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Quantitative evaluation of cortical bone thickness and root proximity at maxillary inter-radicular sites for safe mini-implant placement using CBCT

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Abstract
Objectives: The purpose of this study was to evaluate the interradicular cortical bone thickness, alveolar process width and root proximity for planning mini-implant placement in the maxillary alveolar process.
Material and methods: Twenty three maxillae of 23 Kashmiri routine orthodontic patients were examined. The samples were imaged and measured using a CBCT system. Buccal interradicular cortical bone thickness, alveolar process width, and root proximity were measured in five interradicular sites from distal of lateral incisor to mesial of second molar. Buccal interradicular cortical bone thickness and alveolar process width were measured at 4 different vertical levels. Root proximity was measured at four different vertical levels.
Results: Buccal interradicular cortical bone thickness and alveolar process width tended to increase from crest to base of alveolar process. The buccal interradicular cortical bone thickness between first molar and second molar was the greatest, and between canine and first premolar was the least. The root proximity between second premolar and first molar or first premolar and second premolar was the widest and between lateral incisor and canine it was the narrowest.
Conclusions: The findings of this study suggest the recommendations that when low dose 3D multislice CT or low dose cone beam imaging is not available, the results of this research may be useful in providing indicators for selecting the design of the placement site.

Keywords: cortical bone thickness, maxilla, CBCT, root proximity

Introduction
In recent years, mini-implants are increasingly being used to provide intraoral orthodontic anchorage. Mini-implants are relatively inexpensive compared to extraoral anchorage devices, and the level of patient cooperation is higher. Mini-implants are also advantageous as they are small in size, making surgical procedures less invasive, and they can be placed in a variety of sites. However, mini-implants tend to loosen after orthodontic force is applied, and unsuccessful cases have been reported in which, in the worst outcomes, mini-implants have even fallen out (Wiechmann *et al*. 2007; Schatzle *et al*. 2009) [12]. For these reasons, research has been conducted on the stability of mini-implants used for orthodontic purposes. According to a report by Miyawaki *et al*. (2003) [8], two factors contributing to the stability of mini-implants are the configuration of the implant unit and the thickness of the cortical bone. With respect to the configuration of miniimplants, stability is achieved when the implant is a screw type with a diameter of 1.5 mm or larger and a length of more than 5.0 mm, and the implant is made of titanium. This configuration also assures adequate strength of the implant unit itself. It has also been stated, however, that the thickness of the cortical bone is a necessary element in generating mechanical interdigitation between the mini-implant and the bone and achieving primary stability of the mini-implant (Meredith 1998; Szmukler-Moncler *et al*. 1998; Friberg *et al*. 1999; Miyawaki *et al*. 2003; Ottoni *et al*. 2005; Zhao *et al*. 2009) [7, 13, 3, 8, 10]. In addition, it has been reported that adequate primary stability preventing micromovements of the mini-implant is an important element in achieving osseointegration (Szmukler-Moncler *et al*. 1998) [13]. In other words, the thickness of the cortical bone is possibly the most crucial factor in stabilizing mini-implants. Furthermore, according to a report by Motoyoshi *et al*. (2007) [9], a cortical bone thickness of 1 mm or more reduces the danger of the mini-implant falling out. Little research has been conducted, however, on the cortical bone thickness of the maxillary

alveolar process in Kashmiri population. Moreover, no fullmouth data are available pertaining to sites at which cortical bone thickness of 1 mm or more can be assured. Furthermore, there is a risk of the mini-implant being placed in contact with the tooth root, but to date, little research has been conducted that provides data on root proximity, which serves as an indicator when placing the mini-implant.

Given that, in our research, the authors used CBCT scans and conducted three dimensional measurements of the cortical bone thickness and width of the maxillary alveolar process, as well as the root proximity, to determine safe sites for mini-implant placement.

Materials and methods

Samples

The Data for the study were obtained from CBCT scans taken as part of Orthodontic diagnosis and treatment planning protocol in the department of Orthodontics & Dentofacial Orthopaedics, Government Dental College and Hospital, Shereen Bagh, Srinagar. Maxillary CBCT scans of twenty three patients were selected. The scans were selected according to the following inclusion and exclusion criteria:

Inclusion criteria

1. Complete eruption of permanent dentition (except for third molars).
2. No missing teeth (exclude third molars).
3. No severe craniofacial disorders.
4. No severe periodontitis or periapical lesion.
5. No severe crowding and spacing in the teeth.

