Mid-facial soft tissue changes after maxillary expansion using micro-implant-supported maxillary skeletal expanders

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-ASTRACT-

Mid-facial soft tissue changes after Maxillary Expansion using Micro-implant-supported Maxillary Skeletal Expanders

Background and objectives: This study aimed to assess the mid-facial soft tissue changes following maxillary expansion using micro-implant-supported maxillary skeletal expanders (MSE) in young adults by cone-beam computerized tomography and to evaluate the correlations between hard and soft tissue changes after MSE.

Materials and Methods: Twenty patients (mean age, 22.4 years; range, 17.6-27.1) with maxillary transverse deficiency treated with MSE were selected. Mean expansion amount was 6.5 mm. Cone-beam computerized tomography images taken before and after expansion were superimposed to measure the changes in soft and hard tissue landmarks. Statistical analyses were performed using paired t-test and Pearson's correlation analysis according to the normality of data.

Results: Average lateral movement of the cheek points was 1.35 mm (right) and 1.08 mm (left), and those of the alar curvature points was 1.03 (right) and 1.02 mm (left) ($p < 0.05$). Average forward displacement of the cheek points was 0.59 mm (right) and 0.44 mm (left), and those of the alar curvature points was 0.61 mm (right) and 0.77 mm (left) ($p < 0.05$). Anterior nasal spine (ANS), posterior nasal spine (PNS), and alveolar bone width were significantly increased ($p < 0.05$). The changes in cheek and alar curvature points on both sides significantly correlated with hard tissue changes ($p < 0.05$).

Conclusions: Maxillary expansion using MSE resulted in significant lateral and forward movements of the soft tissues of the cheek and alar curvature points on both sides in young adults, and correlated with maxillary suture opening at the ANS and PNS.

Keywords: Maxillary expansion; Micro-implant-supported maxillary skeletal expander (MSE); Soft tissue change.

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ABBREVIATIONS

ANS	anterior nasal spine
PNS	posterior nasal spine
RME	rapid maxillary expansion
MSE	micro-implant-supported maxillary skeletal expander
CBCT	cone beam computed tomography
SARPE	surgically-assisted rapid palatal expansion

I. INTRODUCTION

Maxillary transverse deficiency is one of the skeletal problems in the craniofacial region encountered during orthodontic treatment (McNamara, 2000). To correct this malocclusion, rapid maxillary expansion treatments have been used for more than a century. (Cross et al., 2000; Haas, 1970). Several studies have proved that RME increased arch width and perimeter to allow the correction of posterior crossbite and to provide space for alleviation of crowding of the dentition (Adkins et al., 1990; Geran et al., 2006). However, limited skeletal movement, dentoalveolar tipping, root resorption, detrimental periodontal consequences, and lack of long-term stability were reported as undesirable side effects (Gurel et al., 2010).

With the widespread use of temporary anchorage devices, the micro-implant-supported maxillary skeletal expander (MSE) was recently developed to open the midpalatal suture and achieve skeletal expansion (MacGinnis et al., 2014; Lagravere et al., 2010; Lee et al., 2010). Numerous positive results pertaining to the skeletal effects of MSE in different studies were reported (MacGinnis et al., 2014; Carlson et al., 2016). However, limited data have been published regarding soft tissue changes and their correlation with hard tissue changes in young adult patients (Abedini et al., 2018; Lee et al., 2020).

Three-dimensional soft tissue analysis using the 3dMD Face system after expansion with MSE showed significant changes in the paranasal region, upper lip, and both cheeks (Abedini et al., 2018). While, another study with stereophotogrammetric analysis was reported that the effect on nasolabial soft tissues after RME appliances in growing patients could be considered as clinically non-significant (Staderini et al., 2018). Cone-beam computerized tomography (CBCT) is a useful 3D imaging method for the accurate evaluation of hard and soft tissue changes (Kim et al., 2012). Progress in software development has allowed improved manipulation and visualization of CBCT images, and thus, collection of reliable and precise information (Moss et al., 2006).

The aim of this study was to assess the mid-facial soft tissue changes induced by MSE use in young adults by CBCT, and to evaluate the correlations between hard and soft tissue changes after expansion with MSE.

II. MATERIAL AND METHODS

A. MATERIAL

1. Subjects

This retrospective study analyzed CBCT images of patients who received orthodontic treatment for the resolution of maxillary transverse deficiency at Samsung Medical Center and was approved by the Institutional Review Board (IRB) (Approval No. SMC MD IRB 2019-09-127-001). Due to the retrospective nature of this study, the Committee waived the need for a signed informed consent. A total of 20 patients (12 men, 8 women) with a mean age of 22.4 years (range, 17.6–27.1 years) whose skeletal growth had stopped were selected. CBCT images before the delivery of the MSE (T0) and post-expansion (T1) were obtained. The mean treatment duration was 48.5 days (range, 31–80 days), and the mean amount of expansion was 6.5 mm (range, 5.2–8.0 mm). The post-expansion CBCT images were acquired within 4 weeks (mean duration, 21 days; range, 1–28 days) of completion of expansion. The mean interval between pre- and post-expansion CBCT images was 76.5 days (range, 42–108 days).

The inclusion criteria were as follows: transverse maxillary deficiency more than 5 mm (Vanarsdall, 1999); absence of any previous mid-facial trauma; absence of functional shift; and no history of previous orthodontic treatment. The exclusion criteria were as the following: systemic disease or syndromes; growing patients; patients with severe facial asymmetry; and patients whose mid-palatal suture separation was not achieved.

