Skeletal effects of monocortical and bicortical mini-implant anchorage on maxillary expansion using cone-beam computed tomography in young adults

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Introduction: This study aimed to evaluate and compare the skeletal effects of monocortical and bicortical mini-implant anchorage on maxillary skeletal expansion (MSE) using cone-beam computed tomography in young adults. **Methods:** The sample comprised 48 patients (aged 19.4 $\pm$ 3.3 years; 19 male, 29 female) treated with maxillary skeletal expander and was divided into 3 groups according to insertion pattern of mini-implants used. G1, 4-all-bicortical penetration (n = 17); G2, 2-rear-bicortical penetration (n = 17); G3, non-4-bicortical penetration (n = 14). Cone-beam computed tomography scans were taken before treatment and 3 months after activation. **Results:** The transverse width of maxilla, nasal bone, lateral pterygoid plate, zygomatic bone, and temporal bone increased similarly in G1 and G2. Contrarily, G3 produced less skeletal expansion, having no effects on the temporal bone. Significant increases in width were seen in all 3 groups regarding transverse dentolinear measurements. A triangular expansion pattern was also observed, but G1 and G2 showed more parallel expansion than G3. In addition, G1 and G2 showed less inclination of anchorage teeth compared with G3. The loss of vertical alveolar bone, although only in a small amount, was observed in all groups. **Conclusions:** MSE with non-4-bicortical penetration produced fewer orthopedic effects and more unwanted dentoalveolar side effects, whereas MSE with 2-rear-bicortical and 4-all-bicortical penetration showed similar skeletal effects, which means that 2-rear-bicortical penetrating mini-implants were critical to skeletal expansion. (Am J Orthod Dentofacial Orthop 2020;157:651-61)

Transverse maxillary deficiency is a relatively common orthodontic problem,[1-4] which has been reported to affect 7.9% and 9.9% of individuals aged 12-18 and 18-50 years,[1] respectively. The condition is often accompanied by crowding, mandible deviation, and unilateral or bilateral posterior crossbite, which cannot be self-corrected.[4] Rapid maxillary expansion (RME) is a common and reliable treatment method to correct transverse maxillary deficiencies for prepubertal and adolescent patients,[5] which has a significantly favorable effect on the sagittal occlusal relationships of Class II and III and improves nasal respiration by increasing nasal cavity volume and reducing nasal resistances.[6-8] However, conventional RME transmits the expansion forces through the teeth, producing some unwanted results such as root resorption, alveolar bone bending, dental tipping, alveolar bone loss, gingival recession, and clockwise rotation of the mandible.[6,9,10] RME in nongrowing patients has been shown to produce limited skeletal expansion effects because of interdigitation of the midpalatal suture and adjacent articulations.[11,12]

Consequently, surgically assisted RME (SARME) is designed to be used for older patients by releasing the closed sutures resisting expansion force, which increases skeletal expansion efficiency and reduces the side effects mentioned earlier.[13-15] However, SARME has higher biological and financial costs. Most patients are reluctant to undergo surgical procedures.[16] In addition, SARME inevitably results in

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tipping of the anchorage teeth, periodontal damage, and higher recurrence.[17,18]

Mini-implant–assisted RME (MARME) has been designed to correct transverse maxillary deficiency in adults based on previous findings that the proportion of ossified tissue in the entire skeletal suture was low in all subjects.[19,20] Some studies[10,21] have shown that MARME can achieve effective expansion of the maxillary base bone. Lin et al[10] concluded that MARME produced more orthopedic effects and fewer dentoalveolar side effects compared with conventional RME in late adolescents. Choi et al[21] reported that MARME could be a clinically acceptable and stable treatment modality.

There are variable designs for MARME, such as C-expander used by Lin et al,[10] MARME by Lee et al,[19] and maxillary skeletal expansion (MSE) invented by Moon et al.[22] In addition, different investigators have different choices of depth for the placement of the mini-implants. Lee et al[23] used 7-mm mini-implants to penetrate palatal cortical bone only. Moon et al[24-26] recommended using bicortical mini-implant anchorage to achieve greater orthopedic effects and more parallel expansion in the coronal plane. Other studies did not indicate whether the mini-implant penetrated the monocortical or the bicortical bone.[27] However, bicortical penetrating miniscrew will traumatize the mucosa of the nasal floor, inevitably based on anatomical and physiological principles. We also found that bicortical engagement of the mini-implants resulted in nasal discomfort in many patients. Furthermore, some scholars observed that the mini-implant with monocortical engagement could also achieve the expected skeletal efficiency.[19,23]

Therefore, we wanted to explore whether it is necessary to guarantee bicortical engagement to achieve a similar expansion. No clinical research on comparing the effects of bicortical and monocortical anchorage during MARME has been found. Our objectives in this study were to evaluate and compare the skeletal effects of monocortical and bicortical mini-implant anchorage on maxillary expansion in young adults using cone-beam computed tomography (CBCT), to provide more evidence for the clinician to choose an appropriate expansion strategy with lower biological and financial costs and larger wanted effects.

MATERIAL AND METHODS

This retrospective study approved by the Ethical Commission of Stomatology Hospital of Shandong University included 82 consecutive young adults (34 male, 48 female) with transverse maxillary deficiencies, who received MARME from 2017 to 2018 at the Department of Orthodontics, Stomatology Hospital of Shandong University. An informed consent form was signed by each patient. The inclusion criteria for this study were as follows: (1) >15 years old; (2) maxillomandibular skeletal transverse discrepancy of 3 mm or more (Fig 1); (3) no history of expansion treatment or orthognathic surgery; and (4) no severe dentofacial anomalies such as a cleft lip or palate.

