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Effects of bicortical anchorage on pterygopalatine suture opening with microimplant-assisted maxillary skeletal expansion

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Introduction: The objectives of this study were to evaluate the effects of bicortical engagement by microimplants with maxillary skeletal expanders on pterygopalatine sutures opening and to analyze the postexpansion skeletal changes associated with it. **Methods:** Eighteen subjects treated with maxillary skeletal expanders were examined for pterygopalatine suture openings. Eight subjects who showed no evidence of the suture opening were assigned to the nonsplit group (NG), whereas 10 subjects with opened sutures were assigned to the split group (SG). Preexpansion and postexpansion cone-beam computed tomography images were superimposed for each group, and the changes in the 2 groups were compared. Finally, cone-beam computed tomography volumes were reoriented along the axis of each microimplant to check the bicortical engagement of the 4 microimplants. **Results:** There was a significant correlation between the bicortical engagement of the orthodontic microimplants and the pterygopalatine suture opening ($P = 0.0003$). In the NG, the average amount of transverse expansion measured at the center of resistance of the maxillary first molars, anterior nasal spine, and posterior nasal spine (PNS) was 4.33 mm, 2.22 mm, and 1.58 mm, respectively, whereas the transverse expansion in the SG was 5.29 mm, 2.21 mm, and 2.46 mm, respectively. The magnitude of transverse expansion at PNS was significantly higher in the SG than in the NG ($P = 0.036$). The PNS also showed a significant anterior displacement in the SG (0.89 mm) compared with the NG (0.06 mm) ($P = 0.033$). **Conclusions:** Bicortical microimplant anchorage is essential for pterygopalatine suture opening in microimplant-assisted maxillary skeletal expansion, which may result in further skeletal expansion and forward movement in the posterior part of the palatomaxillary complex. (Am J Orthod Dentofacial Orthop 2021;■:■-■)

Since the advent of the Hass-type of rapid palatal expander, various tooth-borne appliances have been introduced in an attempt to correct maxillary constriction.[1-3] However, their tooth-borne design has led to many detrimental effects such as dentoalveolar tipping, root resorption, buccal bone dehiscence, gingival recession, reduced skeletal effects of the expansion, and loss of long-term stability.[4] Furthermore, the use of these appliances is limited to prepubertal patients because the midpalatal suture does not have heavy interdigitation in younger patients.[5] For postpubertal patients, surgically assisted rapid palatal expansion is recommended because of the greater amount of interdigitation of the suture.[6,7] Microimplant-assisted rapid palatal expanders were suggested as an alternative to surgically assisted rapid palatal expansion,[8] and a successful expansion was reported in a young adult.[9] Maxillary skeletal expanders (MSEs) are a specific type of microimplant-assisted rapid palatal expander that

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features 4 microimplants located more posteriorly to maximize the likelihood of bicortical engagement into the palatal bone and nasal floor. This design enables the orthopedic force to be delivered more directly to high-resistance areas such as the pterygopalatine suture and zygomatic buttress.[10,11]

Although the midpalatal suture is the primary target to be separated for maxillary transverse expansion, higher resistance against the opening of this suture is found in the structures surrounding the maxillae, such as the sphenoid bone (posterior to the maxilla) or zygomatic bone (lateral to the maxilla).[12] The pterygopalatine suture is reportedly a major source of resistance during palatal expansion,[12-14] which could not be disarticulated with tooth-borne palatal expanders because of excessive interdigitation.[13] Expansion by tooth-borne appliances generates a V-shaped expansion of the palate with a larger opening at the anterior nasal spine (ANS) and gradually less split toward the posterior nasal spine (PNS) as a result of the rigid resistance from the pterygopalatine suture.[2,15,16] The amount of split at PNS (1.15 mm) was reported to be 40% of that at ANS (3.01 mm) with tooth-borne expanders.[15]

The pterygoid notch is an anatomic space on the inferior portion of the pterygoid processes between the medial and lateral plates, in which the pyramidal process of the palatine bone is fitted. Under normal circumstances, there is no visible space between the plates in the presence of the pyramidal process. However, with the expansion force from MSE, the pyramidal process can be pulled away from the pterygoid plates once the rigid pterygopalatine suture that connects them is split. These changes can generate a space between the plates that is detectable on cone-beam computed tomography (CBCT) images. In a previous study, MSE was shown to disarticulate the pterygopalatine suture in almost half of the patients (53%), thus exhibiting more parallel expansion patterns, with the opening at PNS (4.33 mm) being 90% of that at ANS (4.75 mm).[17] However, no study has investigated the factors affecting the suture opening.

