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Comparison of dentopalatal change after maxillary expansion among three different appliances

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Comparison of dentopalatal change after maxillary expansion among three different appliances

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감사의 글

부족한 저의 논문이 나오기까지 관심과 조언을 아끼지 않고 지도해주신 김경호 교수님을 비롯하여, 차정열 교수님, 최윤정 교수님, 김의성 교수님, 강윤구 교수님께 진심으로 감사의 말씀을 올립니다.

강남 세브란스 병원 교정과에 근무하는 동안 따뜻한 관심과 지도를 베풀어 주신 정주령 교수님, 황순신 교수님을 비롯하여, 힘든 수련 과정에도 묵묵히 저를 도와준 강민지, 장호식, 황우찬 선생을 포함한 의국원들 모두에게도 감사의 마음을 전합니다.

무엇보다도 제가 힘들 때마다 옆에서 큰 힘이 되어주신 부모님과 형, 그리고 힘든 학업과 신혼 생활을 병행하면서도 누구보다도 저를 아껴주고 응원해 준 저의 아내에게 깊은 감사를 드립니다.

부족하나마 정진하고 있는 연구의 길에 이번 학위 논문이 조그마한 결실이 되기를 바라며 언제나 초심을 잃지 않게 해주십사 마음을 모아 기도 드립니다.

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Abstract

Comparison of dentopalatal change after maxillary expansion among three different appliances

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Maxillary expansion is a procedure using transverse dental and maxillary expansion to resolve problems such as dental crowding and posterior crossbite. Methods of maxillary expansion can be divided according to the rate of expansion and the anchors used for expansion. There have been several studies reporting the changes in dentition caused by maxillary expansion, but most previous studies have focused on crown movement, and there is a lack of research on patterns of palatal soft tissue expansion or comparing the effects of multiple appliances.

In this study, using three different types of expansion appliance (bonded RME (rapid maxillary expander), 20 persons; M-S (plate with median screw), 25 persons; RPE (rapid palatal expander),

20 persons), we compared dental and palatal soft tissue changes in an experimental group of 65 patients who underwent maxillary arch expansion and a control group of 46 persons who exhibited growth without any orthodontic treatment. To this end, we scanned dental plaster models from before and after expansion using 3D model scanning, which has excellent precision and reproducibility, superimposed the pre- and post-expansion models based on the medial parts of the anterior 3rd rugae and the median raphe, which are stable structures, and compared expansion patterns of dental and palatal soft tissue expansion. We derived the following results:

1. Compared to the untreated control groups, the three expansion groups all showed significantly greater transverse expansion and angular expansion of the teeth and palatal soft tissue. However, none of the three appliances induced significant changes in palatal height.
2. Compared to the control groups, bending height ratio, which is an indicator of the location of palatal soft tissue expansion, was significantly higher in the anterior and posterior regions when using the bonded RME, and in the posterior region when using the M-S or RPE.
3. When using the bonded RME, the anterior teeth showed a significantly higher expansion ratio, at 74–76% of appliance expansion, than the other two appliances ($P<0.05$); the posterior teeth showed an expansion ratio of 72–73%, and the posterior palatal soft tissue showed an expansion ratio of 45%.
4. When using the M-S, the anterior teeth showed an expansion ratio of 53–64% of appliance expansion, the posterior teeth showed an expansion ratio of 73–85%, and the posterior palatal soft tissue showed an expansion ratio of 43%.

5. When using the RPE, the anterior teeth showed an expansion ratio of 55–61% of appliance expansion; the posterior teeth showed an expansion ratio of 110–117%, which was significantly larger than the other two devices (P<0.01), and the posterior palatal soft tissue showed an expansion ratio of 42%.

Keywords: Maxillary expansion, palatal soft tissue, bonded RME, median screw, RPE

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I. Introduction

Angell first published a study on maxillary expansion in 1860,(Angell, 1860) and the maxillary expansion appliance subsequently manufactured by Hass is still being used in orthodontics in the present day.(Andrew J. Haas, 1965) Maxillary expansion appliances are used to alleviate dental crowding, correct posterior crossbite, and expand the width of the maxilla when narrower than the mandible.(Baccetti, Franchi, Cameron, & McNamara, 2001)

Maxillary expansion can be categorized into slow and rapid expansion, depending on the expansion rate and the magnitude of expansion force. Slow expansion uses a relatively small force to provide treatment over a longer duration, and so it is reported to produce more physiological expansion(LaBlonde, Vich, Edwards, Kula, & Ghoneima, 2017; Martina et al., 2012) and more expansion of the posterior teeth compared to rapid expansion.(Zhou et al., 2014) However, the other study reported less buccal alveolar bone loss in rapid expansion.(Brunetto et al., 2013) Moreover, there are conflicting reports that both methods can cause periodontal issues.(Mummolo et al., 2014)

Depending on the anchors used, maxillary expansion appliances include tooth-borne appliances, which are anchored to the teeth, tooth and tissue-borne appliances, which are anchored to the teeth and palatal soft tissue, or the recently introduced tooth and bone-borne (or bone-borne) miniscrew-assisted rapid palatal expanders (MARPEs), which are anchored to the teeth and miniscrews placed in the hard palate. Lagravère et al.(Lagravère, Gamble, Major, & Heo, 2013) reported that using tooth-borne appliances for maxillary expansion results in posterior buccal crown tipping, especially of the premolars. Other studies have also reported that these appliances produce significant transverse expansion but no significant anteroposterior changes.(D'Souza, Kumar, & Shetty, 2015) According to a recent systematic review, the majority of devices produced significant midpalatal suture opening, but there is still a lack of evidence regarding the dental tipping effects.(Algharbi, Bazargani, & Dimberg, 2018)

Maxillary expansion shows different patterns depending on whether or not there is midpalatal suture opening. A systematic review reported midpalatal suture opening was affected by bone density at the suture, which is age-dependent. However, the type of appliance had no significant effect, and the magnitude of expansion was more important than the activation frequency.(Liu, Xu, & Zou, 2015)

Thus, previous studies have mostly observed changes in the teeth and periodontal tissue, focusing on crown movement. As tooth movement affects remodeling of the periodontal tissue, including the alveolar bone, so suture opening and maxillary expansion inevitably cause changes in the shape of the palatal soft tissue. However, there has still been almost no research on changes in the palatal soft tissue which could alter intraoral functions, such as pronunciation, swallowing, or tongue positions. Also, there are lack of researches comparing the expansion efficiency or dental tipping effects when using different expansion appliances.

In order to study maxillary arch expansion, posteroanterior/lateral cephalograms or dental plaster models have been used for analysis, but recent advances in 3-dimensional (3D) model scanning and software have provided much information that could not be observed with previous methods. 3D model scanning has excellent precision and reproducibility,(Sousa, Vasconcelos, Janson, Garib, & Pinzan, 2012) and unlike previous studies using plaster models, is able to provide information about various sections making it useful for observing changes, such as remodeling or expansion patterns, in not only the teeth, but also the palatal soft tissue.

In the present study, we used three different expansion appliances that are commonly used for maxillary expansion in growing children (bonded rapid maxillary expander [RME], plate with median screw [M-S], rapid palatal expander [RPE]), and compared the dentopalatal change of three expansion groups to those of control group who underwent no orthodontic treatments by 3D scanning of dental plaster models. Also, we compared the dentopalatal change after maxillary expansion achieved by three different expansion appliances. The null hypotheses were as follows: The differences of dentopalatal change between experimental and control groups, and between three expansion groups would not be significant.

II. Materials and Methods

1. Materials

There were 268 patients who had visited the Department of Orthodontics, Gangnam Severance Hospital between 2012 and 2018, and received maxillary expansion treatment using a bonded RME, M-S, or RPE (Bonded RME, 67 patients; M-S, 122 patients; RPE, 79 patients). The average maxillary expansion treatment duration was 0.64-0.88 years. All three appliances were used for maxillary arch expansion, and no specific appliance was selected based on the amount of expansion. However, depending on whether or not 1st premolar had erupted, a bonded RME was used before eruption and an RPE was used after eruption. Patients satisfying the following conditions were included in the experimental groups.

1) Dental plaster models prepared before and after maxillary expansion; 2) No appliance detachment or breakage during treatment; 3) No defects or inflammation-related edema that could interfere with measurement of the plaster model; 4) No specific systemic disease or jaw deformities; 5) No previous experience of orthodontic treatment; 6) No change to crown morphology, e.g. due to a prosthesis or trauma

Meanwhile, the control groups consisted of children from Institute of Craniofacial Deformity, College of Dentistry, Yonsei University. Those children did not receive any orthodontic treatment, and had plaster models fabricated at a 1-year interval to monitor changes in the maxillary arch, and satisfied the above conditions. Children of control group 1 were selected to match the age of bonded RME and M-S groups, while those of control group 2 were selected to match the age of RPE group.

A total of 65 subjects were finally selected for the experimental groups (bonded RME, 20 patients (4 males, 16 females); M-S, 25 patients (10 males, 15 females); RPE, 20 patients (10 males, 10 females)). There were 27 patients selected to control group 1 (10 males, 17 females), and 19 patients selected to control group 2 (9 males, 10 females). The characteristics of the experimental and control groups are summarized in Table 1.