Thirty-four patients were excluded because of various reasons. Seven patients stopped treatment because of swelling of palatal mucosa or intolerance to MSE, 14 patients did not take CBCT scans 3 months after activation under consistent shooting condition, and 13 patients had CBCT scans showing only 1 or 3 mini-implants penetrating bicortical bone, or 2 unilateral mini-implants penetrating bicortical bone. Eventually, there were 48 patients (aged 19.4 ± 3.3 years; 20 males and 28 females) who fulfilled the inclusion criteria and were enrolled in the study (Fig 2).

The 48 patients were divided into 3 groups according to the insertion patterns of the mini-implants used, as shown by CBCT scans. The groups were as follows: (1) G1 (4-all-bicortical penetration; n = 17; aged 19.5 ± 3.1 years), 4 mini-implants were applied by penetrating the palatal and nasal cortical bone (Fig 3, *A*); (2) G2 (2-rear-bicortical penetration; n = 17; aged 19.2 ± 3.5 years), 2 posterior mini-implants were applied by penetrating the bilateral cortical bone, 2 anterior mini-implants were applied by penetrating the palatal cortical bone only (Fig 3, *B*); (3) G3 (non-4-bicortical penetration; n = 14; aged 19.6 ± 3.5 years) received 4 mini-implants penetrating the palatal cortical bone only (Fig 3, *C*).

Each patient was treated by MSE type II (BioMaterials Korea, Seoul, South Korea), developed by Dr Won Moon et al at the University of California, Los Angeles,[22] with 2 stainless steel arms soldered to the dental alloy casting crowns on the maxillary first molars. The jackscrew was generally oriented on the palatal region at maxillary first molars. The alloy casting crowns of the expander were bonded to the maxillary first molars, and 4 mini-implants (diameter, 1.5 mm; length, 11 mm; Mplant Series, BioMaterials Korea) were inserted along guided slots under local infiltration anesthesia. The heads of the mini-implants were then attached to the jackscrew with flow resin (3M Unitek Transbond; St Paul, MN) to minimize irritation of the tongue and increase the postinsertion stability of the mini-implants (Fig 4). The jackscrew was activated one-sixth of a turn (0.13 mm) each day until the maxillary skeletal width was no

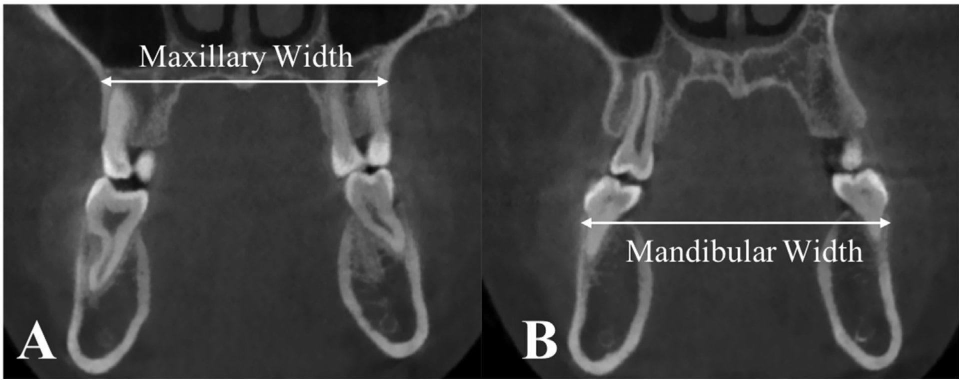

Fig 1. Maxillary width indicates the distance between the most concave points of the maxillary vestibule at the mesial buccal cusp level of the first molars. Mandibular width was the distance between the right and left buccal cortex at the level of 1 mm below the pulp floor and the mesiobuccal groove of the first molars. When the maxillomandibular skeletal transverse discrepancy is 3 mm or greater, the patients would be advised to undergo expansion.

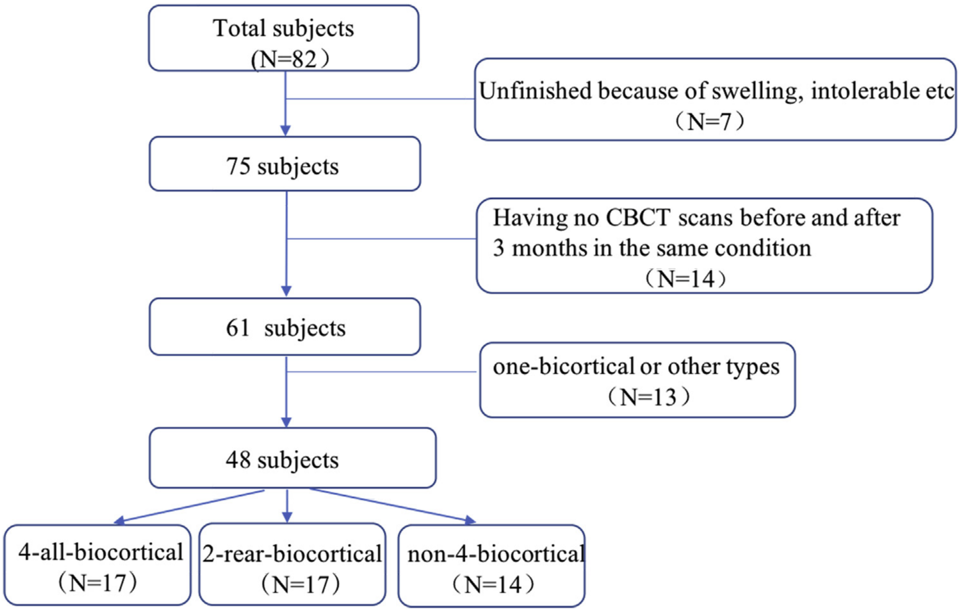

Fig 2. Study flow chart.

longer less than that of the mandible. The postactivation retention duration was 3 months, allowing bone formation in the separated maxillary suture.