The results of palatal expansion have long been evaluated with study models[18] and 2-dimensional radiography such as lateral and posteroanterior cephalograms,[2,19] but the previous studies had fundamental limitations because of their 2-dimensional perspective. The development of 3-dimensional (3D) radiographs such as CBCT images enabled researchers and clinicians to study living subjects more reliably.[20,21] Because of the progressive improvements in CBCT resolution and the introduction of multiplanar 3D reconstruction software, it is now possible to accurately measure and analyze the 3D nature of craniofacial bones and sutures.[22,23]

The specific aims of this study were to evaluate the effects of bicortical engagement of microimplants on the pterygopalatine suture opening and to compare skeletal changes of the split group (SG) with those of the nonsplit group (NG) at the key landmarks around the midpalatal suture using a 3D reconstruction software.

MATERIAL AND METHODS

This retrospective study was approved by the Institutional Review Board of Wonkwang University Dental Hospital (approval no. WKUDHIRB201907-01). A total of 18 patients aged 9-27 years (mean age, 19.8 $\pm$ 4.8 years; 6 males, 12 females) treated in Wonkwang University Dental Hospital were included in the study. CBCT images were reoriented and examined using OnDemand 3D software (Cybermed, Seoul, South Korea) to verify whether or not the patient showed evidence of splits in the lower part of the pterygopalatine suture, as suggested in a recent study.[17] Eight of the 18 subjects showed no evidence of suture opening and were assigned to the NG, whereas 10 subjects showed evidence of disarticulation of the suture in either right, left, or both sides and were assigned to the SG. The suture was considered open when the crescent continuity of the pterygoid plates was lost in the area adjacent to the pyramidal process, and the distance from the most lateral point of the medial pterygoid plate to the most medial end of the lateral plates was measurable (Fig 1).

The inclusion criteria were as follows: (1) patients who presented with either posterior crossbite or airway problems because of maxillary constriction, (2) use of MSE as the first step of treatment, (3) successful opening of the midpalatal suture, and (4) having CBCT images taken before (T0) and within a month after expansion (T1). The exclusion criteria were as follows: (1) history of trauma in the craniofacial area, (2) patients with the craniofacial syndrome, (3) those having had previous orthognathic surgery or (4) previous orthodontic and orthopedic treatment, (5) concomitant facemask therapy, and (6) >6 mm of difference between maxillary and mandibular intermolar width.

MSE II appliances with four 1.5 $\times$ 11.0-mm microimplants (MSE; BioMaterials Korea, Seoul, South Korea) were used in this study (Fig 2). The activation rate was 1 turn per day for early teens (aged <15 years), 2 turns per day for late teens (aged ≥ 15 years), and 4 turns per day for adult patients (aged >20 years) before the midpalatal suture opening. Once a diastema was observed, the activation rate was

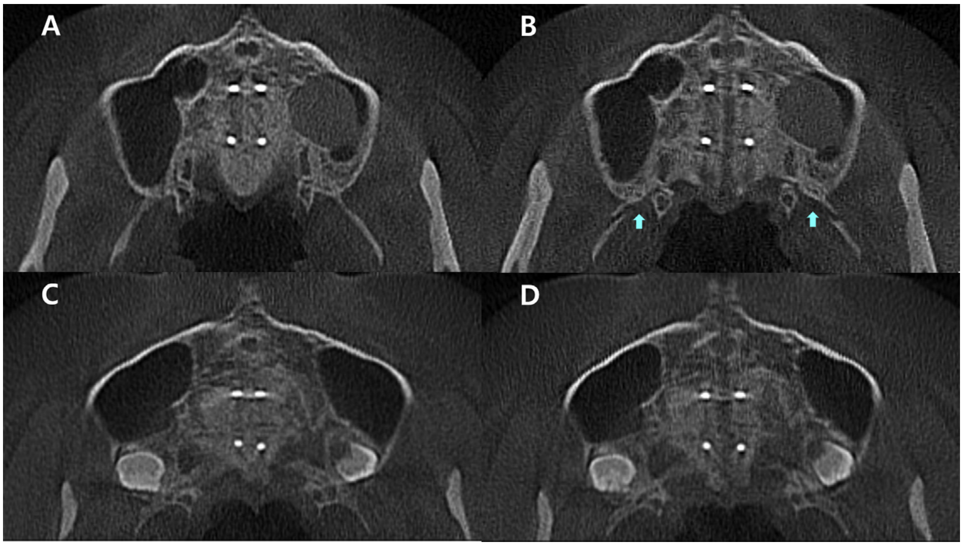

Fig 1. Evaluation of the pterygopalatine suture opening: **A,** before expansion: the pterygoid notch is occupied by the pyramidal process of the palatal bone, maintaining the crescent continuity of the pterygoid plates; **B,** after expansion: the continuity of the pterygoid plates was lost in the area adjacent to the pyramidal process, and the distance from the most lateral point of the medial pterygoid plate to the most medial end of the lateral plates was measurable; **C,** before expansion: the pterygoid notch is occupied by the pyramidal process of the palatal bone maintaining the crescent continuity of the pterygoid plates; **D,** after expansion: the continuity of the pterygopalatine suture remains intact, whereas the midpalatal suture is disarticulated.

set at 2 turns per day regardless of age and was maintained until proper expansion was achieved.