2. Appliance

The MSE type II device (BioMaterials Korea Inc., Seoul, Korea) is a specific type of bone-borne expander using four micro-implants in the posterior area of the palate with bicortical engagement, including an 8-mm expansion jackscrew unit supported by the four palatal micro-implants with diameters of 1.8 mm and lengths of 11 mm attached to the first molars with connecting arms and molar bands (Carlson et al., 2016). The rate of expansion was two turns per day (0.13 mm per turn) until diastema appeared, after which the rate was changed to one turn per day to minimize periodontal side effects. The expansion was stopped when the required amount of expansion was achieved to correct the maxillo-mandibular transverse discrepancy (Vanarsdall, 1999) and 20% of overexpansion was performed (Oh et al., 2019) (Fig. 1). After completion, the MSE was retained for at least 3 months for stabilization.

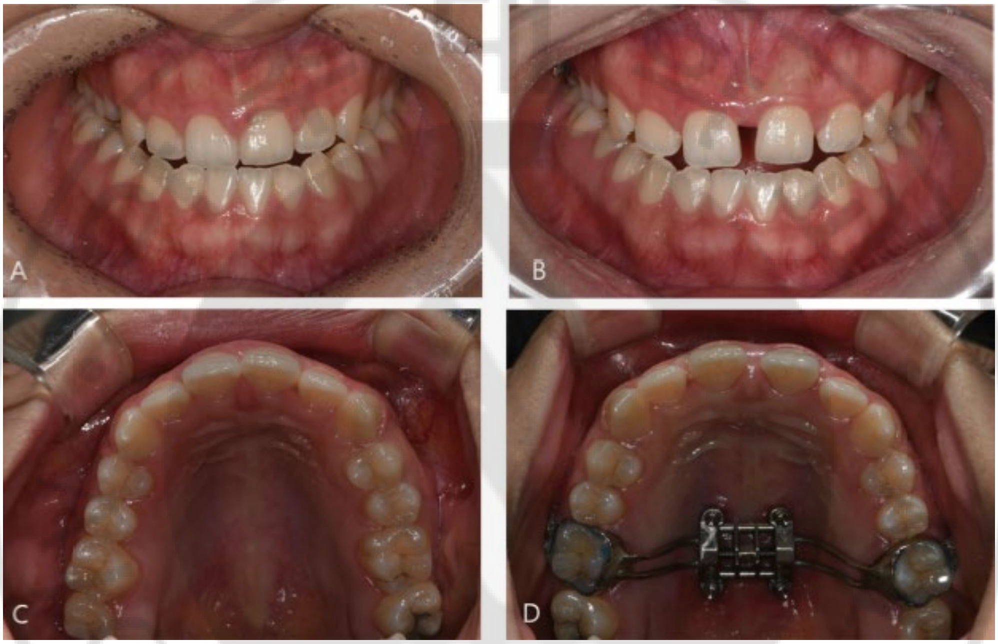

Fig. 1. Intraoral photographs of MSE. **(A; C).** Before activation of the MSE. **(B).** Diastema following MSE. **(D).** After activation of the MSE.

B. METHODS

1. CBCT measurement

All CBCT images were taken by the same technician using a CBCT scanner (CS 9300, Carestream Dental, Atlanta, USA) with image resolution up to 90 μm, exposure parameters of 90 kV and 4 mA, 300-μm voxel size, and volume dimension of 17 × 13.5 cm^2. During image acquisition, the patients were seated in a vertical position, with the Frankfort horizontal plane parallel to the floor and the patient's head stabilized by an ear rod. The images were imported as digital imaging and communications in medicine (DICOM) files using OnDemand3D software (CyberMed Inc, Seoul, Korea). Using the anatomical structures of the anterior cranial base, the superimposition of the post expansion CBCT images onto the pre-expansion CBCT images was performed, as proposed by Cevidanes et al. (Cevidanes et al., 2009; Bazina et al., 2018) (Fig. 2). The superimposition method uses the voxel grayscale and is fully automated by the 'Automatic Registration' tool of the software to avoid operator-related errors (Fig.3), a procedure whose accuracy has been previously validated (Bazina et al., 2018).

The coordinate system featured three axes (x, y and z) with the origin (0, 0, 0) registered at Nasion (N). The x-axis, the transverse axis, was parallel to the Orbitale (Or) line passing through the left and right Or. The y-axis, the anteroposterior axis, was perpendicular to the Or line and parallel to the right Frankfort horizontal (R FH) line. The z-axis, the vertical axis, was perpendicular to both the Or line and R FH line (Fig. 4). Assuming the subject was in an anatomical position, positive values were to the left, posterior, and superior to the N point of the subject (Fig. 5), and negative values were to the right, anterior, and inferior to the N point. The three-dimensional coordinates (x, y, z) of any landmark represented its 3D position relative to N (0, 0, 0).

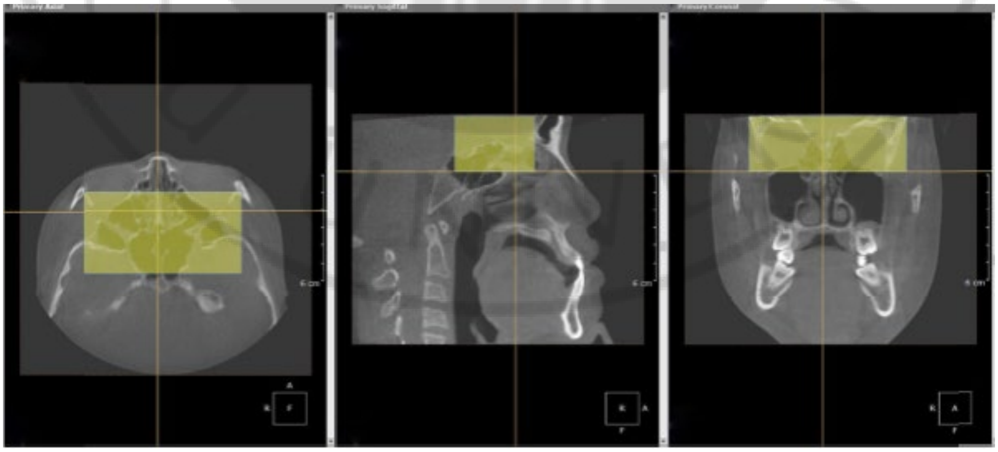

Fig. 2. OnDemand 3D voxel-based superimposition on the cranial base. The yellow

box is used to determine the area of the cranial base to be used as a reference for the superimposition.