CBCT scans (5G; NewTom, Verona, Italy) were obtained before treatment and 3 months after activation. The CBCT device was set at 7.33 mA and 110 kV, and images were acquired for 4.8 seconds, with an 18 × 16-cm field of view and a standard voxel size of 0.3 mm. The obtained data were analyzed by Dolphin (Dolphin Imaging, Chatsworth, Calif). First, the CBCT images were oriented along the palatal suture, tangent to the nasal floor and parallel to the palatal plane (Fig 5). The measured coronal images were then produced by the coronal line that was positioned at the center of the palatal root canal in the most apical region of the maxillary first molars on the right and left sides (choosing the midpoint if the left and right root canal were not at 1 coronal line; Fig 6), then the measurements were taken. The nasomaxillary dentoskeletal and periodontal measurements are shown in Figures 7 and 8. The width of the lateral pterygoid, zygomatic bone, and temporal bone are shown in Figure 9.

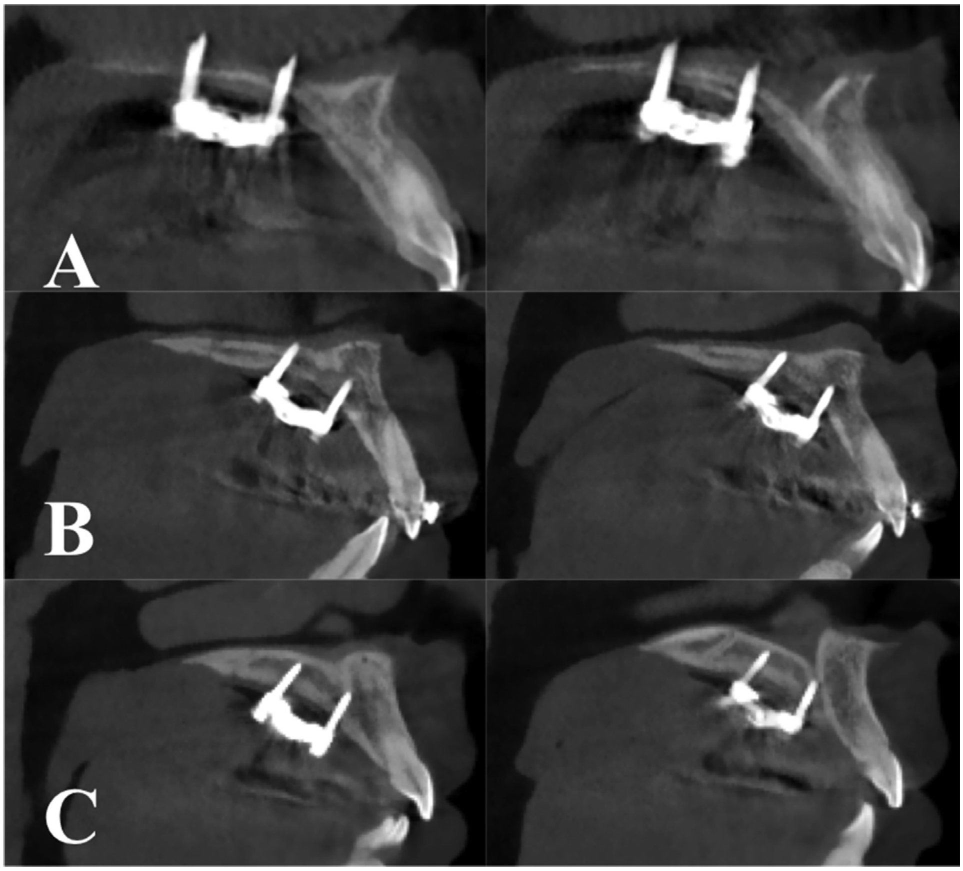

Fig 3. Four mini-implants penetrating the palatal and nasal cortical bone **(A)**, two posterior mini-implants penetrating bilateral cortical bone, and 2 anterior implants penetrating only the palatal cortical bone **(B)**, 4 implants penetrating only the palatal cortical bone **(C)**, Left picture: left side of the maxilla; right picture: right side of the maxilla.

Fig 4. Intraoral view of maxillary skeletal expander design used in the study.

Statistical analysis

For the assessment of method reliability, measurements of all variables on 8 randomly selected patients from each group were repeated after 2 weeks by the same investigator. Intraclass correlation coefficients were used to determine measurement consistency. The intraclass correlation coefficients ranged from 0.989 to 1.000, which showed repeated agreement regarding all measurements.

The normality of the data distribution was confirmed using the Shapiro-Wilk test. The homogeneity of group variance was assessed by the Levene test. A paired *t* test was performed for comparison before treatment and 3 months after activation in each group, and a 1-way analysis of variance and Scheffé post-hoc analysis were performed for comparison among 3 groups. Statistical analysis was performed using SPSS (version 22.0; IBM, Armonk, NY). P values <0.05 were considered statistically significant. The statistical power of considered parameters for the sample size and α of 0.05 was 100%, and the width at the central fossae of the first molars was 77%, which was acceptable. Moreover, the

