ORIGINAL ARTICLE

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Bone density at interradicular sites: implications for orthodontic mini-implant placement

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Structured Abstract

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Objectives – Implant stability is primarily related to local bone density; Few studies have evaluated interradicular bone density related to mini-implant placement for orthodontic anchorage. Therefore, this study evaluated bone density differences between interradicular sites.

Setting and Sample Population – Computed tomographic (CT) images were obtained from 14 males and 14 females (mean age 27 years, range 23–35 years). Bone density in Hounsfield units (HU) was measured at 13 interradicular sites and four bone levels.

Results – Bone densities in most areas were higher than 850 HU. Statistically significant differences in bone density were detected at different levels and sites. Bone densities in both maxilla and mandible significantly increased from the alveolar crest toward basal bone in posterior areas, while the opposite was observed in anterior areas. There were statistically significant differences in bone densities between the maxilla and mandible in posterior areas. Bone densities progressively increased from anterior to posterior areas in the mandible.

Conclusion – The results suggest that mini-implants for orthodontic anchorage may be effective when placed in most areas with equivalent bone density up to 6 mm apical to the alveolar crest. Site selection should be adjusted according to bone density assessment.

Key words: bone density; mini-implant; orthodontic anchorage procedures; orthodontics; stability

Introduction

Recently, mini-implants have gained considerable popularity for orthodontic treatment due to their provision of absolute anchorage and easy clinical management. Many studies have investigated the factors related to stability because the failure rate of mini-implants, ranging from 9% to 30%, is high compared to that of osseointegrated endosseous implants (1–5). Among the factors related to failure, it has been reported that the mini-implant site plays an important role (1, 6).

With regard to placement location, anatomical structures including bone quantity and quality, as well as surrounding soft tissue appear to

Dates:
Accepted 1 November 2008

To cite this article:
Chun YS, Lim WH:
Bone density at interradicular sites: implications for orthodontic mini-implant placement
Orthod Craniofac Res 2009;**12**:25–32

play important roles. Studies evaluating bone quantity have reported no statistically significant difference in cortical bone engagement of mini-implants when placed at 30° and 45° angles in a majority of sites (7, 8). Others have reported that mini-implants placed in keratinized tissue had higher success rates than those in mucosa because of the absence of inflammation (2, 4, 9, 10). Previous studies showed a close association between bone density and the failure rate of dental implants (11–14). The failure rate of dental implant was 3% for types 1, 2 and 3 bone, but 35% for type 4 bone defined by Lekholm and Zarb (11, 12). Additionally, areas with dense cortical bone with minimal trabecular bone have been reported to experience more implant failure compared to those with dense cortical bone with dense trabecular bone or with thin cortical bone with dense trabecular bone (13, 14). Similar to the relationship between bone density and dental implant failure rate, the success of mini-implant can be influenced by bone quality (3, 4).

During early stages, bone density appears to be the key determinant for stationary anchorage in sites with inadequate cortical bone thickness because primary retention of mini-implants is achieved by mechanical means rather than through osseointegration (15). Thus, assessment of bone density in the interradicular site can provide information that is essential for implant site selection and implant success prediction. Among the available radiographic analyses, quantitative computed tomography (QCT) is widely used for bone density assessments in orthopedic medicine (16). Previous studies have shown that QCT can provide valuable bone density data in implant placement regions, an indication that computed tomography (CT) images are clinically useful and that CT can provide accurate bone density measurements (17, 18). However, few studies have assessed interradicular bone density related to mini-implant placement for orthodontic anchorage (18–20). The purpose of this study was to evaluate quantitatively bone density in the maxillary and mandibular interradicular sites to provide guidelines for mini-implant placement.

Materials and methods

Fourteen males and 14 females (mean age 27 years, range for male 23–31 years and for female 23–35 years) provided consent and participated in this study. Patients with severe skeletal discrepancies, high mandibular plane angles, asymmetric occlusions, absence of any permanent teeth except 3rd molars, impacted teeth, moderate to severe crowding, radiographic signs of periodontal disease, or any systemic illness were excluded. The study protocol was approved by the Ewha Womans University Mokdong Hospital Ethics Committee, Seoul, Korea.

