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*A Silvestrini Biavati**
*S Tecco**,†
M Migliorati
F Festa
G Marzo
E Gherlone
S Tetè

Three-dimensional tomographic mapping related to primary stability and structural miniscrew characteristics

Authors' affiliations:
S. Tecco, F. Festa, S. Tetè, Department of Oral Science, Nano and Biotechnology, University G.D'Annunzio, Chieti/Pescara, Italy
A. Silvestrini Biavati, M. Migliorati, University of Genova, Genova, Italy
E. Gherlone, University San Raffaele, Milano, Italy
G. Marzo, University of L'Aquila, L'Aquila, Italy

Correspondence to:
Simona Tecco
Department of Oral Science
Nano and Biotechnology
Via dei Vestini 31
66013 Chieti
Italy
E-mail: simtecc@unich.it

*Dr S. Tecco and A. Silvestrini Biavati contributed in this research in the same way as Principal Investigators.

†Present address: Simona Tecco Via Le Mainarde 26, 65124, Pescara, Italy.

Structured Abstract

Authors – Silvestrini Biavati A, Tecco S, Migliorati M, Festa F, Marzo G, Gherlone E, Tetè S

Objectives – To evaluate the maxilla, mandible, and cortical plates on computerized tomographic (CT) scans to achieve accurate three-dimensional bone thickness measurements.

Setting and Sample Population – We selected the CT scans of 25 subjects (among 102), aged 18–58 years (10 men, 15 women), with nearly complete dentition.

Material and Methods – We performed interradicular and bucco-lingual (including cortical plate thickness) measurements in dental areas distal to the canines in both alveolar arches, at three levels (5, 8, and 11 mm) from the alveolar ridge.

Results – The mean thicknesses of the cortical plates in the maxilla were 1.10 mm buccally and 1.27 mm on the palatal side ($p < 0.05$). In the mandible, cortical plates were 2.23 mm buccally and 2.02 mm lingually. Mandibular buccal and lingual cortical plates became thicker distally in the second and third molar areas. There was considerable variation in cortical thickness (from 0.25 to 5.50 mm).
Based on interradicular distances, only 13% of measured sites in the maxilla were suitable for miniscrew insertion (≥3.3 mm), but 63% of sites were suitable in the mandible.

Conclusion – This study showed considerable individual variation in bone thickness. Our data suggested that the palatal/lingual side may provide greater primary stability for miniscrews. The palatal area, between the second upper bicuspid and the first molar, appeared to be the most suitable area for tapered 7- to 9-mm miniscrews, starting at 1.5–2 mm from the alveolar crest.

Key words: CT scan; miniscrews; three-dimensional; topography

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Introduction

Anchorage management in orthodontics is a key consideration in treatment planning. Recently, temporary anchorage devices (TADs) have been widely used in non-compliance treatments, primarily because they allow the creation of an absolute anchorage, which can tolerate substantial force. Currently, the greatest difficulty for a clinician is making an accurate site diagnosis and the subsequent surgical planning.

Site selection for miniscrew insertion implies an evaluation of the quantity and quality of the alveolar bone for providing primary stability. The clinician must plan a good position from the biomechanical point of view, consider the gingival position (attached gingiva vs. movable mucosa), and minimize the risk of damage to adjacent structures. X-ray or computerized tomography (CT) images are used to examine the relationship between roots and to measure the total bucco-palatal/lingual thickness, the cortical plate thickness, and the interradicular spaces. These measurements are then used to select the appropriate shape, length, diameter, and neck height of commercially available miniscrews. It is recommended that a miniscrew is inserted at the attached gingival level in order to avoid gingival inflammation. Inflammation can lead to screw failures and pain because of compression of gingival tissues.

Many authors have studied anatomical sites on dry skulls (1) and on X-ray images (2–5), because there is substantial risk of damaging the roots (6) or other important anatomical structures during TAD positioning. Several authors (1–10) have underscored the importance of cortical bone thickness in relation to primary stability and future orthodontic load. Other authors have pointed to the physical characteristics of TADs, including the diameter, length, shape, and pitch (11, 12).

It was recently shown (13) that increasing the penetration depth of TADs resulted in greater retention. Conversely, increasing the abutment-tip distance from the cortical plate resulted in reduced retention. Placement of the TAD at 90° to the cortical plate provided the best retention. Insertion at an oblique angle from the line of force reduced the retention of TADs. Generally, for adequate retention, clinicians should embed 71.2% of the length of the screw section of the TAD into the alveolar bone; the required percentage is typically higher in the maxilla than in the mandible (14).

A recent study showed that the most significant factors for predicting TAD failure were inflammation of the soft tissue surrounding a TAD and early loading within 3 weeks after insertion. The other factors tested included gender, type of malocclusion, facial divergence, method of force application (power chain or Ni–Ti coil spring), arch (upper or lower), type of soft tissue (attached gingiva or removable mucosa), and most cephalometric measurements that reflected dento-cranio-facial characteristics (15).

During the first 90 days of canine distalization, the regions between the maxillary second premolars and first molars that are mesial to the maxillary second premolars appear to offer adequate bone quality for safe miniscrew placement. Also, the success of this new anchorage system during maxillary canine distalization requires good surgical technique, appropriate planning for miniscrew placement, inflammation control, and adequate oral hygiene (16, 17).

Currently, approximately 50% of miniscrew placements have shown movement toward the traction area (3). To explain this phenomenon, several authors have underscored the importance of cortical bone thickness in primary stability (3–5, 8–10, 18, 19) and future orthodontic load (11, 12, 20).