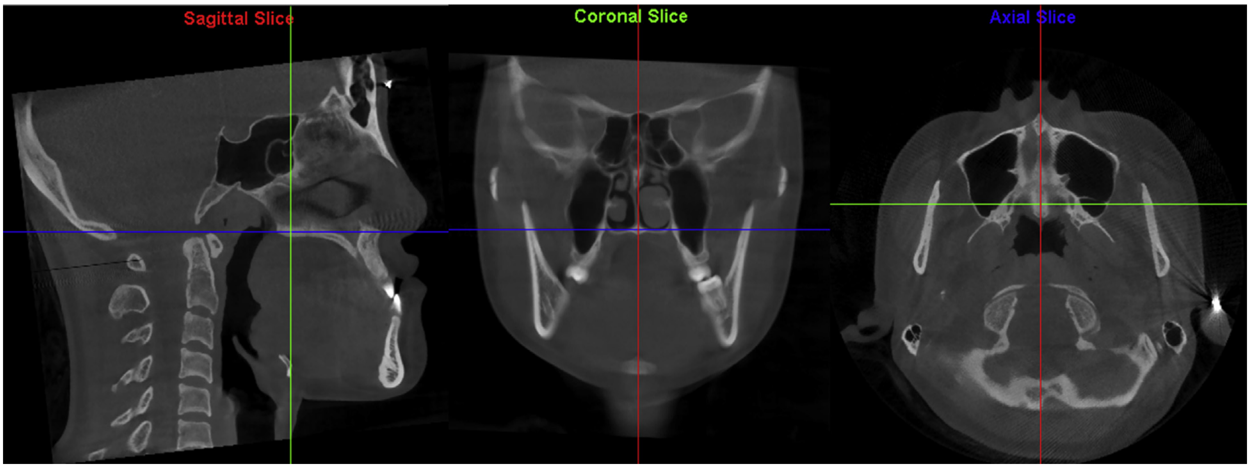

Fig 5. The orientation of the CBCT images.

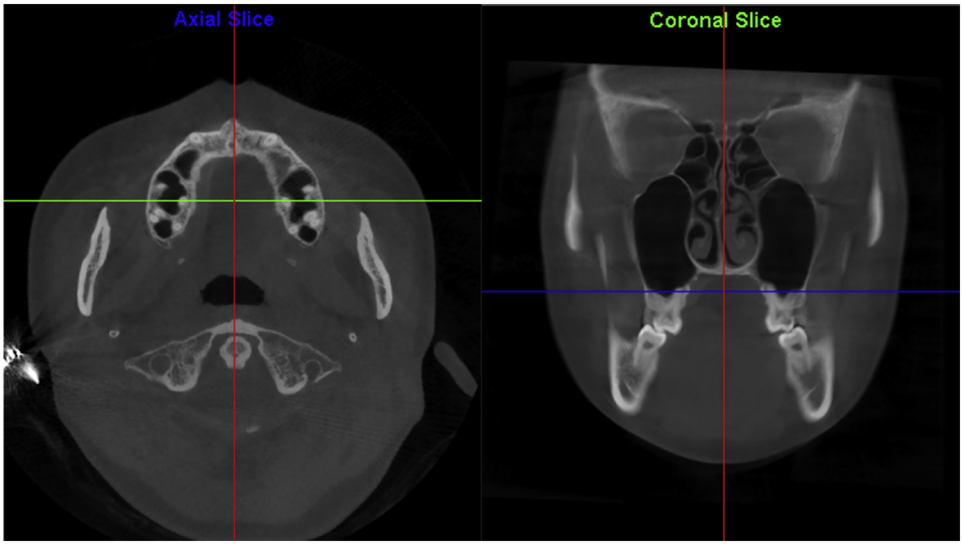

Fig 6. The measured coronal images.

jackscrew opening was 28%, whose mean value was extremely close.

RESULTS

There were no significant differences in the amount of activation of the MSE jackscrew or in the sex, age, and the interval of taking CBCT among the 3 groups, as shown in Table I.

G1, G2, and G3 showed significant increases in the width of the maxilla, nasal cavity (N-N), zygomatic bone (Z-Z), pterygoid plate (Lpt-Lpt), and temporal bone (T-T; $P < 0.05$; Table II), with the exception that G3 did not significantly affect the temporal bone after MSE ($P > 0.05$; Table II). In addition, the amount of maxillary expansion indicated a pyramidal pattern of expansion, with the least increase at NF5 and the greatest increase at HP5. G1 showed slightly greater increases in all the skeletal measurements compared with G2, although they were not statistically significant ($P > 0.05$; Table III). G3 showed fewer statistically significant increases than G1 and G2 ($P < 0.05$; Table III).

In G1, G2, and G3, the transverse dental width at the central fossae of the first molars, as well as the height of the buccal alveolar bone (Alh) changed significantly ($P < 0.05$; Table II), although there were no significant differences among the 3 groups ($P > 0.05$; Table II). Transverse dental expansion at the palatal root apices of the first molars and angular changes of the alveolus (Al) and tooth axes (Tor) were apparent in all 3 groups

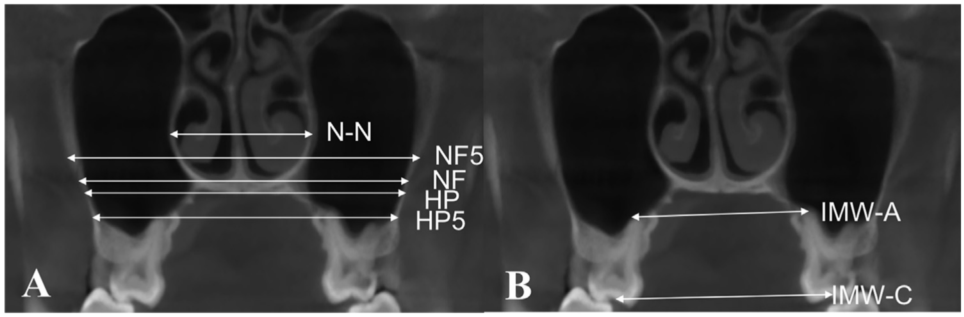

Fig 7. Definition of measurements. **A,** N-N indicates nasal width between the most lateral wall of the nasal cavity; NF5, maxillary width parallel to the line NF and 5 mm above the line NF; NF, maxillary width tangent to the nasal floor at its most inferior level; Hp, maxillary width parallel to the lower border of the computed tomography image and tangent to the hard palate; HP5, maxillary width parallel to the line NF and 5 mm below the line HP. **B,** IMW-A, intermolar width between the tooth apices measured on the palatal root of the first molars; IMW-C, intermolar width between the central fossae of the left and right maxillary first molars.

