Original Article

A CBCT atlas of buccal cortical bone thickness in interradicular spaces

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ABSTRACT

Objective: To provide a road map of buccal cortical bone thickness in interradicular locations where miniscrew implants are commonly placed.

Materials and Methods: Cone-beam computed tomography images from 100 study quadrants (50 maxillary and 50 mandibular) were studied. Cortical bone thickness was measured at the most mesial point, the midpoint, and the most distal point in interradicular areas from the canine to the first molar in both arches at 4 mm and 6 mm from the alveolar ridge. Indicator variables of whether the cortical bone thickness was thinner than 1 mm and thicker than 1.5 mm were constructed and analyzed in a general linear mixed model.

Results: Buccal cortical bone was significantly thinner at a point bisecting two teeth than the bone adjacent to the teeth ($P < .0001$). The site with the greatest percentage of measurements $<$1 mm (20%) was at the midpoint bisecting the mandibular canine and the first premolar. The site with the highest percentage of measurements $>$1.5 mm (50%) was in the mandible adjacent to the first molar (distal to the midpoint of the second premolar and first molar) at 6 mm from the alveolar crest.

Conclusion: Cortical bone thickness is significantly thinner centrally between two teeth than in the areas adjacent to the roots. (*Angle Orthod.* 2015;85:911–919.)

KEY WORDS: Cortical Bone; Interradicular; CBCT

INTRODUCTION

Among all the factors that determine miniscrew implant (MSI) stability and success rate the most important is the thickness of the cortical bone in which the MSI is being placed.[1] Compared with cancellous bone, cortical bone has a higher modulus of elasticity, making it more resistant to deformation and superior for anchorage.[2] Researchers reported that even as small as 0.5 mm differences in cortical bone thickness can have a major impact on success rates.[3] By understanding cortical bone trends vertically and horizontally, orthodontists will be able to maximize the chances for success.

Cone-beam computed tomography (CBCT) has been shown to be an accurate tool for measurements that other imaging methods are unable to reproduce.[4] Numerous studies have attempted to map the cortical bone thickness in the maxilla and mandible using CBCT software. Generally speaking, buccal cortical bone thickness increases apically[5] and posteriorly.[6,7] Ideal areas for placement in the maxilla between canines and molars include placement at 2 mm, 4 mm, and 6 mm apical to the alveolar crest, with the most ideal thickness being at the 6-mm level.[5]

Although much is known about cortical bone thickness in the vertical and anterior-posterior dimension, little is known about whether cortical bone thickness varies in the mesial-distal sites between teeth. Even though it is safest to place an MSI directly in the middle of the interproximal site because of small interradicular spaces,[8] in some clinical scenarios it can be advantageous to place the MSIs mesial or distal to the midpoint between two teeth. For example, MSIs need to be placed as close as possible to the anchor teeth in retracting or protracting a segment of teeth in order to maximize the distalization or mesialization and eliminate the later replacement of MSIs.[9]

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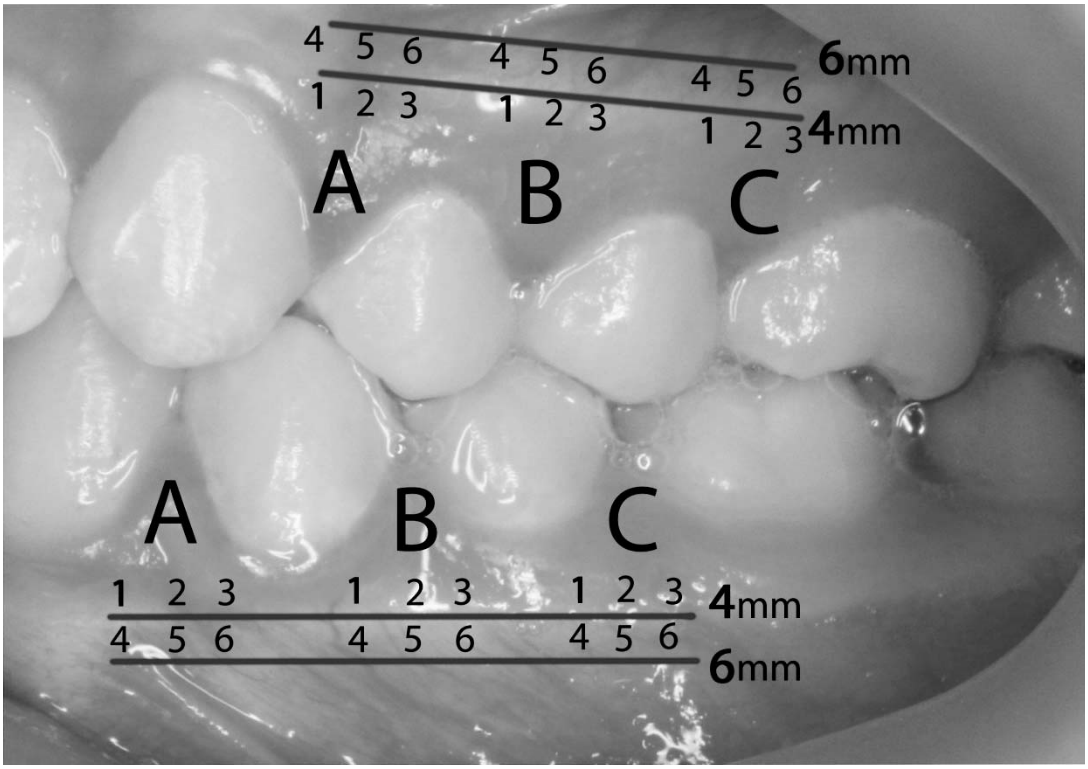

