Original Article

Effects of different rapid maxillary expansion appliances on facial soft tissues using three-dimensional imaging

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ABSTRACT

Objective: To determine three-dimensional (3D) effects of three different rapid maxillary expansion (RME) appliances on facial soft tissues.

Materials and Methods: Forty-two children (18 boys, 24 girls) who required RME treatment were included in this study. Patients were randomly divided into three equal groups: banded RME, acrylic splint RME, and modified acrylic splint RME. For each patient, 3D images were obtained before treatment (T1) and at the end of the 3-month retention (T2) with the 3dMD system.

Results: When three RME appliances were compared in terms of the effects on the facial soft tissues, there were no significant differences among them. The mouth and nasal width showed a significant increase in all groups. Although the effect of the acrylic splint RME appliances on total face height was less than that of the banded RME, there was no significant difference between the appliances. The effect of the modified acrylic splint appliance on the upper lip was significant according to the volumetric measurements ($P < .01$).

Conclusions: There were no significant differences among three RME appliances on the facial soft tissues. The modified acrylic splint RME produced a more protrusive effect on the upper lip. (*Angle Orthod.* 2016;86:590–598.)

KEY WORDS: Rapid maxillary expansion; Three-dimensional imaging; Soft tissue; 3dMD; Face analysis

INTRODUCTION

In orthodontic practice, the rapid maxillary expansion (RME) treatment approach is routinely adopted to expand the maxillary arch. The rationale underlying the approach is that the orthopedic force exerted by fixed appliances with a jackscrew, which apply heavy forces, can mechanically separate the maxillary segments at the midpalatal suture.[1–3] These appliances produce both orthopedic and orthodontic effects by tipping the posterior teeth buccally and enable dental extrusion and lateral rotations of the alveolar segments.[4–6] These effects of RME cause downward and backward rotation of the mandible and increased facial height.[2,7,8]

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In orthodontic evaluation, the most common ways to determine the soft tissue effects of the treatment are soft tissue analysis of the patient's cephalometric radiographs and photographs.[9] These diagnostic records provide limited information because complex three-dimensional (3D) structures are projected onto two-dimensional surfaces.[10] Recently, 3D imaging techniques have been introduced for a more accurate evaluation of facial soft tissue.[11] These techniques can be broadly classified as laser scanning, stereophotogrammetry, structured light techniques, and cone-beam computed tomography (CBCT) scans.[12] The 3dMD face system (3dMD, Atlanta, GA) is an advanced stereophotogrammetry system. This noninvasive system enables clinicians to capture a 180° image of a person's face from ear to ear in only 1.5 milliseconds.

Changes in a patient's skeletal and dental structure that occur after use of different RME appliances are well documented, but there is a need for additional information on how they affect soft tissues. The purpose of this prospective study was to determine the soft tissue effects of three different RME appliances three dimensionally and to compare these effects among groups using the 3dMD face system.

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Table 1. Distribution of Patients in Groups According to Sex, Age, Dental Class, and Amount of Activation

Group[a]	n	Boys	Girls	Mean Age (Year)	Class I	Class II	Activation (Turns)
Banded RME	14	6	8	12.7 ± 0.6	8	6	29.8 ± 4.2
Bonded RME	14	7	7	12.4 ± 0.8	8	6	29.0 ± 4.0
Modified bonded RME	14	5	9	12.5 ± 0.8	7	7	31.6 ± 5.9

[a] RME indicates rapid maxillary expansion.

MATERIALS AND METHODS

This study was approved by the ethical committee of the Inonu University. The sample was selected from among consecutive subjects requiring expansion who applied for orthodontic treatment to the Department of Orthodontics, Inonu University. First, patients with transverse maxillary deficiency were rated clinically by an experienced orthodontist. The study sample included patients with Class I or II malocclusions and associated moderate maxillary constriction that could be treated with approximately 5 mm of expansion. Patients with facial or nasal deformities and those younger than 11 years or older than 15 years were excluded from the study. Sample size was calculated based on data available in the literature,[4] and analysis was performed with G*Power Version 3.0.10 (Franz Faul, Universität Kiel, Germany) software. Based on a 1:1 ratio among groups, a total sample size of 42 was predicted to provide more than 80% confidence to detect differences at an $\alpha = .05$ significance level.