Before taking CBCT images, all patients were instructed to be seated in an upright position such that the imaginary Frankfort horizontal plane of the patients was parallel to the floor. Their heads were fixed with a chincup and ear rods to secure their position during the CBCT scan. The CBCT scanner (Alphard-3030; ASAHI Roentgen IND, Kyoto, Japan) was set to 80 kVp and 7.0 mA for adults and 80 kVp and 3.0 mA for adolescents and children. Scan time was 17 seconds with a voxel size of 0.39 mm and a field of view of 19.97 cm using the cranial mode.

Landmarks around the midpalatal suture were traced on the pretreatment and posttreatment CBCT images of each subject using OnDemand 3D software. Three-dimensional coordinates (x, y, and z) were automatically given to each traced landmark (Fig 3). The landmarks used for measurement were as follows: ANS, PNS, and center of resistance of the maxillary first molar (CoRM6). Landmarks such as nasion (N), sella (S), porion (Po), orbitale (Or), and basion (Ba) were used as reference points for the exact orientation of the CBCT images (Table I). The T1 scan was then superimposed on the T0 scan using stable anatomic structures and anterior cranial base as a reference for adult patients[22] and anterior cranial fossae for growing patients.[23] They were then precisely superimposed again on the basis of the voxel gray scale pattern. The superimposition of the CBCT images is a semi-automatic process that has been validated for accuracy in a recent study.[24] After superimposition, the coordinates of N and S in preexpansion and postexpansion images were checked to see whether they were within the 0.05 mm error limit. The changes in the 3D coordinates of all landmarks at T0 and T1 were measured. Finally, CBCT volumes were reoriented along the axis of each microimplant to check the bicortical engagement of the 4 microimplants (Fig 4). During the entire process, any patient information that might direct the group orientation was concealed to avoid bias.

Statistical analysis

In a preliminary study, the sample size was determined on the basis of the difference in the amount of transverse expansion and anterior movement at PNS between NG and SG randomly selected from 10 patients (5 NG and 5 SG; mean difference, 0.89; standard deviation, 0.58 mm). The measurements at PNS were adopted because of its proximity to the pterygopalatine suture, which might be closely related to the suture opening.

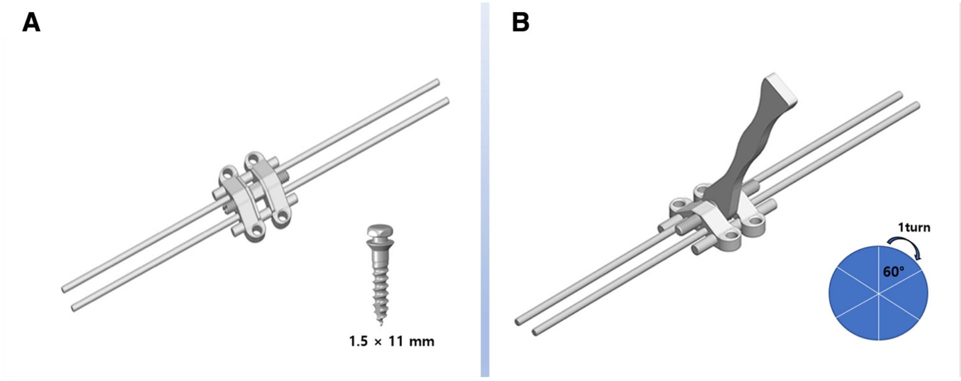

Fig 2. Appliances: **A,** MSE II appliances with four 1.5 × 11.0 mm microimplants were used in this study. The body was fixed with the 4 microimplants in the para-midsagittal area between the maxillary first molars. Two nonrigid arms were connected to the bands for maxillary first molars for ancillary support; **B,** the appliances were activated with a specifically designed spanner (0.133 mm/turn, 0.8 mm/1 revolution, up to 8 mm in total).

