Tomographic mapping of mandibular interradicular spaces for placement of orthodontic mini-implants

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Introduction: The purposes of this study were to determine the ideal sites for placement of orthodontic mini-implants in mandibular interradicular spaces by using computed tomography (CT) and to suggest length, diameter, and angulation of the mini-implants. **Methods:** CT scans were performed on 15 dry human mandibles with 1-mm tomography slices. Measurements were made at 3, 5, 7, 9, and 11 mm heights from the bone crest. Bone thickness was obtained for the buccolingual, lingual cortex, and buccal cortex areas. The mesiodistal interradicular distance and the distance from the bone crest to the mental foramen were also measured. Simulated placement of 1.5 x 9 mm mini-implants was performed in the tomographic images at angulations 10°, 20°, and 30°. Twenty-four 1.5 x 9 mm mini-implants were then placed in the mandibles, and a new set of CT scans was obtained. Mandibles with implants were sectioned, enabling direct observation. **Results:** Based on 3000 measurements, means and standard deviations were obtained. The thickness of the mandibular alveolar bone in the cortical buccal and lingual areas, and the interradicular distances increased from the cervical toward the apical aspects. In descending order, the widest spaces were found between the first and second molars, the second premolars and the first molars, and the first and second premolars. Between the premolars, caution should be exercised starting at 9 mm from the bone crest because of the mental foramen. Between the incisors, the placement of interradicular mini-implants is not feasible. Between the first premolars and the canines, no appropriate region was found. Between the lateral incisor and the canine, at a height of 11 mm, a device can be placed but only with utmost care. **Conclusions:** The most convenient site for implant placement in a mandible was between the first and second molars, with a 10° to 20° inclination, but orthodontic mini-implants should not exceed 1.5 mm in diameter and 6 mm in length. (Am J Orthod Dentofacial Orthop 2009;135:428.e1–428.e9)

Although dental implants were developed primarily to replace lost teeth, orthodontists have attempted to use skeletal anchorage for decades.[1] Implants have aroused considerable interest among orthodontists as a method for the absolute anchorage of dental movements; this has unlocked an enormous and hitherto untapped biomechanical potential.[2-7] As a result, the use of orthodontic mini-implants (OMIs) as temporary anchorage devices has become increasingly common.[8-11]

Mini-implants are a new anchorage paradigm if compared with traditional procedures; they offer many advantages over conventional implants: placement without special preparation, stable and solid anchorage, lower cost, easy placement, and immediate loading.

For orthodontic purposes, an implant should be small enough to allow ready placement in any area of the alveolar bone, including the apical bone, thus enabling various orthodontic movements.[8]

Small implants, screws, pins, temporary anchorage devices, or, more specifically, OMIs used for anchorage are removed after treatment.[12] Therefore, they are functional for only a short time compared with prosthetic dental implants.

To ensure their use as an optimum anchorage alternative, certain factors must be observed, such as the amount of force applied, the direction of the force, the available dimensions, and the sites where the implants will be placed.[13]

Despite the many studies on OMIs, the literature clearly emphasizes the need to develop a more comprehensive body of knowledge comprising accurate indications, proper definition of implant features, appropriate placement sites especially for long-term treatment, and

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accuracy in mini-implant placement. However, few studies have evaluated and measured reliable placement sites in interradicular spaces.[11,14-17]

It is well known that OMI stability is primarily achieved through mechanical interdigitation with the bone.[18] The thickness of the bone cortex, with its greater density, seems to have a bearing on implant success. Thus, an in-depth investigation of bone cortex thickness is strongly recommended.

A limitation of mini-implants concerns the risk of damage to key anatomic structures, such as blood vessels, nerves, and dental roots; these devices can shift up to 1.5 mm under orthodontic forces, compromising the integrity of roots, vessels, or nerves.[19] Surgical placement of miniscrew implants for orthodontic anchorage requires consideration of the placement site and the angle based on anatomic characteristics.[20] Although interalveolar spaces tend to increase toward the apical region, the extent of the increase has not yet been accurately determined.[11]

The prepared site should have cortical bone at least 1.0 mm thick.[21] Cortical bone thickness was measured from 1 to 15 mm below the alveolar crest at 1-mm intervals. Average cortical bone thicknesses was 1.59 to 3.03 mm in the mandible. The greater the height, the thicker the cortical bone tended to be, and mandibular cortical bone was significantly thicker than that of the maxilla.[22]

Whenever possible, it is advisable to place OMIs in areas of attached gingiva,[9,23] because the mucous membrane is more likely to encroach on the implant and compromise hygiene; this can cause tissue irritation or inflammation, thus undermining mini-implant stability. It seems that mini-implants for orthodontic anchorage can be placed with equivalent bone-implant contact anywhere in the zone of attached gingiva up to 6 mm apically to the alveolar crest with adequate interradicular space.[24] Furthermore, the minimum amount of bone between mini-implants and dental roots required to preserve periodontal health and prevent damage to dental roots is 1 mm around the mini-implant.[17]

The purposes of this study were to assess the amount of mandibular interradicular bone and to determine the most reliable implant sites, the appropriate placement angulation, and the ideal diameter and length of OMIs for these areas.