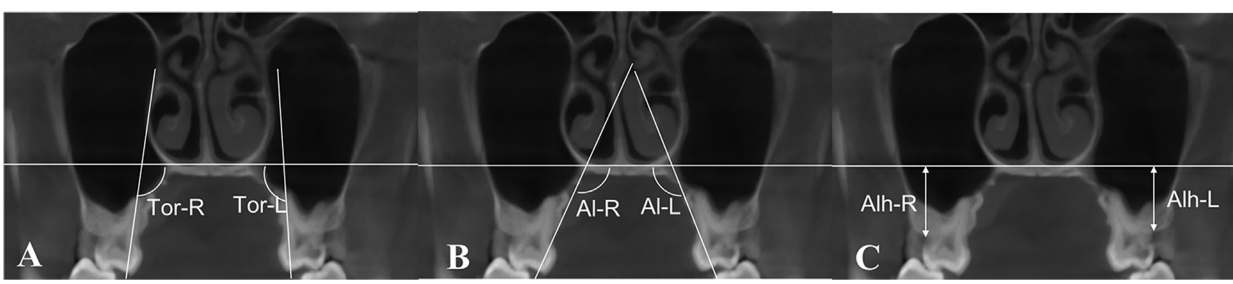

Fig 8. Definition of measurements. Alveolar bone inclination **(A)** indicates the angle between the palatal alveolar slope and NF. Tooth inclination **(B)** indicates the angle between the palatal root axis and NF. Alveolar bone loss **(C)** measured from the alveolar crest on the buccal side to the NF. *R*, right side; *L*, left side.

(P <0.05; Table II). G3 displayed fewer increases in the width at the tooth apices of the palatal root of the first molars and more buccal tipping of the alveolus and tooth axes than G1 and G2 (P <0.05; Table III).

DISCUSSION

Of the 82 consecutive young adults who received a MARME, 34 patients were excluded because of various reasons. Finally, 48 patients with a mean age of 19.4 ± 3.3 years (range, 15-26 years) were retrospectively recruited in this study. The interval between the first and second CBCT was 3.4-4.9 months. Because all the subjects were young adults, the growth and development were slow, and the interval of taking CBCT was very short. There was no need to use a control group without treatment because normal growth was not an influencing factor in this short interval.

For the maxillary transverse dimension, the amount of expansion at the skeletal level was great. Skeletal gain at the hard-palatal level in G1, G2, and G3 accounted for 68%, 62%, and 44%, respectively, of the dental crown expansion because of different kinds of cortical engagements. Previous studies reported that conventional tooth-borne expansion in young adults resulted in a less orthopedic effect, that is, approximately 18% of transmolar expansion at the height of the palate.[28,29] A minireview of Northway[30] concluded that expansion of the midpalatal suture area ranged from 20% to 50% of the total screw expansion. However, MSE in this study, which directly transmitted force to the maxilla, produced a greater orthopedic effect, in agreement with a related study on MARME.[10,23,27] Lin et al[10] concluded that the hyrax group showed a skeletal gain of 25.6%-42.9% of the dental crown expansion, whereas the implant-assisted C-expander group showed a skeletal gain of approximately 57.5%-77.0%, which was similar to G1 and G2 in the study even though the designs were different. The skeletal gain in G3