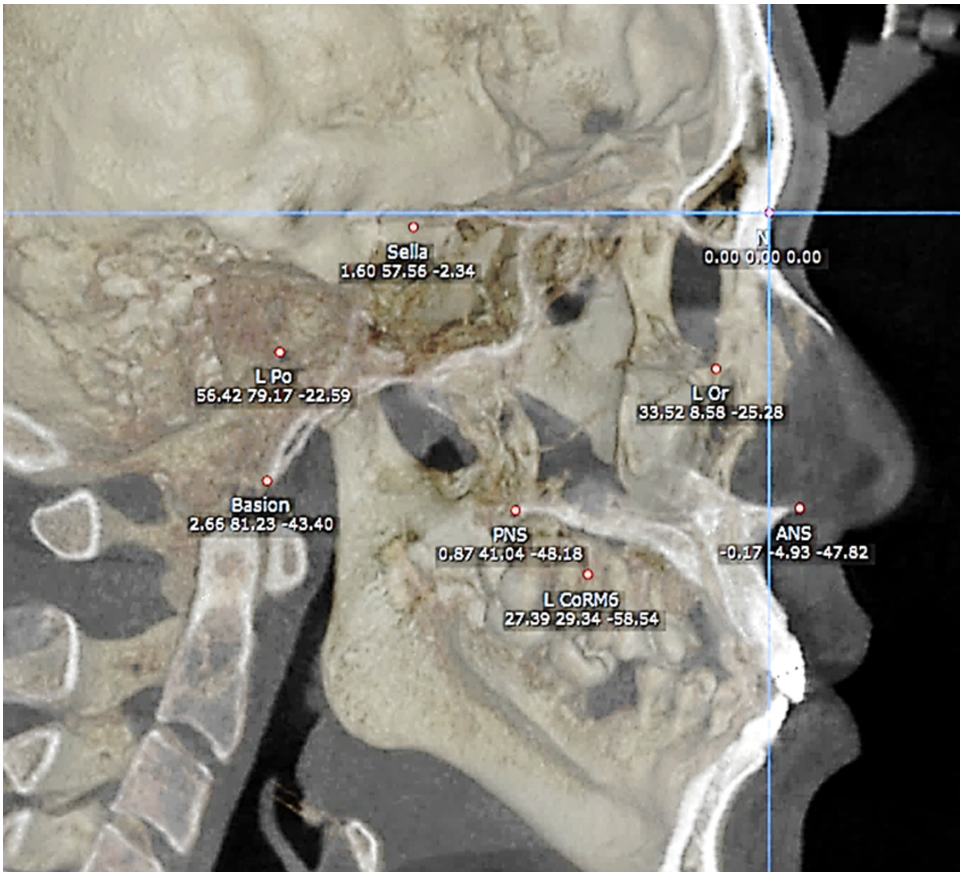

Fig 3. Landmarks and 3D coordination (Ondemand 3D): landmarks around the midpalatal suture were traced on the pretreatment and posttreatment CBCT images of each subject using OnDemand 3D software. Three-dimensional coordinates (x, y, z) were automatically given to each landmark traced. *L*, left.

Table I. Landmarks used in this study

Landmarks	*Definitions*
ANS	A pointed projection at the anterior extremity of the intermaxillary suture
ANSR	The right half of ANS after midpalatal suture is separated
ANSL	The left half of ANS after midpalatal suture is separated
PNS	Medial end of the posterior border of the horizontal plate of palatine bone
PNSR	The right half of PNS after midpalatal suture is separated
PNSL	The left half of PNS after midpalatal suture is separated
CoRM6	The center of resistance of the maxillary first molar; the most superior and buccal point of the furcation area of the mesiobuccal and distobuccal roots of the maxillary first molar
Nasion	The most medial and superior point of the frontonasal suture
Sella	The center of hypophyseal fossa
Porion	The most superior point of external the auditory meatus
Orbitale	The lowest point on the inferior orbital margin
Basion	The anterior margin of the foramen magnum

Note. Bilateral landmarks: CoRM6 (only right porion and orbitale was used for orientation of the CBCT volume).
ANSR, ANS right; *ANSL*, ANS left; *PNSR*, PNS right; *PNSL*, PNS left.

At least 8 subjects were required per group to provide a power of 0.80 with a 2-tailed α value of 0.05. The sample size was also considered enough to detect the correlation between the bicortical engagement of the microimplant and the pterygopalatine suture opening because the number of microimplants is 4 times more than the number of the patients included in this study. Finally, 18 subjects were selected because of the possibility that the final groups (NG and SG) would have an unequal sample size, which might decrease the power level. For the entire computation, G*Power was used (version 3.1.9.2; Franz Faul, Christan-Albrechts Universitat, Kirel, Germany).

The Shapiro-Wilk test was used to check the normal distribution of the samples. To compare the mean difference between the 2 groups, either the independent sample *t* test or the Mann-Whitney U Test was used on the basis of the normality of the samples. Fisher exact test and binary logistic regression analysis were used to evaluate the correlation between the bicortical engagement of the microimplants and suture opening. The landmarks for measurement (ANS, PNS, and CoRM6) were traced twice by the same rater at different times to evaluate the intraclass correlation coefficient. The intraclass correlation coefficient ranged from 0.842 to 0.928, which was considered very reliable. Patients were assigned to either of the 2 groups on the basis of the evidence of their pterygopalatine suture split. The evaluation of the suture split was performed again by another rater to check interclass reliability with Cohen's kappa. Cohen's kappa value was 1.00, which indicated a perfect match between the raters. SPSS software was used for the statistical analyses (version 26.0; IBM Corp, Armonk, NY).