The sample comprised 42 children (18 boys and 24 girls) aged 11.6–13.3 years (Table 1). They were separated, by a block randomization technique, into three equal groups. The first group was treated using a banded RME appliance (Figure 1a).[13] The second group was treated with a bonded acrylic cap splint RME appliance (Figure 1b).[14] The third group was treated with a modified (tooth-tissue borne and full occlusal coverage) bonded acrylic cap splint RME appliance (Figure 1c).[15] The bonded appliances were adjusted to the patient's mouth to obtain the maximum number of occlusal contact points. All appliances included the same hyrax screw (Leone, Firenze, Italy) and were cemented with glass ionomer cement (3M ESPE, Seefeld, Germany). The RME appliances were activated by one turn of the screw (0.20 mm per turn), and the next day they were placed by the patient's parent. The active phase of the expansion was monitored once in 2 weeks until the buccal segments were overcorrected. Thereafter, the screw of the RME appliance was tied with a ligature wire, and the appliances were retained without fixed appliances for approximately 3 months before being removed from the mouth.

Image Acquisition

The 3D facial images were obtained at the beginning of the treatment (T1) and after appliance removal at the end of the 3-month retention period (T2) using the 3dMD face imaging system. All images were taken with the head in a natural head position, teeth in centric occlusion, and lips in repose.

3D Image Analysis

The images obtained are saved automatically as ".tsb" files. These files were imported into 3dMD Vultus software, a software used for analyzing 3D images. All

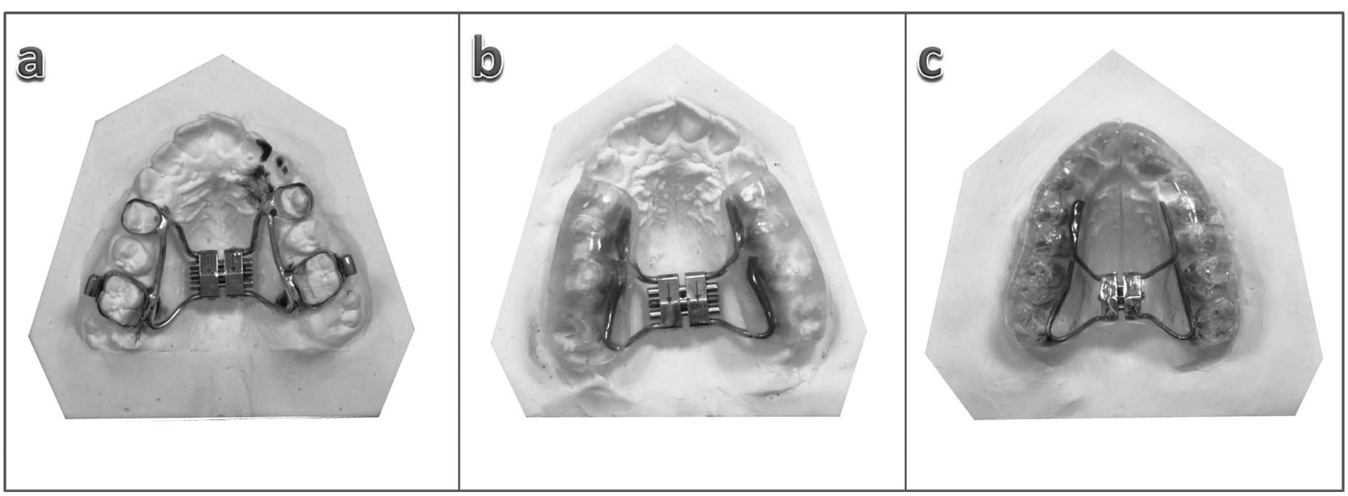

Figure 1. Appliances used in this study. (a) Banded. (b) Acrylic cap splint bonded. (c) Modified acrylic cap splint bonded.