CT images (SOMATOM Sensation, Siemens AG, Erlangen, Germany) were obtained using a 200 mm field of view, 120 kV, 200 mAs, rotation scanning time 0.5 s, average radiation exposure dose 31.32 CTDIvol, and slice thickness 1.0 mm, in high- resolution mode. CT images were saved as Digital Imaging and Communications in Medicine (DICOM) files. Each DICOM file was subsequently copied to a CD-ROM and downloaded to a personal computer for analysis. CT images were analyzed using V-works imaging software (Cybermed, Seoul, Korea).

The monocortical bone density of the buccal cortical plate was measured at 0, 2, 4, and 6 mm intervals apical to the alveolar crest at thirteen interradicular sites from the right 2nd molar to the left 2nd molar in both maxilla and mandible (Figs 1A, B and 2). V-works imaging software was used to map and display bone density in the region of interest (Fig. 1B). Two V-works spatial coordinate tools (x, y) were used to establish locations: the x-coordinate varied horizontally and the y-coordinate, vertically. The y-coordinate was manually set to the alveolar crest and then moved in 2 mm increments into the buccal plate. An interval in the y-coordinate is 0.5 mm in this program. For example, if y-axis was set at the alveolar crest and the number in the y-axis is 224, the 2 mm level from the alveolar crest will be the number 220. At each level, the y-coordinate was held constant, and the x-coordinate varied to reveal the bone density at each interradicular site. Bone density was measured using Hounsfield units (HU), which are directly associated with tissue attenuation coefficients. The center value, among multiple adjacent x-coordinate HU readings, was selected as the cortical bone density value at each y-coordinate level. During preliminary study, the center value among the multiple adjacent values was similar to the mean of the multiple values (data not shown). Based on preliminary study results and those in a previously report where center values were chosen (19), the center value was chosen

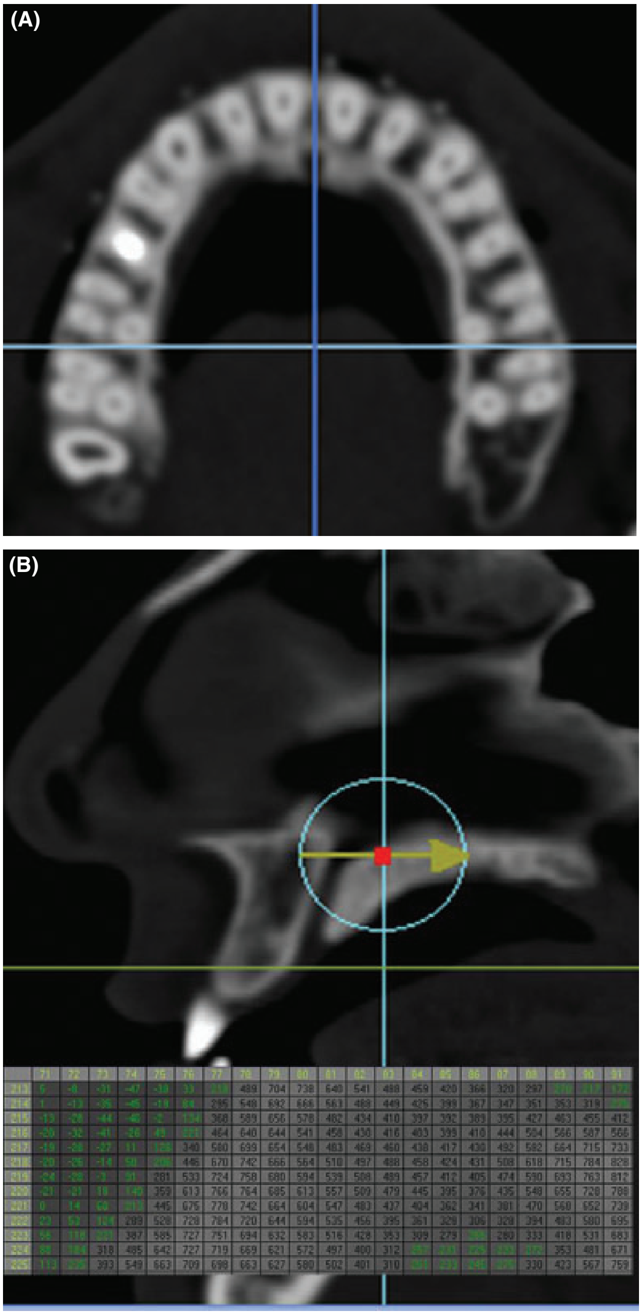

Fig. 1. (A) Horizontal section at the alveolar crest level and parallel to a line drawn between midpoints of roots in the central/central incisors interradicular site. (B) Sagittal section prepared for bone density assessment using V-works software program to map bone density in the region of interest. Multiple readings from the buccal side showed densities of gingiva, periosteum, buccal cortical bone, medullary bone, and palatal cortical bone. The densities of buccal cortical bone have multiple readings because the cortical bone thickness ranged from 1.5 to 3.0 mm.