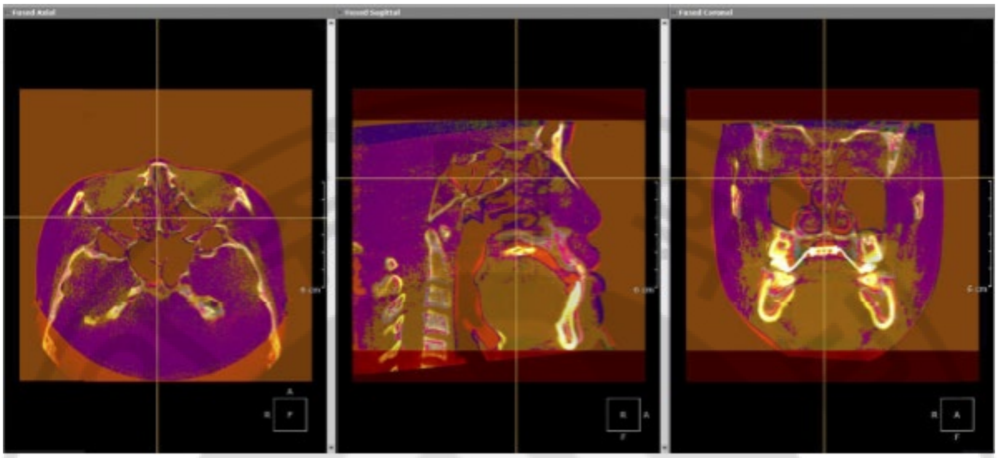

Fig. 3. Superimposed pre- and post-expansion CBCT scans following MSE (Primary CBCT, violet; Secondary CBCT, red).

In the OnDemand3D software, landmark points were defined using the (x, y, z) Cartesian coordinate system, based on the 3 orientation planes. A series of 19 points were marked on each pre- and post-expansion CBCT. On each CBCT, three points (including subnasale, soft tissue A point, and labial superius) with three pairs of soft tissue landmarks (including cheilion, cheek point, and alar curvature point on both sides), and five pairs of hard tissue landmarks (including A point, prosthion, ectocanine, ectomolare, and processus zygomaticus on both sides) were identified based on previous report (Kim et al., 2012) (Table 1; Fig. 6 and Fig. 7). Three-dimensional changes in their position between T0 and T1 were defined as the differences in their three coordinates. To investigate the amount of skeletal expansion, the following parameters were evaluated: amount of expansion at the anterior nasal spine (ANS) and posterior nasal spine (PNS) (Cantarella et al., 2017), and alveolar width (Table 1; Fig. 8A, 8B).

Table 1. Definitions of the landmarks and parameters used in this study

	Landmarks	Description
Soft tissue	Subnasale	The midpoint on the nasolabial soft tissue contour between the columella crest and upper lip
	Alar curvature point	The point located at the facial insertion of the alar base
	Soft tissue A point	The most posterior midpoint of the philtrum
	Labrale superius	The midpoint of the vermilion line of the upper lip
	Cheilion	The point located at each labial commissure
	Cheek point	The point located at the center of the cheek area
Hard tissue	A point	The most posterior and deepest point on the anterior contour of the maxillary alveolar process
	Prosthion	The most antero-inferior point on the maxillary alveolar margin in the mid-sagittal plane
	Ectocanine	The most infero-lateral point on the alveolar ridge opposite the center of the maxillary canine
	Ectomolare	The most infero-lateral point on the alveolar ridge opposite the center of the maxillary first molar
	Processus Zygomaticus	The most infero-lateral point of the processus zygomaticus

	ANS width	Distance between the R and L halves of the ANS in axial section passing through the ANS
Parameter	PNS width	Distance between the R and L halves of the PNS in axial section passing through the PNS
	Alveolar width	Distance between the R and L buccal alveolar bones on a line connecting the R and L M1 furcations in coronal section passing through M1 furcations.

R, right; L, left; M1, maxillary first molar; ANS, anterior nasal spine; PNS, posterior nasal spine.

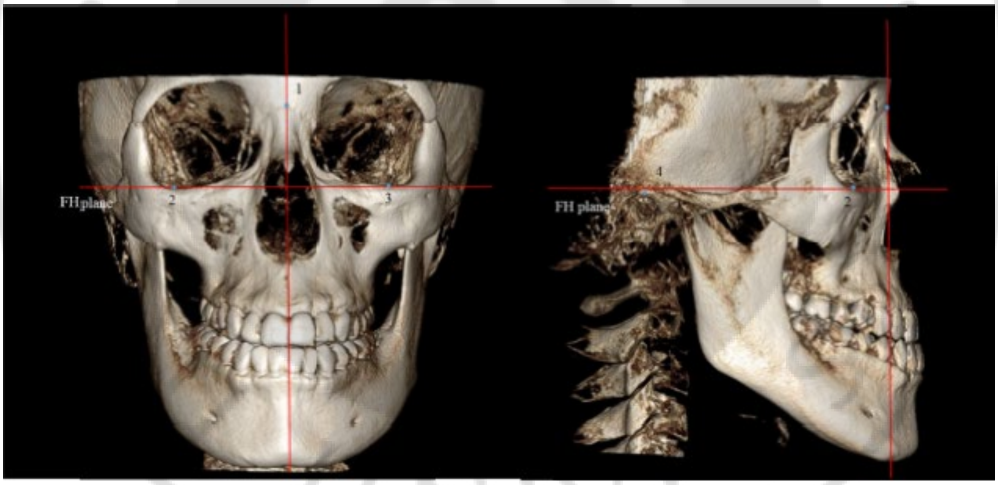

Fig. 4. The coordinate system consists of three axes (x, y, z) with their origin (0, 0, 0) registered at Nasion (N). 1, Nasion; 2 and 3, Orbitale, right and left; 4, Porion, right.