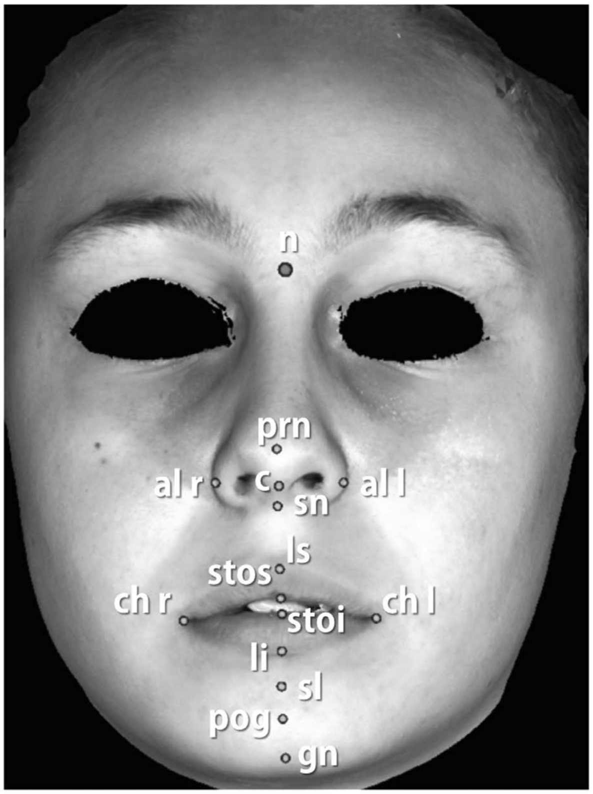

Figure 2. Anthropometric landmarks of soft tissue. n, indicates nasion; prn, pronasale; sn, subnasale; all-alr, left and right alare; c, columella; ls, labiale superius; stos, stomion superius; stoi, stomion inferius; li, labiale inferius; chr-chl, left and right cheilion; sl, sublabiale; pog, pogonion; gn, gnathion.

images were first cleaned up to remove extraneous data, such as clothing and patient hair. Further, 15 facial soft tissue anthropometric landmarks, described by Farkas,[16] were identified on each image (Figure 2). Nine linear and 6 angular measurements were calculated from each 3D image, as listed in Figures 3 and 4, respectively. The linear measurements were calculated using the x, y, and z coordinates of two selected landmarks. After the linear and angular analysis, surface-based registration of pre- and post-treatment images was performed for upper lip volumetric calculation. The registration was performed using the software's paintbrush tool on the nasal bridge and forehead area. The software calculated a root mean square value, which had to be 0.5 or less to be accepted; if the root mean square value was more than 0.5, the procedure was repeated.

Soft tissue alterations were assessed with a modified 3D soft tissue analysis as described by Nada et al.[17] after superimposition. In this analysis, the soft tissue region of interest was traced on the superimposed models. The software cut tool was used to demarcate the region of interest. The region of interest area was limited at the right and left cheilion and subnasale (Figure 5). The upper lip area was calculated for each image, and changes in volume during treatment were calculated using the software volume calculation tool.

Statistical Analysis

Intraexaminer reliability of the measurements was determined by intraclass correlation coefficients. Fifteen 3D facial images were selected, and landmarks were reidentified and the measurements repeated after a 2-week interval. To analyze the effects of the expansion devices, descriptive statistics for each parameter, such as means and standard errors, were calculated. Within-group comparisons were conducted using a dependent sample *t*-test. The analysis of variance was used to compare the data at the T1 and T2 time points. When analysis of variance results were significant, Tukey's honestly significant difference post hoc test was used to determine the individual differences. All evaluations were performed at a significance level of .05.

RESULTS

The intraclass correlation coefficients for all measurements ranged from 0.899 to 0.999, and indicated acceptable reliability and reproducibility of all measurements (Table 2).

The RME was successfully performed for all patients. A diastema between central incisors was presented in all the subjects. The 3D linear and angular soft tissue changes after RME within groups were presented in Table 3. There were significant increases in nasal and mouth widths after RME in all treatment groups ($P < .05$ and $P < .001$). There were statistically significant increases in the upper face height among those in the banded group ($P < .05$). Further, significant changes were observed in the upper lip angle in the banded and bonded groups ($P < .05$). There was an increase in the lower lip angle in the banded and modified bonded groups ($P < .05$). Significant increases in the lower vermillion height were present only in the modified bonded group ($P < .05$).

Comparisons of changes related to RME treatment among the groups are given in Table 4. There were no significant differences for linear and angular measurements among the three groups ($P > .05$). However, significant volumetric soft tissue changes occurred on the upper lip in the modified bonded group ($P < .05$) (Table 4).