A crucial factor for primary stability appears to be cortical plate thickness; it must be sufficient to withstand insertion of a miniscrew. Knowledge of this thickness before miniscrew insertion could facilitate the selection of the most suitable anatomical site. It is also important to consider the differences between buccal and lingual cortical plates and the types of miniscrews that should be inserted. It was reported (8) that the cortical bone thickness must be at least 1.0 mm to ensure success. Ciarelli et al. (22) reported that screw stability was most closely related to cortical bone thickness and bone density. One study found (23) that the bone density was in linear proportion to the strength of the trabecular bone for axial and bending loads. Those studies demonstrated that the density of the trabecular and cortical bones is very important for the stability of a miniscrew. Moreover, one study (21) showed a significant correlation between the insertion torque and the cortical plate density.

In a study on dry skulls (19), monocortical and bicortical miniscrews were inserted between bicuspids; those results suggested that bicortical miniscrews would improve primary stability. That study also showed that bicortical miniscrews assured maximum anchorage, reduced cortical bone stress, and provided higher stability compared with monocortical screws.

Because morphometric analysis of the buccal and lingual cortical bone is clinically important, the objective of this study was to create a three-dimensional alveolar bone map by means of CT scanning. CT scans allow visualization of the thicknesses of the cortical plates, the total bucco-palatal/lingual alveolar region, and the interradicular spaces; thus, these measurements can be related to the neck height, length, and diameter of commercially available miniscrews.

Materials and methods

Data acquisition

The data were recorded at the Gazzerro Radiology Institute in Genoa (Italy). Twenty-five CT scans were selected (among 102 subjects) from adults aged 18–58 years (10 men, 15 women). The selection criteria were as follows: complete dental arches, no tooth crowding distal to the canines, and absence of periodontal disease with horizontal or vertical alveolar bone resorption. Assessments of these criteria were based on accurate X-ray analyses.

The data were obtained with a spiral multisliced Asteion Multi® CT system (Toshiba Medical Systems, Minato-ku, Tokyo, Japan) with a standard monitoring. This scanner, with a HeliCool Radiogenic tube and a real-time spiral of 12 frames/s, produced 0.5-mm scans in a scanning time from 0.5 to 2.3 s with a slice thickness from 0.5 × 4 to 8 × 4 mm and a field of view from 180 to 500 mm. It had detectors of 896 Solid status × 32 mm, with a distortion of 0.4 mm (HU < 10%).

In this study, data processing and all measurements were performed with Dentalvox® software (Implant Technology System [ITS], Padova, Italy).

Measurements

Anatomical sites distal to the canines in both jaws were measured at three different heights from the alveolar crest (i.e., at 5, 8, and 11 mm; Fig. 1). The rationale for the choice of these heights was related to the mean length of the posterior roots and the alveolar bone. Five millimeters from the alveolar crest was considered a safe location because it was not too close to the crest or the gingival border (the smallest miniscrew tip had a 2.5 mm diameter). From the alveolar crest, we decided to measure at 8 and 11 mm, in order to map the area at 3-mm intervals.

The head of each subject was positioned with the Frankfurt plane as the reference horizontal plane. First, we examined the Panorex reconstruction for each interradicular space; in every case, we chose the most occlusal point on the alveolar crest. From this point, three segments were drawn perpendicular to the horizontal plane at 5, 8, and 11 mm. Then, after identification of the slices at the three different heights (3, 8, and 11 mm from the alveolar crest), bone bucco-lingual and mesio-distal measurements were taken with a magnification power of 4 × (ratio 1:1).

Fig. 1. Computerized tomographic (CT) scans were analyzed at different heights to evaluate the buccal plate, the palatal plate, the total bucco-palatal thickness, and the interradicular distances. The CT slices were taken at 5, 8, and 11 mm from the crest.

In the bucco-lingual measurements, the buccal, lingual/palatal, and total bone thicknesses were calculated. In the mesio-distal measurements, the minimum space between the roots was recorded.

The following measurements were recorded:

(1) *Total bucco-lingual/palatal thickness* (Fig. 2): The thickness of a single cortical buccal or lingual/palatal plate was calculated, together with the total bucco-lingual/palatal thickness.
(2) *Interradicular mesio-distal measurements* (Fig. 2): The minimal distances between adjacent roots were measured in the interradicular spaces among

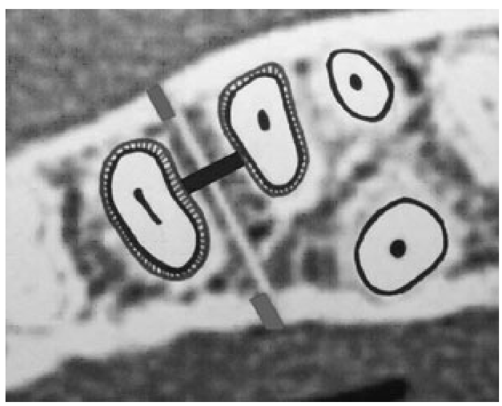

Fig. 2. Computerized tomographic scans showing the interradicular distance (blue), bucco-lingual distance (yellow), and cortical thickness of the buccal and the palatal cortical plates (red).

teeth from the canine to the third molar. These measurements were recorded in both the upper and the lower dental arches on the right and left sides.

(3) *Second upper bicuspid/first molar area:* TADs are often placed between the second bicuspid and the first molar; therefore, this region was analyzed to evaluate interradicular relationships on axial slices cut at 0.5-mm intervals over a vertical distance from 0 to 11 mm. On these slices, three minimal parameters were measured: (a) the bicuspid/mesio-buccal first molar root, (b) the bicuspid/palatal first molar root, and (c) the palatal cortical plate/mesio-buccal first molar root (Fig. 3).