Table 1. Demographic features of experimental and control groups

	Experimental groups			Control groups		
	Bonded RME (n=20)	M-S (n=25)	RPE (n=20)	Control 1 (n=27)	Control 2 (n=19)	*P*-value
Gender						
Male	4 (20.0%)	10(40.0%)	10(50.0%)	10(37.0%)	9(47.4%)	0.284
Female	16 (80.0%)	15(60.0%)	10(50.0%)	17(63.0%)	10(52.6%)	
Skeletal Class						
I	4(20.0%)	11(44.0%)	5 (25.0%)	12(44.4%)	6(31.6%)	
II	1(5.0%)	10 (40.0%)	7 (35.0%)	14(51.9%)	13(68.4%)	<0.001***
III	15(75.0%)	4 (16.0%)	8 (40.0%)	1(3.7%)	0(0.0%)	
Age(year)						
T1	7.40±0.36a	9.24±2.70a	13.20±2.84b	8.63±1.34a	11.74±1.15b	<0.001***
T2	8.17±1.62a	10.12±2.61a	13.84±2.80b	9.63±1.34a	12.74±1.15b	<0.001***
T2-T1	0.76±0.44ab	0.88±0.41ab	0.64±0.48a	1.00±0.00b	1.00±0.00b	<0.01**
ANB(°)						
T1	0.78±1.91a	3.68±2.10b	2.57±3.84ab	3.04±1.61b	4.46±1.39b	<0.001***
T2	1.04±1.43a	3.40±1.80b	3.25±3.41b	3.51±1.64b	4.59±1.46b	<0.001***
T2-T1	0.26±2.02	-0.28±0.87	0.32±1.42	0.47±1.41	0.12±0.73	0.498
SN-MP(°)						
T1	37.96±5.02	37.81±4.72	39.59±6.99	37.95±4.53	37.95±4.81	0.805
T2	39.02±6.28	37.74±4.98	40.70±6.68	37.80±5.21	38.12±4.76	0.446
T2-T1	1.06±2.08	-0.07±2.42	1.11±2.04	-0.15±1.76	0.18±1.48	0.414

T1, before expansion (experimental groups), before growth (control groups); T2, after expansion (experimental groups), after growth (control groups)

Chi-square test was done for comparison of gender between groups

Fisher's exact test was done for comparison of skeletal Class between groups

One-way ANOVA and Bonferroni's post-hoc test were done for comparison of age, ANB, and SN-MP

** *P* <0.01; *** *P* <0.001; Bonferroni corrected post hoc test was done, a<b

2. Methods

As a retrospective study, this was conducted after review and approval by the Gangnam Severance Hospital institutional review board (IRB no.: 3-2017-0320).

2-1. Maxillary expansion appliance design

For the bonded RME, resin blocks (Band-Lok®, Reliance Orthodontic Products, Illinois, USA) were bonded to the teeth to cover the occlusal surfaces of all deciduous molars, premolars, and molars bilaterally, and a Biederman type expander was used. The resin block thickness was around 1–3 mm from the occlusal surface of the posterior teeth, and patients were instructed to turn the expander one quarter of a turn per day. In the case of patients needing to wear a face mask for treatment of skeletal Class III malocclusion, maxillary expansion was performed first, and face mask treatment was started after obtaining the expansion data.

The M-S was designed to cover the entire palate with resin, and retention was provided by an Adams clasp on both 1st molars or deciduous 2nd molars, and labial bow on the anterior teeth. Patients were instructed to turn the screw one quarter of a turn per week, and to wear the expander for as much time as possible, excluding meals and during oral hygiene management.

For the RPE, bands (Band-Lok®, Reliance Orthodontic Products, Illinois, USA) were bonded to the 1st premolars and 1st molars bilaterally, and a Biederman type expander was used anchored to these four teeth. The patients were instructed to turn the expander one quarter of a turn per day (Figure 1).

The aim of maxillary expansion is to resolve arch length discrepancy, and to provide transverse expansion when the maxillary arch is too narrow compared to the mandibular arch. Expansion is performed until the palatal cusps of the maxillary posterior teeth do not go beyond the buccal cusps of the mandibular posterior teeth.

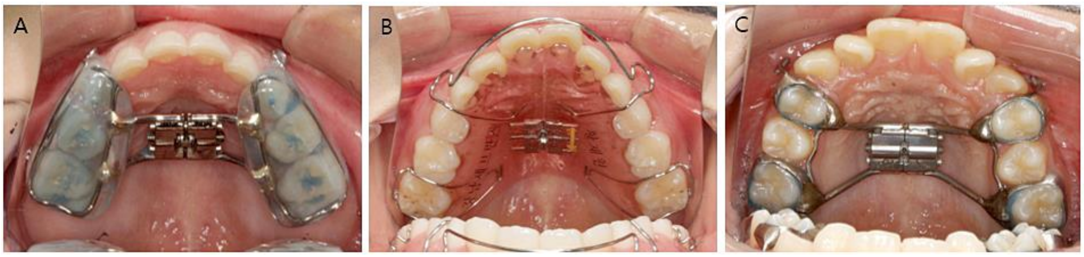


Figure 1. Expansion appliances in this study.

A, Bonded rapid maxillary expander (RME); B, Plate with median screw (M-S); C, Rapid palatal expander (RPE)

2-2. Dental plaster model fabrication before and after expansion and 3D model scanning

Dental impressions were taken before and after maxillary expansion from experimental groups, before and after growth from control groups, and plaster models were fabricated. For the bonded RME, M-S, and RPE groups, after expansion had been completed, the appliances were retained in the mouth for 3–6 months and then impressions were taken. The dental plaster models were scanned using a 3D model scanner (Freedom HD, DOF, California, USA; Definition, 2.0 megapixel; Accuracy, 10 μm).

2-3. 3D model superimposition and setting the reference planes

During maxillary expansion treatment in growing children, the medial parts of the anterior 3rd rugae and the median raphe are known to be stable structures.(Canan & Şenışık, 2017; Kim, Moon, Lee, & Park, 2012) Using these as a reference, 3D models from before and after expansion or growth were superimposed (Rapidform2006, INUS, Seoul, Korea) (Figure 2).

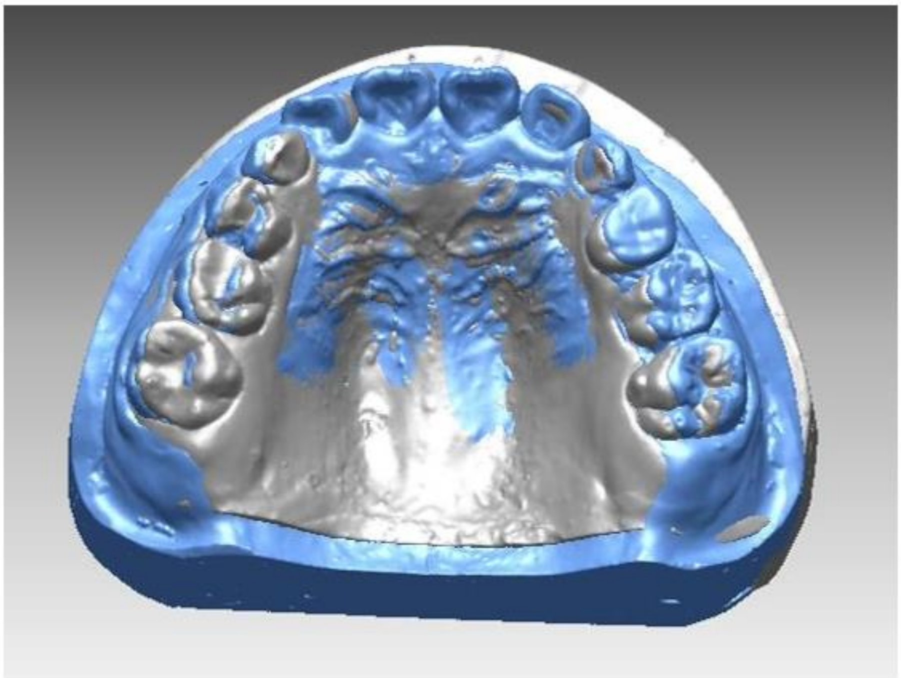


Figure 2. Superimposition of 3 dimensional models before (gray) and after (blue) expansion.

The reference planes were set using the 3D models before expansion (T1). The midpoint of the line (x axis) connecting the bilateral 1st molars at the point (G6R1, G6L1) where the palatal grooves meet the gingival margins was defined as (0,0,0). The line connecting (0,0,0) with the gingival embrasure between the maxillary central incisors (or deciduous central incisors) was defined as the y axis. The plane containing the x and y axes was defined as the horizontal reference plane. The line passing through (0,0,0) at a perpendicular angle to the horizontal reference plane was defined as the z axis. The plane perpendicular to the horizontal reference plane and including the line connecting the most prominent points (G3R1, G3L1) of the palatal gingival margins of canines (or deciduous canines) was defined as the anterior vertical plane. By the same method, the posterior vertical plane was defined as the plane perpendicular to the horizontal reference plane and including the x axis (Figure 3).

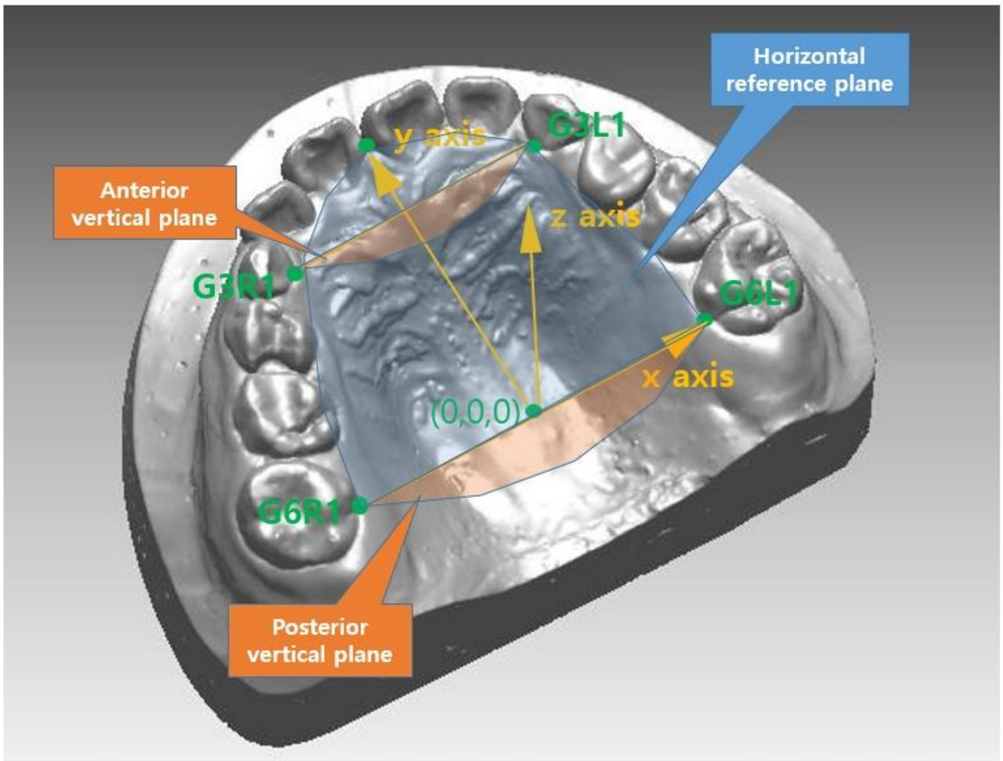


Figure 3. X, y, and z axes and reference planes.