Figure 1. Sites of measurements in each quadrant.

Therefore, this study investigated cortical bone thickness on CBCT images of live patients in interradicular areas commonly used for MSI placements, specifically, from the distal part of the canine to the mesial part of the molar in both arches at 4 mm and 6 mm from the alveolar ridge. The study objective was to provide a road map of buccal cortical bone thickness from the proximal surface of two teeth in areas where MSIs are mostly placed. The null hypothesis was that the buccal cortical bone thickness is not different immediately adjacent to the tooth versus at the midpoint between two teeth.

MATERIALS AND METHODS

With the approval of the institutional review board, CBCT scans taken at the Medical University of South Carolina were examined retrospectively using Anatomage 3D imaging software (version.5.0, Anatomage, San Jose, Calif) to evaluate the cortical bone thickness in areas commonly selected for mini-implant placement. The collection of CBCT scans included contributions from all dental specialties. One hundred study quadrants (50 maxillary and 50 mandibular) were randomly selected from 50 CBCT scans with the following inclusion and exclusion criteria:

- The entire maxilla and mandible were present in that quadrant's scan.
- All teeth were fully erupted.
- No teeth were missing or impacted in areas of inspection.
- No pathology (including periodontal bone loss) was observed in the areas of inspection.

The mean ($\pm$standard deviation) age in the study population was 36 ($\pm$16.3) years (median = 29). The study subjects were 28 women and 22 men and were predominantly white (72%).

Cortical bone thickness (in millimeters) was collected at three interradicular locations in each jaw at levels of 4 mm and 6 mm apical to the alveolar crest (Figure 1): (A) between the canine and first premolar, (B) between the first and second premolars, and (C) between the second premolars and first molars. Measurements were identified by grid number 1 to 6 at each location (Figure 1): the most mesial point without violating the periodontal ligament space, the midpoint, and the most distal point without violating the periodontal ligament space at 4 mm (grids 1~3) and 6 mm (grids 4~6) apical to the alveolar crest.

The three-dimensional CBCT scans were imported into the Anatomage software and evaluated at a 0.33-voxel resolution. The images were all aligned using a standard method for accurate measurements of bone thickness. Briefly, the image was first aligned from the coronal view, and the image was adjusted in the sagittal plane so that the bony architecture was