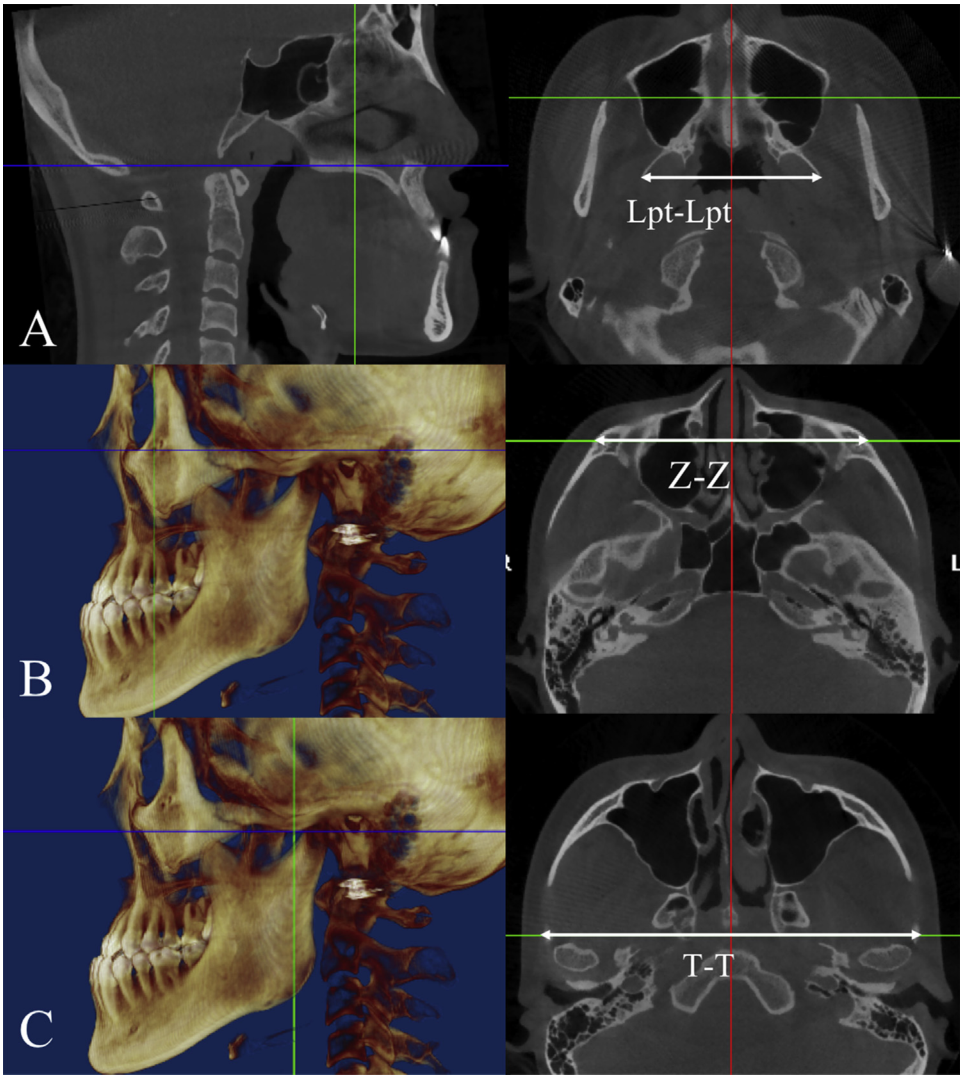

Fig 9. Definition of measurements. Lpt-Lpt **(A)** indicates the linear distance between the left and right lateral pterygoid plate measured at the axial slice crossing the palatal plane. Z-Z **(B)**, the linear distance between the foramina of the left and right zygomatic bone measured at the axial slice. T-T **(C)**, the linear distance between the left and right temporal bone measured at the axial slice crossing the inferior border of joint tubercle.

was significantly lower than that in G1 and G2, similar to the amount reported by Park et al.[23] This was probably because they used a shorter length of mini-implant, which only penetrated the palatal cortical bone, as shown in the x-ray in their study.

Transverse width in G2 at NF5, NF, HP, and HP5 was slightly less than that in G1, although there was no significant difference, which might indicate that the 2-rear-bicortical penetration produced similar effects on the maxilla as 4-all-bicortical penetration. However, the amount of expansion in G3 at NF5, NF, HP, and HP5 was significantly lower than that in G1 and G2. It could be inferred that for better skeletal expansion, mini-implants needed to penetrate the posterior bicortical bone at least. More surface contact area between cortical bone and mini-implant that has been shown to be a more significant contributor to mini-implant stability than cancellous bone allowed for more uniform force transfer; the bicortical model may experience more transverse displacement because the model's less bending leads to proportionate load distribution at the bone-implant interface.[25] In addition, it was found that only the 2 posterior mini-implants penetrating the bicortical bone were crucial for satisfactory maxillary

Table I. The distribution of the age, sex, and the interval of taking CBCT of the patients in 3 groups

Variables	*Group I*	*Group II*	*Group III*	P
Age, y				
Range	15.1-24.5	15.5-25.6	15.7-24.8	
Mean (SD)	19.5 (3.1)	19.2 (3.5)	19.6 (3.5)	NS
Sex				
Female	10	9	9	
Male	7	8	5	NS
Time, mo				
Range	3.4-5.0	3.5-4.9	3.4-4.9	
Mean (SD)	4.0 (0.5)	4.2 (0.5)	4.1 (0.5)	NS

NS, nonsignificant; *SD*, standard deviation.

expansion. Because the greatest resistance against suture opening was located in pterygopalatine sutures, the 2 posterior mini-implants are placed close to the pterygopalatine suture to overcome initial resistance adequately.[26]

The amount of expansion decreased from NF5 to M1W, indicating a pyramidal pattern of maxillary expansion in the 3 groups, which is consistent with previous research findings. However, the geometric shape varied depending on the different designs of expanders. In our study, the shape of the pyramidal pattern in G1 and G2 showed more parallel expansion than G3. In addition, G1, G2, and G3 with MSE showed a more parallel expansion pattern than did conventional rapid palatal expansion.[31,32] Compared with MARME, pyramidal expansion pattern in G1 and G2 was similar to that reported by Lin et al,[10] but more parallel than that reported by Park et al[23] and Mosleh et al.[33] However, the results of the comparison between G3 and other studies varied.

Meanwhile, intermolar distance augmentation at the crown was larger than jackscrew activation, as reported by Cantarella et al.[34] We believe that the rotational movement of the zygomaticomaxillary complex and molar tipping could explain the discrepancy.

The torque of anchorage teeth in G1, G2, and G3 was less notable than that in a study with conventional rapid palatal expansion reported by Lagravère et al[27] (8.42° right side and 8.83° left side). However, compared with Lin et al,[10] the torque of anchorage teeth and alveolar tipping was less in G1, similar in G2, and larger in G3. The torque of anchorage teeth in the study resulted from both alveolar tipping and dental tipping relative to the alveolar housing. As we know, the alveolar tipping was inevitable because of the outward rotation of maxilla. The augmentation of torque of anchorage teeth and alveolar tipping in G1 and G2 was minor (0.4°-1.5°), which was clinically negligible because of greater skeletal expansion. The ratio of dental tipping to alveolar bending was 1.4 and 1.3 in G1 and G2, respectively, which represented a negligible change of tooth axis in the alveolar housing during expansion. However, the amount of dental tipping was 2.3 times of alveolar bending in G3, which implied that there was significant buccal tipping of the first molars relative to alveolar housing.

Garrett et al[35] believed that the total dental expansion derived from skeletal expansion, alveolar bending, and tooth movement was 38%, 13%, and 49%, respectively. In our study, skeletal expansion accounted for a much greater proportion in G1 (68%) and G2 (62%), as well as a similar proportion in G3 (44%). Furthermore, Mohan et al[36] concluded that relapse of total expansion was almost primarily attributed to the lingual movement of the posterior teeth. Accordingly, we suppose that the MSE obtains long-term stability because of greater skeletal expansion, especially in G1 and G2.