MATERIAL AND METHODS

This study was approved by the Research Ethics Committee at the Center for Health Sciences of Universidade Federal Fluminense, Niterói, RJ, Brazil.

The samples consisted of 15 dry human mandibles obtained from the Universidade Federal Fluminense. The criteria guiding their choice focused on sample integrity, particularly with regard to the alveolar bone, to ensure no periodontal disease and the clarity of interradicular tomographic images. All mandibles were from adults; sex and age could not be ascertained.

The 15 mandibles had computed tomography (CT) examinations with a high-resolution (Toshiba-Asteron, 100 mA, 80 Kv, 16.0 FOV, Toshiba-Japan, Tokyo, Japan). Each mandible was positioned under the device, keeping the sagittal planes perpendicular with the mandible's lower borders (mandibular planes) parallel to the floor (horizontal plane). One millimeter thick oblique sagittal slices were made on the tomographic images of all samples, at 1-mm intervals. The images were individually recorded on CD-ROMs in BPT format files (Fig 1, *A*).

A total of 3000 measurements of the tomographic slices were obtained on a high-definition flat-screen computer monitor in the following planes: buccolingual or oblique-sagittal tomographic slices (Fig 1, *B*) and mesiodistal plane or panoramic tomographic slices (Fig 1, *C*) by using Dental Slice software (version 2.1, Bio Parts, Prototipagem Biomédica, Brasília, Brazil). This software program includes a ruler with a hundredth scale in millimeters that was used for the measurements.

Each cortical thickness and mandibular interradicular space was evaluated on both the right and left sides in the following regions: between the lateral incisors and the canines, between the canines and the first premolars, between the first and second premolars, between the second premolars and the first molars, and between the first and second molars.

The mandibular alveolar bone was measured to evaluate (1) the thickness of the buccal bone cortex, (2) the thickness of the lingual bone cortex, (3) the total thickness, (4) the mesiodistal interradicular space, and (5) mental foramen position relative to the bone crest.

The thickness measurements were obtained at 5 heights (3, 5, 7, 9, and 11 mm) from the alveolar bone crest of the interproximal space. The buccal bone cortex measurements were recorded from the spot where each line crosses the outermost point to the innermost buccal cortex region, and the lingual bone cortex measurements were taken from the innermost point to the outermost point in the lingual cortex of the mandibular body.

The panoramic slices were obtained from a curve drawn over the axial image across the center of the dental roots or alveolar bone (Fig 1, *A*). On the buccolingual plane or oblique-sagittal tomographic slices and in the mesiodistal distance or panoramic tomographic slices, the measurements were based on the middle point of the interproximal space bone crest.

The position of the mental foramen was evaluated perpendicular to the occlusal plane, considering the

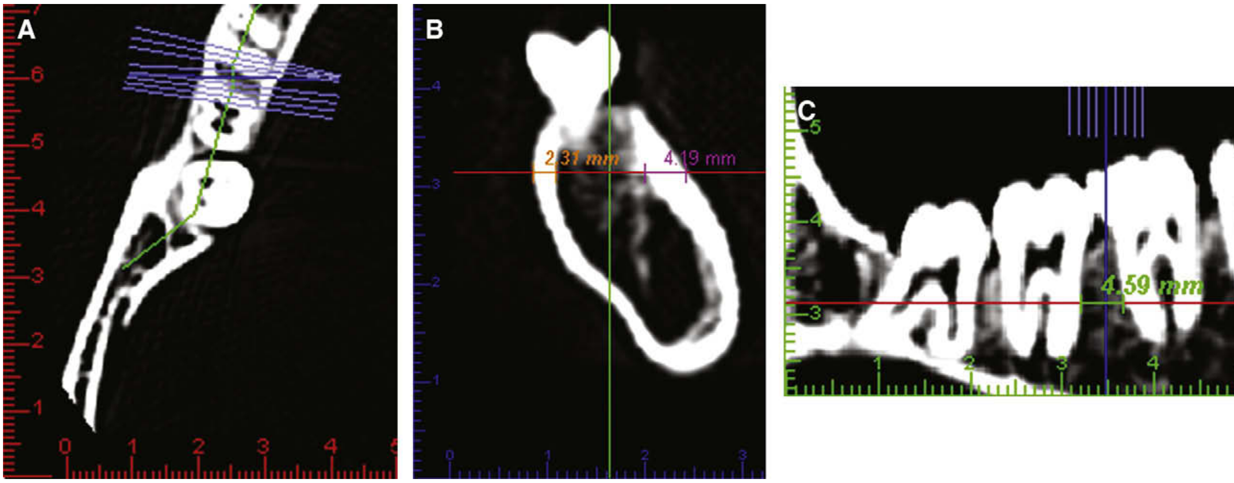

Fig 1. **A**, Axial image showing oblique-sagittal slices; **B,** oblique sagittal slice, illustrating a bone crest measurement in the vestibular-lingual orientation at 7 mm height, between the right first and second molars; **C,** panoramic slice showing the measurement of the distance between right first and second molar roots.

vertical distance between the mental foramen and the alveolar bone crest.