The CT scans of 10 subjects (five maxillary and five mandibular) were randomly selected and remeasured by the same observer after 7 days.

All single measurements were collected. The mean and standard deviation (SD) and the minimum and maximum of the obtained data were calculated for each slice.

Reliability of the measurements

For each measurement, the intra-observer method error (ME) was calculated, in both the maxilla and the mandible, with the Dahlberg formula (23):

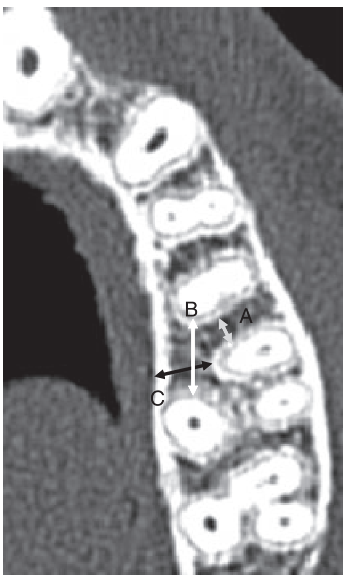

Fig. 3. Interradicular measurements between the second bicuspid and the first molar. (A) Bicuspid/mesio-buccal first molar root, (B) bicuspid/palatal first molar root, and (C) palatal cortical plate/mesio-buccal first molar root.

$$\mathrm{ME} = \sqrt{\sum d^2/2n}$$

where d is the difference between the first and second measurements and n is the number of double measurements.

The differences between the first and second measurements were calculated with the Wilcoxon signed-rank test, and they were not statistically significant ($p > 0.05$).

Data analysis

For each variable, the mean and SD were calculated. In order to determine whether the parametric or non-parametric test should be used for assessing significant differences among groups, the normal distribution of data was assessed through the Kolmogorov–Smirnov test.

The t-test for independent samples was used to test the differences between the buccal cortical plate thickness and the lingual/palatal cortical plate thickness.

Then, one-way analysis of variance (ANOVA) was employed to assess the differences among the thicknesses found at the three different heights from the alveolar crest (5, 8, and 11 mm). Where significant, the Tukey test was employed as a *post hoc* analysis. These tests were applied to investigate the differences among patients in the buccal cortical plate thickness, the palatal/lingual cortical plate thickness, and the bucco-palatal/lingual distance.

The SPSS 9.0 (SPSS Inc., Chicago, IL, USA) software was employed for statistical tests. A p-value < 0.05 was taken to indicate significance.

Results

All data (values in mm) are shown in Tables 1–6.

The maxillary cortical bone showed relatively unvarying thickness at most locations (Tables 1 and 3) (Fig. 4A–C), with statistically significant differences only in a few sites. The bucco-lingual measurements in the mandible tended to show statistically significant increases (Tables 2 and 3) as the distance increased from 5 to 11 mm from the cortical crest (nine sites among 10 showed a statistically significant increase) (Fig. 5A–C). In addition, in the maxilla, the palatal cortical plate showed a significantly greater thickness than the buccal plate (Fig. 4A–C); this difference was not evident with the lingual side of the mandible (Table 3) (Fig. 5A–C).

Considering measurements made at all the sites, the mean upper cortical thickness was 1.10 ± 0.2 mm buccally and 1.27 ± 0.3 mm palatally (Table 3) (t = −2.35; $p < 0.05$). Although significant, these differences did not appear to be clinically important. In the mandible, cortical thickness values were significantly higher than those in the maxilla (Table 3) ($p < 0.05$). Moreover, in the mandible, the cortical thickness was greater buccally (2.23 ± 0.5 mm) than lingually (2.02 ± 0.5 mm) (Table 3) (Fig. 5A–C), but the difference was not significant.

The total bucco-lingual mean thickness was similar in the maxilla and mandible, and it did not differ significantly between the two jaws; it was 11.53 ± 1.3 mm in the maxilla vs. 11.14 ± 1.4 mm in the mandible (Table 3). This thickness is generally suitable for miniscrews of 9 mm in length.

In this study, we assumed that the minimum interradicular space for miniscrew insertion should be

Table 1. **Mean and Standard Deviation (SD) of the buccal cortical thickness, palatal cortical thickness, and bucco-palatal measurement in the maxilla, taken at the heights of 5, 8, and 11 mm from the crest**

	Region 18-17			Region 17-16			Region 16-15			Region 15-14			Region 14-13		
	Bucc. Cort.	Bucc-Palat. dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat. dist.	Palat. Cort.	Bucc. Cort.	Bucco-Palat. dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat. dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat. dist.	Palat. Cort.
5 mm															
Mean	0.85	13.26	0.98	1.08	14.12	1.14	0.99	11.12	1.10	1.10	9.67	1.39	1.12	9.26	1.33
SD	0.34	2.29	0.31	0.21	1.43	0.36	0.14	1.68	0.30	0.24	1.40	0.53	0.29	1.32	0.55
8 mm															
Mean	1.36	13.7	1.45	1.12	14.26	1.31	1.04	11.61	1.40	1.10	9.53†	1.48	1.30	9.34	1.61
SD	0.62	2.40	0.63	0.48	1.96	0.51	0.50	1.50	0.54	0.37	1.28	0.53	0.38	1.35	0.58
11 mm															
Mean	0.91	13.06	1.28	1.14	14.33	1.11	1.08	11.86	1.33	1.18	**10.45****,†	1.31	1.23	10.01	1.27
SD	0.34	1.71	0.45	0.44	1.36	0.45	0.23	1.74	0.37	0.38	1.77	0.40	0.38	2.06	0.35

