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Applied Anatomic Site Study of Palatal Anchorage Implants Using Cone Beam Computed Tomography

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Abstract

Aim The purpose of this study was to conduct quantitative research on bone height and bone mineral density of palatal implant sites for implantation, and to provide reference sites for safe and stable palatal implants.

Methodology Three-dimensional reformatting images were reconstructed by cone beam computed tomography (CBCT) in 34 patients, aged 18 to 35 years, using EZ Implant software. Bone height was measured at 20 sites of interest on the palate. Bone mineral density was measured at the 10 sites with the highest implantation rate, classified using K-mean cluster analysis based on bone height and bone mineral density.

Results According to the cluster analysis, 10 sites were classified into three clusters. Significant differences in bone height and bone mineral density were detected between these three clusters ($P<0.05$). The greatest bone height was obtained in cluster 2, followed by cluster 1 and cluster 3. The highest bone mineral density was found in cluster 3, followed by cluster 1 and cluster 2.

Conclusion CBCT plays an important role in pre-surgical treatment planning. CBCT is helpful in identifying safe and stable implantation sites for palatal anchorage.

Keywords palatal implant, cone-beam computed tomography, bone height, bone mineral density

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Introduction

Over the last 10 years, palatal implants have become widely used for reliable anchorage in orthodontic treatment. Palatine bone has very irregular morphology and structure. Palatal implantation also involves a risk of damage to the nasal cavity, nasopalatine nerve or maxillary sinus, affecting the implant success rate. It is of practical importance to analyse the bone quantity and quality available in this area. Studies on bone mass and bone mineral density at palatal implant sites before placement are therefore a hot topic in present research. Traditional anchorage techniques, such as wearing headgear and intermaxillary elastic traction, are often unable to meet the clinical demands of orthodontic treatment because the traditional techniques affect appearance, and require compliance of patients, as well as having other unpredictable risks. Palatal implants as an anchorage site have been used in clinical practice for over 10 years, and provide the greatest anchorage force when traditional techniques cannot meet the clinical requirements (Asscherickx *et al*., 2005; Gracco *et al*., 2007). Implant anchorage in the palate has numerous advantages compared with conventional anchorage techniques: (1) there is a relatively large bone mass in the median and flanking region palate; (2) there are dense soft tissues on the surface of the hard palate, so compact connective tissues can be formed at the cervical part of the implant; and, (3) a short implant can provide sufficient anchorage. Taken together, palatal implant anchorage has been widely used in clinical practice. However, palatal bone height and bone mineral density differ between individuals and between different sites in the same individual. Implantation may damage adjacent structures or result in failed implantation. Gahleitner *et al*. measured the palatine bone of 32 patients using dental CT, and found that three patients (9.0%) could not undergo palatal implant anchorage due to insufficient bone height (Gahleitner *et al*., 2004). King *et al*. confirmed that the most suitable region for palatal implantation was 4.0 mm posterior to and 3.0 mm lateral to the incisive foramen, but was this region was only suitable for a 3.0-mm long implant (King *et al*., 2006; Oliveira *et al*., 2008). Therefore, it is important to assess the bone height and bone mineral density of the palatal implant sites prior to implantation. In 1999, Wehrbein *et al*. reported that the actual vertical bone height of the anterior and median hard palate was 2 mm higher than that in lateral cephalometric radiographs (Wehrbein *et al*., 1999). It is therefore difficult to precisely measure bone height using lateral cephalometric radiographs. The recent introduction of cone beam computed tomography (CBCT) has allowed for the acquistion of high-resolution three-dimensional image, which can be measured using EZ Implant software in axial, coronal and sagittal views, thus avoiding the problems with image clarity and overlapping bone segment.

In this study, we quantitatively analyzed bone height and bone mineral density of the horizontal plate of the palatine bone using CBCT combined with EZ Implant software (Gahleitner *et al*., 2004). We have also provided references values to identify a safe, stable and reliable palatal implant placement site.