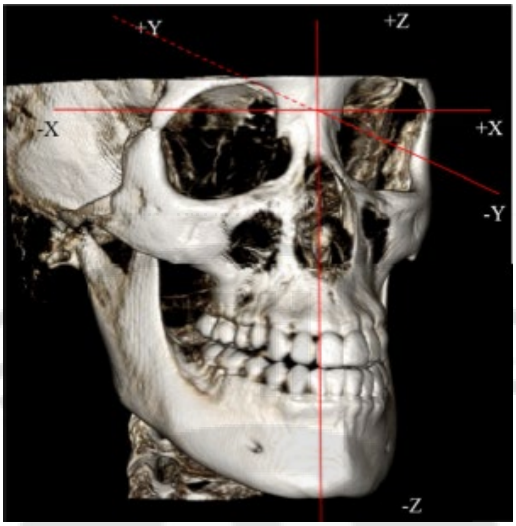

Fig. 5. Positive values are to the left, posterior, and superior to the N point of the subject.

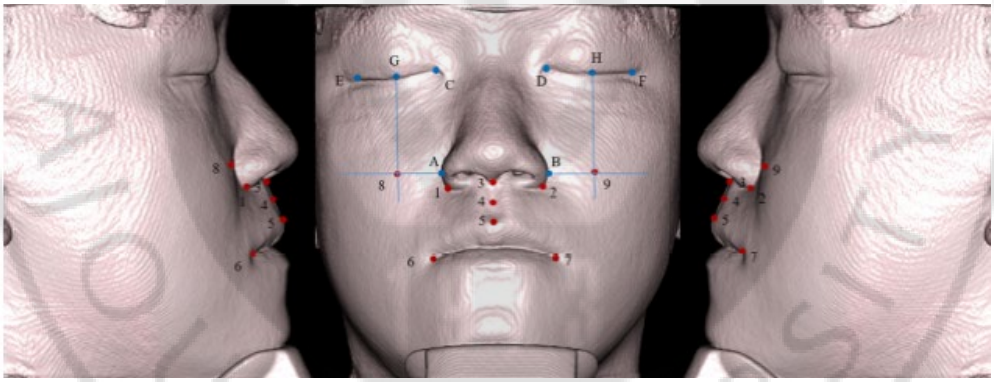

Fig. 6. Soft tissue landmarks used in this study. 1 and 2, Alar curvature points, right and left; 3, Subnasale; 4, Soft tissue A point; 5, Labrale superius; 6 and 7, Cheilion, right and left; 8 and 9, Cheek points, right and left (the intersection point of the vertical and horizontal blue line. The vertical blue line is the line passing through the mid-canthus parallel to the z axis. The horizontal blue line is perpendicular to the vertical line passing through the Alare); A and B, Alare, right and left (the most lateral point on each alar contour); C and D, Endo-canthus, right and left; E and F, Exo-canthus, right and left; G and H, Mid-canthus, right and left.

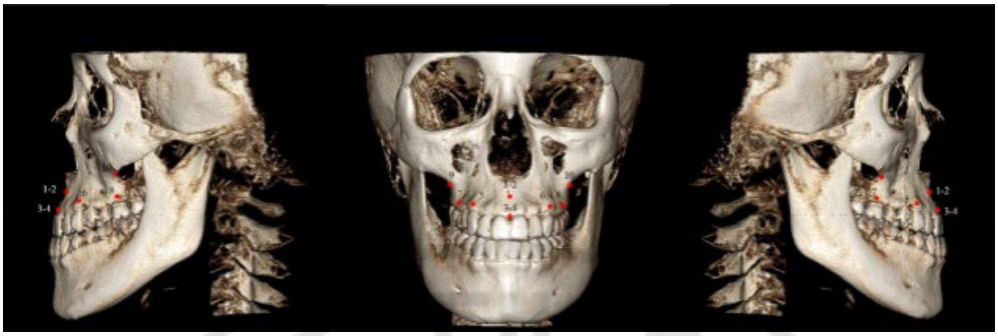

Fig. 7. Hard tissue landmarks used in this study. 1 and 2, A-point, right and left; 3 and 4, Prosthion, right and left; 5 and 6, Ectocanine, right and left; 7 and 8. Ectomolar, right and left; 9 and 10, Processus zygomaticus, right and left.

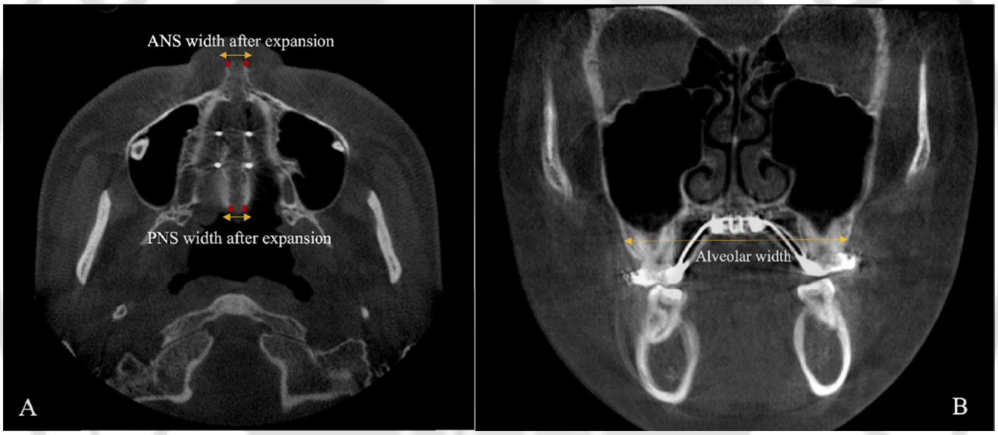

Fig. 8. (A). ANS and PNS width after expansion. **(B).** Alveolar width after expansion. ANS: anterior nasal spine; PNS: posterior nasal spine.