Exclusion criteria

1. Periapical or periradicular pathologies or radioluciences of either periodontal or endodontic origin.
2. A significant medical or dental history (e.g., use of bisphosphonates or bone altering medications or diseases).
3. Severe facial or dental asymmetries.

Methodology

Sample Size and power

A sample size was calculated using G*Power software (Ver. 3.0.10). For a power of 80%, α=0.05 Type I, and β=0.20 Type II error rates, a sample size of at least 20 patients was determined.

The data were obtained using the NewTom 3G Volume Scanner QRsr 1 Verona, Italy. The Newtom 3G Volume Scanner is based on a cone-beam technique that uses x-ray emissions efficiently, thus reducing the dose absorbed by the patient. The following settings were used: X ray source: HF, Constant potential (DC), 90 kV; 2 mA (pulsed)

Imaging mode: CBCT

Focal spot: 0.5 mm

Dose: 80-100 µSv

Scan: 11 cm × 8 cm and 8 cm × 8 cm

Scan time: 18 seconds

All images were oriented using a standardized protocol. On the axial image, the CBCT image was oriented until the green line supplied by the software was perpendicular to the buccal bone surface and bisects the interradicular area to be measured. On the sagittal image, the CBCT image was oriented until the occlusal plane is parallel to the blue line. The cursor was adjusted until the red line in the axial image was centered on each contact area, at approximately the midroot level. For each interradicular area in the maxilla and the mandible, from the distal aspect of the lateral incisor to the mesial aspect of the second molar of maxilla and mandible, the following measurements were done at four different heights from the alveolar crest, that was, at 2, 5, 8 and 11 mm.

Mesiodistal distance: These measurements were taken at the widest distance between each two adjacent teeth.

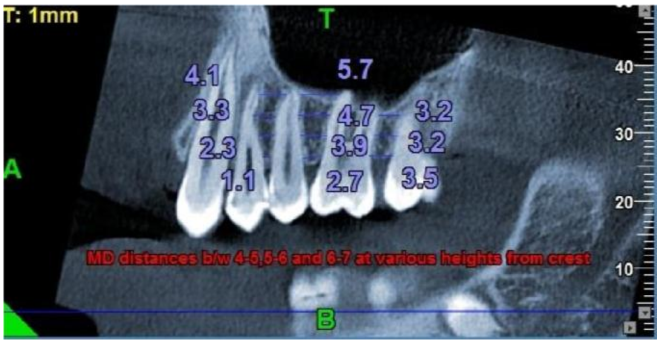

Fig 1: Measurement of the inter-radicular distances at 4 levels from the alveolar crest.

Buccolingual thickness: The thickness was measured from the outermost point on the buccal side to the outermost point on the palatal/lingual side at the middle of the distance between each two adjacent teeth.

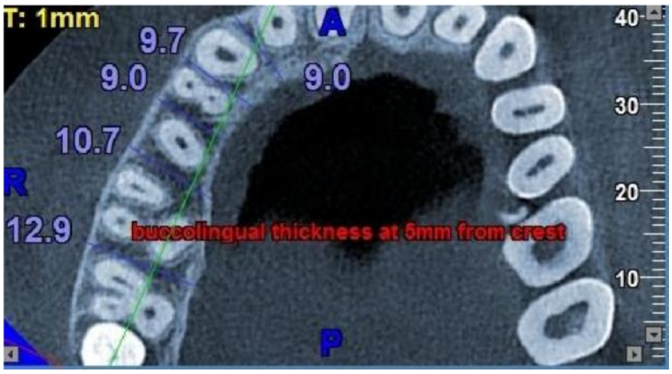

Fig 2: Measurement of the alveolar process width.

Buccal Cortical bone thickness: the distance between the internal and external aspects of the cortex in the middle of the interradicular distance between each two adjacent teeth was measured.