Participants and Methods

Subjects

CBCT data from 34 orthodontic patients were selected at the Academy of Orthodontic/Unit Care Center, Macao, China. Inclusion criteria: Chinese; complete maxillary and mandibular dentition; no impacted teeth, no destruction of bone; no tumor in the hard palate; no systemic or metabolic bone disease. The 34 patients included 11 males and 23 females, aged 18–35 (mean 24.2 ±1.2) years.

Image taking

Using CBCT (Classic i-CAT®, Imaging Sciences International, USA), cranio-maxillofacial scanning was performed from the frontal to the submental region, 16 cm in diameter, 13 cm in height, 120 kV (tube tension), 24 mA (tube current), 0.4 mm in scanning layer height, and saved in 14 bit gray-scale format. After scanning, data were kept in DICOM format.

Three-dimensional image reconstruction

The DICOM format data were obtained and analyzed with the EZ Implant computer software (version 1.5, Vatech, Korea). Three-dimensional image reconstruction was performed, with a space resolution of 0.1 mm. Reconstructed computer models were fixed, cut and measured with a measurement tool in the software.

Measurement and calculation

Measurement of vertical bone height: In the axial plane, a midline sagittal incision was made through the incisive foramen and axia. A coronal incision was made from the posterior border of the incisive foramen, with a spacing of 3.0, 6.0, 9.0 and 12.0 mm. The direction of the incision was simulated as the implanted direction of palatal implant, which was vertical to the contour of the cut point (Figure 1). Coronal planes, at 3.0, 6.0, 9.0, and 12.0 mm posterior to the incisive foramen, were labeled P3, P6, P9, P12, respectively (where P=Plane) (Figure 2).

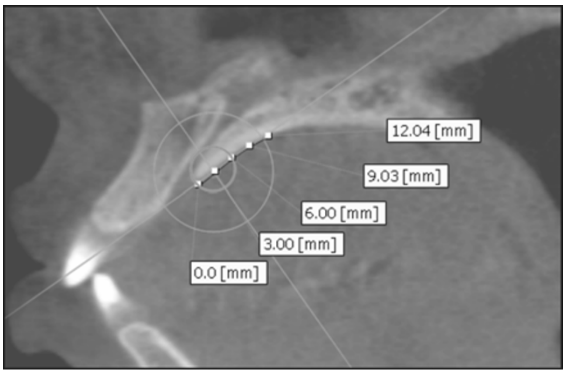

Figure 1 Coronary incision at 3, 6, 9 and 12 mm posterior to the incisive foramen

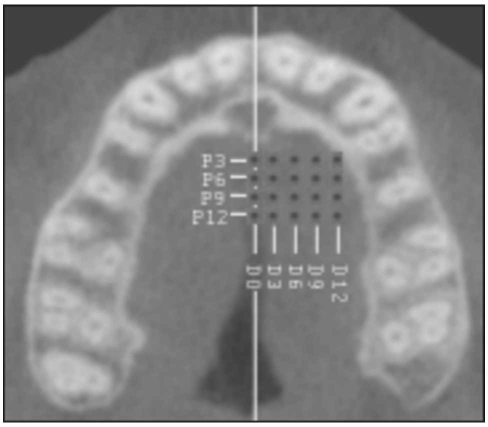

Figure 2 Fixed-point of palate measurement

The height of the hard palatal bone was measured from the left hard palate to 0, 3.0, 6.0, 9.0, and 12.0 mm from the median line of the palatine bone. The measurement direction was simulated as the implanted direction of the palatal implant, which was vertical to the contour of measurement point (Figures 3–6).

These points at 0, 3.0, 6.0, 9.0, and 12.0 mm from the median line of the palatine bone, were labeled D0, D3, D6, D9 and D12, respectively (where D=Distance) (Figure 2). The 20 measurement points were separately labeled P3D0, P3D3, P3D6, P3D9, P3D12, P6D0–12, P9D0–12, P12D0–12. For example, P3D3 represents the region 3.0 mm posterior to the incisive foramen and 3.0 mm from the median line of the palatine bone. The edge of the bone height measurement included the outer layer cortex, the basis nasi, the maxillary sinus floor, the tooth root and lateral wall of the incisive canal of the hard palate bone.

