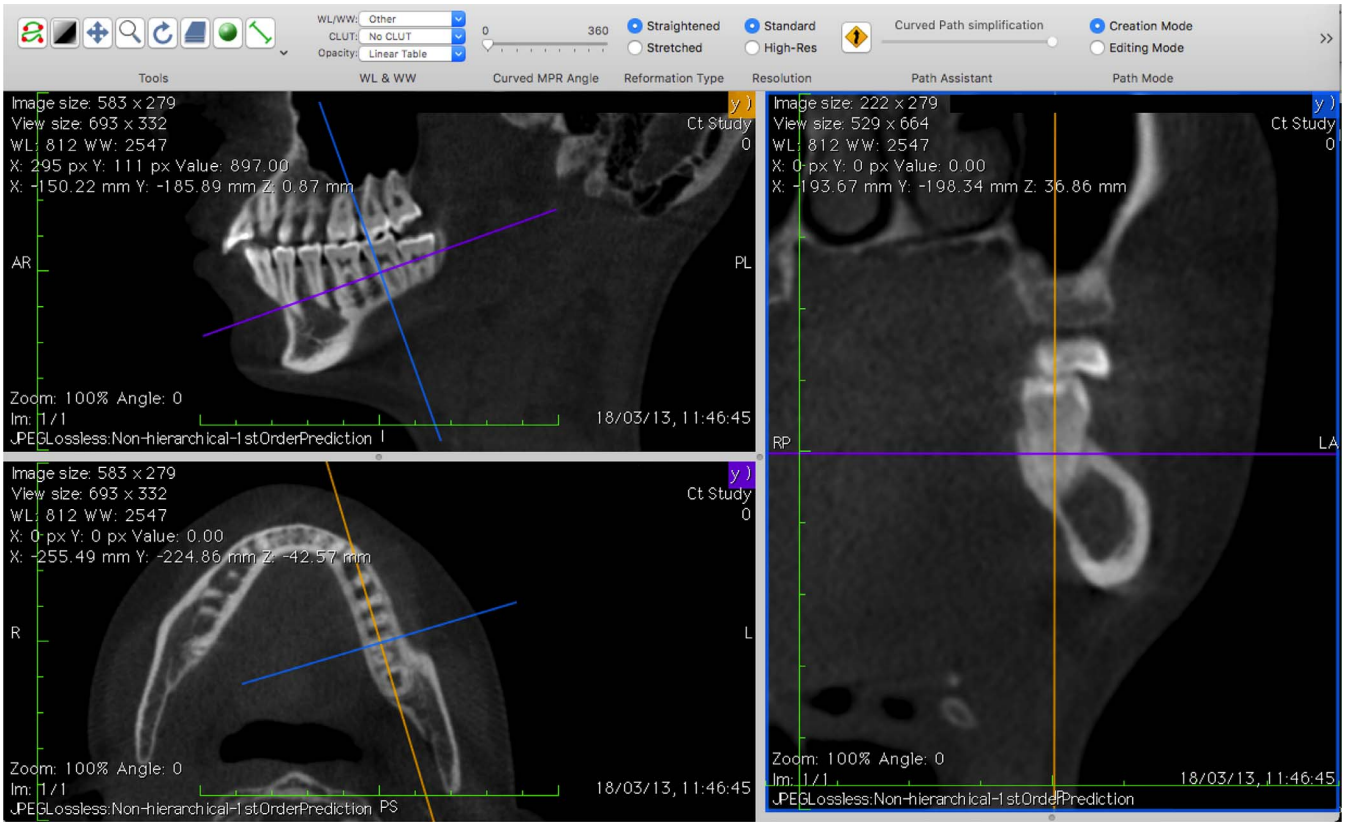

Figure 1. Software interface; reoriented reference scan lines (sagittal: yellow line; axial: violet line; and coronal: blue line) in order to best fit the direction of the long axes of the mesial root of the second left mandibular molar.

at 4 mm (TotDepth-at-4 and CortDepth-at-4) and 6 mm (TotDepth-at-6 and CortDepth-at-6) from the CEJ (Figure 3).