2-4. Measurement of 3D scanned models from before and after expansion (before and after growth)

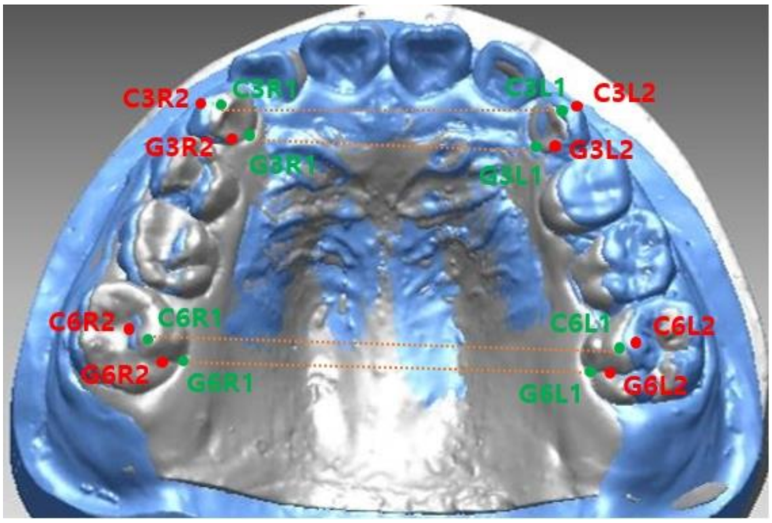
2-4-1. Transverse expansion of the teeth and palatal soft tissue

We measured the transverse expansion of the anterior (canines, deciduous canines) and posterior (1st molar) teeth on the cusp tip and gingival margin levels, and the posterior palatal soft tissue on the vertical level of 1st molar's center of resistance.

Before expansion (T1), C3R1, C3L1, C6R1, and C6L1 were defined as the mesio-palatal cusps of the bilateral deciduous canines, canines, or 1st molars. G3R1, G3L1, G6R1, and G6L1 were on the gingival margin. P6R1 and P6L1 were defined as the points in the posterior vertical plane at the height of the center of resistance of 1st molars. For the 1st molar, the center of resistance was set as the furcation level.(Abe, Taji, Hiasa, Tsuga, & Akagawa, 2010; Black, 1897; Dermaut, Kleutghen, & De Clerck, 1986) (The height of the center of resistance for the first molars is 5.0mm inferior following the vertical axis (z axis) from the gingival margin.) However, the height of the palatal vault in the anterior vertical plane is too low, the anterior (deciduous canines and canines) palatal soft tissue on the center of resistance level could not be measured.

By the same method, the points C3R2, C3L2, C6R2, C6L2, and G3R2, G3L2, G6R2, G6L2, and P6R2, P6L2 were defined in the anterior and posterior palate in models after expansion (T2).

Transverse expansion was calculated by comparing the distance at T1 with the distance at T2 on cusp tip levels (C3R1-C3L1 to C3R2-C3L2, C6R1-C6L1 to C6R2-C6L2), gingival margin levels (G3R1-G3L1 to G3R2-G3L2, G6R1-G6L1 to G6R2-G6L2), and 1st molar's center of resistance level (P6R1-P6L1 to P6R2-P6L2) (Figure 4).



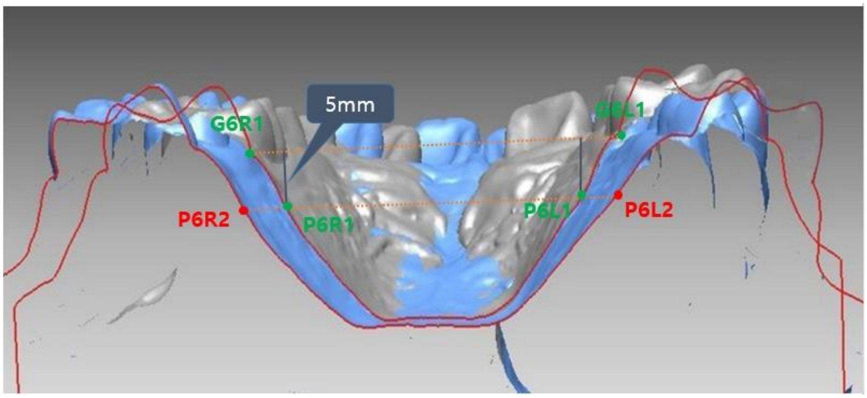


Figure 4. Measurements of transverse expansion.

Transverse expansion on the cusp tip levels, the linear differences between C3R1-C3L1 and C3R2-C3L2, C6R1-C6L1 and C6R2-C6L2; Transverse expansion on the gingival margin levels, the linear differences between G3R1-G3L1 and G3R2-G3L2, G6R1-G6L1 and G6R2-G6L2; Transverse expansion on the 1st molar's center of resistance levels, the linear differences between P6R1-P6L1 and P6R2-P6L2; Gray model, model before expansion; Blue model, model after expansion

2-4-2. Dental and palatal soft tissue expansion ratios

The expansion ratios were defined as the relative amount of transverse expansion of the teeth and the palatal soft tissue if the total width of expansion of the bonded RME, M-S, or RPE appliance is taken to be 1.

2-4-3. Angular expansion of the teeth and palatal soft tissue

In the anterior/posterior vertical plane before expansion (T1), the apex of the palatal vault was defined as Aa1 and Ap1, respectively. Angular expansion was defined as the differences of the angles of the cusp tips (C3R1-Aa1-C3L1, C6R1-Ap1-C6L1), of the gingival margins (G3R1-Aa1-G3L1, G6R1-Ap1-G6L1), and of the palatal soft tissue (P6R1-Ap1-P6L1) before expansion (T1) with the angles of the cusp tips (C3R2-Aa1-C3L2, C6R2-Ap1-C6L2), of the gingival margins (G3R2-Aa1-G3L2, G6R2-Ap1-G6L2), and of the palatal soft tissue (P6R2-Ap1-P6L2) after expansion (T2) (Figure 5).

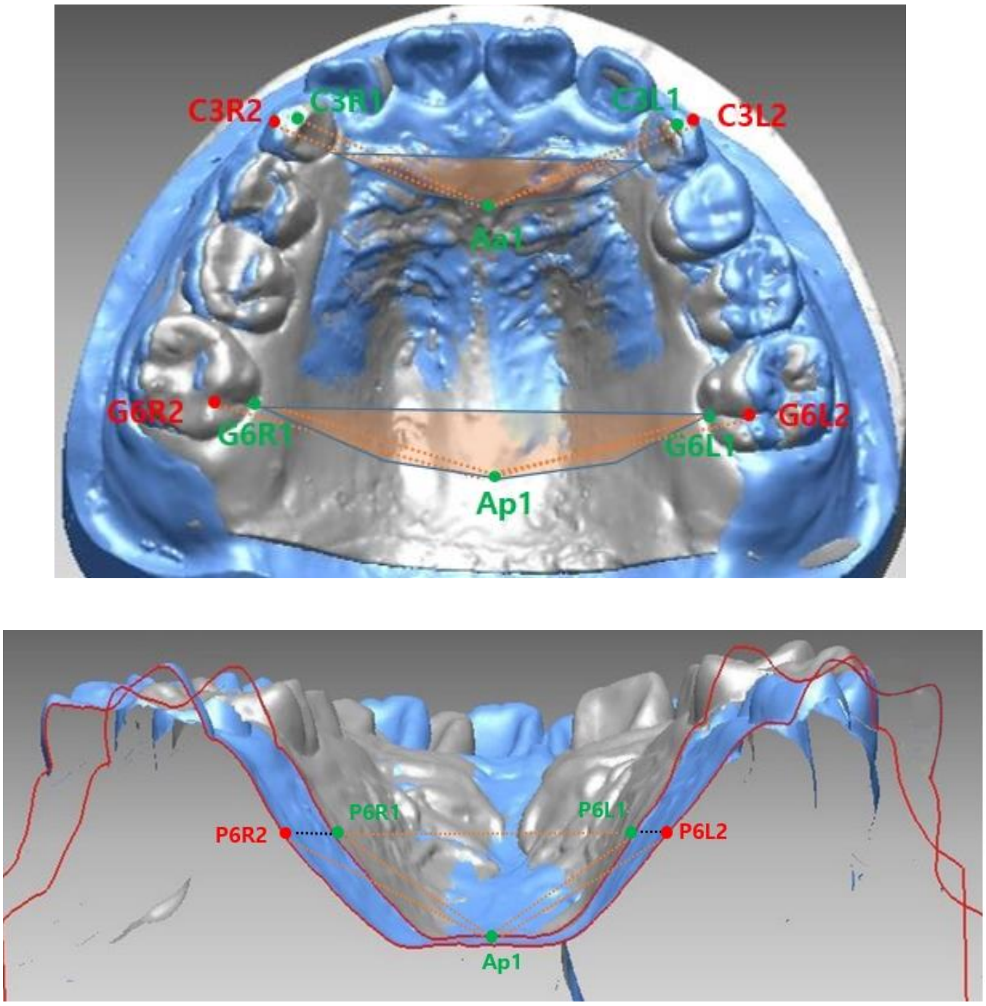


Figure 5. Measurements of angular expansion.

Angular expansion on cusp tips is presented, angular changes between C3R1-Aa1-C3L1 and C3R2-Aa1-C3L2; Angular expansion on gingival margins is presented, angular changes between G6R1-Ap1-G6L1 and G6R2-Ap1-G6L2; Angular expansion on palatal soft tissue is presented, angular changes between P6R1-Ap1-P6L1 and P6R2-Ap1-P6L2 are presented; Gray model, model before expansion; Blue model, model after expansion

2-4-4. Palatal height change

The anterior and posterior palatal height before expansion were defined as Ha1 and Hp1, which were vertical distance from the horizontal reference plane to Aa1 and Ap1.