Regarding width at the apex of the palatal root of the first molar, G1 and G2 (5.4 mm and 5.3 mm, respectively) showed greater expansion at the apex than G3 (3.6 mm). The increases of the width at the apex of the palatal root of the first molar in G1 and G2 was larger than that at NF5, which might imply that the apex moved laterally in the alveolar housing. Lin et al[10] thought that it was the rigidity of the appliance resisting the buccal tipping of the banded teeth that resulted in the lateral movement of the apex.

The tiny loss of vertical alveolar bone in G1, G2, and G3 observed in our study was consistent with a previous study with MARME.[23] It might have adverse effects on periodontal condition and might even cause gingival recession, which requires the attention of an attending clinician. We did not find a statistically significant difference among the 3 groups, although the inclination of the first molars in G3 was greater than that in G1 and G2. Overall, the reduction of the height of the buccal alveolar bone was related not only to the buccal inclination of anchorage teeth in the alveolar housing, but also to the overall buccal movement of the anchorage teeth and as described earlier, the thickness of the alveolar bone itself and even individual periodontal response difference.

Many studies have concluded that MARME could increase the width of the nasal cavity,[23,24] similar to our findings. Increased nasal cavity facilitate nasal ventilation and nasal breathing for patients with constricted airway and mouth breathing.[37,38]

Anatomically, the lateral pterygoid plate and the medial pterygoid plate, parts of the sphenoid bone, fuse at the anterior and upper directions and separate to form a pterygopalatine notch at the lower end, which connects with the palatine pyramidal process to form a

Table II. Descriptive statistics and dentoskeletal changes for the 3 groups

	Group 1			*Group 2*			*Group 3*		
Variables	*Pretreatment*	*Posttreatment*	P	*Pretreatment*	*Posttreatment*	P	*Pretreatment*	*Posttreatment*	P
N-N (mm)	31.5 ± 2.3	34.8 ± 2.7	0.000	31.8 ± 2.7	34.7 ± 2.6	0.000	32.6 ± 3.3	35.4 ± 3.4	0.000
NF5 (mm)	75.8 ± 7.4	79.2 ± 7.9	0.000	77.0 ± 6.5	80.5 ± 6.4	0.000	77.8 ± 7.8	79.6 ± 7.9	0.000
NF (mm)	68.5 ± 5.4	72.7 ± 6.2	0.000	68.4 ± 3.7	72.3 ± 3.9	0.000	70.1 ± 6.2	72.4 ± 6.4	0.000
HP (mm)	65.9 ± 4.9	70.5 ± 5.5	0.000	66.2 ± 3.9	70.5 ± 4.2	0.000	65.7 ± 5.6	68.8 ± 5.6	0.000
HP5 (mm)	62.1 ± 4.0	67.4 ± 4.7	0.000	62.8 ± 4.3	67.8 ± 4.8	0.000	62.5 ± 4.9	66.2 ± 5.0	0.000
IMW-C (mm)	46.2 ± 3.3	53.0 ± 3.8	0.000	48.9 ± 4.4	55.8 ± 4.9	0.000	47.5 ± 4.8	54.7 ± 4.2	0.000
IMW-A (mm)	34.3 ± 3.2	39.8 ± 3.8	0.002	35.5 ± 2.5	40.8 ± 3.0	0.000	36.2 ± 4.8	39.8 ± 4.7	0.000
Al-L (°)	110.0 ± 7.4	110.4 ± 7.3	0.001	111.0 ± 7.4	112.1 ± 7.5	0.000	108.8 ± 6.4	110.9 ± 6.5	0.000
Al-R (°)	110.9 ± 7.9	111.5 ± 7.9	0.000	112.6 ± 8.2	113.6 ± 8.0	0.000	106.8 ± 8.5	108.8 ± 8.5	0.000
Tor-L (°)	100.7 ± 7.4	101.3 ± 7.4	0.003	104.6 ± 9.0	105.9 ± 9.5	0.000	99.6 ± 6.6	104.2 ± 7.4	0.001
Tor-R (°)	103.5 ± 5.3	104.3 ± 5.1	0.000	105.0 ± 9.0	106.4 ± 9.2	0.000	100.3 ± 5.3	105.3 ± 6.2	0.000
Alh-L (mm)	13.4 ± 2.8	12.9 ± 2.8	0.000	12.6 ± 2.8	11.8 ± 2.9	0.000	14.2 ± 2.9	13.8 ± 3.0	0.000
Alh-R (mm)	56.1 ± 5.1	13.1 ± 2.6	0.000	12.4 ± 2.4	11.7 ± 2.4	0.000	14.3 ± 2.8	13.5 ± 2.7	0.000
Lpt-Lpt (mm)	56.4 ± 5.1	58.2 ± 4.7	0.000	58.4 ± 5.4	59.7 ± 5.3	0.000	55.8 ± 4.1	56.2 ± 4.0	0.000
Z-Z (mm)	102.3 ± 4.7	104.4 ± 4.8	0.000	101.7 ± 5.5	103.8 ± 5.7	0.000	104.0 ± 6.8	105.1 ± 6.8	0.000
T-T (mm)	119.6 ± 4.3	120.2 ± 4.3	0.000	120.0 ± 5.7	120.5 ± 5.8	0.000	121.9 ± 6.4	122.0 ± 6.3	0.125

Note. Values are mean (± standard deviation).
L, left; *R*, right.