for use in this study. In addition to determining HU units, maxilla and mandible were categorized according to the D1–D5 Misch and Kircos bone density classification system (21). D1 was defined as densities greater than 1250 HU, D2 as 850–1250 HU, D3 as 350–850 HU, D4 as 150–350 HU, and D5 as < 150 HU.

To evaluate intra-examiner reproducibility, the same examiner remeasured five randomly selected subjects for all points following a 2 week interval.

Statistical analysis

After the statistical tests for gender differences and left vs. right sides differences, two-way analysis of variance (ANOVA) and Student-Newman-Keuls test for multiple comparisons were performed. The significance level was set at $p < 0.05$ to identify differences at different levels and sites.

Results

Measurement error

There was no statistically significant difference between the two sets of measurements using a paired *t*-test.

Bone density

Prior to assessing interradicular site and bone depth differences, gender and side-based differences in bone density were assessed. There were no statistically significant differences between male and female subjects using t-test ($p > 0.05$), or between the left and right sides of the maxilla or mandible using paired t-test ($p > 0.05$). Based on the results of those tests, male and female data were mixed, and then matching measurements of the right and left sides were combined. Cortical bone density ranged between 824 and 1120 HU for maxilla and between 869 and 1700 HU for mandible (Tables 1 and 2). The maxilla consisted of D2 (850–1250 HU) and D3 (350–850 HU) bone density categories while the mandibles consisted of D1 (> 1 250 HU) and D2 categories.

The mean bone densities in the mandibular posterior area were statistically greater compared to those in the maxillary posterior region, while the difference in the anterior area between maxilla and mandible did not show statistically significant differences (Fig. 2).

In the maxilla, most anterior sites at the alveolar crest level exhibited significantly high bone densities while the significantly lowest bone density values were

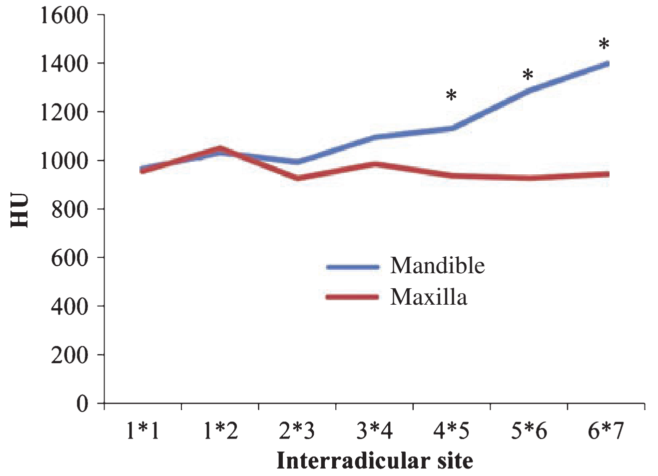

Fig. 2. Mean cortical bone density of maxillary and mandibular interradicular sites (HU = Hounsfield Units). (1) central incisor, (2) lateral incisor, (3) canine, (4) 1st premolar, (5) 2nd premolar, (6) 1st permanent molar, and (7) 2nd permanent molar. 1*1, the central/central incisors interradicular site; 1*2, the central/lateral incisors interradicular site; 2*3, lateral incisor/canine interradicular site; 3*4, canine/1st premolar interradicular site; 4*5, 1st/2nd premolars interradicular site; 5*6, 2nd premolar/1st molar interradicular site; 6*7, 1st/2nd molar interradicular site.