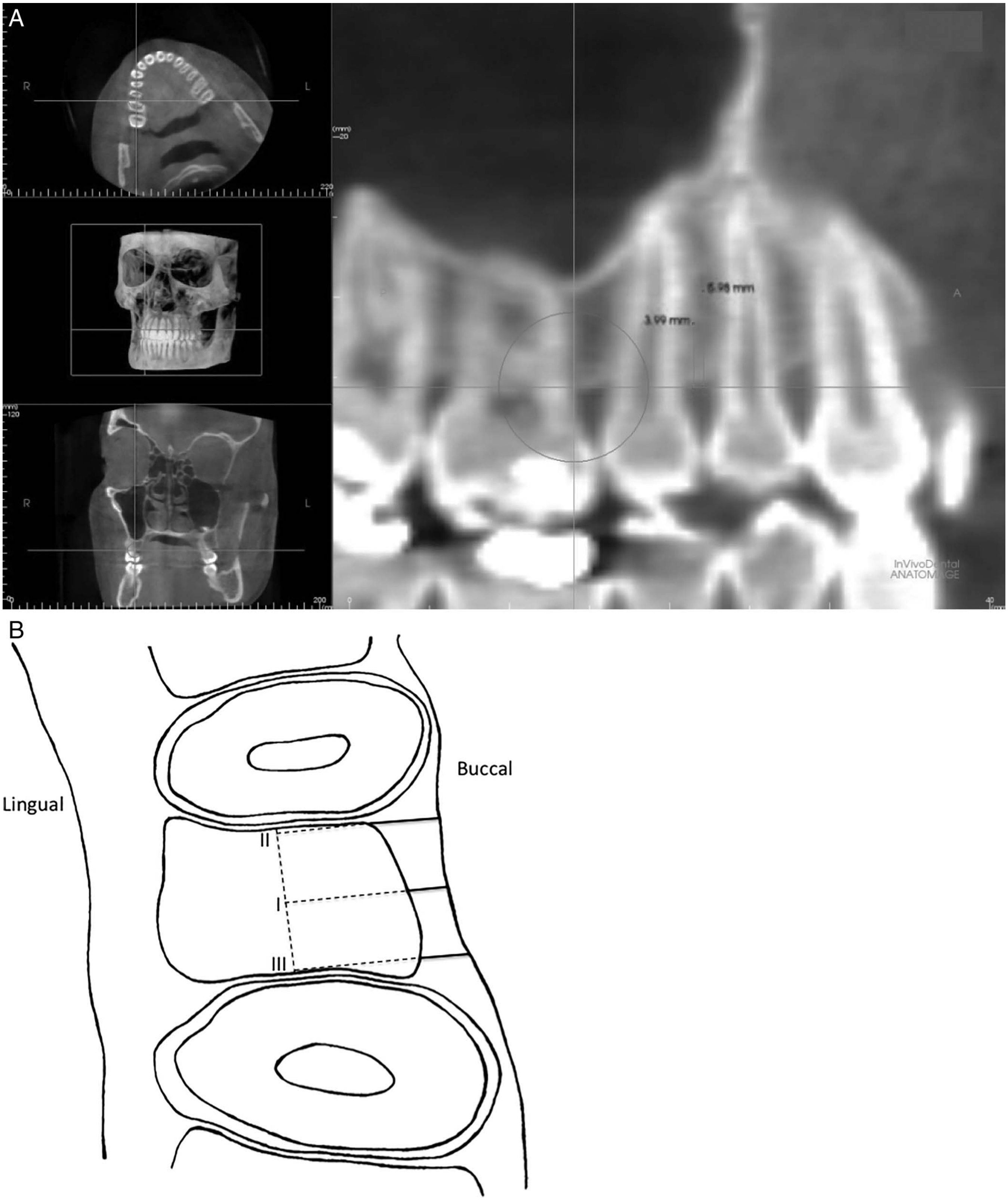

Figure 2. (A) Determination of vertical reference lines on CBCT images for cortical bone thickness measurements. (B) Diagram of the measurements. A line 90° to the cortical bone surface was drawn from the lamina dura of one tooth to the lamina dura of the adjacent tooth at the narrowest area. This line was bisected perpendicularly by line I. Two other lines parallel to line I were drawn closest to the lamina dura (lines II and III). Buccal cortical bone thickness was then measured on the solid parts of these lines by resolution discrimination between the white contrast of the cortical bone and the gray appearance of the cancellous bone.

Table 1. Mean Cortical Bone Thickness (standard deviation) for Different Locations in the Mandible and Maxilla by Height

		Mandible			Maxilla		
Height	Grid	A	B	C	A	B	C
4 mm	1	1.29 (0.19)	1.40 (0.25)	1.40 (0.23)	1.28 (0.17)	1.33 (0.23)	1.29 (0.21)
	2	1.13 (0.18)[a]	1.28 (0.24)	1.28 (0.20)	1.15 (0.17)	1.21 (0.23)	1.19 (0.19)
	3	1.25 (0.22)	1.38 (0.31)	1.48 (0.24)	1.26 (0.16)	1.29 (0.21)	1.28 (0.18)
	Average	1.22 (0.21)	1.35 (0.27)	1.38 (0.24)	1.23 (0.18)	1.28 (0.23)	1.25 (0.20)
6 mm	4	1.30 (0.22)	1.37 (0.24)	1.47 (0.27)	1.35 (0.21)	1.28 (0.20)	1.30 (0.22)
	5	1.16 (0.17)	1.33 (0.22)	1.41 (0.24)	1.23 (0.24)	1.20 (0.19)	1.20 (0.16)
	6	1.29 (0.20)	1.43 (0.25)	1.54 (0.28)[a]	1.30 (0.21)	1.30 (0.20)	1.29 (0.19)
	Average	1.25 (0.21)	1.37 (0.24)	1.47 (0.27)	1.29 (0.22)	1.26 (0.20)	1.26 (0.19)

[a] Indicates overall thinnest and thickest mean cortical bone thickness measurements.

symmetrical and a 0° line would pass through the alveolar crest at the same level bilaterally. The image was then aligned from the sagittal view by adjusting the axial plane to be parallel with the palatal plane. While the image remained in its vertical position, it was then rotated so that the CBCT slice ran through the buccal segment containing all locations to be measured. Maintaining this orientation, axial slices were taken at 4 mm and 6 mm apical to the alveolar crest (Figure 2A). A diagram of the measurements at each location is shown in Figure 2B.