The cortical bone depth was measured considering only the coronal cortical plate because it was assumed that only the cortical bone plate interacts with the mini-screw during mini-screw insertion. A set of eight measurements was taken for each scan root plane assessing the total and cortical bone depth in an apical direction (at 4 and 6 mm from the CEJ buccally) and bone thickness in a buccal direction (at 6 and 11 mm from the CEJ apically). All measurements were taken by the same expert operator (AMB).

Statistics

A preliminary analysis was run on 10 subjects to obtain data for power analysis evaluation. The MBS bone thicknesses measured on a horizontal reference line apically located at 6 mm from CEJ (TotThick-at-6) of the mesial and distal roots of the right second molar were compared, and the difference in means of 1.81 mm and the standard deviation (SD) of 2.47 mm were used as outcomes to perform the power analysis calculation. The results of the power analysis indicated

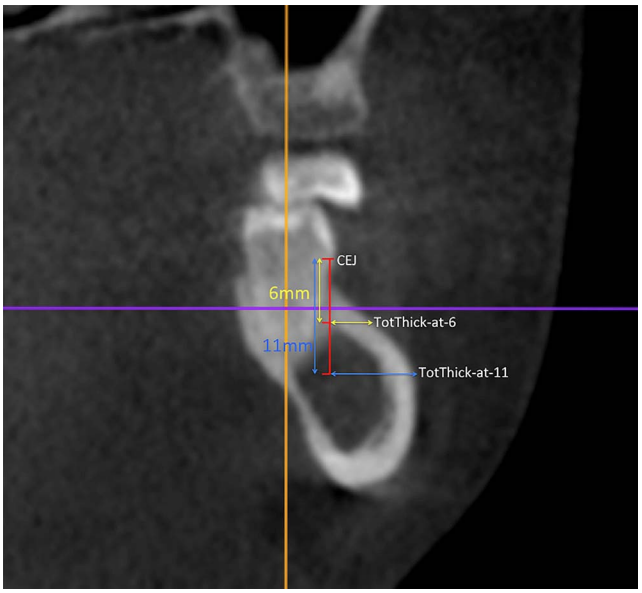

Figure 2. The bucco-lingual thicknesses of total bone (cortical + medullary bone) and cortical bone were measured on two horizontal reference lines apically located at 6 mm (TotThick-at-6) and 11 mm from the CEJ (TotTick-at-11).

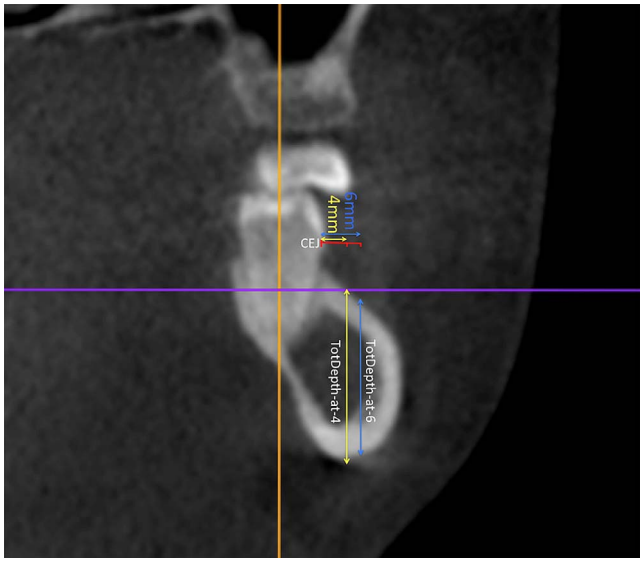

Figure 3. The apico-coronal bone depth thicknesses of total bone (cortical + medullary bone) and coronal cortical bone were measured on two vertical reference lines buccally located at 4 mm (TotaDepth-at4 and CortDepth-at-4) and 6 mm (TotaDepth-at6 and CortDepth-at-6) from the CEJ.

that in order to reach 80% of power it was necessary to analyze a sample of 30 subjects.