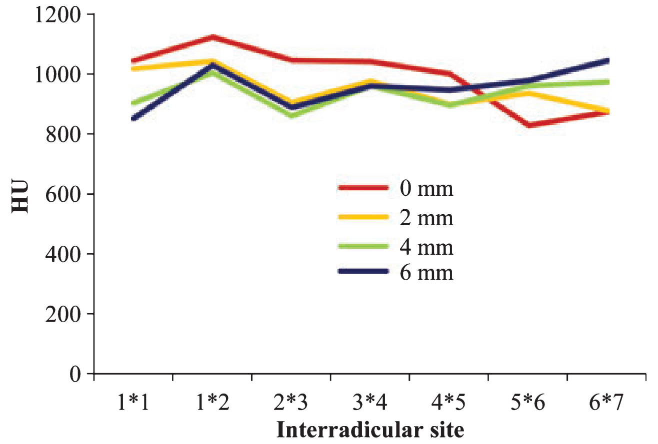

Fig. 3. Maxillary interradicular cortical bone density at 0, 2, 4, and 6 mm apical to the alveolar bone crest. (1) central incisor, (2) lateral incisor, (3) canine, (4) 1st premolar, (5) 2nd premolar, (6) 1st permanent molar, and (7) 2nd permanent molar. 1*1, the central/central incisors interradicular site; 1*2, the central/lateral incisors interradicular site; 2*3, lateral incisor/canine interradicular site; 3*4, canine/1st premolar interradicular site; 4*5, 1st/2nd premolars interradicular site; 5*6, 2nd premolar/1st molar interradicular site; 6*7, 1st/2nd molar interradicular site.

observed in the 2nd premolar/1st molar and 1st/2nd molars interradicular sites at the alveolar crest level. For most sites, the bone densities at the maxillary central/lateral incisors interradicular site were higher than those in the central/central incisors interradicular site. Bone densities in the maxillary lateral incisor/cuspid at 2, 4, and 6 mm and the 1st/2nd premolars interradicular site at 2 and 4 mm apical to the alveolar crest were significantly lower compared to those in other sites (Fig. 3).

Bone densities in the maxillary central/central interradicular sites showed a statistically significant decrease from the alveolar crest to the 6 mm level apical to the alveolar crest, with the lowest density at the 6 mm level. This trend was observed in most anterior areas. The bone densities in the 2nd premolar/1st molar and 1st/2nd molars sites increased from the alveolar crest to the level 6 mm apical to the alveolar crest (Fig. 4).

In most mandibular interradicular sites, cortical bone density progressively increased from the anterior to posterior areas, except for sites at the alveolar crest (Fig. 5). There were significant increases in bone densities from the alveolar crest toward the basal bone in the mandibular posterior area while the opposite trend was observed in the mandibular anterior area. The 2nd premolar/1st molar and the 1st/2nd molars interradicular sites at 2, 4, and 6 mm level apical to the alveolar crest exhibited significantly denser bone than other sites (Fig. 6).

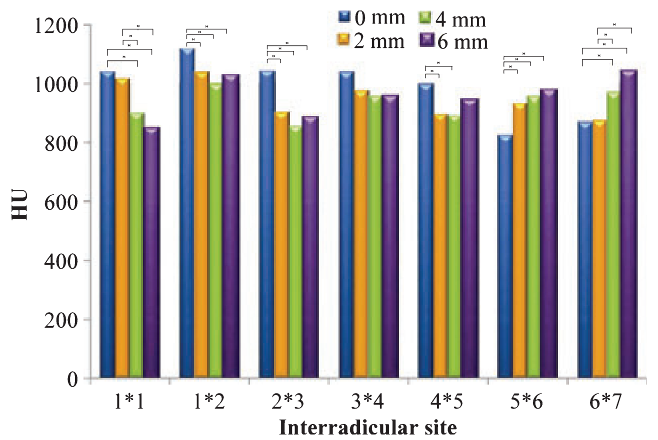

Fig. 4. Maxillary interradicular cortical bone density at 0, 2, 4, and 6 mm apical to the alveolar bone crest, and comparisons within interradicular sites. (1) central incisor, (2) lateral incisor, (3) canine, (4) 1st premolar, (5) 2nd premolar, (6) 1st permanent molar, and (7) 2nd permanent molar. 1*1, the central/central incisors interradicular site; 1*2, the central/lateral incisors interradicular site; 2*3, lateral incisor/canine interradicular site; 3*4, canine/1st premolar interradicular site; 4*5, 1st/2nd premolars interradicular site; 5*6, 2nd premolar/1st molar interradicular site; 6*7, 1st/2nd molar interradicular site.