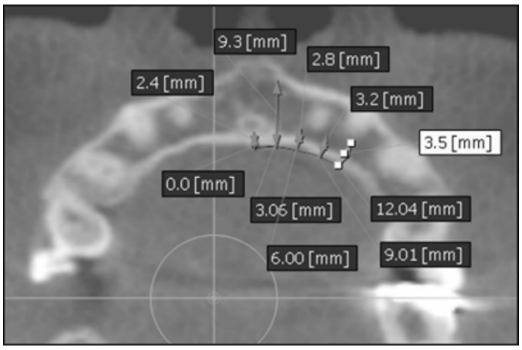

Figure 3 Measurement of vertical bone height on the 3-mm coronal section

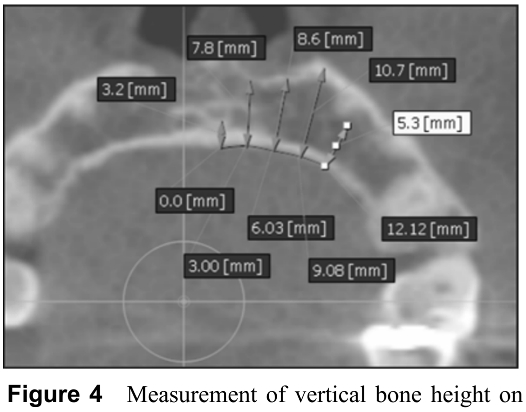

Figure 4 Measurement of vertical bone height on the 6-mm coronal section

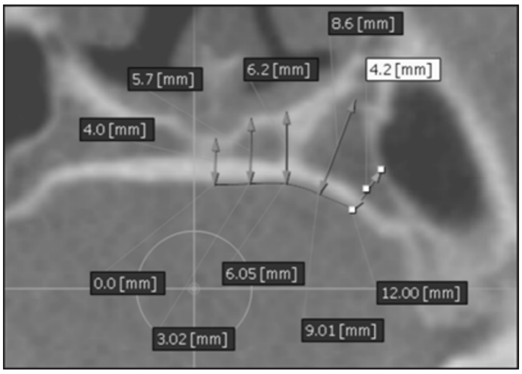

Figure 5 Measurement of vertical bone height on the 9-mm coronal section

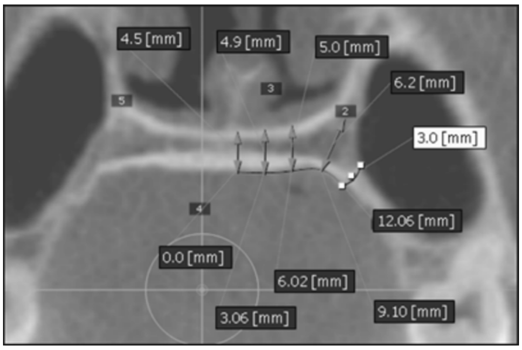

Figure 6 Measurement of vertical bone height on the 12-mm coronal section

Implantation rate: Considering that the surgical procedure requires a 1.0-mm buffer zone (Kokich, 2004), a site where the vertical bone height is ⩾4.0 mm was deemed suitable for implantation of a 3.0-mm implant. The implantion rate of a 3.0-mm implant was calculated at 20 sites according to the formula:

$$\text{Implantation rate} = \frac{\text{Implant number}}{\text{Measurement number}} \times 100\%$$

Measurement of bone mineral density: Ten sites with a high implantation rate were selected. Three popular types of cylindrical implants were defined in the software, sized 3.3 mm diameter × 4.0 mm long; 3.3 mm diameter × 6.0 mm long; and 3.75 mm diameter × 3.0 mm long. According to the bone thickness, the most suitable diameter and length of implant was selected for implantation. The distance was ⩾1 mm between the implant and surrounding structures such as the tooth root of the incisor, the nasal sinus, the maxillary sinus and the incisive canal. The bone mineral density for a region of bone 1 mm thick surrounding the implant was measured using the EZ Implant software.