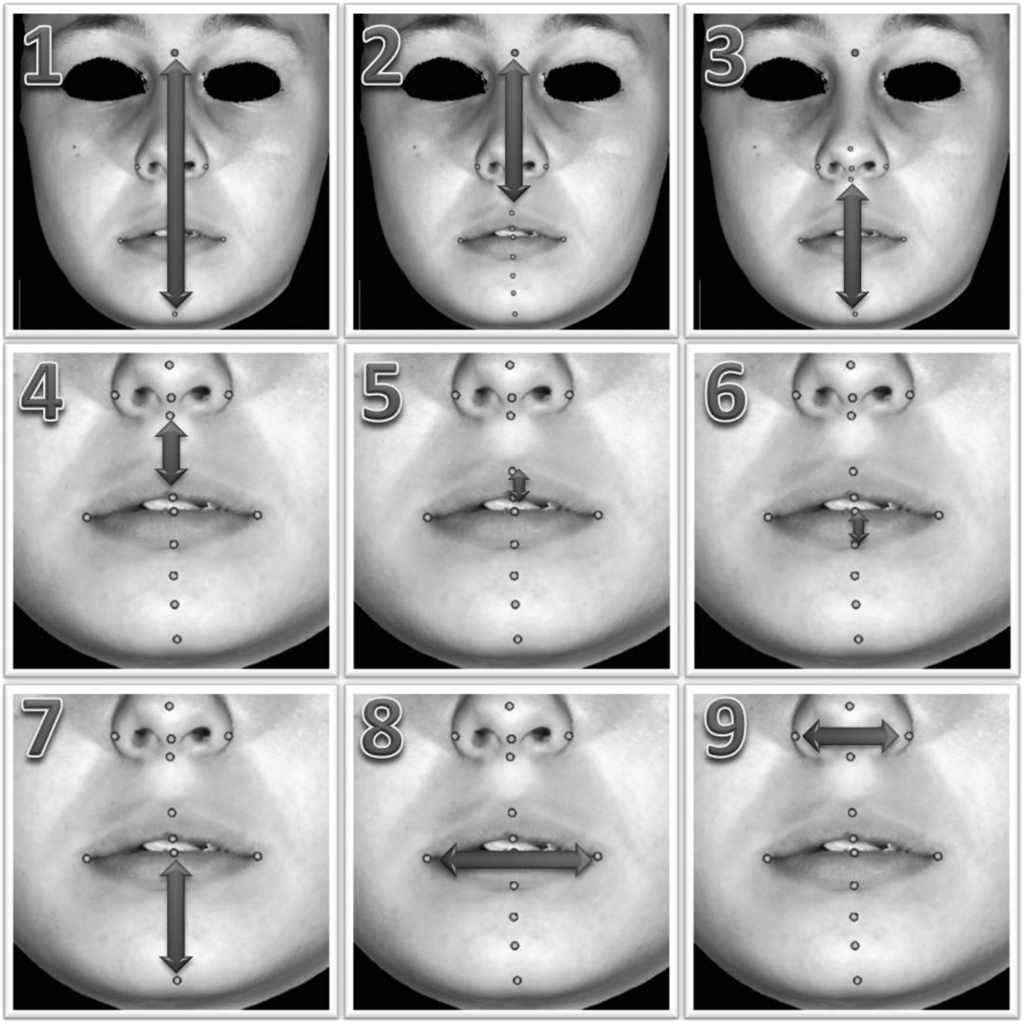

Figure 3. Linear measurements of soft tissue. (1) Total face height (n-gn). (2) Upper face height (n-stos). (3) Lower face height (sn-gn). (4) Upper lip height (sn-stos). (5) Upper vermillion height (ls-stos). (6) Lower vermillion height (stoi-li). (7) Lower lip height (stoi-gn). (8) Mouth width (chr-chl). (9) Nasal width (alr-all).

DISCUSSION

It is important that orthodontists understand the effects of orthodontic treatment on facial soft tissue. Two-dimensional images, such as orthopantograms, posteroanterior and lateral cephalograms, and facial photographs, have been regularly used by orthodontists for diagnosing, treatment planning, and assessing treatment results. Advances in 3D imaging techniques now make it possible to capture and superimpose facial images and measure changes in soft tissue position three dimensionally.[18] The objective of the present study was to determine 3D effects of three different RME appliances on facial soft tissue profiles. These appliances are commonly used in clinical practice and can be easily adjusted and applied in routine clinical conditions.

Soft tissue images obtained from the 3dMD system provide photorealistic views and capture the texture of the skin with better accuracy and reproducibility.[11] Recently, the 3dMD system was tested for measuring angle, distance, and system re-registration on mannequin head measurements. The results of that study showed that the system was reliable and had a mean global error of 0.2 mm (range, 0.1–0.5 mm).[19] Losken et al.[20] investigated the validation of the 3dMD system's ability to determine volume and found that the relative difference between the measured and calculated volumes was approximately 2%.

Downward displacement of the maxilla, dental extrusion, and lateral rotations of the maxillary segment after RME caused the bite to open and the vertical dimension to increase.[1,2,15] Bonded RME has been proposed to avoid the unwanted vertical effects of RME. Restriction of the extrusion of posterior teeth to help keep the bite closed or at least minimize bite opening might be expected with this type of expander.