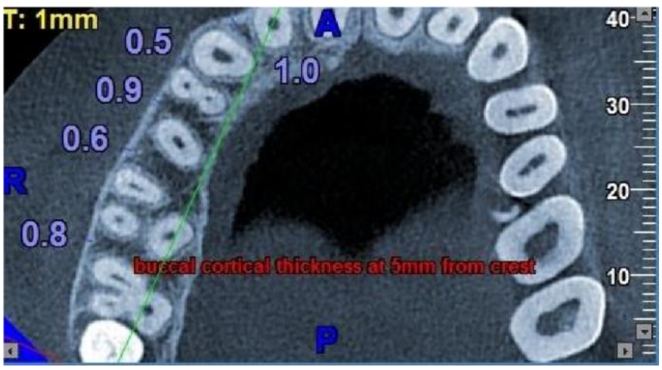

Fig 3: Measurement of the buccal cortical bone thickness.

Each measurement was taken on the computer display monitor with the Newtom® 3G measure softwear.

Statistical analysis

The statistical analysis of data was carried with the help of means, ranges and standard deviations.

Student's t-test was used to test the difference between means of various variables. A P-value of less than 0.05 was considered statistically significant. Statistical package SPSS (Version 20.0) was used to carry out the statistical analysis of data.

Based on the normalcy of the distribution of the data, results obtained were statistically analyzed and compared using SPSS software**.** The statistical analysis included:

- *Descriptive statistics: Including;* mean, minimum, maximum, and standard deviation
- *Independent-samples t-test:* For the comparison of various variables.

  Informed consent regarding the benefits and protocol of study was obtained from all patients.

The study was carried out using the following parameters

1. Evaluation of buccolingual alveolar process width in interdental areas in between lateral incisor and canine, canine and first premolar, first premolar and second premolar, second premolar and first molar, first molar and second molar at 2mm, 5mm, 8mm and 11mm height from the alveolar crest in maxilla.
2. Evaluation of mesiodistal distance (inter-radicular spaces) in interdental areas in between lateral incisor and canine, canine and first premolar, first premolar and second premolar, second premolar and first molar, first molar and second molar at 2mm, 5mm, 8mm and 11mm height from the alveolar crest in maxilla.
3. Evaluation of buccal cortical bone thickness in interdental areas in between lateral incisor and canine, canine and first premolar, first premolar and second premolar, second premolar and first molar, first molar and second molar at 2mm, 5mm, 8mm and 11mm height from the alveolar crest in maxilla.

Results

The means and standard deviations of the buccolingual alveolar process width of the maxilla is shown in Table 1.

Table 1: Descriptive statistics of Buccolingual measurements in maxilla.

Height from alveolar crest		Maxilla				
		2&3	**3&4**	**4&5**	**5&6**	**6&7**
2 mm	Mean	**5.64**	6.68	7.90	9.08	10.64
	SD	1.22	0.95	1.08	1.34	1.88
	Min	3.5	4.4	5.1	6.6	7.5
	Max	7.5	8.2	10.4	11.4	13.8
5 mm	Mean	7.71	8.50	8.63	9.95	12.08
	SD	1.30	0.99	1.02	1.49	2.16
	Min	5.2	6.5	6.3	6.9	7.8
	Max	10.0	9.8	10.3	12.4	16.9
8 mm	Mean	8.39	8.60	8.59	10.42	12.97
	SD	1.80	1.45	1.27	1.84	2.12
	Min	5.2	5.8	6.1	7.1	8.6
	Max	11.4	11.1	11.2	13.0	18.5
11 mm	Mean	8.37	8.68	9.20	11.38	13.07
	SD	2.66	2.35	1.82	2.22	1.93
	Min	4.1	5.0	6.0	7.6	8.8
	Max	12.7	13.8	13.0	15.2	16.1

The greatest buccolingual alveolar process width was between the first and second molar at 11 mm height (13.07±1.93). The least buccolingual alveolar process width was between lateral incisor and canine at 2 mm height (5.64±1.22 mm).

The means and standard deviations of the mesiodistal distances of the maxilla is shown in Table 2.

Table 2: Descriptive statistics of mesiodistal distances (inter-radicular spaces) in maxilla.