2. Statistical analysis

For sample size calculation, 17 data pairs achieved 80% power to reject the null hypothesis of zero effect size when the population effect size was 0.68 and the significance level was 0.05 using a two-sided paired t-test. The normality of data was determined using the Shapiro-Wilk test. Comparison of the coordinates of the soft tissue landmarks and hard tissue changes before and after expansion was performed using paired t-tests, according to the normality of data distribution. Pearson's correlation analysis was used to assess the correlation between hard and soft tissue changes. P-values < 0.05 were considered statistically significant. All statistical analyses were performed using SPSS software, version 23 (SPSS Inc, Chicago, IL, USA).

A single examiner performed all measurements. In order to determine the intraexaminer reliability, the same examiner reanalyzed ten randomly selected patients within a 2-week interval. The resultant correlation coefficient (ICC) indicated high reliability (ICC > 0.90). Cronbach's Alpha was used to evaluate the reliability of the measurements, and was equal to 0.92, showing appropriate superimposition and measurement agreement.

III. RESULTS

A. Changes in soft tissue landmarks

In this study, the cheek points on right and left side moved laterally by 1.35 mm and 1.08 mm respectively, with statistical significance ($p < 0.01$; Table 2), and forward by 0.59 mm and 0.44 mm respectively, with statistical significance ($p < 0.05$; Table 2). The alar curvature points on right and left side moved laterally by 1.03 mm and 1.02 mm, and forward by 0.61 mm and 0.77 mm, respectively and the subnasale point moved downward by 0.34 mm ($p < 0.01$; Table 2).

Table 2. Changes in soft tissue landmarks in the maxilla, assessed in the transverse (x), sagittal (y), and vertical (z) planes, after expansion (mm).

Landmarks		Δ Coordinate	Mean ± SD (mm)	p-value
Subnasale		Δx	-0.07 ± 0.68	0.631
		Δy	-0.23 ± 0.56	0.087
		Δz	-0.34 ± 0.36	0.000*
Soft tissue A point		Δx	-0.18 ± 0.68	0.249
		Δy	-0.35 ± 1.07	0.159
		Δz	-0.59 ± 1.37	0.067
Labiale superius		Δx	-0.19 ± 0.82	0.311
		Δy	-0.13 ± 1.16	0.624
		Δz	-0.30 ± 0.92	0.166
Cheilion	Right	Δx	-0.41 ± 1.39	0.073
		Δy	-0.03 ± 1.77	0.941
		Δz	0.27 ± 1.42	0.400
	Left	Δx	0.22 ± 1.80	0.586
		Δy	-0.38 ± 1.82	0.362
		Δz	0.29 ± 1.48	0.389
Cheek point	Right	Δx	-1.35 ± 0.31	0.000*

		Δy	-0.59 ± 0.60	0.000*
		Δz	-0.53 ± 1.29	0.080
	Left	Δx	1.08 ± 0.28	0.000*
		Δy	-0.44 ± 0.75	0.016*
		Δz	-0.55 ± 1.30	0.072
Alar curvature point	Right	Δx	-1.03 ± 0.68	0.000*
		Δy	-0.61 ± 0.54	0.000*
		Δz	-0.27 ± 1.00	0.242
	Left	Δx	1.02 ± 0.62	0.000*
		Δy	-0.77 ± 0.67	0.000*
		Δz	-0.25± 0.94	0.240

SD, standard deviation

*Statistical significance with p < 0.05.

B. Changes in hard tissue landmarks

According to the result of superimposition of the 3D skull models, all the investigated hard tissue landmarks showed significant lateral movement ($p < 0.001$; Table 3). Furthermore, the A point, ectocanine, and prosthion of each half of the maxilla shifted forward ($p < 0.05$; Table 3), whereas the A point moved downward by 0.30 mm on the right side and by 0.35 mm on the left side following MSE use ($p < 0.05$; Table 3).

Table 3. Changes in hard tissue landmarks in the maxilla, assessed in the transverse (x), sagittal (y), and vertical (z) planes, after expansion (mm).

Landmarks		Δ Coordinate	Mean ± SD (mm)	p-value
A point	To right side	Δx	-2.24 ± 0.64	0.631
		Δy	-0.57 ± 0.58	0.087
		Δz	-0.30 ± 0.54	0.000*
	To left side	Δx	2.21 ± 0.97	0.000*

		Δy	-0.55 ± 0.51	0.000*
		Δz	-0.35 ± 0.57	0.013*
Prosthion	To right side	Δx	-2.56 ± 1.01	0.000*
		Δy	-0.58 ± 0.71	0.002*
		Δz	-0.49 ± 0.66	0.003*
	To left side	Δx	2.47 ± 0.94	0.000*
		Δy	-0.55 ± 1.05	0.030*
		Δz	-0.59 ± 0.67	0.001*
Ectocanine	Right	Δx	-2.12 ± 0.89	0.000*
		Δy	-0.58 ± 0.90	0.009*
		Δz	-0.45 ± 0.54	0.001*
	Left	Δx	2.08 ± 0.92	0.000*
		Δy	-0.43 ± 0.53	0.002*
		Δz	-0.58 ± 0.48	0.000*
Ectomolare	Right	Δx	-2.09 ± 0.67	0.000*
		Δy	-0.27 ± 0.44	0.013*
		Δz	-0.23 ± 0.84	0.228
	Left	Δx	2.02 ± 0.75	0.000*
		Δy	-0.26 ± 0.45	0.020*
		Δz	-0.01 ± 1.25	0.987
Processus Zygomaticus	Right	Δx	-1.63 ± 0.68	0.000*
		Δy	-0.33 ± 0.82	0.091
		Δz	-0.19 ± 0.35	0.023*
	Left	Δx	1.52 ± 0.67	0.000*
		Δy	-0.31 ± 0.85	0.119
		Δz	-0.22 ± 0.36	0.015*

SD, standard deviation; * statistical significance with $p < 0.05$.