Preliminary data analysis of all samples suggested normal distribution (Shapiro-Wilk test) and equality of variances (Levene's test). Descriptive statistics were performed reporting mean, SD, maximum and minimum values for each parameter and for all root scan sections. The descriptive statistics were used to perform a preliminary evaluation of the potentially suitable sites for mini-screw insertion. The insertion sites were considered suitable if they presented a minimum horizontal bone thickness of 5 mm (1.7 mm of root safety distance, 1.6 mm of screw diameter, 1.7 mm of cortical buccal bone safety distance) and a minimum average vertical bone thickness of 6 mm (which represents the minimum standard mini-screw length). The potentially suitable sites were compared using inferential statistics to detect significant bone thickness differences. Unpaired *t*-tests were used to compare data derived from different root scan sections. Paired *t*-tests were used to compare data obtained from the same scan root sections at different vertical locations from the CEJ.

In order to assess the methodological error, view section identification and measurement of parameters were repeated for 10 randomly selected patients 1 week apart. Paired *t*-tests and intraclass correlation coefficients (ICCs) were used to assess the intra-operator reliability. The magnitude of the random error was assessed using the Dahlberg formula. No differences ($P < .05$) were found between the two readings; all measurements were highly reliable, with the ICC varying from 0.76 to 0.84. Random error ranged from 0.5 to 0.9 mm. SPSS Statistics software (version 17.0; IBM Corporation, Armonk, NY) was used for all statistical analyses. The significance levels for all tests were set at $P < .05$.

Table 1. Descriptive Statistics of Total Buccal Bone Thickness Values of Different Root Sites Measured on Two Horizontal Reference Lines at 6 mm Apical to the Cementoenamel Junction (CEJ) (TotThick-at-6) and 11 mm apical to the CEJ (TotTick-at-11). Data Considered "Suitable" for Mini-Screw Insertion Are Labeled with the Light Gray Color; the Data Considered as "Nonsuitable" Are Labeled with the Dark Gray Color[a]

Evaluated root sites	TotThick-at-6				TotThick-at-11			
	Mean	SD	Min	Max	Mean	SD	Min	Max
R1M-m	0.25	0.44	0	1.28	2.18	1.46	0	6.77
L1M-m	0.45	0.77	0	2.71	2.59	1.28	0	5.31
R1M-d	0.88	1.08	0	3.08	3.53	1.73	0	6.76
L1M-d	1.74	1.86	0	7.11	4.45	2.05	0.98	9.62
R2M-m	3.76	2.53	0	10.7	6.86	2.02	3.44	12.48
L2M-m	4.25	2.38	0	8.87	7.04	1.65	3.07	10.01
R2M-d	5.57	2.42	0	10.04	7.88	1.71	5.28	11.73
L2M-d	5.63	2.44	0	9.97	7.71	1.69	4.17	10.80

[a] First column abbreviations: R1M-m indicates right first molar mesial root; L1M-m, left first molar mesial root; R1M-d, right first molar distal root; L1M-d, left first molar distal root; R2M-m, right second molar mesial root; L2M-m, left second molar mesial root; R2M-d, right second molar distal root; and L2M-d, left second molar distal root.