The anterior and posterior apexes of the palatal vault after expansion were defined as Aa2 and Ap2, respectively. The anterior and posterior palatal height after expansion were defined as Ha2 and Hp2, which were vertical distance from the horizontal reference plane to Aa2 and Ap2.

The anterior and posterior palatal height changes were defined as the linear distance changes between Ha1 and Ha2, and between Hp1 and Hp2, respectively (Figure 6).

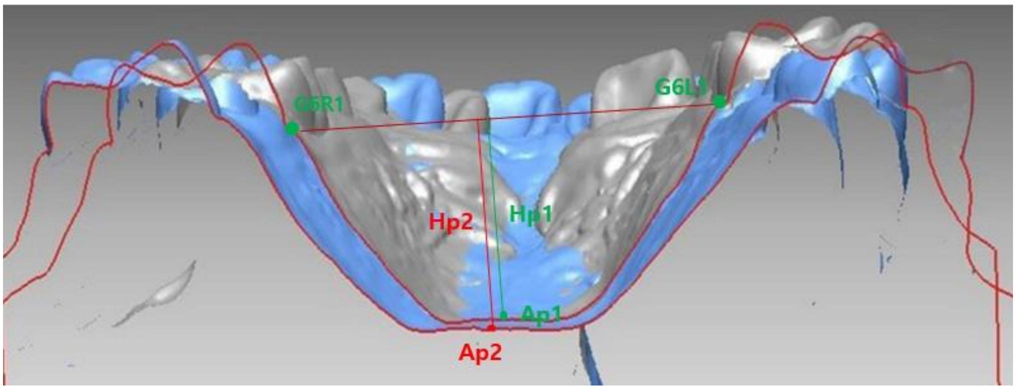


Figure 6. Measurements of palatal height change.

Posterior palatal height change is presented, the linear distance change between Hp1 (T1) and Hp2 (T2)

2-4-5. Bending height ratio

Palatal bending points were defined as the points of intersection between the palatal soft tissue sections in the anterior/posterior vertical plane at T1 and the sections at T2. The bending height ratio was defined as the perpendicular distance from the G3R1-G3L1 (or G6R1-G6L1) to the palatal bending point divided by Ha1 (or Hp1). Here, a positive value indicates palatal soft tissue expansion in the occlusal direction from the palatal bending point, and a negative value indicates palatal soft tissue constriction in the occlusal direction (Figure 7).

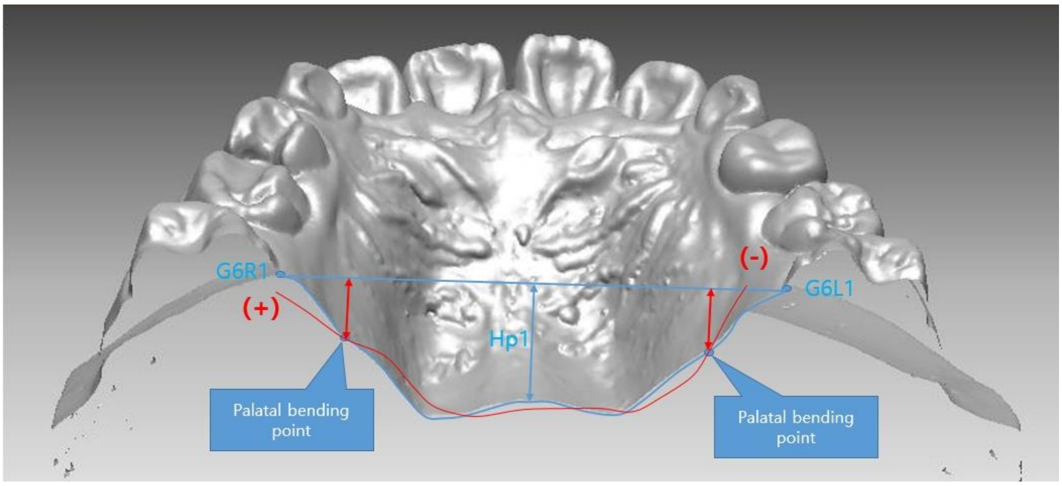


Figure 7. Measurements of bending height ratio.

Posterior vertical plane is presented. Bending height ratio means the perpendicular distance from G6R1-G6L1 line to the palatal bending point divided by Hp1; The positive bending height ratio means the palatal soft tissue expanded from palatal bending point after expansion; the negative bending height ratio means the palatal soft tissue constricted from palatal bending point after expansion

3. Statistical analysis

In order to compare gender ratios between the 3 experimental groups using different expansion appliances and the 2 control groups, chi-square test was done. In order to compare the distribution of skeletal Class I, II, and III patients, Fisher's exact test was done. In order to analyze differences in age, ANB(°), and SN-MP(°), one-way analysis of variance (ANOVA) and Bonferroni post-hoc testing was done.

In order to compare transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio according to measurement location in each experimental group, linear mixed model was done. Also, in order to compare the experimental groups with the control groups, and to compare between the experimental groups, linear mixed models were done.

Multiple regression analysis was done to investigate the effects of appliance expansion, appliance type, gender, age before expansion, ANB(º), SN-MP(º), and deciduous or permanent teeth on transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio.

Transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio were all measured by a single orthodontist. To test for measurement error, measurements were repeated 2 weeks later for samples from 10 randomly selected patients, and the intraclass correlation coefficients were inspected.

All tests were performed with a significance level of $P<0.05$, and all data was processed using SPSS version 23 (IBM®, NY, USA).

III. Results

1. Intraclass correlation coefficients

Measurement of transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio in the dental and palatal soft tissue from 3D scanned models showed high reliability, with intraclass correlation coefficients in the range r=0.945–0.999.

2. Comparison of transverse expansion, angular expansion, palatal height change, and bending height ratio between experimental groups and control groups

2-1. Bonded RME, M-S expansion groups vs control group 1 (Table 2)

In order to compare transverse expansion, angular expansion, palatal height change, and bending height ratio between expansion treatment and no treatment (i.e., changes due to growth), we compared the bonded RME and M-S expansion groups with control group 1.

Transverse expansion and angular expansion were significantly larger at all locations in the two experimental groups compared to control group 1 (P<0.001).

Palatal height changes of two expansion groups were -0.08-0.06 mm in either the anterior or the posterior region, showing no significant differences compared to control group 1 (P>0.05).

Bending height ratio was significantly higher in the anterior and posterior regions in the bonded RME group and in the posterior region in M-S expansion group compared to control group 1 (P<0.001).

Table 2. Comparisons of transverse expansion, angular expansion, palatal height change, and bending height ratio between bonded RME, M-S expansion groups and control group 1.

Locations	Bonded RME	M-S	Control 1	p-value
Transverse expansion (mm)				
Anterior _cusp tip	3.00±0.33b	3.76±0.32b	0.76±0.40a	<0.001***
Anterior _gingival margin	3.11±0.32b	3.14±0.30b	0.56±0.37a	<0.001***
Posterior _cusp tip	2.93±0.30b	5.00±0.28c	0.96±0.32a	<0.001***
Posterior _gingival margin	2.97±0.31b	4.30±0.29c	0.71±0.32a	<0.001***
Posterior _palatal Soft tissue	1.83±0.29b	2.56±0.27b	0.49±0.33a	<0.001***
Angular expansion (°)				
Locations	**Bonded RME**	**M-S**	**Control 1**	p-value
Anterior _cusp tip	3.77±1.07b	3.47±0.70b	-0.90±0.97a	<0.001***
Anterior _gingival margin	3.13±1.04b	1.14±0.68b	-1.94±0.91a	<0.001***
Posterior _cusp tip	4.44±0.98b	4.54±0.63b	0.08±0.75a	<0.001***
Posterior _gingival margin	4.49±1.09b	2.25±0.64b	-0.70±0.76a	<0.001***
Posterior _palatal Soft tissue	3.51±0.98b	2.54±0.62b	0.95±0.76a	<0.001***
Palatal height change (mm)				
Locations	**Bonded RME**	**M-S**	**Control 1**	p-value
Anterior	0.06±0.09	-0.05±0.11	0.10±0.10	0.411
Posterior	-0.08±0.08	0.02±0.10	0.09±0.09	1.000
Bending height ratio				
Locations	**Bonded RME**	**M-S**	**Control 1**	p-value
Anterior	0.62±0.04b	0.25±0.10 ab	-0.10±0.13 a	<0.001***
Posterior	0.97±0.03b	0.83±0.09b	-0.08±0.11a	<0.001***

Linear mixed model was used.

*** *P* <0.001; Bonferroni corrected post hoc test was done, a<b

2-2. RPE expansion group vs control group 2 (Table 3)

In order to compare transverse expansion, angular expansion, palatal height change, and bending height ratio between expansion treatment and no treatment, we compared the RPE expansion group with control group 2.

Transverse and angular expansion were significantly larger in the RPE group than control group 2 at all locations (P<0.05).

Palatal height change of RPE group was -0.03-0.14 mm in the anterior and posterior regions, showing no significant differences compared to control group 2 (P>0.05).

Bending height ratio was significantly larger in the RPE expansion group in the posterior region compared to control group 2 (P<0.001).

Table 3. Comparisons of transverse expansion, angular expansion, palatal height change, and bending height ratio between RPE expansion group and control group 2.

