Palatal Bone Thickness of MSE Implantation area in Adult Patients with Skeletal Class II Malocclusion: A Cone-beam Computed Tomographic Study

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Research Article

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Abstract

Background: Analyze the palatal bone thickness of maxillary skeletal expander (MSE) implantation area in adult patients with skeletal class III malocclusion based on Cone-beam computed tomography (CBCT) data, and to provide a reference for the implantation of the miniscrew.

Methods: A total of 80 adult patients (40 M, 40 F) with an normal angle before treatment were divided into two groups; skeletal class III malocclusion group and skeletal II malocclusion group according to sagittal facial type, with 40 patients in each group, with a male to female ratio of 1: 1. CBCT scanner was used to obtain DICOM data from all patients. The palatal bone thickness was measured at 45 sites with MIMICS 21.0 and SPSS 22.0 was employed for statistical analysis. The bone thickness of different regions of the palate in the same group was analyzed by one-way analysis of variance (ANOVA) method; Fisher's least significant difference (LSD)-t method was used for comparison in pairs, and an independent sample t-test was employed to test the difference of bone thickness in the same area between the two groups.

Results: (1) There was no significant difference among the anterior, middle, and posterior regions of the midline area in patients with skeletal class III malocclusion (P > 0.05). Palatal bone thickness decreased gradually from front to back in the middle and lateral areas in both groups (P < 0.001). (2) The bone thickness of the anterior, middle, and posterior regions of the two groups gradually decreased from the middle area to the parapalatine region. (3) The palatal bone were significant thinner in the area 9.0 mm before the transverse palatine suture in midline area, 9.0 mm before and after the transverse palatine suture in the middle area, and 9.0 mm after the transverse palatine suture in the lateral area.

Conclusion: (1) The palatal bone of patients with class III malocclusion was thinner in some areas, so the MSE implant anchorage position could be moved forward appropriately. (2) The thin palatal bone increased the risk of MSE anchorage screw penetrating nasal mucosa and even inferior turbinate. Patients should be given a more precise and personalized implantation scheme based on factors such as palatine bone thickness and palatal morphology.

Background

Skeletal class III malocclusion, a common misalignment, is caused by maxillary hypoplasia and/or mandibular overdevelopment. The incidence of malocclusion in China is 14.8%[1,2]. Patients with skeletal class III malocclusion often show lateral and sagittal abnormalities, and the common clinical manifestations include maxilla transverse deformity (MTD), the narrow width of maxillary base bone or/and maxillary dental arch, widened buccal space when smiling, v-shaped maxillary dental arch, unilateral or bilateral posterior crossbite, which affects oral function and maxillofacial beauty[3-6]. Maxillary arch expansion is an effective treatment for MTD[7]. Of late, the emergence of bone-borne palatal expanders has enabled adults to expand their arches without surgery[8,9]. The palate includes hard palate and soft palate. In this study, the hard palate composed of the palatine process of the
maxilla and horizontal plate of platine bone) is studied. This area is simple in anatomical structure and has a low risk of root or blood vessel injury. Due to toughness, epithelial tissue is a suitable place for screw implants[10-11]. The bone thickness of the implant area is shown to be the key to maintain the initial stability of the mini-screw implants[12-13]. After a screw is implanted, the surface is mechanically embedded with the surrounding bone tissue so that a certain implant depth can effectively obtain a larger contact area. Therefore, it is very important to evaluate the palatal bone thickness of the implant anchorage.

Commonly used clinical maxillary expansion methods involve dental or mucosal support arch expansion, surgically assisted rapid maxillary expansion (SARME), and miniscrew-assisted maxillary palatal expansion (MARPE) [14-16]. With the increase in age, the maxillary suture gradually changes from fibrous bonding to osseous embedding, and the traditional dental support or mucosal support arch expander is no longer applicable. However, SARME induces large trauma and can have risks such as postoperative infection, pain, jaw, and neurovascular injury, which also increase the economic burden of patients[17]. The miniscrews of MARPE were implanted on both sides of the midpalatal suture and the force generated by the expander are applied to the midpalatal suture and transmitted to the entire maxilla through the palatal implants. This can minimize unnecessary tooth inclination and alveolar bone bending, and achieve true skeletal arch expansion. The success rate of MARPE in young adults is 86.96%, which has proven to be a feasible treatment option for TMD[18-20]. Subsequently, Won Moon and his colleagues improved and developed MSE (Maxillary Skeletal Expander®Bompole Korea Inc) (Fig. 1) based on traditional MARPE. The implant anchorage was implanted at the back, penetrating the double-layer bone cortex for fixation, so that the stress of MSE could act on the pear-shaped hole column, zygomatic strut, pterygopalatine suture, and other structures that provided greater resistance to palatine bone expansion. Compared with other MARPE implants, it can realize the parallel opening of the midpalatal suture in the sagittal direction and effectively expand the entire maxillary complex[8,21,22]. However, there is little research available on the palatal bone thickness in the MSE implantation area in patients with skeletal class II malocclusion.