Statistical analysis

Vertical bone height at 20 sites of interest and the bone mineral density at 10 sites with a high implantation rate at the palate are expressed as means. Bone height and bone mineral density of the 10 sites with a high implantation rate were analyzed by K-means clustering with SPSS 13.0 software. Clustering results were analyzed using analysis of variance. The correlation of bone mineral density to bone height was determined (Gahleitner *et al*., 2004).

Results

Mean bone height and implantation condition at 20 sites for implantation at the palate

The thickest part of the palate was detected at P3D6, with a mean bone height of 8.7 ± 2.7 mm, while the thinnest was measured at P3D0 as 3.6 ± 2.0 mm. The maximal bone height was 15.8 mm, whereas the minimal bone height was 0.8 mm. A total of 10 sites with a high implantation rate were selected, including P3D3, P3D6, P6D0, P6D3, P6D6, P6D9, P9D0, P9D3, P9D9, P12D0 (Table 1).

Table 1 Bone height and implantation condition of 20 palatal implant sites

Site	Bone height /mm ($\bar{x} \pm s$)	Maximum /mm	Minimum /mm	Implantation rate /%
P3D0	3.6 ± 2.0	12.9	1.7	20.6
P3D3	5.8 ± 2.2	10.9	2.8	76.5
P3D6	8.7 ± 2.7	14.4	2.9	94.1
P3D9	6.7 ± 3.2	12.4	2.3	70.6
P3D12	3.9 ± 2.4	12.7	1.4	35.3
P6D0	5.3 ± 2.0	11.6	2.7	76.5
P6D3	6.4 ± 2.5	14.4	2.8	88.2
P6D6	7.9 ± 2.7	14.0	3.0	91.2
P6D9	8.4 ± 3.4	15.8	2.9	88.2
P6D12	5.7 ± 2.9	11.2	1.8	58.8
P9D0	5.9 ± 2.1	13.2	3.0	88.2
P9D3	5.8 ± 2.6	12.8	2.4	76.5
P9D6	5.8 ± 2.8	11.5	1.6	64.7
P9D9	6.7 ± 3.5	14.4	1.1	79.4
P9D12	5.1 ± 1.5	13.5	1.0	55.9
P12D0	5.1 ± 1.5	9.4	3.2	79.4
P12D3	4.3 ± 1.7	8.6	1.8	58.8
P12D6	3.8 ± 1.8	9.4	1.4	41.2
P12D9	4.2 ± 2.6	10.2	1.2	41.2
P12D12	4.8 ± 3.3	11.4	0.8	44.1

Bone mineral density at 10 sites with a high implantation rate

The site with the highest mean bone mineral density was P6D0 (686.0 ± 134.3 HU), whereas the site with the lowest mean mineral density was P9D9 (403.8 ± 154.4 HU). The highest bone mineral density was 964.0 HU, and the lowest bone mineral density was 100.2 HU (Table 2).

Table 2 Bone mineral density (HU) of 10 sites with a high implantation rate for a 3.0-mm long implant

Site	Bone mineral density /HU ($\bar{x} \pm s$)	Maximum	Minimum
P3D3	572.0 ± 138.9	801.4	230.0
P3D6	414.5 ± 177.7	800.6	120.5
P6D0	686.0 ± 134.3	964.0	472.4
P6D3	548.6 ± 159.6	913.1	292.1
P6D6	426.1 ± 171.2	850.6	178.3
P6D9	403.8 ± 154.4	757.3	138.6
P9D0	625.9 ± 144.2	959.1	377.1
P9D3	510.6 ± 192.7	923.7	183.4
P9D9	427.1 ± 193.8	878.0	100.2
P120	603.9 ± 140.2	852.2	343.9

Cluster analysis results at 10 sites with a high implantation rate

According to the cluster analysis results, the 10 sites could be classified into three clusters. P3D3, P6D3, P9D3 and P9D9 were in class type 1; P3D6, P6D6 and P6D9 were in class type 2; and P6D0, P9D0 and P12D0 were in class type 3 (Table 3).