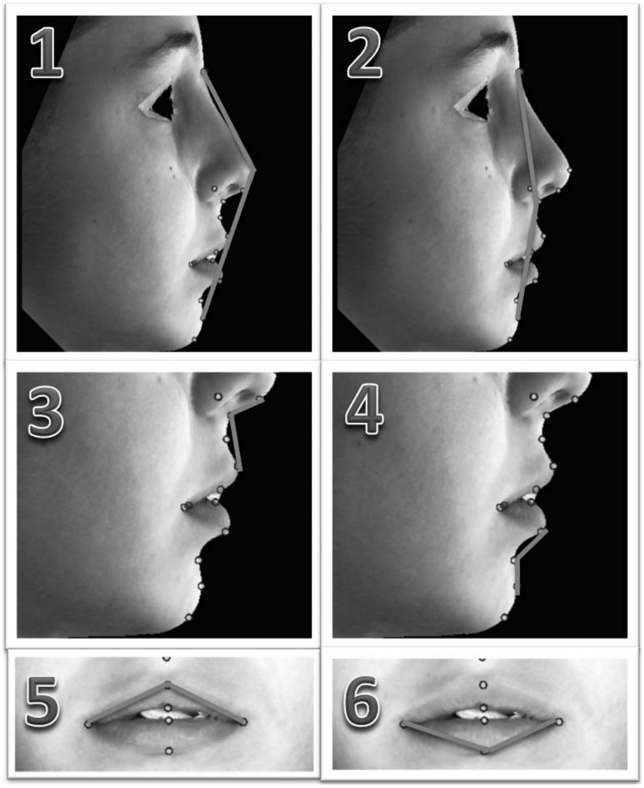

Figure 4. Angular measurements of soft tissue. (1) Total convexity angle (n-prn-pog). (2) Convexity angle (n-sn-pog). (3) Nasolabial angle (c-sn-ls). (4) Labiomental angle (li-sl-pog). (5) Upper lip angle (chr-ls-chl). (6) Lower lip angle (chr-li-chl).

Sarver and Johnston[21] stated that the downward and anterior displacement of the maxilla often associated with the banded appliance may be negated or minimized with a bonded appliance.

Asanza et al.[22] found that the patients treated with bonded posterior occlusal coverage RME appliances showed less inferior movement of the posterior aspect of the palate versus those treated with banded RME appliances. Dos Santos et al.[23] investigated the effects of using bonded appliances on facial soft tissue profile and found no significant alterations in the soft tissues at the end of the retention period. In this study, there was no significant effect on the soft tissue or lower and total facial height with any of the RME appliances. In the two bonded appliances there was less increase in the total facial height, but no significant differences were found among the three groups.

The results of the present investigation supported the findings of earlier studies in which there were significant differences in nasal width after RME.[24,25] Nasal width increased significantly in the banded, bonded, and modified bonded groups by 1.35 mm, 1.16 mm, and 0.94 mm, respectively. Similar changes in soft tissue were observed in a CBCT study performed by Pangrazio-Kulbersh et al.[24] They found a 1.34-mm increase in mean alar width in the banded appliance group and an increase of 1.24 mm in the bonded appliance group. These findings were in accordance with the results of this study. Similarly, Johnson et al.[25] found that alar base width increased after RME in the prepubertal and postpubertal stages. However, they claimed that the actual amount of increase was less than 1.5 mm, which was not clinically significant.

In this study, changes in upper and lower lip heights and upper and lower lip vermillion heights were observed, but RME did not generally modify the upper and lower lip heights significantly. Only the lower lip vermillion height showed significant increases in the modified bonded group. Berger et al.[26] reported that measurements of the upper lip length, lower lip-chin length, upper lip vermilion, and lower lip vermilion demonstrated changes during treatment but showed no significant changes from initial values after a year of retention.

The mouth width was greater after RME than before, perhaps because of lateral movement of the maxillary halves. This was statistically significant in all groups. A recent CBCT study by Kim et al.[27] demonstrated similar changes in mouth width after RME. They found that the left lip commissure for transverse expansion showed a change of 0.65 mm, and the right lip commissure had a mean change of 1.20 mm laterally.

On the other hand, in this study, the angle of upper and lower lips showed an increase in all groups. This increase probably resulted from the effect of transverse expansion and stretching of the soft tissue of the mouth.