RESULTS

Descriptive statistics are reported in Table 1 for total bone thickness. Tables 2 and 3 report descriptive statistics for total bone depth and cortical bone depth, respectively. In Tables 1 and 2, the data cells reporting

Table 2. Descriptive Statistics of Total Bone Depth Values of Different Root Sites Measured on Two Vertical Reference Lines at 4 mm Buccal to the Cementoenamel Junction (CEJ) (Tot-Depth-at-4) and 6 mm buccal to the CEJ (TotDepth-at-6). Data Considered "Suitable" for Mini-Screw Insertion Are Labeled with the Light Gray Color; the Data Considered as "Nonsuitable" Are Labeled with the Dark Gray Color. The Abbreviations in the First Column Are Explained in the Table 1 Footnote

Evaluated root sites	TotDepth-at-4				TotDepth-at-6			
	Mean	SD	Min	Max	Mean		Min	Max
R1M-m	8.27	7.91	0	21.07	2.38	5.21	0	16.27
L1M-m	15.15	7.58	0	23.29	6.73	7.34	0	20.33
R1M-d	14.72	6.64	0	22.64	6.82	7.83	0	19.19
L1M-d	18.56	5.64	0	23.76	14.21	7.24	0	22.22
R2M-m	18.41	3.77	9.57	24.03	12.34	8.21	0	22.38
L2M-m	18.62	4.89	0	24.58	15.95	6.97	0	23.75
R2M-d	19.84	3.28	9.48	24.23	15.56	7.86	0	27.43
L2M-d	19.98	3.22	13.14	24.58	17.44	6.51	0	23.75

Table 3. Descriptive Statistics of Cortical Coronal Thickness Values of Different Root Sites Measured on Two Vertical Reference Lines at 4 (CortDepth-at-4) and 6 mm (CortDepth-at-6) buccal to the Cementoenamel Junction. The Abbreviations in the First Column Are Explained in the Table 1 Footnote[a]

	CortDepth-at-4				CortDepth-at-6			
Evaluated Root Sites	Mean	SD[a]	Min[b]	Max[c]	Mean	SD[a]	Min[b]	Max[c]
R1M-m	7.20	6.94	0	20.75	2.38	5.21	0	16.27
L1M-m	7.66	5.53	0	19.85	4.63	5.27	0	14.73
R1M-d	7.45	5.57	0	17.15	4.34	5.76	0	19.19
L1M-d	5.19	2.38	0	13.2	7.58	6.14	0	21.28
R2M-m	6.63	4.86	2.24	19.62	7.45	6.60	0	21.87
L2M-m	5.45	3.77	0	18.58	7.45	6.68	0	21.93
R2M-d	6.07	5.32	1.24	21.9	10.46	8.08	0	23.23
L2M-d	4.94	3.35	1.9	17.78	6.99	6.31	0	20.48

[a]SD indicates standard deviation; [b]Min, minimum; and [c]Max, maximum. Vs indicates versus.

values considered "suitable" for mini-screw insertion are labeled with the light gray color, and data considered "nonsuitable" are labeled with the dark gray color. Table 4 reports the results of the inferential statistics.

DISCUSSION

To the best of our knowledge, this is the first study in the literature that investigates the anatomic skeletal characteristics of the MBS for mini-screw insertion.

The MBS potentially offers some clinical advantages compared to dento-alveolar interradicular mini-screw insertion sites. The MBS extends buccally with a considerable amount of bone, and this extension allows clinicians to insert mini-screws in an orientation parallel to the long axes of the molar roots.[13] This insertion modality could offer clinical advantages by avoiding possible screw-to-root contact during anterior-posterior dental movements along the dento-alveolar process. Another advantage could be a reduced risk of screw-to-root contact during insertion, considering that screw-to-root contact is one of the most frequent causes of failure.[16] This characteristic could help to explain the observations by Chang et al.,[13] who reported lower failure rates compared to those associated with mandibular interradicular mini-screw insertion. In order to properly insert a mini-screw in the MBS, an understanding of the anatomical bone characteristics of this insertion site is essential.

Upon preliminary evaluation, a minimum cutoff value of the buccal extension of the MBS for safe mini-screw insertion was considered to be 5 mm of buccal bone thickness (1.7 mm of root safety distance, 1.6 mm of screw diameter, 1.7 mm of cortical buccal bone safety distance). Descriptive statistical data showed that the total buccal bone thickness increases in the distal and in the apical portions of the MBS.