Discussion

Mini-implants have been used on a regular basis for orthodontic treatment due to their effectiveness as

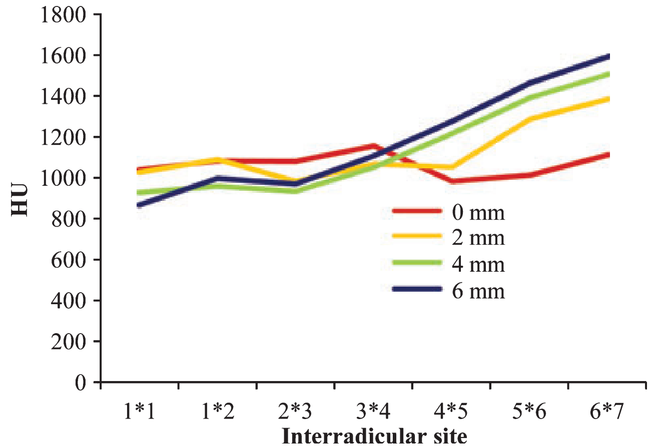

Fig. 5. Mandibular interradicular cortical bone density at 0, 2, 4, and 6 mm apical to the alveolar bone crest, and comparisons between interradicular sites. (1) central incisor, (2) lateral incisor, (3) canine, (4) 1st premolar, (5) 2nd premolar, (6) 1st permanent molar, and (7) 2nd permanent molar]. 1*1, the central/central incisors interradicular site; 1*2, the central/lateral incisors interradicular site; 2*3, lateral incisor/canine interradicular site; 3*4, canine/1st premolar interradicular site; 4*5, 1st/2nd premolars interradicular site; 5*6, 2nd premolar/1st molar interradicular site; 6*7, 1st/2nd molar interradicular site.

skeletal anchors. Among the risk factors related to stability of a mini-implant, anatomic location has been reported to be critical (2). Regarding placement stability, there is some clinical agreement on bone quantity and soft tissues effects, but there is insufficient information on the effects of bone densities.

In the present study, bone density was measured in interradicular sites from the right 2nd molar to the left 2nd molar at 0, 2, 4, and 6 mm from the alveolar crest because the majority of mini-implants are placed within the attached gingiva to minimize soft tissue inflammation and overgrowth. In this region, the attached gingiva have been reported to range from 4.3 to 5.4 mm in maxillary dentition and 3.3–4.6 mm in mandibular dentition (22, 23). Our measurements were performed at 0, 2, 4, and 6 mm from the alveolar crest because cortical bone thickness and root proximity have been measured at those same levels in previous studies (22, 23).

Both bone quality and quantity appear to be critical for successful placement of a mini-implant (6). However, bone densities from different subjects, as well as from different sites within the same subject, exhibit variations, regardless of age, sex, and race (20). This study evaluated whether bone density varies between sexes and between left and right sides, and whether different sites exhibit different densities. Such data can help to explain differential failure rates of mini-implants in interradicular sites at different levels apical to the alveolar crest. A previous study reported significant differences in mean bone mineral densities between male and female cadavers (11 male, 10 female, age range 64–99 years) (24), which is inconsistent with