A total of 36 locations were measured in each of the 50 participants, resulting in 900 maxillary measurements and 900 mandibular measurements. Having 50 subjects provided greater than 90% power to detect a 0.4-mm difference in at least one of the six sites assuming a standard deviation of 0.6 mm at a significance level of .05. The reliability of measurements was estimated using 10 subjects and was evaluated before data collection. The estimated intraclass correlation across subjects, locations, and grid numbers was 0.9218 (intraclass correlation coefficient $>$0.8 is considered excellent agreement).

The multivariable model of cortical bone thickness included age (in years), gender, jaw, tooth location within the jaw, grid location within the jaw, and an interaction between tooth location and grid location nested within the jaw. Neither age nor gender was significant in the final study model, although there are conflicting study reports on whether age and gender are associated with cortical bone thickness.[10–13] A linear mixed model with a random patient effect was constructed to account for the correlation between measures taken on the same subject. The center points versus the exterior points, as well as maxilla or mandible, were considered a main effect. Pairwise comparisons were made between variants using a Bonferroni correction to adjust the significance level for multiple comparisons. Indicator variables of whether the cortical bone thickness was thinner than 1 mm and thicker than 1.5 mm were constructed and analyzed in a general linear mixed model. All analyses were conducted in SAS version 9.3 (SAS institute, Cary, NC).

RESULTS

Cortical bone thickness ranged between 0.71 mm and 2.29 mm in the studied locations. The averages for the three locations studied in both jaws ranged from 1.22 mm to 1.47 mm (Table 1). Mean individual grid locations ranged from as low as 1.13 mm at the 4-mm midpoint between the mandibular canine and first premolar to 1.54 mm at the 6-mm most distal point between the mandibular second premolar and first molar (Table 1).

Cortical bone was thinner at the midpoint between two adjacent teeth than directly adjacent to roots, regardless of tooth location or jaw. Measurements at center grid locations (2 and 5) were significantly thinner than measurements at exterior grid locations (1 and 3 or 4 and 6) in the maxilla (Figure 3A) and the mandible (Figure 3B).

Cortical bone was significantly thicker in the mandible (mean = 1.34 mm) relative to the maxilla (mean =1.26 mm) after controlling for age, gender, tooth location, and grid location ($P < .001$), even though both the thickest and thinnest mean measurements were in the mandible (Table 1). Cortical bone thickness in the mandible significantly increased as the tooth location moved posteriorly; however, cortical bone thickness remained constant in the maxilla (Figure 4).

Less than 14% of all the sites measured reported measurements $<$1 mm. There was no significant difference in the proportion of sites with bone thickness $<$1 mm in the mandible (6.67%) versus the maxilla (7.78%). The percentage of cortical bone thinner than 1 mm at each study location is shown in Figure 5. Tooth location A had a significantly greater proportion of teeth with thickness $<$1 mm relative to site C ($P =$ .007). Across both jaw and tooth location, grid 2 had a significantly greater proportion of sites with bone thickness $<$1 mm relative to all other sites. Two sites