The bone thickness of the palate depends on age, gender, skeletal types, and other factors. Ryu et al. (2012) made a comparative study on the bone thickness of the palatal region in patients with early, late mixed, and early permanent dentitions[23]. The results showed significantly thinner palatal bone in the early mixed dentition group than in the late mixed dentition group and permanent dentition group. Kang [24] demonstrated statistically significant differences between males and females in some areas on both sides of the midpalatal suture area, and the palatal bones of males were thicker than those of females. Piyoros et.al. [25] used CBCT to evaluation the palatal bone thickness in patients with normal and open vertical skeletal configurations. He found that the palatal bone thickness was lower at almost all sites in patients with open bite. In these studies, the bone thickness of palatal bone was analyzed from front to back with incisive foramina as the center[23-25]. The results indicated sufficient bone mass and good bone quality in the anterior region of the palatal bone, which was suitable for screw implanting. However, the measurement range of palatal bone often could not completely cover the MSE implantation area, and the specific type of adult skeletal class II malocclusion was not studied. Therefore, it is suggested to
further study the characteristics of palatal bone thickness distribution, especially in the MSE implantation area in patients with skeletal class III malocclusion.

Two-dimensional X-ray images often fail to accurately verify three-dimensional information due to some inherent defects such as magnification and distortion. The research showed that the accuracy and reliability of cone-beam computed tomography (CBCT) were proved for linear measurement, and the results obtained by using CBCT images to measure the palatal bone structure have been validated[26,27]. Hence, in the current study, the palatal bone thickness of patients with skeletal class III malocclusion was measured quantitatively using CBCT, and the difference of palatal bone thickness between two different malocclusion types was compared, based on which, the suitable implantation site of micro-implants was explored, that offered theoretical guidance for clinical implant anchorage implantation of patients with skeletal class III malocclusion.

**Methods**

**Patients**

All procedures performed in studies involving human participants were approved by the Research Ethics Committee of Shandong University Dental School (Protocol N0.20201204) and were in accordance with the Declaration of Helsinki for research involving human subjects. The study was explained, and written informed consent was obtained from the inpatients. Eighty adult patients in the orthodontic department of Shandong University Dental School admitted from 2017 to 2020 were selected, and CBCT data of the maxillofacial region were collected. Inclusion criteria were as follows:

1. Patients with skeletal age of spine at CS5 or CS6 stage,

2. Patients with permanent dentition and no dentition defect (excluding third molars),

3. Patients with normal angle. The Frankfort-mandibular plane angle (FMA) between the Frankfort horizontal plane and the mandibular plane was measured on lateral cephalogram (Fig. 2), and the selection criterion was $22^\circ \leq \text{FMA} \leq 32^\circ$,

4. After CBCT scanning and clinical examination, there were no serious craniofacial deformity and cleft lip and palate deformity, and impacted teeth, supernumerary teeth, and jaw cyst in the measurement area,

5. Patients without a history of orthodontic treatment, and

6. Patients without systemic diseases and other factors affecting bone metabolism,

All the patients were well informed about the study.

The lateral cephalogram confirmed the sagittal bone face type (Fig. 2). According to Steiner analysis, 80 patients were divided into a skeletal class II malocclusion group (ANB=10.7°) and skeletal III malocclusion
group (0.7° ≤ ANB ≤ 4.7°), with 40 patients in each group. The mean and standard deviation of ages of the class III malocclusion group and malocclusion group were 20.55 ± 3.81 years and 22.42 ± 4.58 years, respectively. To exclude the influence of gender factors, there was an equal number of males and females in each group.