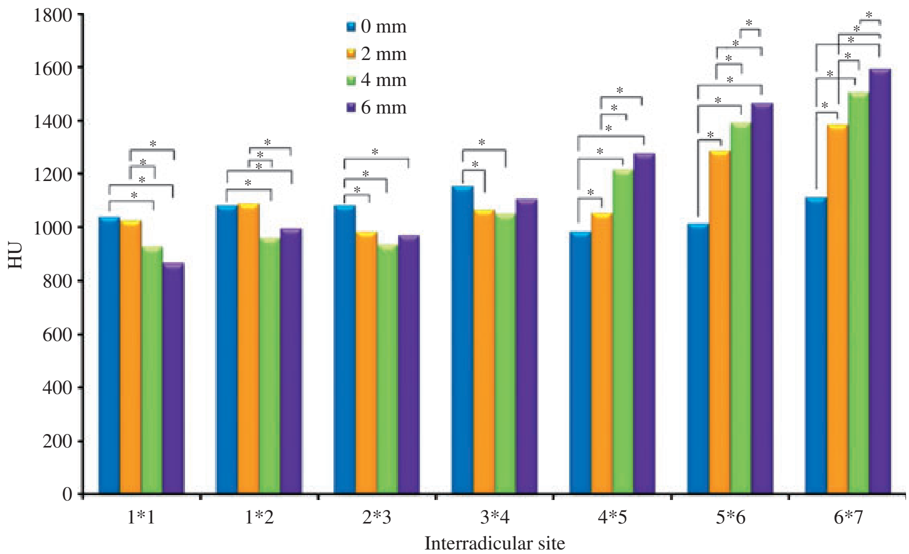

Fig. 6. Mandibular interradicular cortical bone density at 0, 2, 4, and 6 mm apical to the alveolar bone crest, and comparisons within interradicular sites. (1) central incisor, (2) lateral incisor, (3) canine, (4) 1st premolar, (5) 2nd premolar, (6) 1st permanent molar, and (7) 2nd permanent molar. 1*1, the central/central incisors interradicular site; 1*2, the central/lateral incisors interradicular site; 2*3, lateral incisor/canine interradicular site; 3*4, canine/1st premolar interradicular site; 4*5, 1st/2nd premolars interradicular site; 5*6, 2nd premolar/1st molar interradicular site; 6*7, 1st/2nd molar interradicular site.

Table 1. **The maxillary bone density (Hounsfield units)**

Height (mm)	Interradicular site 7–6	6–5	5–4	4–3	3–2	2–1	1–1
0	870.36^{A,a} (145.18)	824.77^{A,a} (161.82)	997.29^{B,a} (119.33)	1038.81^{B,a} (146.60)	1043.35^{B,a} (85.03)	1120.56^{C,a} (122.17)	1041.94^{B,a} (160.32)
2	873.43^{A,a} (178.46)	932.24^{A,B,b} (193.66)	895.02^{A,b} (166.25)	973.45^{A,B,C,a} (178.10)	901.45^{A,b} (177.56)	1040.58^{C,b,c} (147.80)	1015.00^{B,C,a} (165.79)
4	970.37^{A,C,b} (206.71)	957.81^{A,C,b} (192.42)	892.12^{A,B,b} (187.50)	957.46^{A,C,a} (173.75)	856.22^{B,b} (170.33)	1001.21^{C,c} (152.24)	899.63^{A,B,b} (155.17)
6	1042.57^{A,b} (188.56)	975.70^{A,B,b} (174.68)	944.00^{B,C,a,b} (178.03)	957.13^{B,C,a} (165.66)	885.30^{C,D,b} (157.69)	1026.48^{A,B,c} (142.11)	848.44^{D,b,c} (162.28)

Different upper case letters indicate statistically significant differences among sites by two-way analysis of variance and Student–Newman–Keuls test. Different lower case letters indicate statistically significant differences among heights by two-way analysis of variance and Student–Newman–Keuls test. Values between parentheses are standard deviations.

Table 2. **The mandibular bone density (Hounsfield units)**

Height (mm)	Interradicular site 7–6	6–5	5–4	4–3	3–2	2–1	1–1
0	1108.84^{A,B,a} (111.51)	1009.59^{C,D,a} (117.07)	979.67^{D,a} (193.00)	1151.67^{A,a} (134.99)	1077.11^{A,B,C,a} (128.09)	1078.83^{A,B,C,a} (145.20)	1035.61^{B,C,D,a} (159.55)
2	1382.42^{A,b} (94.78)	1284.07^{B,b} (117.18)	1049.27^{C,D,b} (136.90)	1063.91^{C,b} (160.35)	979.66^{D,b} (170.14)	1085.40^{C,a} (151.74)	1023.19^{C,D,a} (172.72)
4	1503.97^{A,c} (87.18)	1389.60^{B,c} (105.75)	1212.96^{C,c} (166.49)	1047.49^{D,b} (159.97)	930.91^{E,b} (151.63)	956.02^{E,b} (154.63)	924.50^{E,b,c} (221.19)
6	1590.83^{A,d} (73.33)	1461.62^{B,d} (104.16)	1273.23^{C,c} (193.12)	1104.06^{D,a,b} (184.02)	967.01^{E,b} (174.15)	993.43^{E,b} (155.21)	863.64^{F,c} (266.22)

Different upper case letters indicate statistically significant differences among sites by two-way analysis of variance and Student–Newman–Keuls test. Different lower case letters indicate statistically significant differences among heights by two-way analysis of variance and Student–Newman–Keuls test. Values between parentheses are standard deviations.

the present study. This inconsistency may be related to subject age differences between two studies, as age range in the present study was 23–35 years. It has also been reported that bone densities in Korean females peak around 35 years of age, slowly decrease until 50-years-old, and then rapidly decrease after 50 years of age. On the other hand, bone densities in Korean male have shown linear decreases (25). Up to 35 years of age, there were no differences in bone densities between Korean male and female were found (25). These results suggest that the sex-based discrepancy between the two studies is age related.