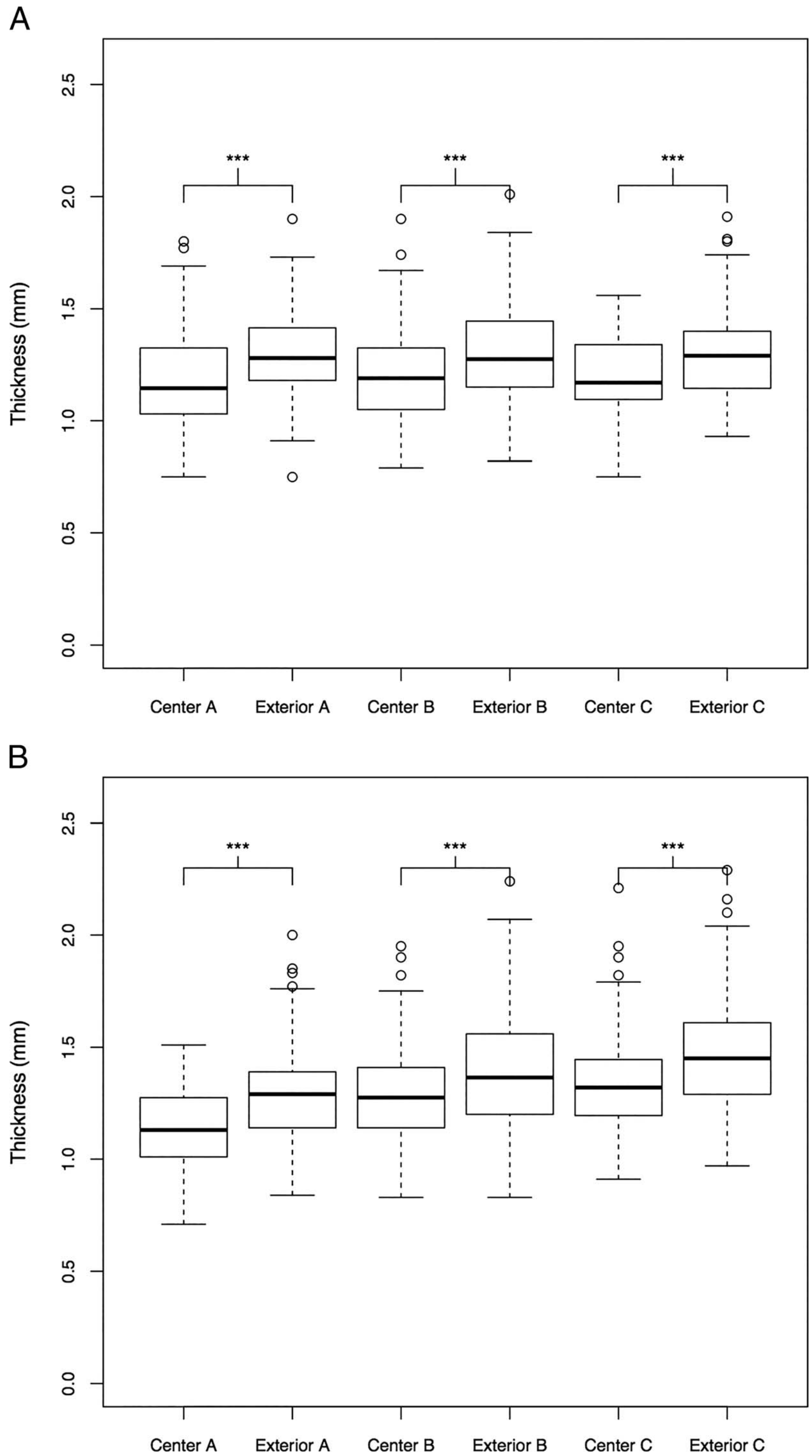

Figure 3. Cortical bone thickness of center grids (2 and 5) and exterior grids (1, 3, 4, and 6) at locations A, B, and C of the maxilla (A) and mandible (B). The dark line represents the median; the bottom and top of the box are the 25th and 75th percentiles, respectively; the bottom and top bars are the 5th and 95th percentiles, respectively; and any points represent extreme values (***$P < .0001$).

had the greatest number of thickness measurements <1 mm: mandibular A2 and A5 (20%, respectively).

The percentage of measurements >1.5 mm at each study location is shown in Figure 6. The mandible had a significantly greater proportion of sites with cortical bone thickness >1.5 mm (22.4%) relative to the maxilla (11.4%) ($P < .001$). Across both jaws and tooth locations, the center grids had a significantly smaller proportion of sites with bone thickness >1.5 mm relative to the outer grids. The two sites that