**CBCT scanning condition**

All the patients received CBCT before orthodontic treatment [(NewTom 5G, QR srl, Verona, Italy) Layer thickness: 0.3 mm; parameters: 110 kV, 5 mA]. During scanning, the patients maintained the maximum occlusal contact, and their lips and tongues were relaxed without swallowing. CBCT data of patients were output in Digital Imaging and Communications in Medicine (DICOM) format and imported into Materialise Interactive Medical Image Control System (MIMICS, Version 21.0; Leuven, Belgium) software, the mask was established, and the three-dimensional model was reconstructed and then measured.

**Analytical method and content**

Following reference planes were set up in the palate (Fig. 3):

(1) Midsagittal plane (MSP): the plane passing through the anterior nasal spine (ANS), posterior nasal spine (PNS), and nasion (N),

(2) Axial palatal plane (APP): the plane passing through ANS and PNS and perpendicular to the midsagittal plane,

(3) Vertical plane (VP): The point passing through the midsagittal plane and located at the transverse palatine suture is defined as the origin point, and the plane passing through the origin point is perpendicular to both the midsagittal plane and the axial palatal plane.

As shown in Fig. 4, Coronal planes Y0, Y3, Y6, Y9, Y12, and Y15 parallel to VP were created at 0.0 mm, 3.0 mm, 6.0 mm, 9.0 mm, 12.0 mm, and 15.0 mm before the origin. And planes Y-3, Y-6, and Y-9 parallel to VP were created at 3.0 mm, 6.0 mm, and 9.0 mm behind the origin. Sagittal planes X0, X3, and X6 parallel to MSP were created at 0.0 mm, 3.0 mm, and 6.0 mm on the left and right sides of the origin. Palatal bone thickness at the junction of each plane was measured, and 45 sites were measured.

The measurement items were divided into groups and X0 was defined as Midline area, X3 was defined as Medial area, and X6 was defined as Lateral area. Similarly, there were three regions in the sagittal direction: Y9, Y12, and Y15 were defined as an anterior area, Y0, Y3, and Y6 were defined as the middle area, and Y-3, Y-6, and Y-9 were defined as posterior area.

**Statistical analysis**
All measurement items were completed by a clinician familiar with the use of MIMICS software. Two weeks later, 20 patients were randomly selected, and repeated measurements were conducted by the same clinician. SPSS version 22.0 software was used for statistical analyses. The intraclass correlation coefficients were calculated.

The difference of bone thickness at the same measurement site between patients with skeletal class II malocclusion and skeletal class III malocclusion was determined by independent sample T-test (the data were normally distributed and showed homogeneous variance) or Wilcoxon rank-sum test (The data did not conform to normal distribution or exhibited heterogeneity of variance). The bone thickness of different regions of the palate in patients with same malocclusion was analyzed by one-way analysis of variance (ANOVA) and compared by the LSD-t method. $P < 0.05$ indicates that the difference is statistically significant.

Results

The intraclass correlation coefficients for all measurements were greater than 0.9, indicating sufficient reliability. And the measurement results revealed no statistical difference in bone thickness measured with respect to MSP symmetrical plane ($P > 0.05$), so the data of the left and right sides were averaged for subsequent calculation.

Palatal Bone thickness in different regions in the two groups

As shown in Tables 1 and 2, the palatal bone thickness of patients with skeletal class II malocclusion and patients with class III malocclusion showed the same trend almost. In the sagittal direction (Fig. 5), the thickness of palatal bone decreased gradually from front to back in the medial and lateral areas in both groups ($P < 0.001$). In the midline area, the bone thickness of class II patients increased initially and then decreased from anterior to posterior ($P < 0.001$), but there was no statistically in anterior, middle, and posterior regions of class III malocclusion patients ($P > 0.05$). In the coronal direction, the bone thickness of the anterior, middle, and posterior regions of the two groups showed a gradual decrease from the midline area to the medial area to the lateral area and the LSD t-test showed significant difference in any two areas of the the midline area, the medial area, and the lateral area ($P < 0.001$). The bone thickness of the middle area was the largest. It shows a decrease in bone thickness from the center to both sides in all nine coronal planes in Fig. 6.
Table 1
Palatal bone thickness in patients with skeletal II malocclusion (mm, x±s)

|        | Midline | Medial | Lateral | F    | P     |
|--------|---------|--------|---------|------|-------|
| Anterior| 6.19±1.84 | 4.41±1.56 | 3.90±1.74 | 58.07 | P<0.001 |
| Middle | 6.75±2.19  | 3.11±1.12  | 2.09±1.00  | 306.02 | P<0.001 |
| Posterior| 6.29±1.79 | 2.16±1.02 | 1.00±0.63 | 599.08 | P<0.001 |
| F      | 2.76      | 97.11   | 173.4    |       |       |
| P      | P<0.05    | P<0.001 | P<0.001  |       |       |