	Region 23-24			Region 24-25			Region 25-26			Region 26-27			Region 27-28		
	Bucc. Cort.	Bucc-Palat Dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat. dist.	Palat. Cort.	Bucc. Cort.	Bucc-Palat. dist.	Palat. Cort.
5 mm															
Mean	1.14	9.17	1.30	1.05	9.48	1.26	0.88	11.00	1.21	1.00	13.02†	0.96	1.32	13.09	0.94
SD	0.44	1.50	0.54	0.47	1.37	0.55	0.30	1.56	0.49	0.53	2.37	0.40	1.19	2.09	0.39
8 mm															
Mean	1.23	8.96†	1.57	1.09	9.61	1.51	0.91	10.85†	1.20	1.01	13.27	1.02	1.13	13.13	1.07
SD	0.45	1.68	0.43	0.47	1.33	0.45	0.40	1.56	0.34	0.38	2.44	0.30	0.49	1.94	0.23
11 mm															
Mean	1.15	**9.80****,†	1.47	1.09	9.96	1.30	0.98	**11.72***,†	1.38	1.21	**14.03***,†	1.25	1.02	13.32	1.25
SD	0.41	1.55	0.87	0.31	1.64	0.33	0.27	1.84	0.42	0.40	2.05	0.47	0.35	1.56	0.47

*$p < 0.05$.
**$p < 0.01$.
†Indicates, among the three compared groups (5, 8, and 11 mm of height), the two significantly different groups (resulted by the *post-hoc* analysis).

Table 2. **Mean and Standard Deviation (SD) of the vestibular cortical thickness, lingual cortical thickness, and bucco-lingual measurement in the mandible, taken at the heights of 5, 8, and 11 mm from the crest**

	Region 48-47			Region 47-46			Region 46-45			Region 45-44			Region 44-43		
	Bucc. Cort.	Bucc-Lingual dist.	Lingual. Cort.	Bucc. Cort.	Bucc-Lingual dist.	Lingual. Cort.	Bucc. Cort.	Bucc-Lingual dist.	Lingual. Cort.	Bucc. Cort.	Bucc-Lingual. dist.	Lingual. Cort.	Bucc. Cort.	Bucc-Ling. dist.	Lingual. Cort.
5 mm															
Mean	3.41†	13.68	1.76	2.06	12.09†	1.64	1.56	10.27†	1.85	1.69	8.85†	1.97	1.46	8.09†	1.76
SD	1.16	3.96	0.44	0.86	1.45	0.43	0.42	1.13	0.51	0.55	1.56	0.50	0.66	1.74	0.49
8 mm															
Mean	3.17	13.90	2.04	2.84	13.08	1.86	1.72	10.80	1.90	1.90	9.47	1.89	1.87	8.90	1.96
SD	0.76	3.22	0.63	0.79	2.07	0.75	0.60	1.52	0.42	0.36	1.47	0.42	0.70	1.64	0.25
11 mm															
Mean	**2.39****,†	13.09	1.95	2.79	**13.58****,†	2.09	2.13	**11.23****,†	2.14	1.76	**9.80****,†	2.16	1.82	**9.70****,†	2.13
SD	0.43	2.41	0.63	0.54	2.19	0.98	0.37	1.67	0.45	0.43	1.65	0.37	0.31	1.79	0.36

	Region 33-34			Region 34-35			Region 35-36			Region 36-37			Region 37-38		
	Bucc. Cort.	Bucc-Lingual distance	Lin. Cort.	Bucc. Cort.	Bucc-Ling. Dist.	Lin. Cort.	Bucc. Cort.	Bucc-Ling. Dist.	Lin. Cort.	Bucc. Cort.	Bucc-Ling. dist.	Ling. Cort.	Bucc. Cort.	Bucc-Ling. dist.	Lin. Cort.
5 mm															
Mean	1.40	8.46†	1.59	1.74	8.54†	1.93	1.74	9.62	1.92	2.08	**11.23****,‡	1.89†	**4.07****,‡	14.11	1.90
SD	0.64	1.79	0.45	0.60	1.69	0.65	0.46	1.59	0.62	0.77	1.40	0.66	1.44	2.94	0.64
8 mm															
Mean	1.61	9.07	2.21	1.87	9.51	2.12	1.83	10.80	2.14	2.75	13.67	2.03	3.19	**15.06****,‡	2.39
SD	0.48	1.38	1.11	0.49	1.57	0.46	0.70	1.65	0.43	0.69	1.91	0.58	0.64	1.78	0.52
11 mm															
Mean	1.97	**9.36****,†	2.17	2.18	**9.72****,†	2.16	2.25	**11.31****,‡	2.09	2.86	13.87	**2.73****,†	2.78	13.43	2.27
SD	0.43	1.78	0.50	0.44	1.90	0.45	0.35	1.75	0.49	0.37	2.16	0.80	0.39	2.69	0.70

*$p < 0.05$.
**$p < 0.01$.
†Indicates, among the three compared groups (5, 8, and 11 mm of height), the two significantly different groups (resulted by the post-hoc analysis).
‡Indicates, among the three compared groups (5, 8, and 11 mm of height), the group that is significantly different with respect to the other two groups.