Regarding the midpalatal suture, the amount of splits at the ANS (4.83 mm) and PNS (3.95 mm) were statistically significant ($p < 0.001$; Table 4) and the amount of PNS split corresponded to 81.78 % of that of the ANS. Additionally, at the furcation of the maxillary first molars, the alveolar bone width after treatment showed a statistically significant increase of 4.19 mm ($p < 0.001$; Table 4).

Table 4. Lateral displacement of ANS and PNS, and alveolar bone width following expansion.

	Before		After		Difference		p-value
Parameter	Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD	
ANS width	0.00	0.00	4.83	0.53	4.83	0.53	0.000*
PNS width	0.00	0.00	3.95	0.50	3.95	0.50	0.000*
Alveolar bone width	61.97	2.38	66.16	2.55	4.19	0.67	0.000*

ANS, anterior nasal spine; PNS, posterior nasal spine; SD, standard deviation
*Statistically significant at $p < 0.05$.

C. The correlations between hard and soft tissue changes after expansion with MSE

Table 5 shows that while the changes in the x-coordinates of the cheek and alar curvature points on the left side were positively affected by changes in ANS and PNS, those on the right side were negatively affected ($p < 0.01$). Moreover, the changes in the y-coordinates of the cheek and alar curvature points on both sides were negatively affected by the separation at the ANS and PNS ($p < 0.05$).

Table 5. Pearson's correlation between the changes in soft tissue landmarks and in the parameters used in the study.

Parameter			ANS		PNS		Alveolar bone	
Landmark		Axis	Pearson's correlation	p-value	Pearson's correlation	p-value	Pearson's correlation	p-value
Subnasale		z	-0.422	0.064	-0.423	0.063	-0.209	0.376
Cheek point	R	x	-0.912	0.000*	-0.880	0.000*	-0.304	0.192
		y	-0.594	0.006*	-0.576	0.008*	-0.015	0.951
	L	x	0.976	0.000*	0.946	0.000*	0.308	0.187
		y	-0.494	0.027*	-0.494	0.027*	-0.042	0.862
Alar curvature point	R	x	-0.786	0.000*	-0.780	0.000*	-0.411	0.072
		y	-0.487	0.029*	-0.468	0.037*	-0.138	0.563
	L	x	0.906	0.000*	0.883	0.000*	0.316	0.175
		y	-0.559	0.010*	-0.546	0.013*	-0.115	0.515

x, x-axis, the transverse axis; y, y-axis, the anteroposterior axis; z, z-axis, the vertical axis; ANS, anterior nasal spine; PNS, posterior nasal spine; R, right; L, left.
*Statistically significant at $p < 0.05$.

The comparison of the effects of ANS and PNS separation with the movements of cheek and alar curvature points are shown in Table 6. Only the regression coefficients between movement in the x-axis of the cheek points on both sides and the separation at ANS were statistically significant ($p < 0.05$). For these soft tissue points on both sides, the separation measured at the ANS had a stronger effect than that at the PNS.

Table 6. Regression coefficients between the changes in the cheek and alar curvature points on both sides and for ANS and PNS separation.

Variables	Model	Standardized coefficients	p-value

Landmark		Coordinate (Axis)		Beta	
Cheek point	Right	x	ANS	-0.862	0.028*
			PNS	-0.052	0.887
		y	ANS	-0.535	0.457
			PNS	-0.061	0.932
	Left	x	ANS	0.873	0.000*
			PNS	0.107	0.574
		y	ANS	-0.255	0.741
			PNS	-0.249	0.747
Alar curvature point	Right	x	ANS	-0.513	0.358
			PNS	-0.278	0.616
		y	ANS	-0.484	0.535
			PNS	-0.003	0.997
	Left	x	ANS	0.754	0.056
			PNS	0.158	0.672
		y	ANS	-0.451	0.542
			PNS	-0.113	0.878

x, x-axis, the transverse axis; y, y-axis, the anteroposterior axis; ANS, anterior nasal spine; PNS, posterior nasal spine.

*Statistically significant at $p < 0.05$

The unstandardized coefficients produced by regression analysis, shown in Table 7, reflect the expected lateral movement of both cheek points depending on the separation at the ANS, and have high statistical significance ($p < 0.001$). Thus, they can be used to predict the lateral displacement of the cheek points from the split at the ANS using the following regression equations:

$$\text{Cheek point R(x) change} = 1.189 - 0.526 \times \text{ANS separation}$$

$$\text{Cheek point L(x) change} = -1.385 + 0.510 \times \text{ANS separation}$$

Table 7. Regression coefficients between the changes in the cheek points on both sides and the separation at the ANS

Variables			Model	Unstandardized coefficients		p-value
Landmark		Coordinate		Beta	SE	
Cheek point	Right	x	Constant	1.189	0.272	0.000*
			ANS	-0.526	0.056	0.000*
	Left	x	Constant	-1.385	0.129	0.000*
			ANS	0.510	0.027	0.000*

x, x-axis, the transverse axis; SE, standard error; ANS, anterior nasal spine

*Statistically significant at $p < 0.05$.