Moreover, the nasolabial angle increased in the banded and bonded groups, but decreased in the modified bonded group. These findings are in agreement with a previous study, which reported an increase of 0.5° in the nasolabial angle with bonded RME.[23] The changes in the nasolabial angle were observed in all groups in the present study, but there was no significant difference among groups. The slight increase in this angle in the banded and bonded groups may result from retrusion of the upper incisors after RME. Several studies reported how RME affected the upper incisors. Sarver and Johnston[21] found that the maxillary incisors became retroclined after banded and bonded RME. In a recent CBCT study, Habeeb et al.[28] showed that the maxillary central incisors moved posteriorly and became more retroclined after bonded RME. In contrast, Basciftci and Karaman[15] found that the maxillary incisors were more proclined after modified bonded RME. In addition, acrylic coverage of anterior teeth in the modified bonded RME appliances prevents spontaneous closure of

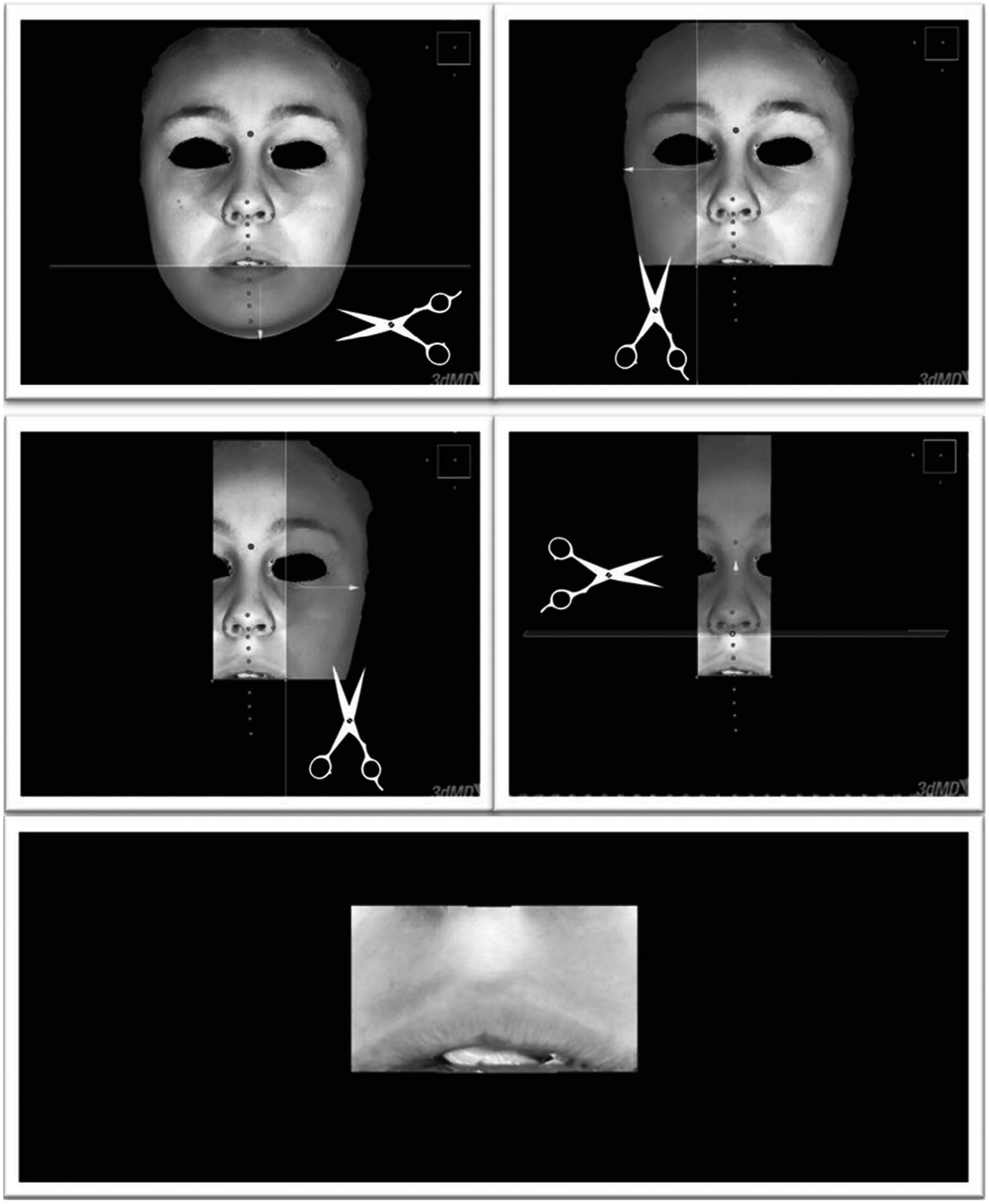

Figure 5. Determination of region of interest area for upper lip volumetric calculation.

anterior diastema after RME. The decrease in the nasolabial angle in the modified group in our study may be caused by this reason.