3.3 mm (1.3-mm minimum miniscrew diameter available, plus 1 mm on each side, between the root and miniscrew) (11). The mean values of the interradicular spaces are reported in Tables 4 and 5 for the upper and lower dental arches, respectively, at 5, 8, and 11 mm of height from the crest. For each measurement, we reported the mean mesio-distal values ± SD and the maximum and minimum values. The single interradicular measurements showed a wide range, from 0.25–5.65 mm in the maxilla (Table 4) and from 0.65 to 8.72 mm in the mandible (Table 5). Mean values in the maxilla increased (from 2.62 to 3.03 mm) in the cranial direction (Table 4); the same occurred in the mandible (means from 2.98 to 3.84 mm) (Table 5). In the maxilla, 13% of sites were suitable for miniscrew insertion at 8 mm or more from the alveolar crest; in the mandible, 63% of sites were suitable at 8 and 11 mm from the alveolar crest (Tables 4 and 5).

Mean values for the region between the second upper bicuspid and the first molar are reported in Table 6. Palatally, the site above a distance of 5 mm

Table 3. **Mean and Standard Deviation (SD) of the buccal cortical thickness, lingual cortical thickness, and bucco-lingual measurement in the maxilla and in the mandible, taken at the heights of 5, 8, and 11 mm from the crest**

	Buccal Cortical plate Mean ± SD	Palatal Cortical plate Mean ± SD	*t*	*p*	95% confidence interval of difference		Total B-L thickness Mean ± SD	Mean ± SD	Buccal Cortical plate Mean ± SD	Lingual Cortical plate	*t*	*p*	95% confidence interval of difference		Total B-L thickness Mean ± SD
Maxilla-5 mm	1.06 ± 0.3	1.16 ± 0.3	−1.18	0.2 NS	−0.27	0.07	11.32 ± 1.5	Mandible-5 mm	2.12 ± 0.7	1.82 ± 0.4*,†	1.86	0.06 NS	−0.02	0.62	10.49 ± 1.3*,†
Maxilla-8 mm	1.13 ± 0.4	1.36 ± 0.4	−2.03	0.04*	−0.45	0.00	11.43 ± 0.9	Mandible-8 mm	2.27 ± 0.6	2.05 ± 0.6	1.29	0.2 NS	−0.12	0.56	11.43 ± 1.4
Maxilla-11 mm	1.10 ± 0.2	1.29 ± 0.4	−2.12	0.03*	−0.36	−0.10	11.85 ± 1.2	Mandible-11 mm	2.29 ± 0.6	2.19 ± 0.5*,†	0.64	0.52 NS	−0.21	0.41	11.51 ± 1.2*,†
F	0.32	1.88					1.32	*F*	0.54	3.4					4.74
p	0.72 NS	0.15 NS					0.27 NS	*p*	0.58 NS	0.039*					0.012*
Maxilla (mean cortical plate thickness)	1.10 ± 0.2	1.27 ± 0.3	−2.35	0.02*	−0.17	0.07	11.53 ± 1.3	Mandible (mean cortical plate thickness)	2.23 ± 0.5 significantly different from the maxilla (**)	2.02 ± 0.5 significantly different from the maxilla (*)	1.48	0.14 NS	−0.07	0.49	11.14 ± 1.4

NS, non-statistically significant.
*$p < 0.05$.
**$p < 0.01$.
[†]Indicates, among the three compared groups (5, 8, and 11 mm of height), the two significantly different groups (resulted by the post-hoc analysis).

Table 4. **Upper dental arch: interradicular measurements (mean, SD, maximum and minimum values) expressed in millimeters in the regions among the teeth**

	18-17	17-16	16-15	15-14	14-13	23-24	24-25	25-26	26-27	27-28
5 mm										
Mean	**3.49***	2.02	2.66	2.61	2.44	2.34	2.75	2.78	2.16	2.91
Max	5.65	3.2	3.54	3.68	3.69	3.55	4.4	4.12	3.5	5.21
Min	1.8	0.55	1.12	2	1.67	0.8	1.41	1.15	1.12	0.5
SD	1.38	0.77	0.64	0.51	0.68	0.7	0.81	0.79	0.81	1.55
8 mm										
Mean	2.97	2.15	2.99	2.66	2.64	2.47	3.03	3.02	2.65	2.49
Max	5.5	4	4.56	5	3.51	3.68	4.5	5.3	4.25	3.95
Min	1.5	0.25	1.35	1.21	1.51	1.41	1.51	1.3	0.55	0.75
SD	1.48	1.05	0.83	1	0.61	0.83	0.83	1.05	1.05	1.23
11 mm										
Mean	**3.6***	2.43	**3.59***	2.79	2.81	2.75	3.17	**3.8***	3.02	2.31
Max	5.45	5.2	5.7	3.8	3.9	4.5	4.25	5.58	4.86	4.07
Min	2.7	1.27	0.8	0.7	1.25	0.7	1.12	1.82	0.35	0.5
SD	1.12	1.39	1.27	0.83	0.87	1.11	0.86	1.22	1.42	1.38

*Suitable values for miniscrew insertion (≥3.3 mm).