After the measurements, means and standard deviations were obtained for each height (3, 5, 7, 9, and 11 mm) of all mandibular regions.

In a simulation run with the implant placement tool of Dental Slice software, 1.5-mm diameter and 9-mm length mini-implants, at 10°, 20°, and 30° angulations, were placed into the tomographic images of the mandibles on the buccal surface. This procedure aimed to evaluate the reliability of the tomographic images (Fig 2, *A*). By using the tooth's long axis as a reference, the angulations were verified by placing a protractor on the top of the tomographic images on the flat screen of the computer monitor.

After measurements and image analysis, 24 mini-implants (1.5 × 9 mm, Orto-implante, #994109, Conexão, São Paulo, Brazil) were placed at 4 sites (between canines and premolars, between premolars, between second premolars and first molars, and between first and second molars, at 3 and 5 mm heights from the alveolar crest, at 10°, 20°, and 30° angulations, in 6 randomly selected mandibles.

After placement of the mini-implants in the mandibles, a second set of CT scans was made with the same device to determine whether the criteria used for suggesting the sizes of the mini-implants and the placement sites and inclinations were reliable. We used a descriptive approach to evaluate certain aspects of these images: the proximity of the mini-implants to the roots and the mental foramen and their contact relationship with the buccal cortex (Fig 2, *B*).

Subsequently, the alveolar bones with all 24 mini-implants in place were sectioned with diamond disks in the transverse plane (buccolingual) at the interproximal space. Thus, the position of the mini-implants and their relationship with cortical and medullary bone of the mandibular body became fully visible in the bone fragments (Fig 2, *C*). The initial measurements (Table), the images of the simulation with the implant placement tool of Dental Slice software (Fig 2, *A*), the images with the implants (Fig 2, *B*), and the actual placement procedure (Fig 2, *C*) were used to suggest appropriate sites, sizes, and inclinations for mini-implants in the mandible.

RESULTS

No significant differences were found between the right and left sides for any variable. Thus, the measurements for both alveolar bone sides of all 15 mandibles were grouped to facilitate determining central trend measurements.

The means and standard deviations of buccal cortex, lingual cortex, total thickness of the mandibular body, interradicular space in the mesiodistal orientation, and at 3-, 5-, 7-, 9-, and 11-mm heights from the alveolar crest are shown in the Table.

The mental foramen position as measured from the bone crest was calculated; the mean value was 12.38 mm (± 3.25 mm).

The thickness and quality of the bone cortex are the most important factors in ensuring OMI stability; at these sites, anchorage can be most adequately achieved.

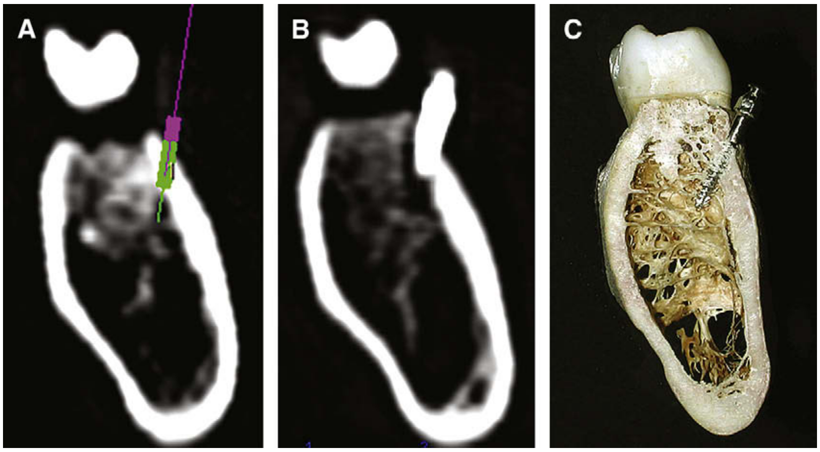

Fig 2. A, Simulation of mini-implant placement with Dental Slice software; **B,** CT image after placement of a 1.6 x 9-mm mini-implant; **C,** sectioned mandible used for direct inspection of implant position.