IV. DISCUSSION

The prediction of the possible changes in soft tissues caused by hard tissue alteration after orthodontic treatment should precede treatment planning because the results have an important influence not only on macroesthetics such as profile, vertical proportion, and nasal projection but also on microesthetics such as smile symmetry and incisor display (Sarver, 2015). Recently, the increased use of MSE in adult patients encountered the concern of clinicians about the impact on facial esthetics. However, limited number of studies have evaluated the effect of MSE on the soft tissues of the mid-facial region in adults (Abedini et al., 2018; Lee et al., 2020).

In this study, we evaluated the mid-facial soft tissue changes following MSE use and their correlation with changes in hard tissues in young adults with transverse maxillary discrepancy using CBCT. We used voxel-based registration, one of the six methods to obtain a rigid registration (Cevidanes et al., 2010), on the cranial base of pre- and post-expansion CBCT images to evaluate soft tissue displacement. A previous study indicated that CBCT overcomes the limitations of 2D radiographs without exposing the patient to high levels of radiation, and allows the simultaneous evaluation of hard and soft tissues (Nur et al., 2016). In recent years, the evaluation of soft tissue displacement using CBCT has become more common (Kim et al., 2012; Lee et al., 2014; Torun et al., 2017). While 3D stereophotogrammetry was used to investigate nasal soft tissue response to MSE, it provided limited information about the underlying skeletal changes and only expansion amount was used for the evaluation of transverse changes (Lee et al., 2020).

Regarding soft tissue changes, we observed lateral and forward movements of the cheek points; and lateral and forward movements of the alar curvature points on both sides. These trends of soft tissue displacement in lateral and forward directions and higher magnitude around the cheek compared to the paranasal area after MSE use were similar to those observed in a previous study using 3D facial scanning (Abedini et al., 2018). In this study, the amount of lateral movement was greater than forward movement while the previous study primarily showed forward direction (Abedini et al., 2018). Another study with MSE using 3D stereophotogrammetry reported an increase in alar base width of 1.214 mm after expansion by 7mm (Lee et al., 2020). This increase was lesser than that observed in this study estimated from the sum of transverse movement of both alar curvature points (2.05 mm). Cheek projection was reported after surgically assisted rapid palatal expansion (SARPE) also and the amount (mean 1.48 mm) was greater than that observed in this study (Nada et al., 2013). Magnusson *et al.* reported an increase in alar base width of 2.88 mm after expansion by over 5 mm with SARPE, which was greater than that of present study after expansion by 6.5 mm. The reason for limited skeletal changes after MSE than those after SARPE is presumed that SARPE could reduce stress to separate the midpalatal suture (Lima et al., 2011). Torun *et al.* reported the cheek projection as 1.6 mm in the prepubertal group after RME which was greater than that of this study. Lateral movements of the alar base, soft tissues over the infraorbital foramen, and soft tissue zygion were previously reported in growing patients after RME (Kim et al., 2012). This discrepancy might be attributable to the age variation among samples and the factor of growth. However, it could hardly be explained simply but might be attributed to the differences in procedure techniques, method of analysis, and individual variations of patients.

The anterior and lateral movements of these soft tissue landmarks could be the result of the corresponding movement of the maxilla, which could be explained by the location of the maxillary rotational fulcrum (Cantarella et al., 2018). The maxilla is located medially and anteriorly relative to this fulcrum. Due to the outward rotation of the zygomaticomaxillary complex around the proximal part of the zygomatic process, each half of the maxilla will be displaced forward and laterally (Cantarella et al., 2018). Additionally, the asymmetrical lateral movement of the cheek and alar curvature points between the left and right side presented in this study could be explained by the unequal movement of the two maxillary bones. Previous studies showed that the displacement of the anterior part of the maxillary bones could affect mid-facial soft tissue during maxillary expansion (Torun et al., 2017) and might result in esthetic alterations in this region, which could become asymmetrical (Cantarella et al., 2017).

In this study, a significant downward movement of the subnasale by 0.34 mm was observed. The amount of displacement was small and less significant. Magusson *et al.* reported significant inferior movement of the subnasale after SARPE, which is consistent with the result of this study. This could be explained by the median and inferior location of the maxilla relative to the fulcrum. Due to the outward rotation of the zygomaticomaxillary complex around the frontozygomatic suture area, the maxillary halves moved downward and outward (Cantarella et al., 2018).

Concerning hard tissue changes, there were significant lateral movements of all evaluated hard tissue landmarks, a significant forward displacement of the A point, prosthion, ectocanine and significant downward shift of the A point following MSE use. These types of movements are consistent with previous studies (Cantarella et al., 2018). The data obtained in this study showed that the midpalatal suture was successfully split in all patients after MSE use. The mean separation at the PNS was about 81.78% of that at the ANS. This ratio demonstrates that MSE created an almost parallel split of the midpalatal suture, in agreement with previous studies (Cantarella et al., 2017; Oh et al., 2019). The amount of separation at the midpalatal suture produced by MSE in this study (4.94 mm at the ANS and 4.01 mm at the PNS) was nearly equivalent to that in the study by Cantarella *et al.* (4.8 mm and 4.3 mm at the ANS and PNS, respectively). In comparison with traditional RPE, expansion by MSE produced much greater suture opening, as compared with the findings of Oh *et al.* using a tooth-anchored maxilla expander (2.97 mm and 2.26 mm at the ANS and PNS, respectively). The reason could be found in the mechanism of action of MSE. This appliance is located in the posterior portion of the hard palate, with 4 bicortical miniscrews positioned medial to the zygomatic buttress, allowing the opening force to be distributed along the entire suture length (Cantarella et al., 2017). As a result, while the tooth-borne maxillary expanders (Hyrax-type expander, RME) created a Vshaped expansion pattern of the maxillary palatal suture, MSE could produce an almost parallel split at the midpalatal suture (Lim et al., 2017). The amount of expansion by the appliance (6.5 mm; range, 5.2-8.0 mm) was calculated according to the patient statement, which was greater than the increase in the ANS/PNS. It could imply errors in counting the number of turns of the appliance. Moreover, the possibility of deformation of the appliance can be expected.