Table 5. **Lower dental arch: interradicular measurements (mean, SD, maximum and minimum values) expressed in millimeters in the regions among the teeth**

	48-47	47-46	46-45	45-44	44-43	33-34	34-35	35-36	36-37	37-38
5 mm										
Mean	3	2.91	3.02	**3.31***	3.03	2.49	**3.33***	2.32	3.05	**3.38***
Max	4.71	4.8	4	5.4	4.8	4.42	5.48	3.5	4.59	8.72
Min	1.46	1.58	1.85	1.5	1.45	1.06	1.8	1.6	1.56	1
SD	1.19	1.14	0.74	0.99	0.99	1	1	0.62	1.01	2.08
8 mm										
Mean	**4.05***	**3.51***	**3.5***	**3.58***	**3.55***	2.97	**4.02***	3.14	**3.5***	3.22
Max	6.83	5.9	5.5	5.27	5.7	4.42	5.5	5.5	4.9	6.17
Min	2.5	1.5	1.85	2	2.15	1.6	2.2	1.5	1.25	0.65
SD	1.38	1.41	1.08	1.11	1.2	0.83	1.05	0.97	1.33	1.46
11 mm										
Mean	**4.21***	**4.12***	**3.8***	**3.65***	**4.21***	**2.94**	**4.26***	**3.46***	**3.65***	**4.1***
Max	5.3	7.71	5.2	6	5.15	4.9	6	4.81	5.8	7
Min	2.9	2.71	3.13	2.65	3.2	1.95	1.5	2.2	1.9	1
SD	0.99	1.61	0.78	1.16	0.65	0.98	1.51	0.87	1.23	1.91

*Suitable values for miniscrew insertion (≥3.3 mm).

from the crest was suitable for miniscrew insertion; buccally, the site above a distance of 9 mm from the crest was suitable for miniscrew insertion.

Table 6. **Measuraements made on slices cut (Mean and SD) each 0.5 mm in the area between the roots of the second upper bicuspid and of the upper first molar**

Slice (mm)	a	b	c
0.5	0.79 ± 0.05	2.69 ± 0.22	2.76 ± 0.26
1	0.79 ± 0.08	2.85 ± 0.25	2.76 ± 0.25
1.5	1.27 ± 0.1	**3.33*** ± 0.28	**3.8*** ± 0.29
2	1.34 ± 0.09	3.33* ± 0.28	4.12* ± 0.25
2.5	1.58 ± 0.1	3.95* ± 0.25	4.60* ± 0.24
3	1.90 ± 0.1	4.19* ± 0.3	4.91* ± 0.26
3.5	1.67 ± 0.09	4.43* ± 0.3	5.15* ± 0.27
4	1.80 ± 0.15	4.98* ± 0.25	5.46* ± 0.29
4.5	2.13 ± 0.2	5.06* ± 0.3	5.70* ± 0.3
5	2.24 ± 0.2	5.06* ± 0.32	6.01* ± 0.31
5.5	2.57 ± 0.15	5.38* ± 0.3	6.28* ± 0.27
6	2.57 ± 0.25	5.48* ± 0.3	6.42* ± 0.31
6.5	2.79 ± 0.24	5.59* ± 0.28	6.42* ± 0.3
7	2.95 ± 0.2	5.59* ± 0.29	7.21* ± 0.32
7.5	2.91 ± 0.2	5.36* ± 0.3	7.45* ± 0.34
8	3.06 ± 0.25	5.25* ± 0.27	7.52* ± 0.33
8.5	3.25 ± 0.25	5.48* ± 0.28	7.83* ± .34
9	**3.40*** ± 0.25	5.48* ± 0.29	8.00* ± 0.32
9.5	3.58* ± 0.25	5.71* ± 0.3	8.31* ± 0.31
10	3.81* ± 0.28	5.81* ± 0.27	8.68* ± 0.35
10.5	3.84* ± 0.28	6.04* ± 0.3	9.10* ± 0.36
11	4.16* ± 0.3	6.14* ± 0.28	9.65* ± 0.34

Slice: mm of slices cut; see Fig. 3:
a, measurement between the second bicuspid and the mesio-buccal root of the first molar; b, measurement between the second bicuspid and the palatal root of the first molar; c, measurement between the palatal cortical plate and the mesio-buccal root of the first molar.
*$p < 0.05$.
Bold values indicate the values with clinical significance.

Discussion

This investigation can be considered a pilot study in this field. Future studies should include greater samples to obtain greater statistical power.

Our results suggested that the mandibular cortical plates were more suitable than the maxillary cortical plates for miniscrew insertion, because of the greater thickness of the former, which seemed to confer higher primary stability. We also found that cortical plate thickness was rarely symmetrical, even in the same subject. In the maxilla, both buccal/palatal cortical plates became thicker at 8 mm from the alveolar crest (Table 3). In addition, we found seven interferences