Table. Means and standard deviations for the buccal cortical, lingual cortical, total thickness buccolingual, and mesiodistal interradicular space measurements of the mandibular bone at 3, 5, 7, 9, and 11 mm heights from the alveolar crest

		2-3		*3-4*		*4-5*		*5-6*		*6-7*	
Area	*Height (mm)*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Buccal cortical	3	1.43	0.26	1.56	0.29	1.78	0.35	1.83	0.36	2.33	0.93
	5	1.43	0.26	1.56	0.29	1.78	0.35	1.83	0.36	2.33	0.93
	7	1.74	0.21	1.67	0.29	2.05	0.77	2.03	0.52	2.68	0.67
	9	1.79	0.37	1.80	0.34	2.01	0.54	2.14	0.54	2.60	0.70
	11	1.79	0.37	1.80	0.34	2.01	0.54	2.14	0.54	2.60	0.70
Lingual cortical	3	1.79	0.37	1.80	0.34	2.01	0.54	2.14	0.54	2.60	0.70
	5	2.55	0.82	2.60	0.52	2.38	0.66	2.06	0.37	2.06	0.37
	7	2.40	0.40	2.46	0.42	2.44	0.49	2.12	0.38	2.07	0.39
	9	2.41	0.37	2.42	0.46	2.47	0.45	2.32	0.78	2.09	0.53
	11	2.09	0.53	2.57	0.66	2.55	0.50	2.26	0.60	2.17	0.42
Total thickness	3	7.44	0.96	7.86	0.79	7.73	1.10	8.02	1.99	10.5	2.61
	5	7.44	0.96	7.86	0.79	7.73	1.10	8.02	1.99	10.5	2.61
	7	7.44	0.96	7.86	0.79	7.73	1.10	8.02	1.99	10.5	2.61
	9	8.42	1.65	9.79	1.57	10.34	1.81	11.25	2.78	13.71	2.00
	11	9.04	1.92	10.44	1.88	10.94	1.94	11.80	2.53	13.58	2.04
Mesiodistal interradicular	3	1.82	0.47	1.94	0.68	2.61	0.71	3.00*	1.50	3.74†	0.96
	5	2.17	0.60	2.17	0.74	3.07*	0.91	3.28*	1.66	4.17†	1.13
	7	2.42	0.68	2.22	0.80	3.49*	1.13	3.89†	2.22	4.95†	1.38
	9	2.69	0.82	2.44	0.87	3.74†	1.43	3.93†	2.02	5.90†	1.56
	11	3.08	1.04	2.84	1.03	3.94†	1.32	4.55†	2.02	6.28†	1.48

2-3, Lateral incisor to canine; *3-4,* canine to first premolar; *4-5,* first to second premolars; *5-6,* second premolar to first molar; *6-7,* first to second molars.
*Caution needed; †safe area.

These data show that, for all regions under study, the buccal cortex thickness generally increases in the cervical to apical area (Table). A small variation from this trend was observed between the second premolar and the first molar at the 5-mm height from the bone crest, which was less thick than areas between the first and second premolars and between the first and second molars.

Particularly noteworthy is the evidence that lingual cortex thickness decreases from the cervical toward the apical areas in all regions under evaluation. The lingual cortex near the incisors and canines and between the canine and the first premolar is the thickest of all areas, notably in the apical regions. Mean variations of these measurements, however, are negligible, whereas an analysis of the standard deviations shows that these variations have no clinical significance in terms of OMI placement.

The total buccolingual thickness showed a progressive increase of the bone dimension from the cervical to the apical regions in all measured areas. The thickest areas of the mandibular body were between the first and second molars.

According to the Table, a consistent increase of the mesiodistal interradicular spaces was observed in the cervical to apical areas and te anterior to posterior regions. It also became clear that the interradicular spaces between the mandibular first and second molars have enough space for OMI placement starting from 3 mm on the bone crest for screws with a diameter of 1.2 or 1.5 mm; at that height, an average interradicular distance of 3.74 mm was found (SD 0.96 mm).

The regions between the mandibular incisors were not assessed because they are too narrow and not suitable for OMIs. On the other hand, the site below the incisor apices would be suitable for OMI placement, but this area was beyond the scope of this study.

The mental foramen restricts OMI placement, and it is strongly advised, therefore, that the position of the mental foramen should be carefully evaluated before OMI placement. Standard deviation values, however, show considerable variations at this foramen site, pointing to potential risks in certain patients if the site selected for OMI placement is farther toward the cervical area.

The simulation of mini-implant placement in the CT images with the Dental Slice software, the placement of 24 OMIs in the mandibles at various sites and angulations, and the CT images followed by sectioning of the anatomic pieces were analyzed to confirm the data previously described in the Table. A comparison of descriptive aspects was similar to the data in the Table with few clinical differences, thereby reaffirming the most favorable areas for OMI placement in the mandible.