Further, 3D images with specialized software appear useful in assessing the objective and quantitative evaluation of the volume changes.[17] The volumetric analysis offers orthodontists the opportunity to obtain more information on the effects of treatment in facial curved areas. In this study, upper lip volumetric changes were evaluated. The modified bonded group produced a more protrusive effect on the upper lip than the other group. Some of these effects may be clinically desirable in Class III malocclusion, while in Class II malocclusion they may represent unfavorable side effects of the expansion.

CONCLUSIONS

- The results of this study revealed that RME treatment caused slight soft tissue changes. However, this can be considered clinically insignificant.
- According to the volumetric analysis, the modified acrylic splint RME appliance produced a more protrusive effect on the upper lip.
- The two bonded appliances produced some increase in total facial height, but no significant differences were found among the three groups.

Table 2. Assessment of Measurement Error[a]

	Intraclass Correlation Coefficient	(95% Confidence Interval) Lower Limit	Upper Limit
Linear measurements			
Nasal width (alr-all)	0.988	0.962	0.996
Mouth width (chr-chl)	0.981	0.941	0.994
Upper lip height (sn-stos)	0.967	0.902	0.989
Upper vermillion height (ls-stos)	0.899	0.716	0.966
Lower lip height (stoi-gn)	0.946	0.842	0.982
Lower vermillion height (stoi-li)	0.950	0.851	0.984
Upper face height (n-stos)	0.995	0.983	0.998
Lower face height (sn-gn)	0.984	0.951	0.995
Total face length (n-gn)	0.993	0.978	0.998
Angular measurements			
Nasolabial angle (c-sn-ls)	0.993	0.979	0.998
Labiomental angle (li-sl-pog)	0.982	0.946	0.994
Convexity angle (n-sn-pog)	0.996	0.987	0.999
Total convexity angle (n-prn-pog)	0.997	0.990	0.999
Upper lip angle (chr-ls-chl)	0.975	0.924	0.992
Lower lip angle (chr-li-chl)	0.964	0.893	0.988
Volumetric measurements			
Upper lip changes	0.999	0.962	0.999

[a] all-alr indicates left and right alare; chr-chl, left and right cheilion; sn, subnasale; stos, stomion superius; ls, labiale superius; stoi, stomion inferius; gn,gnathion; n, nasion; c, columella; li, labiale inferius; sl, sublabiale; pog, pogonion; prn, pronasale.

Table 3. Comparisons of Pretreatment (T1) and Posttreatment (T2) Values Within the Groups[a,b]

	Banded					Bonded					Modified Bonded				
	T1		T2			T1		T2			T1		T2		
	Mean	SD	Mean	SD	*P*	Mean	SD	Mean	SD	*P*	Mean	SD	Mean	SD	*P*
Linear measurements (mm)															
Nasal width (alr-all)	29.39	2.09	30.74	2.31	.001**	31.28	2.78	32.44	2.57	.001**	32.22	3.37	33.15	2.92	.022*
Mouth width (chr-chl)	44.67	4.01	46.48	3.94	.003**	43.28	3.31	45.30	3.04	.001**	44.12	3.34	45.74	2.90	.001**
Upper lip height (sn-stos)	17.79	3.06	17.99	3.04	.564	20.30	2.34	20.05	2.40	.379	19.02	2.00	19.33	2.09	.258
Upper vermillion height (ls-stos)	6.79	1.19	6.78	0.92	.986	7.38	0.78	7.01	0.83	.080	6.95	1.52	7.31	1.20	.237
Lower lip height (stoi-gn)	33.71	2.16	34.18	2.50	.170	33.94	2.48	34.58	2.02	.159	35.25	2.41	35.61	2.18	.496
Lower vermillion height (stoi-li)	9.16	2.38	9.27	1.50	.746	9.45	1.00	9.54	1.16	.621	9.15	2.20	9.82	1.68	.030*
Upper face height (n-stos)	68.51	3.81	69.86	4.24	.006**	71.41	4.30	71.68	4.15	.602	71.58	4.44	72.10	4.48	.331
Lower face height (sn-gn)	55.68	3.76	55.42	3.75	.393	57.83	4.08	58.27	3.14	.448	57.41	4.93	57.97	4.57	.168
Total face height (n-gn)	105.1	4.64	106.11	5.25	.079	107.87	5.36	108.74	4.96	.138	109.13	6.12	109.85	6.33	.311
Angular measurements (°)															
Nasolabial angle (c-sn-ls)	111.57	4.70	111.82	6.32	.796	108.62	8.46	108.72	9.49	.888	112.85	8.57	110.5	7.38	.149
Labiomental angle (li-sl-pog)	116.95	20.00	120.41	15.18	.303	117.54	13.27	120.43	12.92	.405	129.07	16.68	127.67	15.22	.599
Convexity angle (n-sn-pog)	158.91	5.94	159.27	6.16	.436	160.69	5.67	161.19	6.46	.289	162.09	5.64	161.39	5.85	.137
Totoal convexity angle (n-prn-pog)	130.45	4.63	129.92	4.55	.142	132.05	4.23	131.27	4.62	.141	132.26	5.41	131.76	5.34	.220
Upper lip angle (chr-ls-chl)	102.42	4.97	105.84	5.58	.001**	99.62	6.28	102.71	6.05	.001**	103.74	7.10	105.22	7.12	.173
Lower lip angle (chr-li-chl)	120.64	8.11	124.47	8.49	.014*	117.24	9.21	119.28	7.97	.152	115.14	4.97	119.12	6.14	.005**