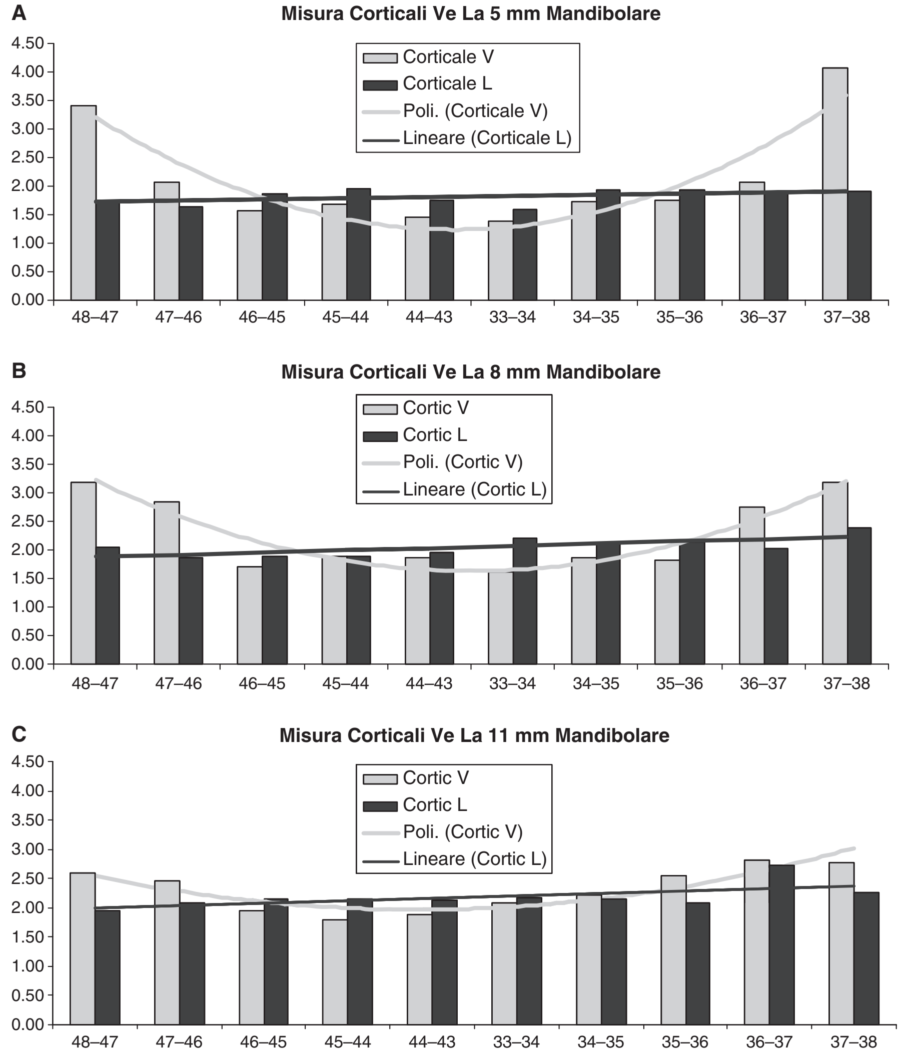

Fig. 4. (A–C). Buccal cortical thickness and palatal cortical thickness in the maxilla, taken at heights of (A) 5, (B) 8, and (C) 11 mm from the crest.

with the maxillary sinus in this sample. In the mandible, both cortical plates became thicker at distances >11 mm (Table 3), and we observed a total of 12 interferences with the lower alveolar nerve (no 4 at the mentalis foramen).

Between the second upper bicuspid and first upper molar, buccally, we observed an interradicular space of only 2.24 at 5 mm of height from the crest (Table 6); this was probably related to the mesially curved first molar mesio-buccal root. These findings are not in accordance with Deguchi et al. (5) and may be related to individual anatomical differences. As observed in Table 4, we observed very high SD values and range values for the interradicular spaces; this indicated high inter-individual variation.

It was previously suggested (5) that miniscrews with a 15–30° inclination could allow the clinician to use a longer TAD in cases with a mesially curved first molar mesio-buccal root. This approach would increase the miniscrew/bone contact area. It was affirmed (5) that, by varying the TAD inclination, the bone/miniscrew interface may be improved by up to 50%.

In clinical practice, there may be two reasons, in general, to vary the insertion axis of miniscrews. First, to avoid accidental damage of adjacent dental roots, and second, to increase the bone/miniscrew contact surface by using a longer TAD that would have greater stability against the forces loaded on it. A previous histological study (6) demonstrated that, when TAD insertion damaged the dental roots, a healing process was initiated by cementum cells. Furthermore, a study (7) with mongrel dogs showed that miniscrews failed when they contacted dental roots, probably due to high