Locations	RPE	Control 2	p-value
Transverse expansion (mm)			
Anterior _cusp tip	3.11±0.43	0.13±0.41	<0.001***
Anterior _gingival margin	2.79±0.42	-0.08±0.39	<0.001***
Posterior _cusp tip	5.96±0.40	0.42±0.35	<0.001***
Posterior _gingival margin	5.60±0.41	0.60±0.34	<0.001***
Posterior _palatal Soft tissue	2.12±0.38	0.22±0.36	<0.01**
Angular expansion (°)			
Locations	**RPE**	**Control 2**	p-value
Anterior _cusp tip	2.65±1.37	-3.54±1.20	<0.001***
Anterior _gingival margin	1.03±1.32	-1.80±1.17	<0.05*
Posterior _cusp tip	7.04±1.24	-1.94±1.12	<0.001***
Posterior _gingival margin	6.04±1.25	-1.66±1.23	<0.001***
Posterior _palatal Soft tissue	3.48±1.20	0.55±1.15	<0.05*
Palatal height change (mm)			
Locations	**RPE**	**Control 2**	p-value
Anterior	-0.03±0.22	-0.07±0.17	0.658
Posterior	0.14±0.20	0.05±0.16	0.723
Bending height ratio			
Locations	**RPE**	**Control 2**	p-value
Anterior	0.05±0.17	-0.41±0.16	0.057
Posterior	0.79±0.11	-0.14±0.14	<0.001***

Linear mixed model was used.

* *P*<0.05, ** *P* <0.01, *** *P* <0.001

3. Transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio of different expansion appliances

3-1. Bonded RME expansion group (Table 4)

The mean appliance expansion in patients treated with the bonded RME was 4.08 mm. The posterior palatal soft tissue showed the least expansion (1.83 mm, $P<0.01$), and the other 4 locations all showed similar expansion of around 3.0 mm.

The expansion ratios of anterior and posterior teeth on cusp tip and gingival margin were 0.72-0.76, and that of the posterior palatal tissue was 0.45 ($P<0.01$).

Angular expansions were 3.13-4.49 degrees showing no significant differences by position ($P>0.05$).

Palatal height changes of anterior and posterior regions did not show significant changes ($P>0.05$).

Bending height ratio was significantly smaller in the anterior region (0.62) compared to the posterior region (0.97) ($P<0.001$). This indicates that expansion of the palatal soft tissue occurs in a more occlusal location in the anterior region compared to the posterior region.

Table 4. Transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio of bonded RME expansion group

Locations / Variables	Anterior _cusp tip	Anterior _gingival margin	Posterior _cusp tip	Posterior _gingival margin	Posterior _palatal soft tissue	p-value
Transverse expansion (mm)	3.00±0.33b	3.11±0.32 b	2.93±0.30b	2.97±0.31b	1.83±0.29 a	<0.01**
Expansion ratio	0.74±0.08b	0.76±0.08b	0.72±0.07b	0.73±0.08b	0.45±0.06a	<0.01**
Angular expansion (°)	3.77±1.07	3.13±1.04	4.44±0.98	4.49±1.09	3.51±0.98	1.000

Locations / Variables	Anterior	Posterior	p-value
Palatal height change (mm)	0.06±0.09	-0.08±0.08	0.103
Bending height ratio	0.62±0.04	0.97±0.03	<0.001***

Average expansion amount of bonded RME appliance was 4.08 mm

Linear mixed model was used.

** *P* <0.01; *** *P* <0.001; Bonferroni corrected post hoc test was done, a<b

3-2. M-S expansion group (Table 5)

The mean appliance expansion in patients treated with the M-S was 5.91 mm. The greatest expansion was observed at the posterior cusp tip (5.00 mm), and the least expansion was observed at the posterior palatal soft tissue (2.56 mm) (P<0.001).

Expansion ratios were 0.53-0.64 on the anterior teeth region, 0.73-0.85 on the posterior teeth region, and 0.43 on the posterior palatal soft tissue (P<0.001).

Angular expansion was largest at the posterior teeth cusp tips (4.54 º) (P<0.001).

Palatal height changes of anterior and posterior regions did not show significant changes (P>0.05), and bending height ratio was significantly larger in the posterior region (0.83) compared to the anterior region (0.25) (P<0.001).

Table 5. Transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio of M-S expansion group

Locations / Variables	Anterior _ cusp tip	Anterior _gingival margin	Posterior _cusp tip	Posterior _gingival margin	Posterior _palatal Soft tissue	p-value
Transverse expansion (mm)	3.76±0.32bc	3.14±0.30b	5.00±0.28d	4.30±0.29c	2.56±0.27a	<0.001***
Expansion ratio	0.64±0.06ab	0.53±0.06a	0.85±0.05c	0.73±0.07b	0.43±0.04a	<0.001***
Angular expansion (°)	3.47±0.70ab	1.14±0.68a	4.54±0.63b	2.25±0.64a	2.54±0.62a	<0.001***
Locations / Variables	**Anterior**	**Posterior**	**p-value**			
Palatal height change (mm)	-0.05±0.11	0.02±0.10	0.799			
Bending height ratio	0.25±0.10	0.83±0.09	<0.001***			

Average expansion amount of M-S appliance was 5.91 mm

Linear mixed model was used.

*** P <0.001; Bonferroni corrected post hoc test was done, a<b<c<d

3-3. RPE expansion group (Table 6)

The mean appliance expansion in patients treated with the RPE was 5.10 mm. The largest transverse expansion, expansion ratio, and angular expansion were observed at the posterior cusp tip (5.96 mm, 1.17, 7.04°, respectively) and gingival margin (5.60 mm, 1.10, 6.04°, respectively) ($P<0.001$).

Palatal height changes of anterior and posterior regions did not show significant changes ($P>0.05$), and bending height ratio was significantly larger in the posterior region (0.79) compared to the anterior region (0.05) ($P<0.01$).

Table 6. Transverse expansion, expansion ratio, angular expansion, palatal height change, and bending points of RPE expansion group

Locations / Variables	Anterior _cusp tip	Anterior _gingival margin	Posterior _cusp tip	Posterior _gingival margin	Posterior _palatal Soft tissue	p-value
Transverse expansion (mm)	3.11±0.43a	2.79±0.42a	5.96±0.40b	5.60±0.41b	2.12±0.38a	<0.001***
Expansion ratio	0.61±0.08a	0.55±0.07a	1.17±0.07b	1.10±0.08b	0.42±0.05a	<0.001***
Angular expansion (°)	2.65±1.37ab	1.03±1.32a	7.04±1.24c	6.04±1.25c	3.48±1.20b	<0.001***

Locations / Variables	Anterior	Posterior	p-value
Palatal height change (mm)	-0.03±0.22	0.14±0.20	0.648
Bending height ratio	0.05±0.17	0.79±0.11	<0.01**

Average expansion amount of RPE appliance was 5.10 mm

Linear mixed model was used.

** *P* <0.01, *** *P* <0.001; Bonferroni corrected post hoc test was done, a<b<c

4. Comparison of transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio between the three expansion groups (Table 7, Figure 8-12)

Differences between the Bonded RME, M-S, and RPE expansion groups were compared at each location.

When transverse expansion was compared, there were no significant differences between the three groups in the anterior region (2.79-3.76 mm). In the posterior region, the M-S (5.00 mm) and RPE groups (5.96 mm) showed significantly greater expansion than the bonded RME group (2.93 mm) at the cusp tip ($P<0.001$), and at the gingival margins, the RPE group (5.60 mm) showed significantly greater expansion than the other two groups ($P<0.001$). However, there were no significant differences between the three groups in the posterior palatal soft tissue (1.83-2.56 mm) ($P>0.05$).

When expansion ratio was compared, there were no significant differences between the three groups at the cusps in the anterior region (0.61-0.74) ($P>0.05$). At the gingival margins in the anterior region, the Bonded RME group (0.76) showed significantly greater expansion than the other two groups (0.53-0.55) ($P<0.05$). In the posterior region, at the cusps and the gingival margins, the RPE group (1.10-1.17) showed significantly greater expansion than the other two groups (0.72-0.85) ($P<0.01$). However, at the posterior palatal soft tissue, there were no significant differences between the three groups (0.42-0.45) ($P>0.05$).

Angular expansion was significantly higher in the RPE group at the posterior cusp tips (7.04°) and gingival margins (6.04°) ($P<0.05$).

Palatal height changes of anterior and posterior regions did not show significant differences between the three expansion groups (-0.08-0.14 mm) (P>0.05).

Bending height ratio, in the anterior region, was significantly higher in the Bonded RME group (0.62) than the other two groups (0.05-0.25) (P<0.05). In the posterior region, there were no significant differences between the three groups (0.79-0.97) (P>0.05).

Table 7. Comparisons of transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio between bonded RME, M-S, and RPE expansion groups.

Locations	Transverse expansion (mm)			
	Bonded RME	**M-S**	**RPE**	p-value
Anterior _cusp tip	3.00±0.33	3.76±0.32	3.11±0.43	0.157
Anterior _gingival margin	3.11±0.32	3.14±0.30	2.79±0.42	0.287
Posterior _cusp tip	2.93±0.30a	5.00±0.28b	5.96±0.40b	<0.001***
Posterior _gingival margin	2.97±0.31a	4.30±0.29ab	5.60±0.41b	<0.001***
Posterior _palatal Soft tissue	1.83±0.29	2.56±0.27	2.12±0.38	0.493
	Expansion ratio			
Locations	**Bonded RME**	**M-S**	**RPE**	p-value
Anterior _cusp tip	0.74±0.08	0.64±0.06	0.61±0.08	0.164
Anterior _gingival margin	0.76±0.08b	0.53±0.06a	0.55±0.07a	<0.05*
Posterior _cusp tip	0.72±0.07a	0.85±0.05a	1.17±0.07b	<0.01**
Posterior _gingival margin	0.73±0.08a	0.73±0.07a	1.10±0.08b	<0.01**
Posterior _palatal Soft tissue	0.45±0.06	0.43±0.04	0.42±0.05	0.872

	Angular expansion (°)			
Locations	**Bonded RME**	**M-S**	**RPE**	p-value
Anterior _cusp tip	3.77±1.07	3.47±0.70	2.65±1.37	0.536
Anterior _gingival margin	3.13±1.04	1.14±0.68	1.03±1.32	0.275
Posterior _cusp tip	4.44±0.98a	4.54±0.63a	7.04±1.24b	<0.05*
Posterior _gingival margin	4.49±1.09ab	2.25±0.64a	6.04±1.25b	<0.05*
Posterior _palatal Soft tissue	3.51±0.98	2.54±0.62	3.48±1.20	0.545
	Palatal height change (mm)			
Locations	**Bonded RME**	**M-S**	**RPE**	p-value
Anterior	0.06±0.09	-0.05±0.11	-0.03±0.22	0.118
Posterior	-0.08±0.08	0.02±0.10	0.14±0.20	0.649
	Bending height ratio			
Locations	**Bonded RME**	**M-S**	**RPE**	p-value
Anterior	0.62±0.04b	0.25±0.10a	0.05±0.17a	<0.05*
Posterior	0.97±0.03	0.83±0.09	0.79±0.11	0.304

Linear mixed model was used.