DISCUSSION

We assessed cortical bone thickness and mandibular interradicular spaces with a view to the placement of OMIs. This assessment was carried out by measuring CT images in buccolingual and mesiodistal slices, simulating implant placements in the images, and placing OMIs in the mandibles. New CT scans were taken, and the anatomic pieces were directly inspected by sectioning the mandibles at the heights where the OMIs had been placed to evaluate space size and site safety.

Teeth and key anatomic structures can be damaged when mini-implants are placed, but both teeth and mini-implants can shift under orthodontic forces, jeopardizing root, vessel, and nerve integrity.[19] This serious consequence should be considered, since interradicular space has been a major site of choice for mini-implant placement, mainly because of abundant attached gingiva and also for allowing force application across the occlusal plane.

Liou et al[19] recommended allowing a 2-mm buffer zone between the implant and the root. To achieve this, the ideal site must have at least 5.2 mm of mesiodistal width for an OMI of 1.2 mm in diameter. Since this amount of bone is hardly ever found in interradicular spaces, the use of mini-implants as an orthodontic resource would be severely limited. Nevertheless, the minimum amount of bone between mini-implants and dental roots must be 1 mm around the mini-implant to preserve periodontal health and prevent damage to dental roots.[17]

Before implant placement, the type of movement to be performed should already be defined. When anterior-to-posterior movements are desired, the OMI should be placed as far toward the cervical region as possible to favor the resultant force.

Studies conducted to assess the amount of bone required for OMI placement found no significant differences with regard to sex, age, or right or left side of the mandible for bone cortex thickness and radicular proximity.[11,14-17] We found no significant difference between the right and left sides in terms of measurement means. These data were grouped to comprise all samples—30 measurements for each region and height under evaluation.

Based on our results, it is apparent that there is more buccal bone cortex in the posterior region (Table), particularly between the molars. The least amount is between the lateral incisor and the canine. The thickness of the mandibular buccal cortex increased toward the apical area in all regions under investigation.

The Table shows that the mandibular lingual cortex thickness increased toward the apical area in all regions under study. However, the difference between the highest and lowest figures when the regions were individually assessed is neither clinically nor statistically significant, implying that mini-implants can be placed at any height. This is a favorable aspect, since, toward the apical region, surgical access is an issue because patient discomfort tends to increase.

The Table shows that the total buccolingual thickness of the mandibular body at the assessed heights

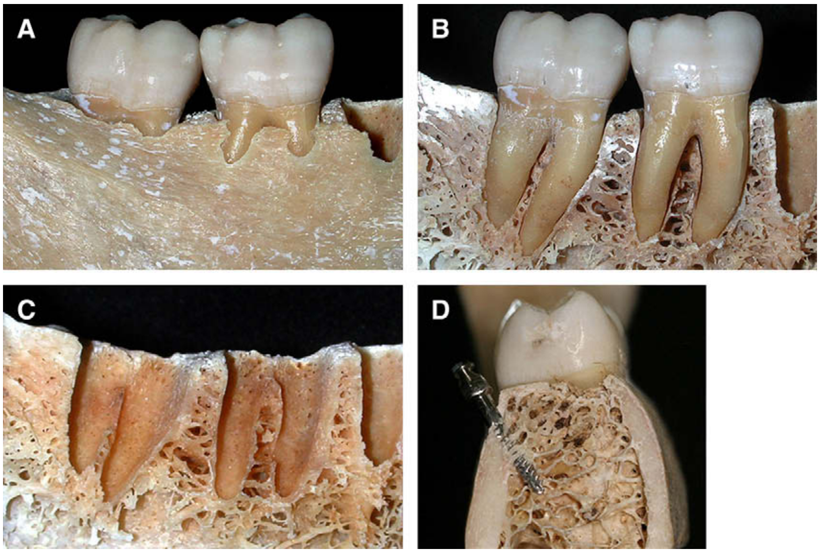

Fig 3. Buccal cortex: **A,** between the first and second molars, where the most interradicular space was found; **B** and **C,** in the mesiodistal orientation; and **D,** the vestibular-lingual orientation with a mini-implant in place.

increased toward the apical area in all regions under study. The greatest amount of bone was found between the first and second molars at a height of 9 mm (mean, 13.71 mm; SD, 2.00), and the least amount was between the lateral incisor and the canine at a height o 3 mm (mean, 7.44 mm; SD, 0.96). These data are clinically significant, considering that there are mini-implants as long as 15 mm. These figures can guide dentists in choosing the appropriate mini-implant size and placement angulation. It would be advisable to use shorter implants in narrow mandibles.

