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Original Article

Three-dimensional stereophotogrammetric analysis of facial soft tissues following bone-borne rapid maxillary expansion

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Abstract

Aim: Bone-borne rapid maxillary expander (RME) is one of the latest expander designs being used for skeletal expansion by applying forces through palatal mini-screws. The purpose of this retrospective study was to evaluate soft tissue facial changes following RME using 3D stereophotogrammetry.

Materials and Methods: A total of 15 subjects (6 males and 9 females) with a mean age of 12.1±1.4 years who underwent upper arch expansion using bone-borne RME as a component of their orthodontic therapy were recruited in this retrospective study. 3D facial images (3dMD Ltd, Atlanta, Ga) generating 3D soft tissue meshes before expansion (T0), immediately after expansion (T1), and after a 3-month retention phase (T2) were used to capture facial scans of 15 subjects. Based on twenty-three landmarks, 10 linear measurements were made from each of 3D images. Comparisons of measurements at 3 different times were evaluated with one-way Repeated Measures Analysis of Variance ($p < 0.05$).

Results: Statistically significant changes were observed in the mouth (chr-chl) and nasal (alr-all) width in T0-T1 and T0-T2. No significant differences were found in the upper and lower face heights, total face height, upper and lower lip heights, upper and lower vermillion heights and intercanthal width.

Conclusion: Significant increases in mouth and nose width were obtained by bone-borne RME. These changes remained stable for 3 months. 3D stereophotogrammetric facial imaging method is an easy and non-invasive method that can be used to analyze the changes of facial soft tissues after RME treatment.

Keywords: Rapid maxillary expansion; skeletal anchorage; soft tissue; 3D stereophotogrammetry

INTRODUCTION

Rapid maxillary expansion (RME) is a kind of treatment procedure that has been widely used in orthodontics for more than thirty years and is based on the principle of opening the midpalatal suture under the effect of orthopedic forces (1). The effects of many conventional expander types on the dentofacial structure have been studied and documented (2). These expanders cause buccal tipping and extrusion in the posterior teeth along with a lateral rotation of the alveolar segments, causing both orthopedic and orthodontic effects (3-5). These outcomes of RME can lead to the rotation of the mandible back and down and also may lead to undesirable effects such as increased facial height (6,7). Recently, with the introduction of micro-implants, tooth and tissue-borne appliances have been replaced by bone-borne maxillary expansion appliances. With bone-borne maxillary expanders, the force can be transmitted directly to the maxilla preventing the occurrence of side effects that occur in conventional tooth-bone RME appliances (8).

Since the maxilla is articulated with many bones, all craniofacial bones that articulate with the maxilla are displaced along with the maxilla after RME (9). Therefore, the effects of RME treatment are not only limited to the oral structures, but also affect the entire nasomaxillary complex.

With the development of the soft tissue paradigm in modern orthodontics, it has become important to analyze all facial aesthetics in orthodontic diagnosis and treatment planning (10). For this purpose, studies focusing on soft tissue aesthetics besides the ideal relationships of hard tissues have gained importance recently (11). Numerous studies have investigated skeletal and dental effects of RME, but there is no consensus on whether RME produces

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temporary or permanent changes in the patient's facial soft tissues and profile (12).

In orthodontic evaluation, most of the authors used the patient's lateral cephalometric radiographs and photographs to determine soft tissue effects. However, these diagnostic records ensure limited data as they allow two-dimensional examination of complex three-dimensional (3D) structures (13). Due to the limitation of these methods, 3D imaging methods have been produced for 3-dimensional and clearer assessment of facial soft tissue (14). These methods are cone beam computed tomography (CBCT), laser scanning, stereophotogrammetry and structured light techniques (15).

Today, the modern technology of the 3dMD Face System (3dMD, Atlanta, GA) is considered to be the most reliable of all 3D soft tissue imaging methods. This method is based on the principle of obtaining images of an object from different angles with multiple cameras simultaneously and creating 3-dimensional images of the soft tissue morphology with the help of special computer software (9, 16). This non-invasive system which enables a clinician to capture a 180u picture of one individual's face from ear to the other in just 1.5 milliseconds is also repeatable and highly accurate (17).