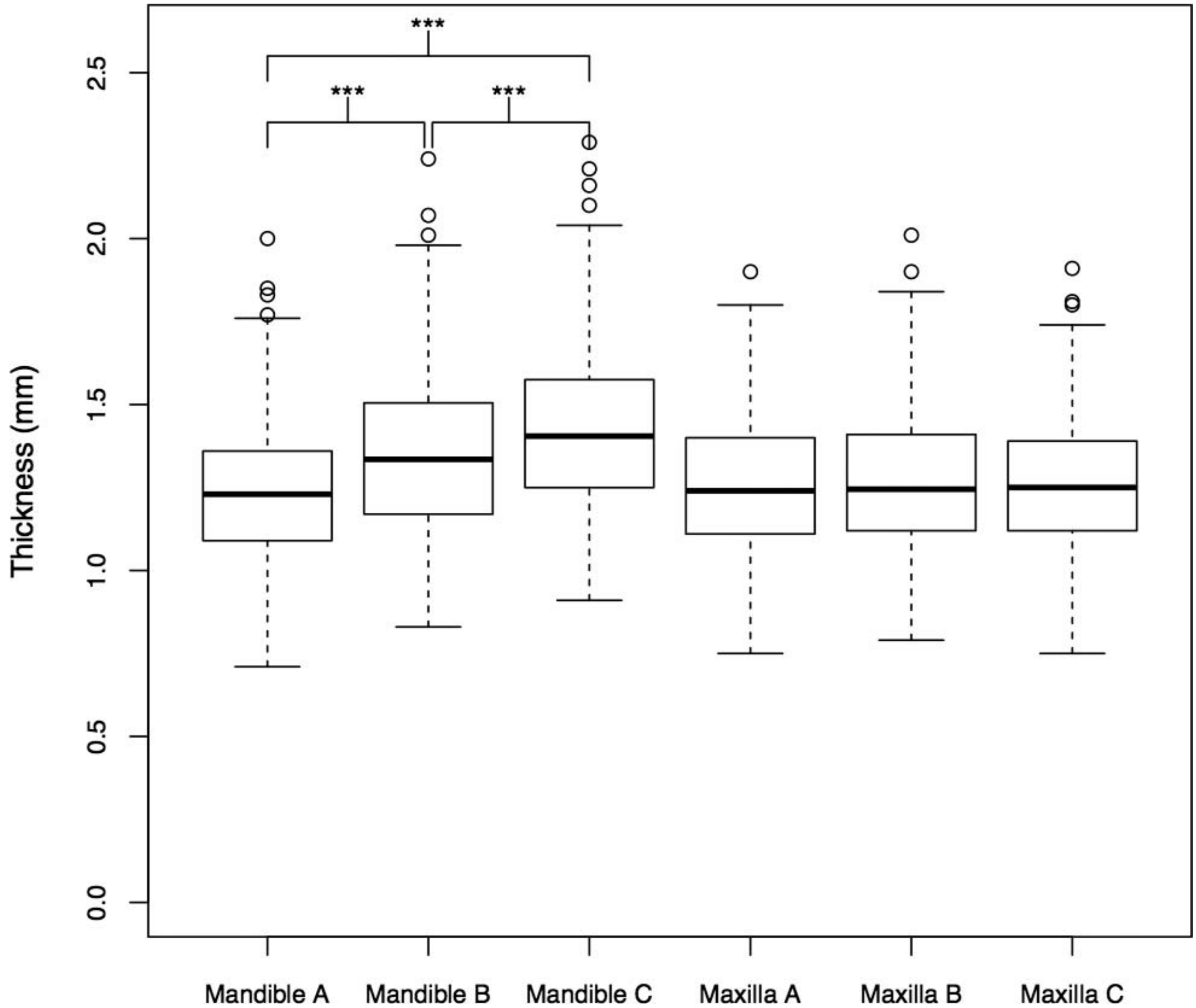

Figure 4. Cortical bone thickness at locations A, B, and C of the maxilla and mandible. The dark line represents the median, the bottom and top of the box are the 25th and 75th percentiles, respectively; the bottom and top bars are the 5th and 95th percentiles, respectively; and any points represent extreme values (***$P < .0001$).

were most posteriorly located within the mandible were also the two sites that reported the largest percentage of their measurements being >1.5 mm: mandibular C3 and C6 (40% and 50%, respectively).

DISCUSSION

To our knowledge, this is the first study that identified horizontal buccal cortical bone patterns in interradicular spaces. The null hypothesis was rejected, and there was a significant pattern of cortical bone thinning approaching the point bisecting two teeth. Once again, the findings confirmed Wolff's law that healthy physiological load strengthens the bone, even in the mini environment between two teeth.[14] Because of the small interradicular spaces and risk of root proximity,[15–17] the safest strategy is most likely to place every MSI in the middle of the interproximal site.[8] Nevertheless, in certain clinical scenarios MSIs may need to be placed immediately adjacent to the anchor teeth to achieve treatment goals. These include, but are not limited to, retracting or protracting a segment of teeth or eliminating the later replacement of MSIs.[9] In these situations, the road map in this study can be very helpful.

It is believed that at least 1 mm of buccal cortical bone thickness is necessary for sufficient primary stability.[7] The current study indicated that less than 14% of all measurements were <1 mm. Because so few locations had measurements <1 mm, it should be reasonably acceptable to place an MSI in any of the more anterior locations with any insertion angle whether it is directly between two teeth or off to one side. Jung et al.[15] reported that the success rate of orthodontic microimplants is not affected by placement angles and is more significantly affected by root