RESULTS

In the NG, the average amount of transverse expansion measured at the CoRM6, ANS, and PNS was 4.33 mm, 2.22 mm, and 1.58 mm, respectively, whereas the transverse expansion in the SG was 5.29 mm, 2.21 mm, and 2.46 mm, respectively. A significant difference was found in the amount of transverse expansion at PNS between the 2 groups ($P = 0.036$), whereas it was insignificant at CoRM6 and ANS ($P > 0.05$) (Table II). The amount of expansion at PNS was 71% of that at ANS in the NG, whereas the expansion at PNS was 111% of that at ANS in the SG (Fig 5). PNS also showed significant anterior displacement in the SG (0.89 $\pm$ 0.49 mm) compared with the NG (0.06 $\pm$ 0.64 mm) ($P = 0.033$) (Table III).

In this study, 22 of the 72 microimplants failed to achieve bicortical engagement (30.6%). In the NG, 17 of the 32 microimplants failed to achieve bicortical engagement (53.1%), whereas in the SG, 5 of the 40 microimplants failed to achieve bicortical engagement (12.5%). There was a significant correlation between the bicortical engagement of the orthodontic microimplants and the pterygopalatine suture opening ($P = 0.0003$) (Table IV). There was a significant correlation between the suture opening and the bicortical engagement of orthodontic microimplant in all positions, the anterior and posterior portions ($P = 0.017$ and $P = 0.004$, respectively) and left and right sides ($P = 0.014$ and $P = 0.011$, respectively) (Table V). There was a significant positive correlation between the number of microimplants with successful bicortical engagement and pterygopalatine suture opening ($P = 0.047$) (Table VI).

Significantly more microimplants failed to achieve bicortical engagement in the anterior portion of the MSEs than in the posterior portion ($P = 0.002$) (Table VII). There was no statistically significant difference between the left and right sides in achieving bicortical engagement ($P = 0.80$) (Table VIII).

DISCUSSION

In this study, the average amount of transverse expansion measured at ANS and PNS was 2.22 mm and 1.58 mm, respectively, in the NG; the same measurements were 2.21 mm and 2.46 mm, respectively, in the SG. In the NG, the magnitude of the expansion at PNS

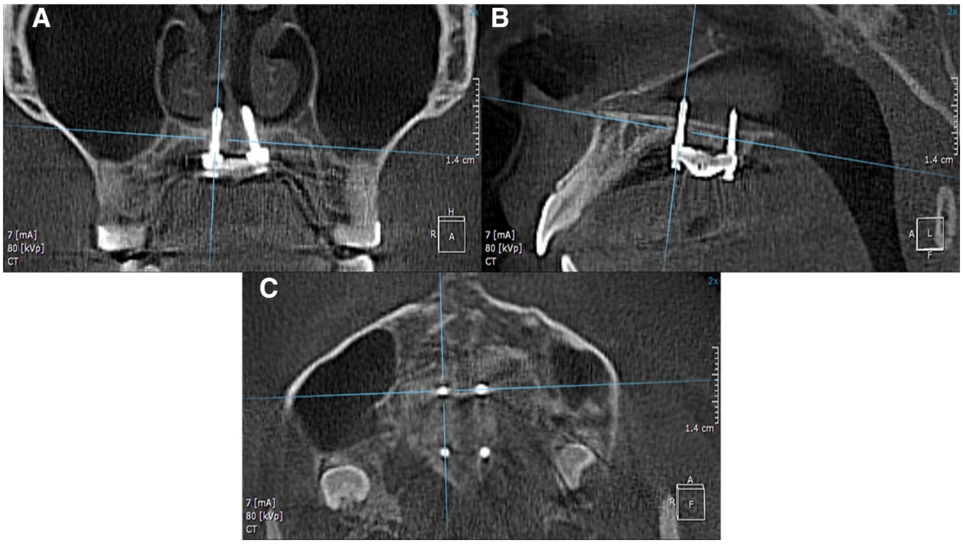

Fig 4. Bicortical engagement in 3D multiplanar reconstruction mode: CBCT volumes are reoriented along the axis of each microimplant to check the bicortical engagement of the 4 microimplants used (OnDemand 3D software): **A,** coronal view; **B,** sagittal view; **C,** axial view.