The amount of buccal bone thickness was evaluated at two different vertical levels: 6 and 11 mm apical to the CEJ. Distal root of the second molar scan sections, on both the right and left sides, were the only sections that showed an average of more than 5 mm of total buccal bone thickness 6 mm apical to the CEJ (Table 1). Both the mesial and distal second molar root scan sections on both sides (right and left) showed enough buccal bone for mini-screw insertion at 11 mm apical to the CEJ. Significant differences ($P < .05$) in buccal bone thickness were found between measurements at 6 and 11 mm (Table 4). Inferential statistics also revealed that the distal root of the second molar site

Table 4. Inferential Statistics of Buccal Bone Thickness Data of Right and Left Second Molar. The Abbreviations in the First Column Are Explained in the Table 1 Footnote[a]

	Right Second Molar			Left Second Molar		
Evaluated Root Sites	R2M-m		R2M-d	L2M-m		L2M-d
TotThick-at-6	3.76 (±2.53)	Vs**	5.57 (±2.42)	4.25 (±2.38)	Vs**	5.63 (±2.44)
	Vs*		Vs*	Vs*		Vs*
TotThick-at-11	6.86 (±2.02)	Vs**	7.88 (±1.71)	7.04 (±1.65)	Vs**	7.71 (±1.69)
TotDepth-at-4	9.46 (±3.64)	Vs (NS)	8.81 (±4.41)	8.44 (±3.47)	Vs (NS)	8.19 (±2.8)
	Vs (NS)		Vs (NS)	Vs (NS)		Vs (NS)
TotDepth-at-6	8.69 (±6.33)	Vs (NS)	11.41 (±7.44)	9.44 (±5.96)	Vs (NS)	9.34 (±5.63)
TotCort-at-4	6.63 (±4.86)	Vs (NS)	6.07 (±5.32)	5.45 (±3.77)	Vs (NS)	4.94 (±3.35)
	Vs (NS)		Vs (*)	Vs (NS)		Vs (NS)
TotCort-at-6	7.45 (±6.6)	Vs (NS)	10.46 (±8.08)	7.45 (±6.68)	Vs (NS)	6.99 (±6.31)

[a] NS indicates not significant.
** Significant difference with $P < .05$ (unpaired *t*-test); * Significant difference with $P < .05$ (paired *t*-test).

showed significantly thicker bone compared to the mesial root of the second molar on both the left and right sides ($P < .05$), signifying the region of the distal root of the second molar as a safer zone for insertion, compared to the mesial root (Table 4).

Other than the characteristic of horizontal bone thickness, evaluation of the corono-apical (vertical) bone depth dimension of the MBS is also important in order to select the proper screw length. Data showed that the sites of the MBS with adequate bone depth on average are at the mesial and distal roots of the second molar. Evaluation of the vertical bone depth dimension of the MBS was performed at 4 and 6 mm buccal to the CEJ (Table 2). The mesial root of the mandibular second molar showed average bone depth dimensions of 18.51 and 14.14 mm at 4 and 6 mm buccal to the CEJ, respectively. The distal root of the mandibular second molar showed average vertical bone depth dimensions of 19.91 and 16.5 mm, respectively. These data indicate that the insertion sites evaluated offer the opportunity to insert any screw length commercially available. The average amount of bone depth dimension was greater at 4 mm buccal to the CEJ compared to 6 mm buccal (Table 2). However, no significant differences were found comparing bone depths between the 4- and 6-mm insertion sites or between the mesial and distal insertion sites of the second molars (Table 4). Only the bone depth difference measured between the 4- and 6-mm sites buccal to the distal right second molar was found to be statistically significant (Table 4); however, this difference would be clinically irrelevant, considering the great amount of available vertical bone depth at these locations.