[a] Dependent samples t test: * $P < .05$; ** $P < .01$.

[b] all-alr indicates left and right alare; chr-chl, left and right cheilion; sn, subnasale; stos, stomion superius; ls, labiale superius; stoi, stomion inferius; gn, gnathion; n, nasion; c, columella; li, labiale inferius; sl, sublabiale; pog, pogonion; prn, pronasale.

Table 4. Comparisons of Treatment Changes Among the Groups (Pretreatment to Posttreatment)[a,b]

	Banded		Bonded		Modified Bonded		
	Mean	SD	Mean	SD	Mean	SD	*P*
Linear measurements (mm)							
Nasal width (alr-all)	1.35	1.08	1.16	1.02	0.94	1.35	.645
Mouth width (chr-chl)	1.80	1.85	2.02	1.04	1.62	1.16	.756
Upper lip height (sn-stos)	0.20	1.26	−0.25	1.03	0.31	0.98	.369
Upper vermillion height (ls-stos)	−0.01	1.32	−0.37	0.72	0.36	1.09	.214
Lower lip height (stoi-gn)	0.48	1.22	0.65	1.62	0.36	1.91	.892
Lower vermillion height (stoi-li)	0.11	1.26	0.10	0.71	0.67	1.02	.253
Upper face height (n-stos)	1.35	1.55	0.27	1.91	0.52	1.93	.266
Lower face height (sn-gn)	–0.26	1.10	0.44	2.10	0.56	1.44	.353
Total face height (n-gn)	1.02	1.99	0.87	2.07	0.72	2.57	.942
Angular measurements (°)							
Nasolabial angle (c-sn-ls)	0.24	3.45	0.10	2.60	–2.35	5.73	.191
Labiomental angle (li-sl-pog)	3.46	12.07	2.89	12.56	–1.40	9.70	.482
Convexity angle (n-sn-pog)	0.35	1.65	0.50	1.70	–0.70	1.64	.129
Total convexity angle (n-prn-pog)	–0.53	1.27	–0.78	1.87	–0.50	1.45	.871
Upper lip angle (chr-ls-chl)	3.42	2.89	3.09	2.78	1.49	3.85	.245
Lower lip angle (chr-li-chl)	3.83	5.07	2.04	5.01	3.98	4.37	.502
Volumetric measurements (mL)							
Upper lip changes	–0.47[A]	0.76	–0.16[A]	0.86	0.63[B]	0.79	.003**

[a] One-way analysis of variance: ** $P < .01$. Groups with the same superscripts (capital letters) are not significantly different ($P > .05$).
[b] all-alr indicates left and right alare; chr-chl, left and right cheilion; sn, subnasale; stos, stomion superius; ls, labiale superius; stoi, stomion inferius; gn, gnathion; n, nasion; c, columella; li, labiale inferius; sl, sublabiale; pog, pogonion; prn, pronpronasale.

- The 3D imaging system is a useful tool for analyzing 3D changes in the facial soft tissues induced by the orthodontic treatment. This system may be efficiently and reproducibly applied to 3D images by clinicians.

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