Height from alveolar crest		Maxilla				
		2&3	**3&4**	**4&5**	**5&6**	**6&7**
2 mm	Mean	**1.75**	2.06	2.15	2.36	2.25
	SD	0.52	0.66	0.49	0.63	0.86
	Min	0.9	0.9	1.1	1.2	0.6
	Max	3.0	3.5	3.0	4.4	4.2
5 mm	Mean	2.30	2.32	2.50	2.47	2.01
	SD	0.73	0.93	0.63	0.87	0.96
	Min	1.1	0.9	1.4	1.0	0.2
	Max	4.1	4.1	3.6	4.2	4.1
8 mm	Mean	2.93	2.80	2.93	**3.10**x	1.97
	SD	0.97	0.98	0.83	0.90	1.06
	Min	0.9	0.9	1.7	1.2	0.2
	Max	5.1	4.7	4.1	5.4	5.3
11 mm	Mean	**3.07**x	**3.51**x	**3.38**x	**″3.72**	2.13
	SD	0.97	1.31	1.02	1.09	1.40
	Min	1.2	0.9	1.5	1.7	0.6
	Max	4.4	5.3	4.8	5.7	5.0

Average risk site x ″ Safe site

The greatest mesiodistal distance (inter-radicular space) was between the second premolar and first molar at 11 mm height from the alveolar crest (3.72±1.09 mm). The least mesiodistal distance (inter-radicular space) was between lateral incisor and canine at 2 mm height (1.75±0.52 mm).

The means and standard deviations of the buccal cortical bone thickness of the maxilla is shown in Table 3.

Table 3: Descriptive statistics of buccal cortical bone thickness in maxilla.

Height from alveolar crest		Maxilla				
		2&3	**3&4**	**4&5**	**5&6**	**6&7**
2 mm	Mean	0.93	0.92	0.86	0.86	1.00
	SD	0.39	0.34	0.30	0.32	0.34
	Min	0.3	0.3	0.3	0.3	0.3
	Max	1.9	1.5	1.5	1.7	2.0
5 mm	Mean	0.88	0.83	0.86	0.84	0.87
	SD	0.32	0.23	0.29	0.34	0.24
	Min	0.2	0.3	0.3	0.3	0.5
	Max	1.6	1.2	1.5	1.5	1.5
8 mm	Mean	1.11	1.15	0.91	0.93	0.93
	SD	0.33	0.35	0.25	0.35	0.43
	Min	0.3	0.5	0.2	0.5	0.3
	Max	2.0	2.1	1.4	1.6	1.9
11 mm	Mean	1.11	1.11	0.95	1.16	1.35
	SD	0.34	0.31	0.22	0.60	0.59
	Min	0.5	0.5	0.5	0.4	0.6
	Max	1.8	1.8	1.3	3.3	3.0

The greatest buccal cortical bone thickness was between the first and second molar at 11 mm height (1.35±0.59 mm). The least buccal cortical bone thickness was between canine and first premolar at 5 mm height (0.83±0.23 mm).

These data show that, for all variables, the measurements are gradually increased from cervical area to apical area. Small variations from this trend were observed between the first premolar and second premolar at 8 mm height and between lateral incisor and canine at 11 mm height (for BL). The variation was also observed between the first molar and second molar at 5 mm and 8 mm height (for MD). The buccal cortical thickness (BC) also showed variations from the general trend between lateral incisor and canine at 5 mm height; between canine and first premolar at 5 mm and 11 mm height; between second premolar and first molar at 5 mm height; and between first molar and second molar at 5 mm height, which were less than the height above them. The buccolingual alveolar process width increases from the anterior to posterior regions.