Table 2
Palatal bone thickness in patients with skeletal III malocclusion (mm, x±s)

|        | Midline | Medial | Lateral | F    | P     |
|--------|---------|--------|---------|------|-------|
| Anterior| 6.69±1.76 | 4.98±1.98 | 4.22±2.09 | 49.877 | P<0.001 |
| Middle | 7.73±1.76  | 3.91±1.42  | 2.43±1.18  | 414.005 | P<0.001 |
| Posterior| 6.63±1.87 | 2.70±1.15 | 1.25±0.55 | 544.513 | P<0.001 |
| F      | 14.11     | 64.01   | 132.7    |       |       |
| P      | P<0.001   | P<0.001 | P<0.001  |       |       |

Palatal bone thickness difference between the two groups

The difference of palatal bone thickness between patients with skeletal class II malocclusion and skeletal class III malocclusion at the same measurement site is shown in Table 3. In the midline area, the palatal bone of patients with skeletal class III malocclusion was thinner than that of patients with skeletal class I malocclusion on three measuring planes (Y3, Y6, and Y9), and the results were found statistically insignificant (P< 0.05). In the medial area, the palatal bone of patients with skeletal class III malocclusion in seven planes (from Y-9 to Y9) was comparatively thinner (P< 0.05). In the lateral area, the palatal bone in patients with skeletal class III malocclusion was relatively thicker on Y-3, Y-6, and Y-9 planes (P< 0.05). The palatal bone thickness and regions with significant differences between the two groups were marked with different colors (Fig. 7).
Table 3
Comparison of the differences between the two groups (mm, x±s)

| Class 1   | Class 2   | Difference (mm) | P     |
|-----------|-----------|-----------------|-------|
| Midline   |           |                 |       |
| Y15       | 6.55±1.91 | 7.09±1.87       | -0.53±0.43 | 0.217 |
| Y12       | 6.02±1.67 | 6.41±1.73       | -0.39±0.39 | 0.316 |
| Y9        | 6.00±1.91 | 6.59±1.64       | -0.58±0.40 | 0.047* |
| Y6        | 6.41±2.04 | 7.38±1.74       | -0.96±0.42 | 0.026* |
| Y3        | 6.83±2.27 | 7.96±1.79       | -1.13±0.46 | 0.015* |
| Y0        | 7.00±2.28 | 7.85±1.73       | -0.85±0.45 | 0.064 |
| Y-3       | 7.04±1.94 | 7.35±1.73       | -0.31±0.41 | 0.452 |
| Y-6       | 6.44±1.55 | 6.75±1.89       | -0.31±0.39 | 0.425 |
| Y-9       | 5.37±1.46 | 5.79±1.69       | -0.42±0.36 | 0.239 |
| Medial    |           |                 |       |
| Y15       | 5.47±1.63 | 5.85±2.30       | -0.38±0.45 | 0.404 |
| Y12       | 4.16±1.25 | 4.75±1.73       | -0.59±0.34 | 0.087 |
| Y9        | 3.62±1.16 | 4.34±1.56       | -0.72±0.31 | 0.022* |
| Y6        | 3.40±1.17 | 4.15±1.45       | -0.76±0.30 | 0.012* |
| Y3        | 3.19±1.08 | 4.03±1.41       | -0.83±0.28 | 0.004**|
| Y0        | 2.75±1.02 | 3.56±1.37       | -0.81±0.27 | 0.004**|
| Y-3       | 2.67±1.04 | 3.40±1.20       | -0.73±0.25 | 0.005**|
| Y-6       | 2.19±0.98 | 2.71±1.01       | -0.53±0.22 | 0.021* |
| Y-9       | 1.62±0.74 | 1.99±0.75       | -0.37±0.17 | 0.029* |
| Lateral   |           |                 |       |
| Y15       | 5.19±1.78 | 5.42±2.38       | -0.23±0.48 | 0.624 |
| Y12       | 3.58±1.36 | 3.99±1.76       | -0.41±0.36 | 0.251 |
| Y9        | 2.94±1.23 | 3.28±1.48       | -0.34±0.30 | 0.267 |
| Y6        | 2.41±1.08 | 2.81±1.34       | -0.40±0.27 | 0.146 |
| Y3        | 2.10±0.99 | 2.45±1.10       | -0.35±0.23 | 0.141 |
| Y0        | 1.76±0.82 | 2.04±0.97       | -0.28±0.20 | 0.166 |
| Y-3       | 1.24±0.65 | 1.62±0.65       | -0.37±0.14 | 0.012* |
| Y-6       | 0.97±0.52 | 1.11±0.38       | -0.14±0.10 | 0.040* |
The proportion of different palatal bone thickness in the common MSE implantation area