Table II. Comparison of the mean differences in transverse expansion between NG and SG

	Group N		*Group S*		
Landmarks	*Mean*	*SD*	*Mean*	*SD*	P *value*
CoRM6 (mm)	4.33	1.50	5.29	1.20	0.15
ANS (mm)	2.22	0.99	2.21	0.83	0.72
PNS (mm)	1.58	0.83	2.46	0.79	0.036*

Note. Independent sample *t* tests were performed for CoRM6, and Mann-Whitney U tests were performed for ANS and PNS. Group N represents pterygopalatine suture NG. Group S represents pterygopalatine suture SG.
SD, Standard deviation.
**P* <0.05.

was 71% of that at ANS, whereas the expansion at PNS was 111% of that at ANS in the SG. Although the NG showed remarkably larger posterior expansion (71%) compared with conventional rapid palatal expansion (40%),[15] the SG showed greater substantial expansion toward the posterior part (111%)—a formerly unknown pattern according to previous studies.[15,17]

As discussed in the introduction, decreased skeletal expansion can lead to the loss of long-term stability. Because the posterior expansion acquired with pterygopalatine suture opening is a pure skeletal expansion, even a small difference of 1 mm can be clinically significant because less than 1 mm can bring about a relapse of the posterior crossbite. In addition, this study excluded patients who showed >6 mm of difference between maxillary and mandibular intermolar width to rule out outliers that come with extreme expansion. This amount might have increased more, maintaining the parallel expansion pattern if the patients with greater activation had been added to the study. The substantial expansion in the posterior part that SG exhibited may partly stem from the MSE's biomechanics, especially the position of the anchorage compared with that of a conventional rapid palatal expander. The posteriorly positioned 4 microimplants seem to enable a further expansion around the posterior portion of the midpalatal suture. As the posterior portion is separated adequately, the force of the vector generated from the bone anchorage may be transmitted more directly to the pterygoid plates. As a result, the lower part of the pterygopalatine suture splits, giving rise to even greater posterior expansion around the midpalatal suture. Although there was previous research that studied the force distribution of MSE with finite element analysis, it focused heavily on initial force distribution after activation.[25] The aspect of force distribution after the separation of midpalatal suture is still unknown.

In this study, when both groups were combined, the magnitude of expansion at PNS was 93.6% of that at ANS, which is similar to the result from a previous study (90%).[17] However, the data suggested that the previous study might have presented a mixed result of 2 distinctly different groups (NG and SG), as indicated in our study (71% and 111%, respectively).

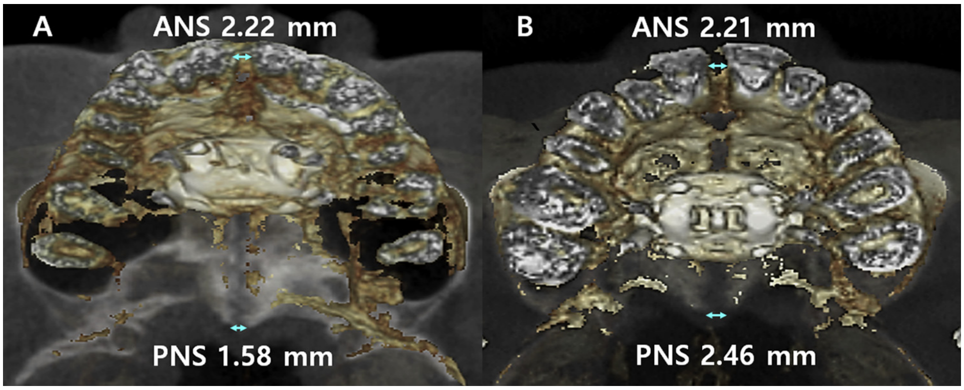

Fig 5. The pattern of expansion in pterygopalatine suture nonsplit group and split group: **A,** the NG; the average amount of expansion measured at ANS and PNS was 2.22 mm and 1.58 mm, respectively. The amount of expansion at PNS was 71% of that at ANS. Pterygopalatine sutures are intact; **B,** the SG: the average amount of expansion measured at ANS and PNS was 2.21 mm and 2.46 mm, respectively. The amount of expansion at PNS was 111% of that at ANS. Pterygopalatine sutures are split.

According to a recent study, expansion of the zygomaticomaxillary complex was greater in the lower portion than in the upper portion in the transverse dimension because the center of resistance of the expansion was located higher in the z-axis than in the zygomaticomaxillary complex itself.[26] Because CoRM6 was in a lower portion of the complex than ANS and PNS, a greater molar expansion (CoRM6) than skeletal expansion (ANS and PNS) was also observed in the present study.

In this study, 22 of the 72 microimplants failed to achieve bicortical engagement (30.6%). In the NG, 17 of the 32 microimplants failed to achieve bicortical engagement (53.1%), whereas in the SG, 5 of the 40 microimplants failed to achieve bicortical engagement (12.5%).

Because the primary suture discussed in the article was the pterygopalatine suture, patients who failed to show midpalatal expansion were excluded because it would be impossible to disarticulate pterygopalatine sutures without first opening the midpalatal suture. However, the failure rate of bicortical engagement in NG might have increased even more if we had added failed expansion to the study.