Tomographic images from the incisor region show little bone in the interradicular space in the mesiodistal orientation, thus rendering mini-implant placement between incisor roots impossible (Table). If it is necessary to place mini-implants in the mandibular anterior region to enable tooth intrusion, basal bone seems to be a viable site.[14] Nevertheless, it is difficult to apply force to implants in this region. It might be necessary to develop a special mini-implant for use in this area.

The least amount of bone in the mesiodistal orientation was between the lateral incisor and the canine at a height of 3 mm (1.82 ± 0.47 mm). It also became evident that interradicular space measurements increased toward the apical area for all regions under assessment. No reliable space was found for OMI placement between the canines and the premolars at any height studied. Between the incisors, at 11 mm of height, however, some space was found (3.08 ± 1.04 mm) for placement, although utmost care is necessary (Table).

The greatest amount of bone in the interradicular space in the mesiodistal orientation (Table) was between the first and second molars at a height of 11 mm (mean, 6.28 mm; SD, 1.48). Poggio et al[17] found the greatest amount of bone in the mesiodistal orientation between the first and second premolars, whereas Deguchi et al[16] found it between the second premolar and the first molar. These differences are probably due to difference in the samples in those studies.

After virtual and actual implant placement in the mandibles, the placement areas were sectioned, and it became clearly evident that the most suitable site for mini-implant placement according to this study was between the mandibular first and second molars (Fig 3), with an angulation of 10° to 20° to take advantage of thick cortical bone.

Sites with dense and thick cortical bone tend to favor greater mini-implant stability. This can be easily ascertained in the photographs of a sectioned mandible (Figs 2, *C*; 3, *D;* and 4, *D*), which show complete interdigitation between mini-implant and cortical bone, a phenomenon that does not occur with medullary bone.

With a minimum distance of 1 mm around the implant in the alveolar bone, it is possible to identify and determine the safest, average-risk, and highest-risk areas for mini-implant placement. Figure 5 shows the means for interradicular space in the mesiodistal orientation. Any areas above 3.5 mm can be considered perfectly safe; between 3 and 3.5 mm, the risk is average; and below 3.5, the risk is high for the placement

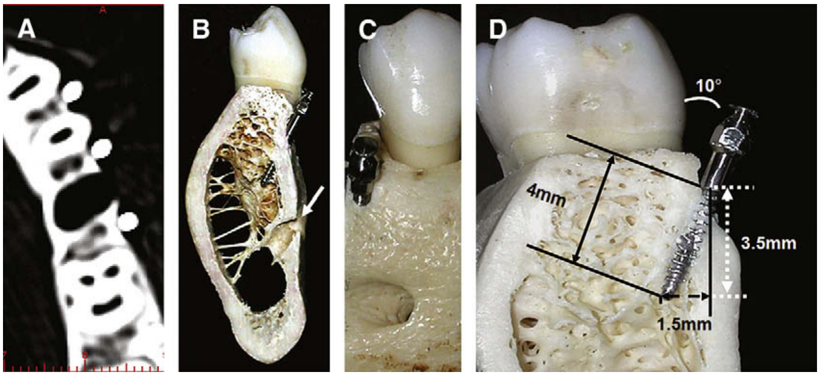

Fig 4. **A,** Buccal cortex between canine and first premolar, between premolars, and between second premolar and first molar; **B,** position of the mental foramen in a lateral photograph; **C,** buccal photograph relative to the mini-implant; **D,** 10° angulation relative to the tooth's long axis shows a 4-mm long screw with a mere 1.5 mm of penetration into the bone, thus reducing the risk of damage to the dental roots while increasing contact with bone cortex.

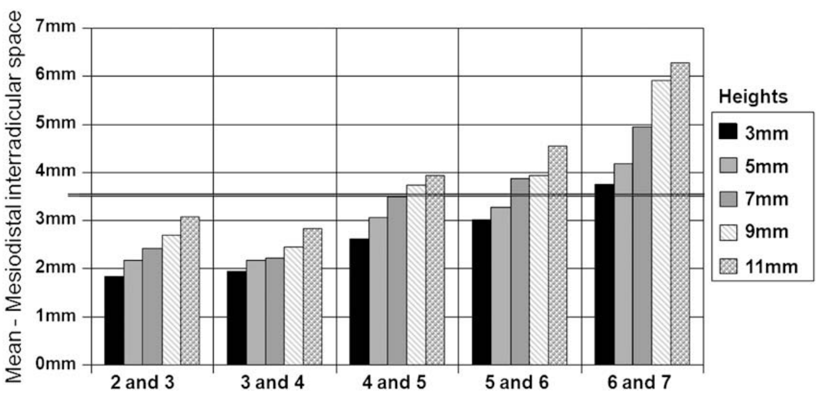

Fig 5. Means for the mesiodistal interradicular space measurements at 3, 5, 7, 9, and 11 mm heights. Safe placement areas starting from 3.5 mm width (line across the figure) can be located between the first and second molars for all heights; between the second premolar and the first molar for heights at 7, 9, and 11 mm; and between the first and second premolars for heights of 9 and 11 mm. With caution, mini-implants can be placed between the second premolar and the first molar at heights of 3 and 5 mm, and between the first and second premolars at heights from 7 mm. (*2-3,* Lateral incisor to canine; *3-4,* canine to first premolar; *4-5,* first to second premolars; *5-6,* second premolar to first molar; *6-7,* first to second molars.)

of mini-implants up to 1.5 mm in diameter. The areas above the line across Figure 5 are safety areas.