By using Pearson's correlation analysis, the lateral and forward movements of cheek and alar curvature points on both sides correlated with the amount of suture opening at the ANS and PNS after MSE use. The correlation between the lateral changes in bilateral cheek and alar curvature points and hard tissue changes was greater than that seen for the forward changes in soft tissue landmarks and skeletal movements.

The regression coefficients derived from these correlations were used to investigate to what extent the separations at the ANS and PNS affects the changes in soft tissue landmarks. The ANS split had greater effect than the PNS split on the cheek and alar curvature points in the x- and y-axes. The reason could lie in the fact that the ANS is anatomically closer to the cheek and alar curvature points than the PNS. Additionally, the only statistically significant regression coefficients were seen between the lateral movement of the cheek points on both sides and the separation at the ANS. The effect of MSE on soft tissues has rarely been studied using CBCT and up to our knowledge, this is the first study to evaluate the three-dimensional changes in mid-facial soft tissues and correlation of soft tissue changes with underlying skeletal alteration after MSE in young adults. The results suggested that limited changes in cheek point width were observed up to a certain amount of ANS separation (right side by 2.26 mm, left side by 2.71 mm), while they would be increased beyond that point. The sum of the average amount of lateral displacement of both cheek points was 2.43 mm, which is 57.9% of the underlying transverse alveolar expansion and 37.38% of appliance expansion in this study. These findings indicate that clinicians need to be aware of the possibility of this change.

Considering the age of included patients (mean, 22.4 years; range, 17.6–27.1 years) in this study and the short period between T0 and T1, it could be expected that confounding factors such as potential growth and possible weight change of samples were minimized. As the soft tissue changes could be affected by not only the extent and direction of the skeletal movement but multifactorial components such as tonicity of surrounding muscle and tissue thickness, skin elasticity, facial type, and weight change, different results from the same treatment might be demonstrated by individual patients. It is therefore conceivable that some patients could show improvement, while others deterioration (Pangrazio et al., 2012). Nevertheless, this study could be useful for clinicians to provide information for predicting the soft tissue changes related to MSE. The results of this study imply that MSE would be beneficial in young adult patients with narrow face, mid-facial deficiency, and paranasal depression without additional maxillary surgery (Pangrazio et al., 2012) However, this study has limitations, such as a relatively small sample size and short follow-up period. Further prospective research with a larger sample size, using CBCT, is required to evaluate the long-term stability of these changes. Even though the spatial resolution of CBCT scan was reported as 0.22–0.23 mm (Abouei et al., 2015), the results should be interpreted with caution as we have considerable values in tables that are smaller than the spatial resolution (Molen et al., 2010).

V. CONCLUSION

The mid-facial soft tissue landmarks, in particular, the cheek and alar curvature points on both sides, were displaced in forward and lateral directions following MSE use. Opening of the maxillary palatal suture observed at the ANS and PNS correlated with the lateral and forward movements of cheek and alar curvature points on both sides. The correlation between the lateral changes in soft and hard tissue was higher compared to the forward changes. Two regression equations predicting the forward movement of the two cheek points were established.

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-ABSTRACT-

마이크로 임플란트를 이용한 상악골 확장장치 사용 후 중안모의 연조직 변화

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연구 목적: 본 후향적 연구의 목적은 젊은 성인의 미니 스크류를 이용한 상악 골격 확장 장치(MSE)를 사용하여 상악 확장 후 중안모 연조직 변화를 Cone beam computed tomography (CBCT)로평가하여 경조직과 연조직 변화의 상관관계를 평가 하고자 하였다.

연구 재료 및 방법: 상악 횡적 폭경이 부족하여 MSE 로 치료한 20 명의 환자군을 선택하였음.(평균 연령 : 22.4 세, 범위 : 17.6-27.1). 평균 확장량은 6.5 mm 였다. 연조직과 경조직 계측점의 변화를 측정하기 위해 확장 전후에 촬영한 CBCT 이미지를 중첩하였다. 통계적 분석은 데이터 정규성에 따라 paired t-test 와 Pearson 의 상관 관계 분석을 사용하였다

결과: Cheek point 의 평균 측면 이동은 1.35mm (오른쪽), 1.08mm (왼쪽)이었고, Alar curvature point 는 1.03 (오른쪽), 1.02mm (왼쪽) ($p < 0.05$)였다. cheek point 의

평균 전방 변위는 0.59 mm (오른쪽) 및 0.44 mm (왼쪽)이었고, Alar curvature point 의 경우는 0.61 mm (오른쪽) 및 0.77 mm (왼쪽) (p <0.05)였다. 전비극(ANS), 후비극(PNS) 그리고 치조골 폭이 유의미하게 증가했다 (p <0.05). 양측의 cheek point 과 Alar curvature point 의 변화량는 경조직 변화량과 유의미한 상관 관계가 있었다 (p <0.05).

결론: MSE 를 이용한 상악 확장을 한 젊은 성인에서 양측 cheek point 와 Alar curvature point 의 측면 및 전방 움직임이 유의미하게 나타났으며 이를 통해 연조직 움직임을 측정했으며 또한 이것은 치료 전후 ANS 의 변화량과 PNS 의 변화량에서 측정된 상악 봉합 개방과 상관 관계가 있었다.

Keywords: 상악 확장; Micro-implant-supported maxillary skeletal expander (MSE); 연조직 변화.