Among 8 patients in the NG, 2 patients showed bicortical engagement in all 4 microimplants, 3 patients failed to achieve bicortical engagement in all 4 microimplants, 2 patients failed to achieve bicortical engagement in 2 anterior microimplants, and 1 patient failed to achieve bicortical engagement in 1 anterior left microimplant. Of 10 patients in the SG, 7 patients exhibited successful bicortical engagement in all 4 microimplants, 1 patient failed to achieve bicortical engagement in 1 anterior left microimplant, and 2 patients failed to achieve bicortical engagement in 2 anterior microimplants. There was a significant correlation between the bicortical anchorage of the orthodontic microimplant and the pterygopalatine suture opening in this study ($P = 0.0003$).

Table III. Comparison of the mean differences of anterior displacement at PNS between NG and SG

	Group N		*Group S*		
Landmarks	*Mean*	*SD*	*Mean*	*SD*	P *value*
PNSR (mm)	0.07	0.64	0.88	0.49	
PNSL (mm)	0.05	0.65	0.90	0.48	
Average (mm)	0.06	0.64	0.89	0.49	0.033*

Note. Independent sample *t* tests were performed. Group N represents pterygopalatine suture NG. Group S represents pterygopalatine suture SG.
SD, Standard deviation; *PNSR*, PNS right; *PNSL*, PNS left.
$^{*}P < 0.05$.

Table IV. Relationship between bicortical engagement and pterygopalatine suture openings

	Success	*Failure*	*Total*
Group N	15	17	32
Group S	35	5	40
Total	50	22	72 (18 × 4)
P value	0.0003*		

Note. Fisher exact test was performed. Success represents the number of microimplants that succeeded in achieving bicortical engagement. Failure represents the number of microimplants that failed to achieve bicortical engagement. Group N represents pterygopalatine suture NG. Group S represents pterygopalatine suture SG.
$^{*}P < 0.001$.

Table V. Relationship between the bicortical engagement of the microimplants in various positions and pterygopalatine suture openings

	Anterior MIs		*Posterior MIs*		*Left MIs*		*Right MIs*	
	Success	*Failure*	*Success*	*Failure*	*Success*	*Failure*	*Success*	*Failure*
Group N	5	11	10	6	7	9	8	8
Group S	15	5	20	0	17	3	18	2
P value	0.017*		0.004**		0.014*		0.011*	

Note. Fisher exact test was performed. Anterior MIs represents anterior microimplants used in MSE (right and left). Posterior MIs represents posterior microimplants used in MSE (right and left). Left MIs represents left microimplants used in MSE (anterior and posterior). Right MIs represents right microimplants used in MSE (anterior and posterior). Success represents the number of microimplants that succeeded in achieving bicortical engagement. Failure represents the number of microimplants that failed to achieve bicortical engagement. Group N represents pterygopalatine suture NG. Group S represents pterygopalatine suture SG.
*P <0.05; **P <0.01.
MI, Microimplant.

Table VI. Relationship between the number of microimplants with successful bicortical engagement and pterygopalatine suture openings

	No. of microimplants with bicortical engagement
Pterygopalatine suture openings	0.047*

Note. Binary logistic regression analysis was performed.
*P <0.05 (positive correlation).

Table VII. Relationship between the positions of microimplants and success and failure rates in achieving bicortical engagement (anterior and posterior)

	Success	*Failure*	*Total*
Anterior MIs	20	16	36
Posterior MIs	30	6	36
Total	50	22	72
P value	0.002*		

Note. Fisher exact test was performed. Success represents the number of microimplants that succeeded in achieving bicortical engagement. Failure represents the number of microimplants that failed to achieve bicortical engagement. Anterior MIs represents anterior microimplants used in MSE (right and left). Posterior MIs represents posterior microimplants used in MSE (right and left).
MI, Microimplant.
*P <0.01.

The subjects who failed to achieve bicortical anchorage in any of the 4 microimplants displayed no evidence of pterygopalatine suture split, although even in these patients, midpalatal sutures were separated. This result suggests that the factor that enables the disarticulation of the pterygopalatine suture is not only the existence of bone anchorage itself but also the bicortical engagement of the microimplants.

Table VIII. Relationship between the position of the orthodontic microimplants and success and failure rates in achieving bicortical engagement (left and right)

	Success	*Failure*	*Total*
Left MIs	24	12	36
Right MIs	26	10	36
Total	50	22	72
P value	0.80		

Note. Fisher exact test was performed. Success represents the number of microimplants that succeeded in achieving bicortical engagement. Failure represents the number of microimplants that failed to achieve bicortical engagement. Left MIs represents left microimplants used in MSE (anterior and posterior). Right MIs represents right microimplants used in MSE (anterior and posterior).
MI, Microimplant.