By associating these data with the patients' radiographic examinations, one can choose the most suitable sites for implant placement. In addition to determining a reliable placement site, it is also important to define the length and diameter of the mini-implants to prevent damage to the dental roots. The mini-implants simulated and actually placed in this study were 1.5 × 9 mm. In the CT images in Figure 4, *A*, one can observe the proximity of the mini-implants to the dental roots between the canine and the first premolar, the first and second premolars. and the second premolar and the first molar. It is also evident that the mini-implants between the canine and the first premolar are dangerously close to the dental roots at heights of 7 and 9 mm. An assessment of the interradicular distances between the canines and the first premolars supports the assertion of insufficient space for reliable placement in this region.

The placement of mini-implants between premolars is not recommended because of the mental foramen.[25] In this study, however, in both the tomographic measurements and the assessment of the mandibular slices with implants already in place, a considerable distance to the mental foramen was observed (12.4 ± 3.25 mm), and damage to the mental nerve was therefore ruled out. Nevertheless, caution is advised when placing OMIs between the mandibular premolars, particularly starting at the height of 9 mm from the bone crest. However, because of wide individual variability, each patient should be carefully evaluated (Fig 4, *B* and *C*).

The deeper an implant penetrates the bone in the buccolingual orientation, the greater the likelihood of root damage. It is safer to use shorter mini-implants and smaller placement angulations. Furthermore, with a smaller placement angle, there will be more contact between the implant and the cortex. The outcome will be greater mechanical screw retention. Park[14] recommended a placement angle between 10° and 20° in the mandible. When a 1.2 × 6 mm implant is placed with that angulation in the alveolar bone, there will be a mere 1.5 mm of actual screw penetration into the bone and considerable contact with the cortical bone (Fig 4, *D*).

Such implant penetration depth into the bone is compatible with the bone cortex thickness of the buccal and lingual surfaces of all regions in this study. This is a clear indication that it would be desirable to place mini-implants at about a 10° inclination relative to the tooth's long axis, thereby benefiting from the bone cortex thickness and ensuring less damage to the dental roots, while achieving greater mechanical retention for the implant. Tapered implants, with their thinner tips, are more likely to minimize the risk of damage to dental roots.

With a minimum distance of 1 mm around the implant in the alveolar bone, it is possible to identify and determine the safest, average risk, and highest-risk areas for mini-implant placement. Figure 5 shows the mean for interradicular space in the mesiodistal orientation. Any areas above 3.5 mm can be considered safe; between 3 and 3.5 mm, risk is average; and below 3.5 mm, the risk is high for the placement of mini-implants up to 1.5 mm in diameter. The area above the line across Figure 5 are safety areas. In certain cases, the sites to be used for mini-implant placement can be determined through routine radiographic examinations. However, the use of more accurate examinations, such as CT, might be necessary to define the best site in dubious areas.[26] Stringent criteria for choosing the best diagnostic tools and procedures are necessary to ensure reliable selection of both implants and placement sites. For simple cases with adequate bone space, clinical and radiographic examinations—panoramic or periapical x-rays—might be sufficient for diagnosis.

The quantitative assessment of alveolar bone should be further investigated. Factors such as bone quality, quantity, and force orientation are important for mini-implant stability and should be studied further.

CONCLUSIONS

After evaluating the amount of bone in the interradicular spaces of the mandible with the methodology described above, the following conclusions can be made.

1. The buccal cortex, lingual cortex, total thickness of the interradicular mandibular alveolar bone, and the buccolingual and interradicular distances increased from the cervical to the apical aspects.
2. The widest interradicular spaces were found, in descending order, between the first and second molars, between the second premolars and the first molars, and between the first and second premolars.
3. For the space between the premolars, special care should be taken starting at a 9-mm height from the bone crest, because of the position of the mental foramen.
4. The placement of mini-implants in the interradicular spaces of the incisor region is not viable. Between the first premolar and the canine, no safe space was identified at any height measured. Between the lateral incisor and the canine, placement needs utmost care at the height of 11 mm only.
5. According to this study, the most favorable interradicular area for OMIs in the mandible was between the first and second molars from 3 mm to the alveolar crest, with 10° to 20° angulations relative to the tooth's long axis; implant diameter should not exceed 1.5 mm, and length should not exceed 6 mm.