The mid-posterior palatal region of patients with skeletal class II malocclusion is a common area for MSE implantation. The measured values of bone thickness in the middle and back palatal region and the palatal region were also evaluated. The proportions of different thickness values in each region are shown in fig. 8. Among them, the proportion of palatal bone thickness less than 1.0 mm in the posterior region of the medial area, the middle region of the lateral area, and the posterior region of the lateral area were 6%, 12%, and 62%, respectively.

Discussion

There is close relationship between the morphology of palate and the growth and development of cranial-maxillary complex. Studies have shown that midpalatal suture is one of the important ways in maxillary growth. The development of the palate is done mainly by absorbing the old bone at the bottom of the nasal cavity and increasing the deposition of new bone tissue on the inner surface of the mouth [28]. This study showed differences in the thickness of palatal bone between patients with skeletal class II malocclusion and skeletal I malocclusion, and the palatal bone of the former was thinner. The statistical differences in palatal bone thickness in the same part of adolescent patients with different sagittal facial types, which might be attributed to the influence of palatal growth and development on maxillary growth and development. Most patients with skeletal class II malocclusion have maxillary hypoplasia, which may affect the thickness of palatal bone. Resultantly, the palatal bone in some areas is thinner in patients with class II malocclusion.

The anchorage screw of MSE is usually implanted 1.0-2.0 mm away before the junction of the soft and hard palate, and the rear two screws is located in the horizontal plate of palatine bone behind the transverse palatine suture, which can make the arch expansion force closer to the wing plate and other structures that provide greater resistance to palatal bone expansion which is more conducive to the parallel opening of the maxilla[22]. The results of this measurement demonstrated that the average thickness of palatal bone of patients with class II malocclusion was smaller at each measurement site. There were statistical differences noticed in area 9.0 mm before the transverse palatine suture in the midline area, 9.0 mm before and after the transverse palatine suture in the medial area, and in 9.0 mm after the transverse palatine suture in the lateral area (P< 0.05). This suggests that when implant anchorage was implanted in these areas, the available bone was thinner in patients with class II malocclusion. Ichinohe et al.(2007) highlighted that the thickness of the bone cortex in the group with a
higher success rate of anchorage screw was significantly higher than that in the group with a lower success rate, especially in the part where the thickness of anchorage screw was less than 1.0 mm, and the failure rate was 6.93 times higher than that of bone cortex[29]. Palatal bone thickness decreased gradually from front to back in the parapalatal and palatal areas. As shown in Fig. 6, that palatal bone thickness was more than 1.0 mm in the middle region of the medial area, and palatal bone thickness was less than 1.0 mm in 6% of sites in the posterior region of the medial area, and the proportion of palatal bone thickness less than 1.0 mm in the lateral area from the middle region to the posterior region increased from 12% to 62%. Considering the expansion force of MSE up to 5.9 kg, the implant anchorage needs to bear greater force, and the possibility of loosening of implant anchorage is greater when the thickness of palatal bone is insufficient. The implant site of MSE screws in patients with class Ⅲ malocclusion may need to move forward suitably compared with patients with skeletal malocclusion.

This study showed that the thickness of palatal bone in the same coronal plane declined gradually from the middle to the sides. The palatal bone thickness in the midline area was the largest and the average value in the front, middle and back midpalatal suture was greater than 6.0 mm. Previous studies have also shown that the thickness of palatal suture in the middle and posterior palatal region in adult patients is larger than that within 6.0 mm on both sides [24,30,31]. However, Ichinohe et al. showed that the success rate of implanting screws in the group with a long distance from the midpalatal suture (1.5-2.7 mm) was significantly higher than that in the group with a distance of 0–1.4 mm. This may be associated with the presence of defective calcified areas in the midpalatal suture area[29]. Hence, the bilateral screws of MSE should be implanted symmetrically as far as possible, so that the bilateral implant anchorage is located in the medial area (the distance between MSE left and right nail holes were about 5.0-6.0 mm). Also, no significant difference was documented before, during, and after the midpalatal suture in patients with class Ⅲ malocclusion. This finding contradicts finding by from Poon's finding that the thickness of palatal bone gradually increased from front to back in the midpalatal suture area[29], which may be related to the fact that other studies took the incisive foramina as the origin, and this study divided the region with the transverse midpalatal suture as the center.