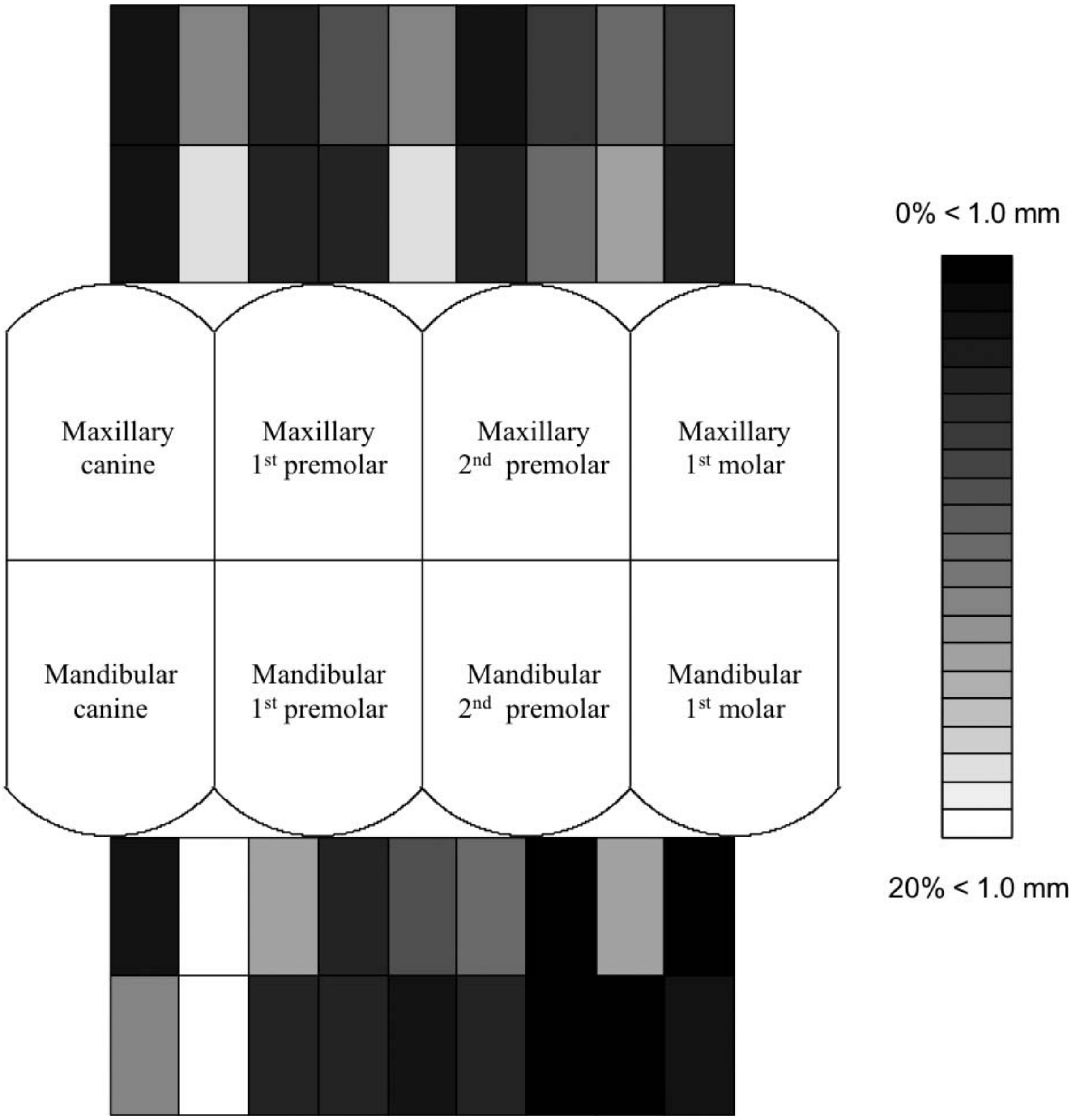

Figure 5. Percentage of cortical bone measurements thinner than 1 mm at each study location. The lighter the color, the greater the percentage of sites in the study with thickness $<$ 1.0 mm.

proximity than by cortical bone thickness. If the MSIs need to be placed at areas with thicker bone, clinicians may consider placing the MSI away from the midpoint between two teeth. This is especially applicable for MSIs placed anteriorly, where bone thinner than 1 mm is mostly detected (Figure 5). Additional consideration of the mesial distal position of MSIs may also be beneficial for high-angle patients, as a recent study[13] reported that high-angle patients might have thinner cortical bone than low-angle patients.

On the other hand, in some locations the buccal cortical bone is too thick for successful MSI placement without pilot holes. Baumgaertel[2] suggested drilling pilot holes for placing MSIs when cortical bone is thicker than 1.5 mm. The current study showed that the mandible had a significantly greater proportion of sites with cortical bone thickness $>$1.5 mm (22.4%) relative to the maxilla (11.4%). The thickest area reported was at the location 6 mm apical to the alveolar ridge mesial to the mandibular first molars (a commonly recommended first choice for mandibular posterior anchorage[6,18–20]), where 50% of the measurements were thicker than 1.5 mm (Figure 6). If MSIs are to be placed closer to the root surface or more