* *P*<0.05, ** *P* <0.01, *** *P* <0.001; Bonferroni corrected post hoc test was done, a<b

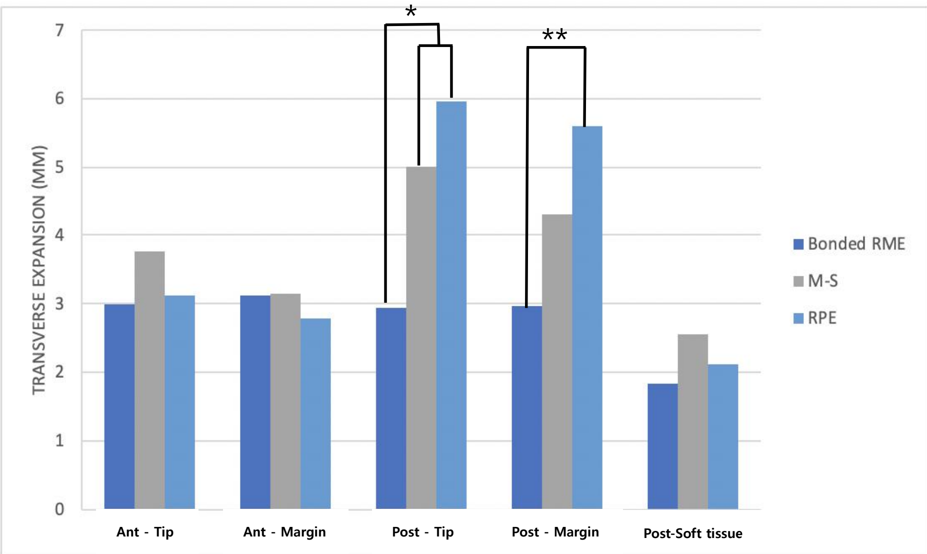


Figure 8. Comparisons of transverse expansion between bonded RME, M-S, and RPE expansion groups; ** *P* <0.01, * *P* <0.001**

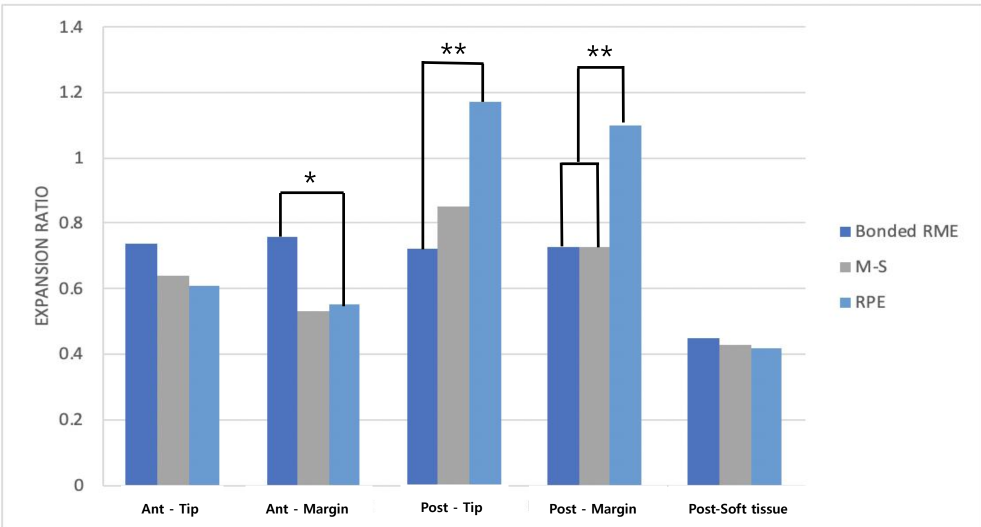


Figure 9. Comparisons of expansion ratio between bonded RME, M-S, and RPE expansion groups; * *P* <0.05, ** *P* <0.01

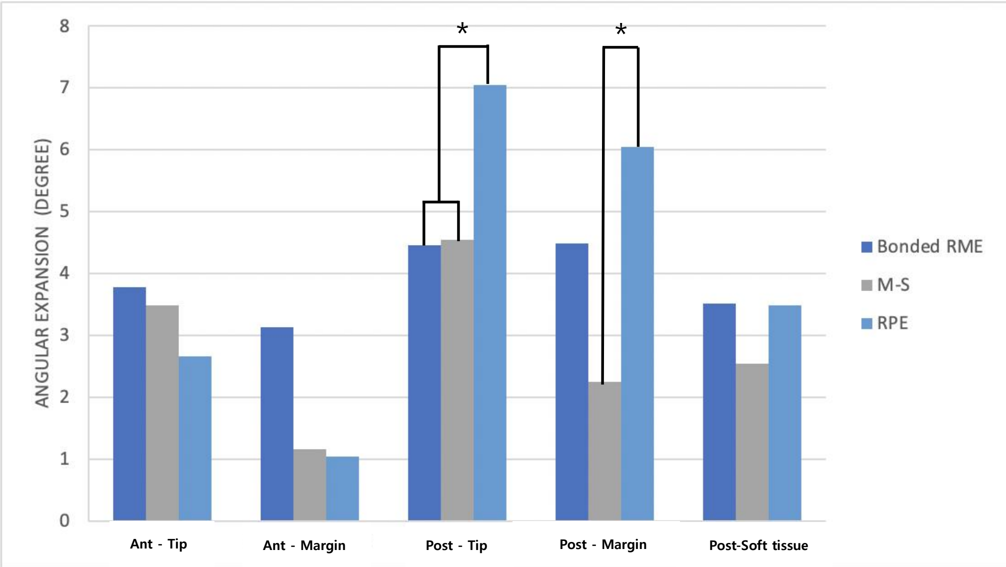


Figure 10. Comparisons of angular expansion between bonded RME, M-S, and RPE expansion groups; * *P* <0.05

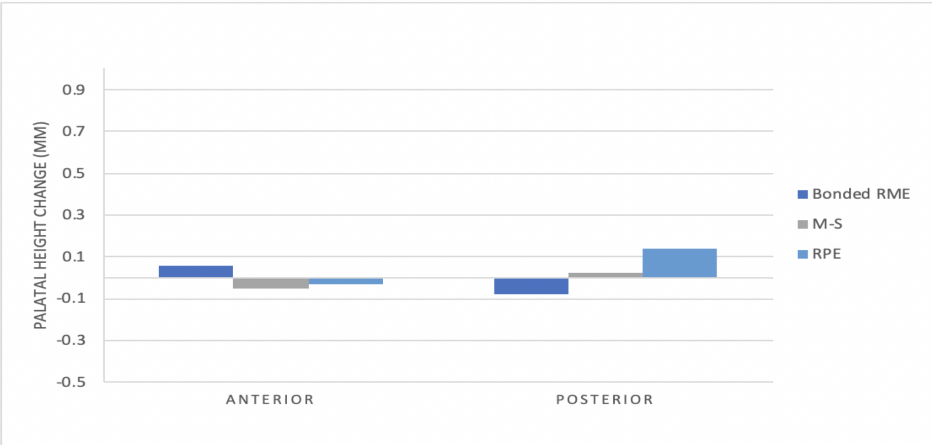


Figure 11. Comparisons of palatal height change between bonded RME, M-S, and RPE expansion groups

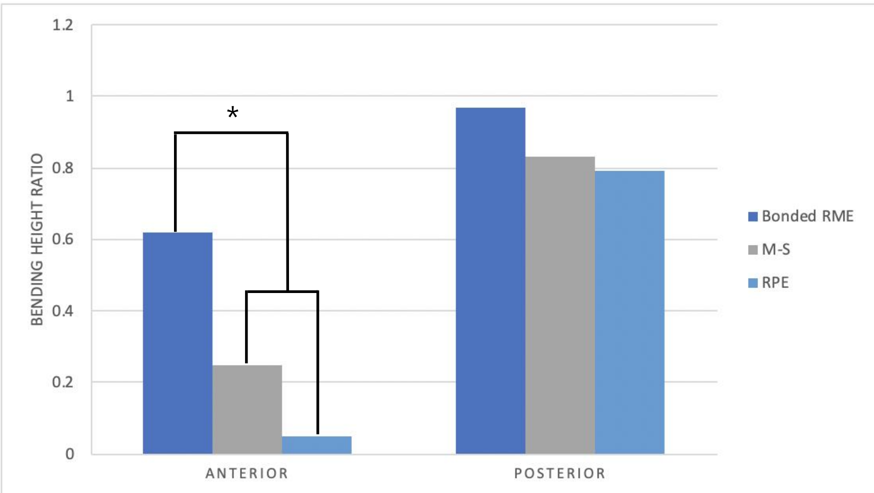


Figure 12. Comparisons of bending height ratio between bonded RME, M-S, and RPE expansion groups; * *P* <0.05

5. Affective variables on transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio in experimental groups (Table 8)

The factors affecting transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio were investigated in the three expansion groups, and the following results were derived.

Transverse expansion was affected by appliance expansion at all locations ($P<0.05$). When expansion was performed using the RPE, there was significantly more expansion at the cusp tips and gingival margins in the posterior teeth compared to the other two appliances ($P<0.01$).

Expansion ratio was significantly higher at the posterior cusp tips and gingival margins when the RPE was used ($P<0.01$). The posterior palatal soft tissue showed a 5% decrease in expansion ratio with every 1-year increase in age ($P<0.05$).

Angular expansion was significantly affected by appliance expansion at the cusp tips, gingival margins, and palatal soft tissue in the posterior region ($P<0.05$). When using the RPE, there was significantly more expansion at the posterior cusp tips ($P<0.05$), and when using the M-S, there was significantly less expansion at the posterior gingival margins ($P<0.01$). The posterior palatal soft tissue showed a decrease in angular expansion of 0.54º for every 1-year increase in age ($P<0.05$).