The miniscrew of MSE is 1.5 mm×11.0 mm in size. In theory, the length of anchorage minicrew includes 2.0 mm thickness of nail hole, 1.0-2.0 mm clearance between arch reamer and palatal mucosa, 1.0-2.0 mm thickness of palatal mucosa, and 5.0-6.0 mm thickness used for double-layer cortical bone binding. This study showed that for patients with skeletal class Ⅲ malocclusion, the thickness of palatine bone in the middle and posterior regions of medial area and lateral area was less than 4.0 mm; and the 11.0 mm screw was enough to penetrate the double cortical bone. However, thin palatine bone in the middle and rear parts also increased the risk of penetration of implant anchorage into nasal mucosa and could even penetrate the inferior turbinate (Fig.1 d), causing discomfort to patients, and even causing local infection and affecting the implant stability of screws. Therefore, the size of the MSE screw, especially the length of the rear two-implant screws, should be designed more accurately and individually according to the palatal bone shape and implant direction, and short implant anchorage should be considered for implantation when necessary[32].
Limitations:

In this study, patients with a normal angle were selected, and there were some limitations in the sampling. The influence of different vertical facial types on palatal bone thickness needs to be further explored.

Conclusion

Overall, this study showed that in the common MSE implantation area, the palatal bone of adult patients with class II malocclusion is thinner, and the minisrew implant of MSE is at higher risk, so the implant anchorage position can be moved forward appropriately. Minisrew with a length of 11.0 mm increases the risk of penetrating the nasal mucosa and even the inferior turbinate. It is suggested to treat patients with skeletal class II malocclusion with a more precise and personalized implantation scheme considering factors such as palatal bone thickness and palatal morphology. Though bicortical micro-implant anchorage could improve the stability of micro-implants and reduce the deformation and fracture of micro-implant, more clinical data are needed to support the influence of different palatal bone thickness on the stability of minisrew.

Abbreviations

CBCT: Cone-beam computed tomography; MTD: Maxillary transverse deficiency; SARME: Surgically assisted rapid maxillary expansion; MARPE: Miniscrew-assisted maxillary palatal expansion; MSE: Maxillary Skeletal Expander; MSP: Midsagittal plane; APP: Axial palatal plane; VP: Vertical plane

Declarations

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Authors’ contributions

CWT searched and reviewed the literature, analyzed the data, and wrote the manuscript. ZKL collected and analyzed the data, and assisted in editing the original manuscript. LDX designed the study, critically reviewed the manuscript and supervised the whole study process. All authors have read and approved the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

All procedures performed in studies involving human participants were approved by the Research Ethics Committee of Shandong University Dental School (Protocol NO.20201204) and were in accordance with the Declaration of Helsinki for research involving human subjects. The study was explained, and written informed consent was obtained from the inpatients.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures
Figure 1

Clinical application of Maxillary Skeletal Expander (MSE). a: Intraoral photo before the maxillary expansion treatment; b: Intraoral photo two weeks after the maxillary expansion treatment; c: The CBCT image shows the opening of the midpalatal suture. d: Relationship between miniscrews and adjacent tissues
Figure 2

Schematic diagram of cephalometric measurement. FMA: The angle formed by FH (Frankfort horizontal plane) and MP (mandibular plane); ANB: The angle formed by point N (nasion) and point A (subspinale) and point B (supramental)
Figure 3

Palatal reference planes established in Mimics software.

Figure 4
Reference planes for measuring palatal bone thickness.

Figure 5

Palatal bone thickness changes in the anterior, middle and posterior regions. **Significance of the effect of the anteroposterior position (P<0.01)
Figure 6

Palatal bone thickness in nine coronal planes.
Figure 7

Mean palatal bone thickness maps of a, class I malocclusion and b, class II malocclusion. * Sites have significant differences between the two groups.

Figure 8

The proportion of different palatal bone thickness. a: middle region in medial area; b: posterior region in medial area; c: middle region in lateral area; d: posterior region in lateral area.