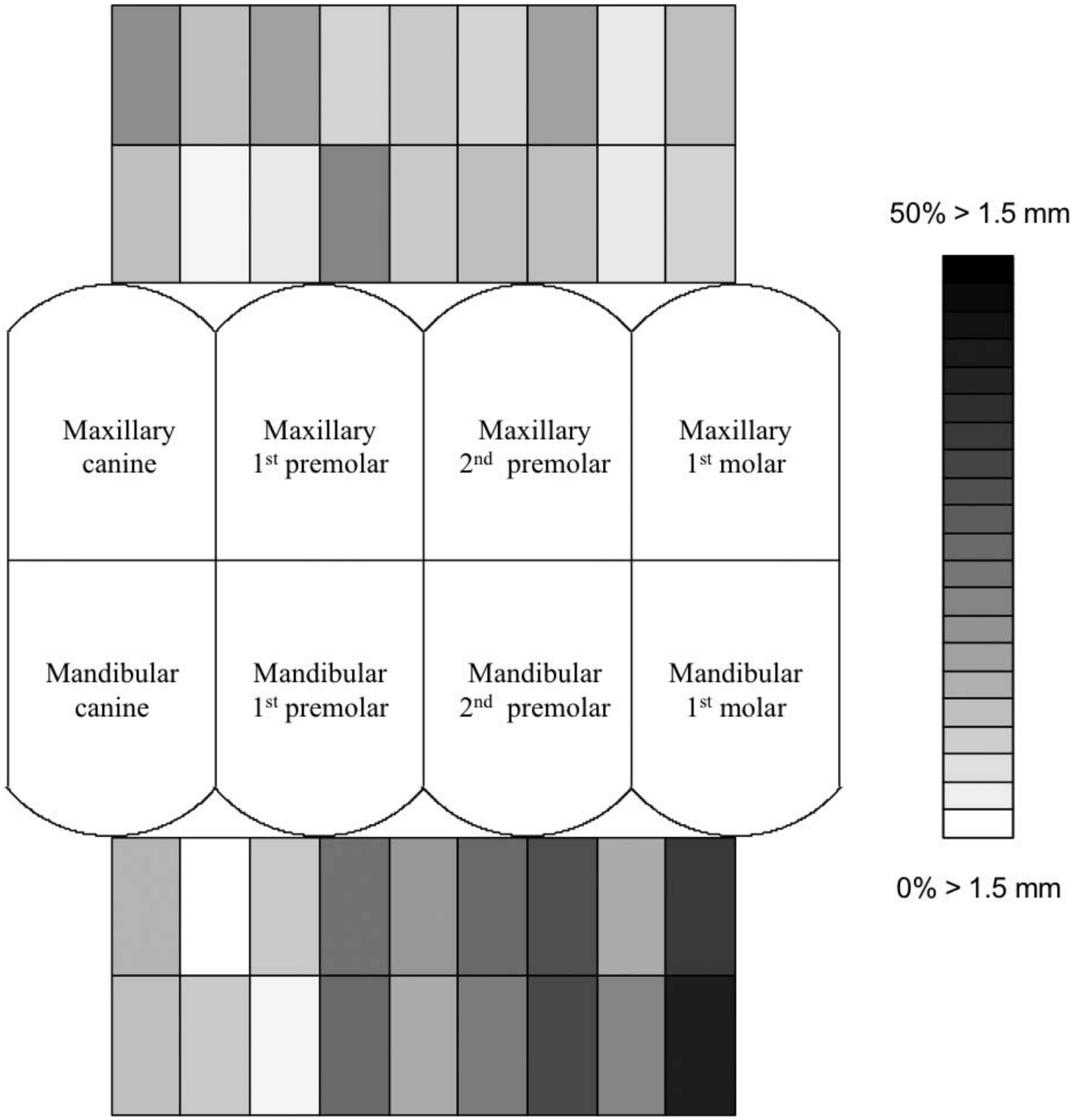

Figure 6. The percentage of cortical bone measurements thicker than 1.5 mm at each study location. The darker the color, the greater the percentage of sites in the study with thickness >1.5 mm.

gingivally, the thickness of bone can be >2 mm. Therefore, it is recommended that clinicians should consider placing a pilot hole for these locations.

Increased insertion resistance or torque is also usually considered a warning for root proximity during MSI placement. Kuroda et al.[21] reported that root proximity is a major factor for MSI failure. Increased root contact or violation of the periodontal ligament may lead to a greater chance of failure.[21–24] A distance of 0.5 mm to 0.6 mm from implant to root has been recommended to provide adequate space to prevent early failure.[23,25] Therefore, the accidental violation of the periodontal ligament should be differentiated when MSIs are intentionally placed close to one side of the interradicular space. Theoretically, the initial resistance from the relatively thicker cortical bone closer to the root should not increase in a smooth insertion, whereas an insertion with a root contact may be accompanied by an increased insertion torque and pain reported from the patient.[26]

Conflicting results have been reported on whether age and gender are associated with cortical bone thickness.[10–13] A future study that includes more age- and gender-specific groups of subjects will provide more accurate information, even though neither age nor gender was significant in our final study model. Controlling for study population and ensuring an even distribution could shed light on a highly debated topic in bone studies. In addition, a follow-up study may be performed using microcomputed tomography that enables higher-resolution scanning of teeth beyond the capabilities of CBCT.[27]

CONCLUSIONS

- Cortical bone thickness is significantly thinner centrally between two teeth than the areas adjacent to the roots.
- Of all the jaw locations studied, the average thinnest cortical bone was between the mandibular canine and the first premolar, whereas the thickest cortical bone was measured distal to the midpoint of the second premolar and first molar.

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