In this study, we were unable to find any factors that significantly affected palatal height change.

Bending height ratio was affected by appliance type in the anterior region. When the bonded RME was used, bending height ratio was 0.29 higher than the M-S and 0.39 higher than the RPE ($P<0.05$).

Table 8. Affective variables on transverse expansion, expansion ratio, angular expansion, palatal height change, and bending height ratio

Transverse expansion										
Locations	Anterior _cusp tip		Anterior _gingival margin		Posterior _cusp tip		Posterior _gingival margin		Posterior _palatal soft tissue	
Variables	B(SE)	*P*	B(SE)	*P*	B(SE)	*P*	B(SE)	*P*	B(SE)	*P*
Expansion of appliances (mm)	0.47	<0.001***	0.44	<0.001***	0.75	<0.001***	0.70	<0.001***	0.33	<0.05*
Appliances										
1.Bonded RME										
2.M-S	0.20	0.751	-0.66	0.265	0.32	0.535	-0.03	0.953	-0.11	0.857
3.RPE	0.43	0.602	-0.64	0.439	2.03	<0.001***	1.72	<0.01**	-0.17	0.754
ANB (T1, °)	0.02	0.772			0.14	0.056			0.09	0.301
Deciduous tooth /Permanent tooth	-1.02	0.141	-0.38	0.580						
Gender										
Female										
Male			-0.55	0.189			0.66	0.099		
R^2	0.523		0.468		0.677		0.607		0.173	
p-value	<0.001***		<0.001***		<0.001***		<0.001***		0.063	

Expansion ratio

Locations / Variables	Anterior _cusp tip B(SE)	P	Anterior _gingival margin B(SE)	P	Posterior _cusp tip B(SE)	P	Posterior _gingival margin B(SE)	P	Posterior _ palatal soft tissue B(SE)	P
Expansion of appliances(mm)	-0.02	0.264	-0.02	0.422	-0.01	0.697	-0.01	0.681	-0.03	0.259
Appliances										
1.Bonded RME										
2.M-S	-0.08	0.469	-0.17	0.211	0.11	0.267	0.01	0.957	0.09	0.439
3.RPE	-0.17	0.095	-0.15	0.425	0.37	<0.001***	0.31	<0.01**	0.28	0.070
Deciduous tooth /Permanent tooth			-0.14	0.375						
Age (T1, year)									-0.05	<0.01**
R^2	0.118		0.211		0.264		0.189		0.162	
p-value	0.183		0.062		<0.01**		<0.01**		0.087	

Angular expansion

Locations / Variables	Anterior _cusp tip B(SE)	P	Anterior __gingival margin B(SE)	P	Posterior _cusp tip B(SE)	P	Posterior _gingival margin B(SE)	P	Posterior _ palatal soft tissue B(SE)	P
Expansion of appliances(mm)	0.79	0.070	0.66	0.097	1.35	<0.001***	1.27	<0.01**	0.66	<0.05*
appliances										
1.Bonded RME										
2.M-S	-2.98	0.185	-3.19	0.128	0.90	0.412	-4.58	<0.01**	0.99	0.466
3.RPE	-2.60	0.202	-3.73	0.062	2.47	<0.05*	0.06	0.964	2.29	0.185
ANB (T1, °)	0.46	0.204							-0.13	0.878
Age (T1, year)									-0.54	<0.05*
R^2	0.206		0.137		0.406		0.315		0.287	
p-value	0.081		0.147		<0.001***		<0.001***		<0.01**	

Palatal height change

Variables (Locations)	Anterior B(SE)	Anterior *P*	Posterior B(SE)	Posterior *P*
Expansion of appliances(mm)	0.02	0.475	0.004	0.953
Appliances				
1.Bonded RME				
2.M-S	-0.29	0.129	0.08	0.751
3.RPE	-0.03	0.884	0.20	0.394
ANB (T1, °)	-0.06	0.138		
R^2	0.255		0.018	
p-value	0.122		0.835	

Bending height ratio

Variables (Locations)	Anterior B(SE)	Anterior *P*	Posterior B(SE)	Posterior *P*
Expansion of appliances(mm)	0.05	0.203	0.01	0.573
Appliances				
1.Bonded RME				
2.M-S	-0.29	<0.05*	-0.12	0.343
3.RPE	-0.39	<0.05*	-0.01	0.940
Deciduous tooth /Permanent tooth	-0.27	0.303		
Age (T1, year)			-0.03	0.157
R^2	0.258		0.100	
p-value	<0.05*		0.281	

Multiple regression analysis was used.

* *P*<0.05, ** *P* <0.01, *** *P* <0.001

IV. Discussion

In this study, we compared dentopalatal change between three different expansion groups in various positions of crown cusp tip, gingival margin, and 1st molar's root levels. As a result, the anterior and posterior teeth and posterior palatal soft tissue showed different expansion patterns between groups, while the posterior palatal soft tissue expansions and palatal height changes were similar between groups.

In order to compare the effects of the three expansion appliances, we inspected the expansion ratios. The bonded RME showed a consistent expansion ratio of 70–80% of appliance expansion at the posterior and anterior teeth. The M-S showed an expansion ratio of 50–60% of appliance expansion at the anterior teeth and an expansion ratio of 70–80% at the posterior teeth. The RPE showed an expansion ratio of 50–60% of appliance expansion at the anterior teeth, and an expansion ratio of 110–120% at the posterior teeth. This indicates that a bonded RME should be selected to provide even expansion of the anterior and posterior dentition, and that an RPE should be selected to provide significantly more (around 2-fold) expansion of the posterior dentition compared to the anterior dentition. If only slightly more (around 20%) expansion of the posterior dentition is desired, an M-S should be selected.

When maxillary expansion was performed using three different appliances, each appliance showed different effects depending on the location on the teeth and palatal soft tissue. In the bonded RME group, transverse expansion was the same, at around 3mm, at the anterior and posterior cusp tips and gingival margins. Expansion ratio showed a similar pattern, in the range of 0.72–0.76. This indicates that the bonded RME causes equal expansion of the teeth in the posterior and anterior regions; thus, we concluded that, compared to other appliances, which show stronger expansion in the posterior region, the bonded RME produced parallel expansion in the anterior and posterior regions. Angular expansion also increased by the same amount in the anterior and posterior cusp tips and gingival margins; this is consistent with a report by Wertz et al., stating that expansion follows a pyramidal shape, starting from the base of the maxillary bone and moving towards the dental cusp tips.(Wertz, 1970)

When the M-S was used for expansion, the largest transverse expansion, expansion ratio, and angular expansion were all observed at the posterior cusp tips. This appears to be because retention was relatively weak at the anterior teeth.

When the RPE was used for expansion, the largest transverse expansion, expansion ratio, and angular expansion were observed at the posterior cusp tips and gingival margins. The RPE was the only one of the three appliances to show an expansion ratio higher than 1 at the posterior cusp tips and gingival margins, and this can be considered to be the result of significantly more buccal tipping of the 1st molars compared to the other appliances. Therefore, when using an RPE for treatment, it is important to be cautious of periodontal issues such as gingival recession at the 1st molars. Kilic et al. also performed rapid expansion using a Hyrax appliance, and reported more dental and alveolar bone tipping at the 1st molars compared to expansion using a bonded RME.(Kılıç, Kiki, & Oktay, 2008)

In the posterior palatal soft tissue, the three appliances did not show any significant differences in transverse expansion, expansion ratio, angular expansion, or bending height ratio. Thus, for all appliances, the posterior palatal soft tissue began expanding from a similar location (bending height ratio), and showed no differences in the magnitude or ratio of expansion. We investigated the factors affecting posterior palatal soft tissue expansion using multiple regression analysis, and found that only angular expansion was affected by appliance expansion and age, while the other measurements were not affected by any of the variables included in our study. This suggests that posterior palatal soft tissue expansion can be achieved irrespective of appliance design, anchorage (fixed type or removable type), and expansion activation frequency. In other words, the three devices all induced significant expansion of the teeth and palatal soft tissue, but whereas the patterns of dental expansion differed depending on the appliance type, similar patterns of posterior palatal soft tissue expansion were achieved irrespective of appliance type. On the other hand, unlike the posterior region, the anterior palatal soft tissue showed different locations for the start of expansion depending on the appliance type. Bending height ratio was significantly larger for the bonded RME compared to the other appliances, and this suggests that the bonded RME showed not only greater dental expansion than the other appliances, but also a greater ratio of orthopedic expansion. This can be explained as follows: the bonded RME uses more tooth anchors than the M-S, and since it was a fixed appliance, more of the expansion force will have been conveyed to the anterior region. In addition, the bonded RME uses a broader resin block than the RPE, extending to the superior part of the alveolar bone, it covers more teeth, providing stronger anchorage, and the bone density of the midpalatal suture was relatively low in the Bonded RME group.(Liu et al., 2015)

In this study, by comparing groups that underwent expansion with control groups that did not receive any treatment, we confirmed that expansion treatment caused significant transverse and angular expansion of the teeth and palatal soft tissue. On the other hand, none of the appliances used in our study caused significant changes in the palatal height. Haas et al. reported flattening of the palatal dome following rapid maxillary expansion,(Andrew J Haas, 1961) and Muchitsch et al.(Muchitsch et al., 2012) and Marini et al.(Marini, Bonetti, Achilli, & Salemi, 2006) reported a decrease in palatal height when expansion was performed using a bonded RME. Meanwhile, Phatouros et al. reported a small increase in palatal height,(Phatouros & Goonewardene, 2008) and Davis et al. reported that there was no changes in vertical height of the maxillary arch.(Davis & Kronman, 1969) The reason for these discrepancies between previous studies is thought to be due to including vertical growth of the alveolar bone or tooth movement in the measurement of palatal height. In our study, because we only measured remodeling around the palatal apex, we could assess the contour changes of palatal soft tissue more precisely.

When we compared bending height ratio between the experimental groups and the control groups, the control groups showed negative values in both the anterior and posterior palate. This can be interpreted as reflecting vertical growth around the alveolar bone rather than transverse constriction of the palatal soft tissue.