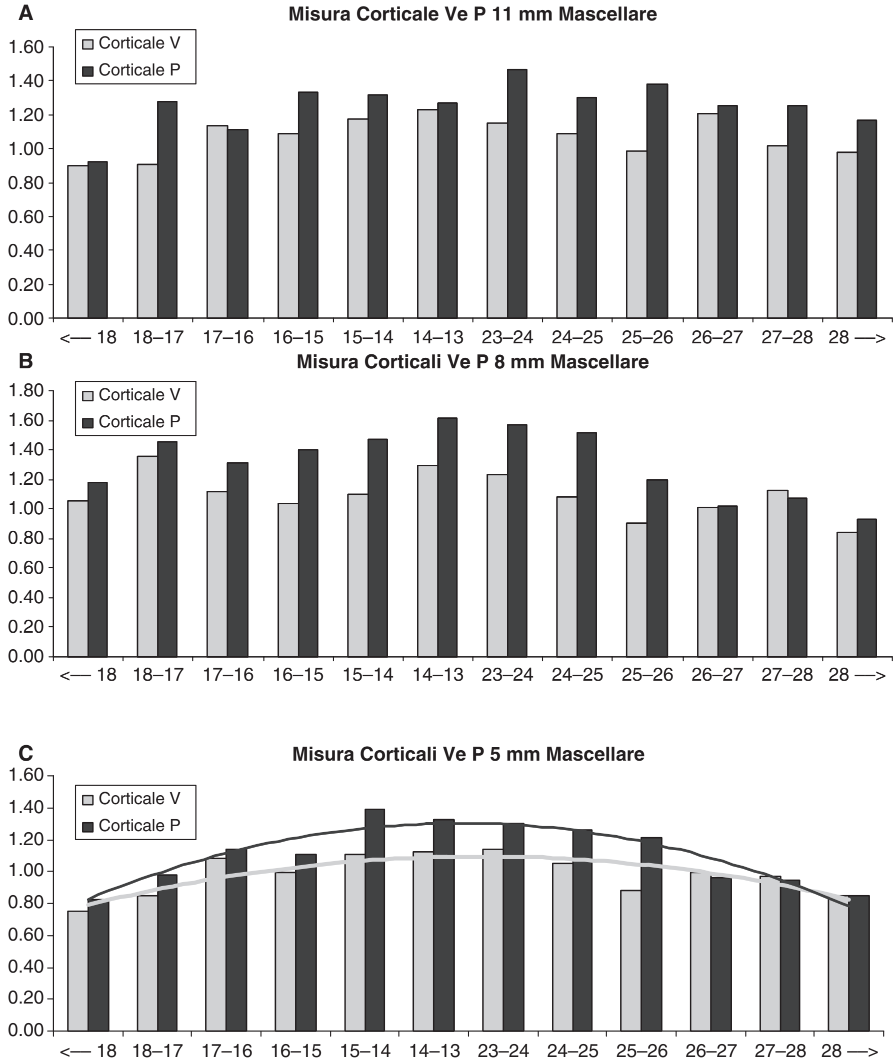

Fig. 5. (A–C). Buccal cortical thickness and palatal cortical thickness in the mandible, taken at heights of (A) 5, (B) 8, and (C) 11 mm from the crest.

local inflammation, which caused both miniscrew failure and root resorption.

Our results were in accordance with the fact that cortical bone plates tend to be thicker at greater heights and thinner at shallow locations (9). The observed differences were not always significant (Tables 1 and 2), and no statistical significance was observed for the mean data (Table 3). Thus, for the most part, the observed differences were clinically irrelevant. Furthermore, no significant difference was found among the sites measured at different heights from the alveolar crest at the occlusal and apical levels (5). In accordance with other authors (5, 9), we observed high anatomical variations both inter-individually and in the same subject.

Moreover, other researchers (9) found significant differences in cortical bone plates at locations higher than 5 mm. The same authors found significant gender differences in the maxilla; at sites mesial to the first molar, the cortical bone was thinner in women than in men at any location.

Based on our results on interradicular distances, we concluded that there are fewer suitable sites in the maxilla (13%) (Table 4) than in the mandible (63%) (Table 5). The maxilla exhibited more sites ≥3.3 mm at 8–11 mm from the alveolar ridge. At these heights, miniscrews are often inserted in movable mucosa, and this may cause gingival inflammation and pain that could lead to miniscrew failure.

In a previous study, in a sample of 10 subjects, a cortical bone thickness of 1.7 mm mesially and 1.5 mm distally was observed in the maxillary palatal area near the first molar (5). A greater cortical bone thickness was observed palatally, but it was distal to the second molar, where the buccal cortical bone appeared thinner and more porous. They found that, buccally, cortical thicknesses were 1.6–1.8 mm between the upper second bicuspid and the upper first molar and 1.5–1.6 mm distal to the upper first molar. They also found that, buccally, mandible thicknesses were 1.8–1.9 mm mesial to the first molar and 1.8–2.0 mm between first and second molar (5). Those results suggested (5) that miniscrews should be inserted in the interradicular palatal space between the second upper bicuspid and the upper first molar, where a statistically significant difference ($p < 0.05$) was found. In contrast, in the present study, we found an appropriate space on the palatal side, between the second upper bicuspid and the first molar (Table 6), owing to the anatomical configuration of molar roots. A single palatal root provided a larger space than the buccal roots (maximum space, 5.5–8 mm). This triangular site, with the base at the top, may be suitable for TAD insertion (e.g., after the first molar distalization).

This detailed CT study revealed a very high inter-individual variation, both between different subjects and between different areas in the same subject. All these data are related to adult subjects.

Conclusion

The most important features of this research are the following:

- There was a considerable individual variation in cortical thickness (from 0.25 to 5.50 mm). The upper buccal cortical plate measurements were significantly different ($p < 0.05$), with means of 1.10–1.27 mm on the palatal side; the lower buccal plate measurements were significantly larger than those of the upper plate; they ranged from means of 2.23 to 2.02 mm on the lingual side. The cortical thickness increased with height at sites 5–11 mm from the crest; however, in the mandible, this increase appeared more marked (more sites with significantly different thicknesses). The total bucco-palatal/lingual distances showed no significant differences between the lower and the upper dental arches, with means of 11.53 and 11.14 mm, respectively.
- In the maxilla, only 13% of measured sites were suitable (≥3.3 mm) for miniscrew insertion, vs. 63% in the mandible.
- In the palatal region between the second upper bicuspid and the first molar, starting from 1.5 to 2 mm from the alveolar ridge, a suitable region was identified for tapered 6- to 9-mm miniscrews.
- In the upper arch, a greater interradicular space was found at >8 mm from the alveolar ridge, but this area did not seem suitable for miniscrews, because it was very close to the maxillary sinus; thus, it presented the potential of miniscrew insertion into movable mucosa.

According to these data, the clinician must perform single measurements in specific anatomical sites for potential TAD insertion in order to minimize failure risks and obtain the most favorable clinical results.

Clinical relevance

Recently, TADs have been widely used in non-compliance treatments, primarily because they allow the creation of an absolute anchorage, which can tolerate substantial force. However, the greatest difficulty for a clinician is making an accurate site diagnosis and the subsequent surgical planning. This three-dimensional study of anatomical sites for miniscrews is important in guiding clinicians in site selection in order to find safe, adequate zones of miniscrew insertion.

The present results advance knowledge of site selection for TADs insertion.

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