Discussion

To date, the success rates for screw-type mini-implants used in the alveolar process has been lower than those for dental implants and mini-plates (Kuroda *et al*. 2007a) [4]. Two factors affecting the success of mini-implants are the thickness of the cortical bone and root proximity (Miyawaki *et al*. 2003; Kuroda *et al*. 2007b) [8, 5]. According to Turkyilmaz *et al*. (2006), the primary stability of the implant can be estimated by CT scanning prior to surgery. Given that, CT scans should preferably be carried out on all patients. However, because it is not feasible to perform CT scans and cone beam CT scans in all cases, we do not always obtain important information. Therefore, in our research we focused our efforts on acquiring anatomical data of the placement site. When mini-implants are used in the maxilla, in many cases they are placed in an inter-radicular site of the maxillary alveolar process. For this reason, we measured the buccal cortical bone thickness, and root proximity at every inter-radicular site from 2–3 to 6–7. A cortical bone thickness of at least 1 mm is necessary to achieve mini-implant stability. When we measured cortical bone thickness, there was a tendency for the superior part of the alveolar process to be thicker than the inferior part. Because of this, in view of the stability of the mini-implant, placement in the portion above the alveolar process is preferred whenever possible. In the upper portion, however, the presence of the nasal cavity and maxillary sinus needs to be considered, as well as the anatomical limitations imposed by the transition from the attached gingiva to the alveolar mucosa. Therefore, while still considering the stability of the mini-implant, we believed it was important to identify sites with a thickness of 1 mm or more in the portion farther down of the alveolar process as well, to assure safe placement.

The safe site for placing miniscrew implant in the maxilla of our study is between the second premolar and first molar at 11 mm height (3.72±1.09 mm), however it should be careful about maxillary sinus position at this height. The average risk site is between the second premolar and first molar at 8 mm height (3.10±0.90 mm); between the first and second premolar (3.38±1.02 mm); between the canine and first premolar (3.51±1.31 mm) and between the lateral incisor and canine (3.07±0.97 mm) at 11 mm height from the alveolar crest, that is suitable for 1.2-1.3 mm diameter of miniscrew implant. The results of this study in terms of the placement site of miniimplant screws in maxilla are in agreement with the results obtained by Poggio *et al*. and Fayed *et al*. This study determines the inter-radicular areas in the maxilla for safe and suitable orthodontic miniscrew implant placement. We reported the greatest mesiodistal distance was between the maxillary second premolar and first molar. According to the Table 4, this result agreed with those obtained in previous studies of both 2D and 3D method. However, they are slightly different from the study of Poggio *et al.* probably due to the difference in the method of measurement in these studies.

Table 4: Summary of articles identifying the greatest mesiodistal distance in the inter-radicular areas of maxilla.

Author	Method	Greatest Inter-radicular distance
Poggio *et al.*, 2006	CBCT	4-5, 5-6
Park and Cho, 2009	CBCT	5-6
Fayed *et al.*, 2010	CBCT	5-6
Chaimanee *et al.*, 2011	IOPAR	5-6
Schnelle *et al*., 2004	OPG	5-6
Our study	CBCT	5-6

It has been reported that contact between the mini-implant and a tooth root is one reason that mini-implants sometimes fail (Kuroda *et al*. 2007b) [5]. Because of this, it is important to ascertain the root proximity. Mini-implants currently used have a diameter of 1.3–1.5 mm (Park *et al*. 2001; Bae *et al*. 2002; Kyung *et al*. 2003; Deguchi *et al*. 2006; Kuroda *et al*. 2007a) [11, 1, 6, 2, 4]. Taking the width of the periodontal membrane into consideration, it is necessary to assure root proximity of at least 2.5 mm. The root proximity increases in the direction of the root apex, so adequate root proximity can be assured at a site close to the root apex. When placement is necessary at a lower level, however, adequate root proximity can be assured in the lower portion at 2–3, 3-4, 4–5 and 5–6. Because there is less interdental space at 6–7, particular caution is required concerning contact between the mini-implant and the tooth root when placing the mini-implant at these sites. Mini-implants currently in use measure from 6 to 8 mm in length (Deguchi *et al*. 2006) [2]. We confirmed, based on our measurement results that the maxillary alveolar process has a width of 6 mm or greater at most sites. There are also reports indicating that the longer the mini-implant, the higher the success rate of implantation (Kuroda *et al*. 2007a) [4]. At sites above the alveolar process and in the molar region, a width of at least 8 mm can be assured for the alveolar process, suggesting that longer mini-implants can be used at these sites.

Conclusion

In the present study, we obtained anatomical data necessary when placing mini-implants only for the maxilla in Kashmiri skulls. Because individual differences exist, performing CT scans or similar imaging procedures prior to surgery is the optimal approach, but in cases where such preoperative imaging is not possible, the results of this research may be useful in providing indicators for selecting the design of the placement site and the type of mini-implant unit to be used.

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