The value of this study is that we compared patterns of expansion for both the teeth and the palatal soft tissue when using three maxillary expansion appliances that are commonly used in growing children. To this end, we used 3D model scanning and superimposition to examine patterns of palatal soft tissue remodeling that are difficult to analyze with conventional quantitative methods.

Among methods of comparing 3D scanned models from before and after maxillary expansion or growth, there is the quantitative method of comparing measurements at each time point, and there is the qualitative method of superimposing models from each time point based on stable structures. The advantages of the latter method of superimposition are that the pattern of changes can be understood be direct observation of each structure of interest, and that it is also possible to identify changes in structures that were not measured. Another reason that we used the superimposition method in this study is that changes in specific locations of the palatal soft tissue, such as the palatal apex, can be measured more accurately, and it also allows us to inspect changes in cross-sections of the palatal soft tissue, represented by the bending height ratio. For example, in previous studies that used quantitative methods, palatal height was measured by measuring the vertical distance from a certain point on the teeth to the palatal apex pre- and post-treatment.(Muchitsch et al., 2012) However, in addition to remodeling around the palatal apex, this method can also be affected by buccal tipping of the teeth or vertical growth of the alveolar bone, and so the results cannot be considered to only reflect changes in the soft tissue around the palatal apex. Moreover, bending height ratio is difficult to measure by quantitative methods, and this measurement can help to provide a direct understanding of the vertical height at which expansion occurs in model cross-sections. In the present study, the low palatal height in the anterior region made it impossible to measure changes in the palatal soft tissue at the height of the center of resistance of the deciduous or permanent canines. However, we were able to inspect the superimposed cross-sections, and to use the bending height ratio to identify changes in the anterior palate.

To utilize the superimposition method in research, it is first necessary to assess the reliability of superimposition of models from before and after growth or expansion. Although there have been many studies on 3D model superimposition before and after growth or orthodontic treatment, there is still debate about its stability and reliability.(Kapoor & Miglani, 2015) However, several recent studies have reported that annual changes in the palate due to growth are negligible,(Kim et al., 2012),(Yang et al., 2013) and that, in orthodontic treatment combined with maxillary expansion, taking measurements after superimposition of pre- and post-treatment models based on stable structures is a clinically acceptable method.(Canan & Şenışık, 2017; Choi, Cha, Jost-Brinkmann, Choi, & Jang, 2012; Shahen et al., 2018; Talaat et al., 2017) In this study, we measured the mean changes within 1 year in the experimental groups and the control groups; with reference to previous reports that there can be changes around the alveolar bone and the lateral areas of the rugae when the arch is expanded, we performed superimposition based on the median raphe and the medial parts of the anterior 3rd rugae.(Canan & Şenışık, 2017; Kim et al., 2012)

One of the basic assumptions of this study was that the palatal soft tissue reflects remodeling of the inferior parts of the palatine bones. However, in addition to bony changes, the soft tissue can also be affected by factors such as inflammation and soft tissue hyperplasia. In addition, because we were unable to measure the length of individual dental roots, we used mean values for each tooth in Koreans, but there could still be differences in the root length or dental age of individuals. Since we did not perform CT in this study, we were unable to reflect these individual factors in the analysis, and could no examine patterns of maxillary expansion in CT sections. This is because CBCT imaging could not be performed at such as short interval (6 months – 1 year) pre- and post-treatment in patients who were still growing. There was another limit of this study that post- and pre- treatment interval of control group (1 year) was longer than that of experimental groups.

In this study, we examined gender, age, ANB (º), and SN-MP (º) in each group and analyzed differences between the groups. Gender, age, and SN-MP showed no significant differences between the groups, but ANB did show significant differences. This is thought to be because the bonded RME expansion group contained more patients undergoing face mask treatment for skeletal Class III malocclusion. However, face mask treatment was performed after expansion, and in our multiple regression analysis, ANB did not show a significant effect on expansion patterns.

In this study, we performed a multiple regression analysis to investigate factors that could affect patterns of expansion. Naturally, appliance expansion has the greatest effect on transverse expansion. In addition, when using the RPE, transverse expansion at the 1st molar was found to be around 2mm larger at the height of the cusp tips and gingival margins. Meanwhile, gender, age before expansion, ANB (º), SN-MP (º), and deciduous/permanent teeth did not have significant effects on transverse expansion.

When we examined factors affecting expansion ratio, appliance expansion did not have a significant effect. Gender, age, ANB (º), SN-MP (º), and deciduous/permanent teeth also did not affect expansion ratio. However, at the posterior teeth, use of the RPE was associated with an increase of around 30–40% in expansion ratio.

Using the M-S was associated with significantly less angular expansion at the posterior gingival margins compared to the other two devices. This can be explained as follows: while the other two appliances induce rapid dental expansion, the M-S is relatively slow, and so there is less buccal crown tipping of the 1st molars, and even if buccal tipping does occur, because the M-S is a removable type appliance, rather than bonding type, physiological movement of the 1st molars is permitted, and so we can surmise that uprighting of the posterior teeth occurred simultaneously with expansion. Meanwhile, the posterior palatal soft tissue decreased by around 0.5º for every 1-year increase in age. This seems to be because, rather than the posterior part of the palate becoming narrower, it was less affected by appliance expansion than the posterior dentition, and this may reflect vertical growth of the maxillary arch.

Around 10–68% of variance in the transverse expansion, expansion ratio, angular changes, and bending height ratio of the maxillary dentition and palatal soft tissue could be explained by factors explored in this study (R^2). This suggests that even when performing maxillary expansion using the same appliance, in patients with the same age, gender, and dental and skeletal disharmony, the responses of the hard and soft tissues can still vary on an individual basis. In orthodontics, changes resulting from maxillary arch expansion have been widely studied in several areas, even outside the scope of the oral cavity.(Altorkat et al., 2016; Baratieri, Alves Jr, de Souza, de Souza Araújo, & Maia, 2011; Iwasaki et al., 2013) However, more researches are still needed to find out structural and functional changes induced by maxillary expansion.

V. Conclusions

We performed maxillary arch expansion using three different types of appliance (bonded RME, M-S, RPE) and compared the patterns of dental and palatal expansion. We obtained the following results:

1. Compared to the untreated control groups, the three expansion groups all showed significantly greater transverse expansion and angular expansion of the teeth and palatal soft tissue. However, none of the three appliances induced significant changes in palatal height.

2. Compared to the control groups, bending height ratio, which is an indicator of the location of palatal soft tissue expansion, was significantly higher in the anterior and posterior regions when using the bonded RME, and in the posterior region when using the M-S or RPE.

3. When using the bonded RME, the anterior teeth showed a significantly higher expansion ratio, at 74–76% of appliance expansion, than the other two appliances ($P<0.05$); the posterior teeth showed an expansion ratio of 72–73%, and the posterior palatal soft tissue showed an expansion ratio of 45%.

4. When using the M-S, the anterior teeth showed an expansion ratio of 53–64% of appliance expansion, the posterior teeth showed an expansion ratio of 73–85%, and the posterior palatal soft tissue showed an expansion ratio of 43%.

5. When using the RPE, the anterior teeth showed an expansion ratio of 55–61% of appliance expansion; the posterior teeth showed an expansion ratio of 110–117%, which was significantly larger than the other two devices (*P*<0.01), and the posterior palatal soft tissue showed an expansion ratio of 42%.

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국문요약

세 가지 다른 장치를 이용한 상악 확장 시 치아 및 구개의 변화 비교

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장우원

상악 확장은 상악골 및 치열의 횡적 확장을 통해 치아 배열을 위한 공간 부족, 구치부 반대교합 등의 문제를 해결하기 위해 이루어지는 교정 술식이다. 상악을 확장하는 방법은 확장의 속도와 확장 시 이용하는 고정원 등에 따라 나누어 볼 수 있으며 이로 인한 치열의 변화는 여러 문헌들을 통해 보고되었다. 그러나 기존의 연구는 치관의 이동을 중심으로 한 치열의 변화에 대한 것이 대부분이며, 구개 연조직의 확장 양상이나 다수의 확장 장치의 효과에 대한 비교는 부족한 실정이다.

본 연구에서는 세 가지 다른 종류의 확장 장치(bonded RME, 20명; M-S, 25명; RPE, 20명) 로 상악궁을 확장한 실험군 65명과, 교정 치료를 받지 않고 성장을 관찰한 대조군 46명을 대상으로 치아 및 구개 연조직의 변화 양상을 비교해 보았다. 이를 위해 확장 전후의 치아 석고 모형을 스캔한 후 안정적인 구조물인 anterior 3rd rugae의 medial part와 median raphe를 기준으로 중첩하였다. 세 가지 장치에 의한 전방 치아, 후방 치아 및 후방 구개 연조직의 확장 양상을 대조군과 비교하여 다음의 결과를 얻었다.

1. 세 확장군 모두 대조군에 비해 전후방 치아 및 후방 구개 연조직의 횡적 확장량과 각도 확장량이 유의하게 증가하였다. 그러나 세 장치 모두 구개 높이의 변화를 유발하지 않았다.

2. Bending height ratio는 구개 연조직의 확장이 일어나는 위치에 대한 지표로서 bonded RME 사용시 구개 연조직 전후방에서, M-S 및 RPE 사용시 구개 연조직 후방에서 대조군보다 유의하게 증가하였다.

3. Bonded RME 사용 시 전방 치아는 장치 확장량의 74-76%의 비율로 다른 두 장치에 비해 유의하게 많이 확장되었고 ($P<0.05$), 후방 치아는 장치 확장량의 72-73%, 후방 구개 연조직은 45%의 비율로 확장되었다.

4. M-S 사용 시 전방 치아는 장치 확장량의 53-64%, 후방 치아는 73-85%, 후방 구개 연조직은 43%의 비율로 확장되었다.

5. RPE 사용 시에는 전방 치아는 장치 확장량의 55−61%, 후방 치아는 110−117%의 비율로 다른 두 장치에 비해 유의하게 많이 확장되었고 ($P<0.01$), 후방 구개 연조직은 42%의 비율로 확장되었다.

핵심이 되는 말: 상악 확장, 구개 연조직, bonded RME, median screw, RPE