The high standard deviation of vertical bone dimensions at 6 mm buccal to the CEJ (TotDepth-at-6) of the mesial and distal root scans of the mandibular second molars indicates the high anatomic variability of the MBS. Minimum values at 6 mm buccal to the CEJ (Table 2) were zero for all the considered parameters, indicating the presence of at least one subject with reduced buccal extension of the MBS. The variability of the MBS observed in this study emphasizes the importance of preliminary clinical evaluation of potential insertion sites on an individual basis.

Evaluation of cortical bone thickness before mini-screw insertion is appropriate since pre-drilling may be indicated in order to improve primary stability and to avoid excessive insertion torque and screw failure.[17–23] Cortical bone depth was measured (Table 3) in order to evaluate the necessity for pre-drilling in the MBS. All sites evaluated displayed cortical bone thicknesses that were greater than 2 mm, with average values at the distal root of the second molar of 5.5 mm measured 4 mm lateral to the CEJ and 8.72 mm measured 6 mm lateral to the CEJ (Table 3). These data indicate that pre-drilling is always recommended before mini-screw insertion in the buccal shelf in order to avoid excessive insertion torque.[16]

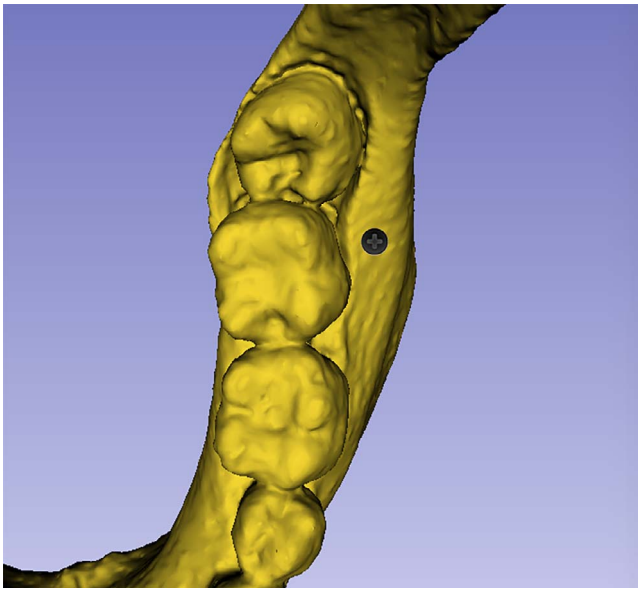

Figure 4. Occlusal drawing of left mandibular buccal shelf. A mini-screw representation was placed corresponding to the insertion site with the optimal anatomic characteristics. It is the zone of MBS adjacent to the distal root of the second molar and 4 mm buccal to the CEJ.

One limitation of this study is that it evaluated only the bony anatomical characteristics of possible MBS insertion sites. Evaluation of the MBS periodontal soft tissue characteristics was beyond the purpose of this study. However, in order to select the proper mini-screw insertion site, soft tissue should be considered, because mobility of the alveolar mucosa can affect long-term mini-screw stability. Moreover, this study evaluated only Caucasians, and the bony characteristics of the MBS could be different in other ethnic groups. Further studies are necessary to evaluate MBS characteristics in different ethnic groups. However, the results of this study showed that specific sites of the MBS (specifically the distal root of the second molar) present great amounts of bone that may be adequate even when considering possible ethnic variations.

CONCLUSIONS

- Specific sites of the MBS offer enough bone quantity and adequate bone quality for mini-screw insertion. The insertion site of the MBS with the optimal anatomic characteristics is the buccal bone lateral to the distal root of the second molar, with screw insertion located 4 mm buccal to the CEJ (Figure 4). For particular biomechanical needs, it is possible to consider an insertion site lateral to the mesial root of

the second molar, but insertion will likely need to be more apical to attain adequate buccal bone thickness.
- Because of anatomical variation among individuals, potential insertion sites should always be evaluated on an individual basis.
- Considering the cortical bone thickness of optimal insertion sites of the MBS, pre-drilling is always recommended in order to avoid high insertion torque.

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