There was no difference in bone density between left and right sides of the mandible in this study. This agrees with observations of bilateral symmetry in bone density in the same anatomic sites reported for rhesus monkey (26). Another study also showed no difference in bone densities between left and right sides (19). However, these results conflict the report that mini-implants in the right side of the mandible exhibit a higher failure rate than those in the left side. This may be partly explained by the observation that people chew more frequently in the right side than the left side, resulting in more force applied to the implant (6).

Generally, the bone densities in the present study were higher than those reported in past studies (19, 27). This may be the result of including the outer cortical shell during measurement in this study. In our study, most mandibular posterior sites showed statistically greater bone densities compared to those in maxillae while the differences in the anterior areas were not significant. This is consistent with a previous study (27). Also, bone densities progressively increased from the anterior to the posterior area in the mandible, which agrees with another previous study (19). Furthermore, cortical bone thickness in the mandible showed a gradual increase from anterior to posterior areas (8). The results suggest that the mandibular posterior area may contain denser and thicker cortical bone.

In situations where bone thickness and root proximity have the same characteristics between sites, site-specific modification of interradicular level apical to the alveolar crest and adjustment of site after considering bone density may be helpful when placing a mini-implant. Most maxillary and mandibular anterior sites showed higher bone densities close to the alveolar crest. In such cases, a mini-implant can be placed close to the alveolar crest instead of nearer the basal bone. Higher densities were also found in the maxillary central/lateral incisors interradicular site than in the central/central incisors interradicular site, and the same trend was found in the mandibular 1st/2nd molar interradicular site compared to the 2nd premolar/1st molar interradicular sites. These differences may be partly explained by the different anatomic characteristics in these areas (28). Such differences in bone densities between neighboring sites should be considered, especially when selecting a second site after an initial mini-implant failure.

Bone densities in the maxillary central/central incisors interradicular site, where mini-implants are commonly placed for the purpose of intrusion, significantly decreased from the alveolar crest toward the basal bone. It has been reported that intrusive forces result in the highest failure rates (6). Thus, special consideration may be required when placing a mini-implant up to 6 mm apical to the alveolar crest or in the central/lateral incisors interradicular site if loosening occurs during the intrusion process. Additionally, the maxillary 2nd premolar/1st molar interradicular site showed the lowest bone densities at the alveolar crest. Placing a mini-implant more than 2 mm level apical to the alveolar crest in this site is recommended to avoid possible loosening.

In the mandible, several sites, including 1st/2nd premolar interradicular site at 6 mm apical to the alveolar crest, both 2nd premolar/1st molar and 1st/2nd molar interradicular sites at 2, 4, and 6 mm from the alveolar crest, were categorized as D1 (>1250 HU), dense cortical bone. It has been reported that placing implants in D1 bone results in more failures than in D2 and D3 bones (13). This may be partly explained by the observation that heat generation during implant placement increases in dense bone, resulting in implant failure due to bone necrosis (29). Clinical observations also indicate that mini-implant placement may result in a fracture in sites with thick, dense cortical bone, most often in the mandibular posterior area (6).

The present study, derived from 28 young adult subjects, showed cortical bone density ranging from 869 to 1700 HU, with densities dependant on the interradicular sites measured. Our observations indicate that bone densities vary with the distance from the alveolar crest in the interradicular sites. Further studies evaluating success rates of mini-implants related to bone densities as well as to other factors, such as soft tissue inflammation, length of mini-implants, and root proximity, may elucidate the relative importance of these different causes of implant failure.

Conclusion

The observations suggest that mini-implants for orthodontic anchorage may be successfully placed in most areas with equivalent bone density up to 6 mm apical to the alveolar crest and the site selection should be adjusted depending on the density measurements.

Clinical relevance

Anatomical structures including bone quantity and quality appear to play an important role when placing a mini-implant. The present study on bone quality suggests that mini-implants for orthodontic anchorage may be effective when placed in areas with equivalent bone density up to 6 mm apical to the alveolar crest.

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