Table 3 Cluster analysis results of 10 sites with a high implantation rate

Site	Type	Distance /mm
P3D3	1	0.644
P3D6	2	0.269
P6D0	3	0.486
P6D3	1	0.372
P6D6	2	0.355
P6D9	2	0.128
P9D0	3	0.381
P9D3	1	0.303
P9D9	1	0.975
P12D0	3	0.419

Analysis of variance results of the cluster analysis

As shown in Table 4, there were significant differences in bone height (F=36.17, P=0.000) and bone mineral density (F=16.52, P=0.002) between the three site types. Differences between types were compared using the least significant difference (LSD) method. There were significant differences in bone height in type 2 compared with types 1 and 3 (P<0.05) and there were significant differences in bone mineral density between all three types (P<0.05). Overall, the rank order for bone height was type 2 > type 1 and type 3 and that for bone mineral density was type 3 > type 1 > type 2.

Correlation between bone mineral density and bone height

Pearson's correlation coefficient was r = –0.874, P=0.001. Bone mineral density was negatively correlated with bone height (a=0.05).

Table 4 Differences in mean bone height and bone mineral density between the three types after cluster analysis

Index	Type	Mean ($\bar{x} \pm s$)	F	P	Rank order
Bone height /mm	1	6.2 ± 0.5	36.17	0.001	Type 2 > type 1, type 3
	2	8.3 ± 0.4[a]			
	3	5.4 ± 0.4[b]			
Bone mineral density /HU	1	514.6 ± 63.6	16.52	0.002	Type 3 > type 1 > type 2
	2	414.8 ± 11.1[a]			
	3	638.6 ± 42.5[ab]			

[a]P<0.05, *vs*. type 1 of the same index; [b]P<0.05, *vs*. type 2 of the same index.

Discussion

The optimal position for implantation depends on the depth, morphology and level of calcification of the hard palatal plate. Insufficient vertical bone height and low bone mineral density are common reasons for failure implantation (Tinsley *et al*., 1999; Mesa *et al*., 2008). In this study, the type 2 cluster of sites (P3D6, P6D6, P6D9) had greater bone height, followed by types 1 and 3. These correspond, respectively to the sites 3.0 mm posterior to the incisive foramen and 6.0 mm from the median palate, 6.0 mm posterior to the incisive foramen, and 6.0 or 9.0 mm from the median palate. This result differs slightly from those of Bernhart *et al*. who believed that only the site 6.0–9.0 mm posterior to the incisive foramen and 3.0–6.0 mm from the median palate was suitable for implantation (Bernhart *et al*., 2000). This difference may be due to different races or different age groups in the two studies. Bone mineral density is known to affect the stability of the implant, so the bone mineral density of palatal implant sites should be measured before implantation. We found that type 3 (P6D0, P9D0, P12D0) sites had the greatest bone mineral density at the median palatal suture of the hard palate, followed by types 1 and 2. The lateral site of the palate has a lower bone mineral density compared with the median palate. Implantation at the median palatal suture appears, therefore, to be the most stable site for implants. However, the bone height of the median palatal suture is lower compared with the lateral site, suggesting that short implants should be used in this region. Uncertainty remains over whether to choose the median palatal suture or the lateral site. Some researchers have shown that the median palatal suture was the center of maxillary growth and development (Bernhart *et al*., 2000; Schlege *et al*., 2002; Gahleitner *et al*., 2004; King *et al*., 2006). For children and teenagers, implantation should not be conducted at the median palatal suture, but at the lateral region to avoid affecting maxillary growth and development. The anatomic structure of the palatine bone differs between individual and between different sites in the same individual (Lascala *et al*., 2004; Asscherickx *et al*., 2005; Kang *et al*., 2007). Thus, it is necessary to measure the bone height and bone mineral density of the palatal implant sites prior to implantation. Overall, our study reveals that CBCT is useful to quantitatively analyze bone mineral density and bone height of the palatine bone in order to assess and select suitable palatal implant sites. Results from this study demonstrated that bone mineral density is negatively correlated with bone height. However, the ideal region is not necessarily the region with both the largest bone height and greatest bone mineral density. In the clinic, suitable palatal implant sites can be chosen by assessing the bone height and bone mineral density of the patient's hard palate.

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