There was a significant correlation between pterygopalatine suture opening and the bicortical engagement of the orthodontic microimplant in the anterior and posterior portion ($P = 0.017$ and $P = 0.004$, respectively). These results suggest that bicortical anchorage of the anterior portion might not be as crucial as that of the posterior part for the suture opening. However, there was also a significant positive correlation between the number of microimplants with successful bicortical engagement and pterygopalatine suture opening ($P = 0.047$). Furthermore, the most frequent failure in bicortical anchorage happened at the 2 anterior microimplants in this study. All failed bicortical engagements in the anterior portion occurred because of a deep palatal curvature, inclined palatal plane, and thicker anterior palatine bone. The use of longer anterior microimplants might be needed in these patients. No bicortical anchorage failed in the posterior part alone in this retrospective study. All failed bicortical engagements happened because they did not contact the cortical bone of the nasal floor.

Two patients showed bicortical anchorage in all 4 microimplants but still failed to overcome their pterygopalatine suture. This finding could have been due to the anatomic and biological features of the subjects (eg, thin palatal bone) or the expansion protocol used.

According to a recent study,[26] most of the landmarks in zygomaticomaxillary complexes, including ANS and PNS, showed slight anterior displacement after expansion by MSE. Our study revealed that the anterior displacement of PNS was significantly higher in the group with pterygopalatine suture opening, that is, the SG ($P = 0.033$). Although other landmarks also showed anterior displacement similar to the results of a previous study, there was no significant difference between the groups. This might have been a result of the bones adjusting to the expansion force with multiple centers of rotations in different planes (axial, coronal, and sagittal), something that needs further study.

The skeletal and sutural changes generated by the opening of the pterygopalatine suture may be beneficial for the treatment of patients with Class III malocclusion, in which facemask therapy is often applied. With the help of the displaced pyramidal process and skeletal anchorage achieved with microimplants, protraction may be more manageable.[27] Collectively, clinicians should secure successful bicortical anchorage in all 4 microimplants when treating patients with a large posterior crossbite and Class III skeletal patterns.

In this study, the gap between lateral and medial pterygoid plates was noticeable in 56% of the patients—a frequency of opening similar to a previous study (53%). According to the previous study, bilateral and complete suture displacement was the most common aspect of the pterygopalatine suture split. However, this study detected more partial and unilateral displacements (30% and 33%, respectively) than bilateral and complete displacements. These results might be explained by the difference in the anatomic and biological features of the patient groups and the expansion protocol. In this study, all patients were of Korean ethnicity, whereas, in the previous research, patients were mainly Hispanic in ethnicity.[17]

Although no patients have been reported yet who included major complications relative to the procedure, clinicians might worry about the potential for complications with increased expansion. In the case of orbit, because the optic canal through which optic nerve pass is located in a solid bone mass, the lesser wing of the sphenoid bone, it is unlikely that the expansion damages this structure. However, the structures in the superior and inferior orbital fissures may theoretically be impacted by the expansion because they go through the fissures created by more than 2 different bones. Pterygopalatine fossa also contains important neural and vascular structures. Although the chance of them being damaged is very low because the zygomaticomaxillary complex moves anteriorly with the expansion,[26] further studies are needed.

The overall age distribution of the NG and SG groups was very similar. One patient in the prepubertal stage was aged 9 years. She remained in the study due to the following reasons: (1) the duration of expansion for this patient was only 13 days, and thus, it is unlikely that facial growth would affect the outcome of the study and (2) pterygopalatine sutures have been reported to be heavily interarticulated structures that would not be able to disarticulate without the help of surgery or microimplants regardless of the age,[13] and she was a patient with successful bicortical engagement with all 4 microimplants and showed a pterygopalatine suture opening. Collectively, the patient's results were similar to those of the other patients in this study.

Although there were significant differences between NG and SG in terms of the magnitude of transverse expansion and anterior movement at PNS, the limitation of this study was the small sample size, which might increase the possibility of type 2 error. In addition, bicortical engagement may not be the sole factor contributing to pterygopalatine suture opening. Factors such as palatal bone thickness in the area where microimplants are inserted, bone density, and the extent of the interdigitation of the suture may also play significant roles in splitting the suture. Further research with larger sample sizes that enable cross-evaluation of such factors is needed.

CONCLUSIONS

1. The expansion in the posterior part of the midpalatal suture significantly increased with pterygopalatine suture opening.
2. PNS showed significant anterior displacement after the pterygopalatine suture opening.
3. Bicortical microimplant anchorage is an essential factor with pterygopalatine suture opening in skeletal expansion with MSE.

AUTHOR CREDIT STATEMENT

Dong-Wook Lee contributed to the original idea, data collection, and writing of the article; Jae Hyun Park contributed to critical revision of the article; Won Moon contributed to literature review; Hye Young Seo contributed to statistical analysis; and Jong-Moon

Chae contributed to supervising the overall project and had the final responsibility.

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