Table III. Comparison of jackscrew, skeletal, and dental mean changes between the 3 groups

	Changes			P *values*			
Variables	*Group 1*	*Group 2*	*Group 3*	*Overall* P	*Group 1-2*	*Group 1-3*	*Group 2-3*
Jackscrew (mm)	6.0 ± 1.4	6.2 ± 1.2	6.2 ± 1.4	0.396	0.452	0.476	0.476
N-N (mm)	3.3 ± 1.1	3.0 ± 1.2	2.1 ± 1.0	0.005	0.463	0.002	0.011
NF5 (mm)	3.5 ± 1.3	3.3 ± 1.6	1.8 ± 0.8	0.001	0.721	0.001	0.002
NF (mm)	4.2 ± 1.2	4.0 ± 1.1	2.3 ± 1.1	0.000	0.605	0.000	0.000
HP (mm)	4.6 ± 1.2	4.3 ± 1.0	3.2 ± 1.1	0.002	0.758	0.001	0.003
HP5 (mm)	5.2 ± 1.2	5.0 ± 1.1	3.7 ± 1.2	0.002	0.709	0.001	0.003
IMW-C (mm)	6.8 ± 1.3	6.9 ± 1.1	7.2 ± 1.4	0.634	0.800	0.354	0.492
IMW-A (mm)	5.4 ± 0.9	5.3 ± 1.0	3.6 ± 1.3	0.000	0.975	0.000	0.000
Al-L (°)	0.4 ± 0.5	1.0 ± 0.8	2.1 ± 1.2	0.000	0.054	0.000	0.001
Al-R (°)	0.6 ± 0.6	1.1 ± 0.6	2.0 ± 1.3	0.000	0.133	0.000	0.003
Tor-L (°)	0.6 ± 0.5	1.3 ± 1.1	4.7 ± 3.9	0.000	0.373	0.000	0.000
Tor-R (°)	0.8 ± 0.9	1.4 ± 1.2	4.9 ± 3.3	0.000	0.379	0.000	0.000
Alh-L (mm)	−0.5 ± 0.5	−0.7 ± 0.6	−0.4 ± 0.9	0.359	0.336	0.633	0.167
Alh-R (mm)	−0.7 ± 0.5	−0.6 ± 0.3	−0.8 ± 0.4	0.136	0.931	0.128	0.073
Lpt-Lpt (mm)	1.7 ± 1.6	1.3 ± 0.3	0.3 ± 0.3	0.001	0.272	0.000	0.009
Z-Z (mm)	2.1 ± 0.8	2.0 ± 0.7	1.1 ± 0.9	0.002	0.781	0.001	0.003
T-T (mm)	0.6 ± 0.4	0.5 ± 0.4	0.2 ± 0.3	0.007	0.695	0.003	0.009
HP/IMW-C	0.68	0.62	0.44				
NF5/HP5	0.67	0.66	0.49				
IMW-C/jackscrew	1.13	1.11	1.16				
Tor/Al	1.4	1.3	2.3				

IMW-C, intermolar width between the central fossae of the left and right maxillary first molars; *IMW-A*, intermolar width between the tooth apices measured on the palatal root of the first molars; *L*, left; *R*, right.

pterygopalatine suture. Ghoneima et al[39] found that the pterygopalatine suture could not be split by the tooth-borne palatal expanders. Lagravère et al[27] reported that both the tooth-borne expander and the bone-borne expander did not result in significant increases of width between the lateral pterygoid plates. However, our study observed this increase in the width of the lateral pterygoid plate. Cantarella et al[40] also concluded that the maxillary skeletal expanders could tear the pterygopalatine suture. We speculate that the increase in the distance between the lateral pterygoid plates was due partly to the opening of the pterygopalatine suture by the skeletal expander.

Some clinical studies have reported that tooth-borne expanders produced negligible or very small lateral displacements of the zygomatic bone.[28,41] Conversely, in our study, MSE used in G1 and G2 significantly increased the interzygomatic distance by 2.1 mm and 2.0 mm, respectively, and jackscrew activation by 35.0% and 32.3%, respectively, which was less than the findings of Carlson et al[24] (72.3% of the jackscrew activation). As for G3, MSE with non-4-bicortical engagements produced lesser expansion (1.1 mm; 17.7% of jackscrew activation) compared with the results of Park et al[23] (0.8 mm; 11.9% jackscrew activation). Changes in interzygomatic distance may have unwanted impacts on the facial esthetics of patients, especially for patients with prominent cheekbones. Clinicians should consider patients' complaints about zygomatic bone and choose the most appropriate expansion method carefully.

The articular fossa is a part of the temporal bone. Our study also found that MSE in G1 and G2 could increase the transverse width of the temporal bone (0.6 mm, 0.5 mm) as well. It might mean the skeletal expander could increase the distance between the left and right articular fossa, which may be favorable to the position of the bilateral condyles relative to the articular fossa.

In the study, although we designed approximately the standard position of the jackscrew before it was sent to the processing plant, the final position of the jackscrew relative to maxilla in sagittal direction varies slightly because of the differences of hard palatal shape and other factors. This slight variation might have resulted in a different dentoskeletal effect. However, it is worth mentioning that although it seemed that the placement of implant engaging was more anterior in G2 and G3; G2 produced a similar expansion effect with G1, whereas G3 produced less skeletal expansion than G2 and G1. This finding might suggest that a small difference in the anterior and posterior position of implant engaging would not have a significant impact on the expansion effect. Additional studies are needed to investigate this further. Thirty-four patients were excluded from our study because of the limitation of its retrospective nature. However, the effect of MSE with the insertion pattern of mini-implants on the dentoskeletal effect is quite reasonable. Further longitudinal studies and prospective studies should be conducted.

CONCLUSIONS

MSE with 2-rear-bicortical penetration produced the same dentoskeletal effects as MSE with 4-all-bicortical penetration. However, MSE with non-4-bicortical mini-implants generates fewer skeletal effects and larger dentoalveolar side effects.

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