REFERENCES

1. Gainsforth BB, Higley LB. A study of orthodontic anchorage possibilities in basal bone. Am J Orthod Oral Surg 1945;31:406-17.
2. Creekmore TD, Eklund MK. The possibility of skeletal anchorage. J Clin Orthod 1983;17:266-7.
3. Gray JB, Steen ME, King GJ, Clark AE. Studies on the efficacy of implants as orthodontic anchorage. Am J Orthod 1983;83:311-7.
4. Roberts WE, Smith RK, Zilberman Y, Mozsary PG, Smith RS. Osseous adaptation to continuous loading of rigid endosseous implants. Am J Orthod 1984;86:95-111.
5. Roberts WE, Helm FR, Marshall KJ, Gongloff RK. Rigid endosseous implants for orthodontic and orthopedic anchorage. Angle Orthod 1989;59:247-56.
6. Roberts WE, Nelson CL, Goodacre CJ. Rigid implant anchorage to close a mandibular first molar extraction site. J Clin Orthod 1994;28:693-704.
7. Higuchi KW, Slack JM. The use of titanium fixtures for intraoral anchorage to facilitate orthodontic tooth movement. Int J Oral Maxillofac Implants 1991;6:338-44.
8. Kanomi R. Mini-implant for orthodontic anchorage. J Clin Orthod 1997;31:763-7.
9. Park YC, Lee SY, Kim DH, Jee SH. Intrusion of posterior teeth using mini-screw implants. Am J Orthod Dentofacial Orthop 2003;123:690-4.

10. Park HS, Kwon TG, Kwon OW. Treatment of open bite with miniscrew implant anchorage. Am J Orthod Dentofacial Orthop 2004; 126:627-36.
11. Costa A, Pasta G, Bergamaschi G. Intraoral hard and soft tissue depths for temporary anchorage devices. Semin Orthod 2005; 11:10-5.
12. Gray J, Smith R. Transitional implants for orthodontic anchorage. J Clin Orthod 2000;34:659-66.
13. Ohnish HI, Yagi T, Yasuda Y, Takada K. A mini-implant for orthodontic anchorage in a deep overbite case. Angle Orthod 2005;75: 393-401.
14. Park HS. An anatomical study using CT image for the implantation of micro-implants. Korean J Orthod 2002;32:435-41.
15. Schnelle MA, Beck FM, Jaynes RM, Huja SS. A radiographic evaluation of the availability of bone for placement of miniscrews. Angle Orthod 2004;74:832-7.
16. Deguchi T, Nasu M, Murakami K, Yabuuchi T, Kamioka H, Takano-Yamamoto T. Quantitative evaluation of cortical bone thickness with computed tomographic scanning for orthodontic implants. Am J Orthod Dentofacial Orthop 2006;129: 721.e7-12.
17. Poggio PM, Incorvati C, Velo S, Carano A. "Safe zones": a guide for miniscrew positioning in the maxillary and mandibular arch. Angle Orthod 2006;76:191-7.
18. Miyawaki S, Koyama I, Inoue M, Mishima K, Sugahara T, Takano-Yamamoto T. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. Am J Orthod Dentofacial Orthop 2003;124:373-8.
19. Liou EJ, Pai BC, Lin JC. Do miniscrews remain stationary under orthodontic forces? Am J Orthod Dentofacial Orthop 2004;126: 42-7.
20. Kim HJ, Yun HS, Park HD, Kim DH, Park YC. Soft-tissue and cortical-bone thickness at orthodontic implant sites. Am J Orthod Dentofacial Orthop 2006;130:177-82.
21. Motoyoshi M, Yoshida T, Ono A, Shimizu N. Effect of cortical bone thickness and implant placement torque on stability of orthodontic mini-implants. Int J Oral Maxillofac Implants 2007;22: 779-84.
22. Ono A, Motoyoshi M, Shimizu N. Cortical bone thickness in the buccal posterior region for orthodontic mini-implants. Int J Oral Maxillofac Surg 2008;37:334-40.
23. Melsen B. Mini-implants: where are we? J Clin Orthod 2005;39: 539-47.
24. Lim WH, Lee SK, Wikesjö UM, Chun YS. A descriptive tissue evaluation at maxillary interradicular sites: implications for orthodontic mini-implant placement. Clin Anat 2007;20:760-5.
25. Prager TM, Brochhagen K, Holtgrave EA. Suitability of the mandibular alveolar process for orthodontic micro-implants [abstract]. Lectures from the European Orthodontc Society, 80th Congress; Aarhus, Denmark; 7–11 June 2004.
26. Jeffcoat M, Jeffcoat RL, Reddy MS, Berland L. Planning interactive implant treatment with 3-D computed tomography. J Am Dent Assoc 1991;122:40-4.