Since the maxilla is articulated with many bones, craniofacial bones that articulate with the maxilla are displaced along with the maxilla after RME. Therefore, the treatment effects of RME may lead to changes in the entire nasomaxillary complex (9). Abedini et al. (2) analyzed soft tissue facial changes with 3dMD method induced by RME and reported significant changes in paranasal, upper lip, and at both cheeks. Baysal et al. (9) Baysal et al evaluated three-dimensional (3-D) soft tissue facial changes following RME and compared these changes with an untreated control group. They reported nonsignificant differences in soft tissue changes with RME in the treated group compared to the control group except for alar base width. Although many studies have documented changes in the skeleton and tooth structure with RME in the literature, additional information is needed on how these influence soft tissues (18). The aim of this retrospective study was to evaluate the soft tissue efficacy of bone-borne RME appliance using the 3dMD face method.

MATERIALS and METHODS

Study design

This retrospective study was confirmed by the ethics committee of Izmir Katip Celebi University (No: 0069). Sample size was calculated according to Altorkat et al's (19) study to show a clinically significant difference of 3 mm with a standard deviation of 1.13 mm in soft tissue change with software G*Power Version 3.1.3 (Franz Foul, University, Kiel, Germany). In accordance with the calculation, at least 14 subjects were predicted to provide at least 80% power at α=0.05 significance level (19).

The study included 15 post-RME treatment subjects (6 males, 9 females) with a mean age of 12.1±1.4 years. The patients who had bilateral posterior cross bite, needed RME treatment and had suitable in terms of both time and recording quality 3dMD facial images were included in the study. The patients with craniofacial anomalies and body mass index (BMI) ≥30 [weight (kg) / height (m^2)] (20) which can be misleading in measurements of soft tissues were excluded. All patients were treated by the single specialist (GG).

Bone-borne expander design includes two mini-screws (Tomas, Dentaurum, Germany) with a diameter of 1.6 mm and a length of 10 mm which are located on the right and left sides between the roots of the 2nd premolar and 1st molar teeth with 60-70° angle (Figure 1). The expansion screw was activated two quarter rounds a day in the first week (0.5 mm) followed by a quarter turn (0.25 mm) per day until the maxillary molar palatal cusps contacted with the buccal cusps of the mandibular molar (21). When the desired expansion was achieved, the expansion screws were fixed and then in order to improve the midpalatal suture and the formation of new bone, appliances were left passively until the end of the 3 months retention phase.

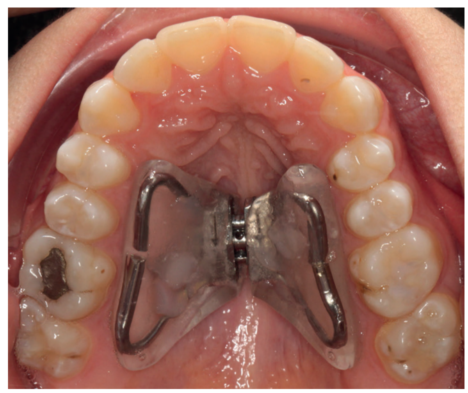

Figure 1. Bone-borne maxillary expander

Image Acquisition

Three-dimensional facial soft tissue images using 3dMD imaging system (3dMD, Atlanta, Ga) of all patients were taken before (T0), immediately after expansion with bone-borne RME (T1), and after the 3-month retention phase (T2). All images were captured when the patient's head was in a natural position, eyes were looking through a mirror placed between cameras, teeth were in centric occlusion and lips in relaxed in less than 1.5 milliseconds.

3D Image Analysis

All images were automatically saved as ".tsb" files and then imported into 3dMD Vultus software for analyzing. For standardization, all 3D images were reoriented and the regions (neck, hair, ear) not included in the analysis were removed from the image. The landmarks used in the present study are given in Figure 2 and Table 1. Based on twenty-three landmarks, the primary 10 linear measurements [mouth width (chr-chl), nasal (alr-all) width, total facial height (n-gn), upper facial height (n-sto), lower facial height (sn-gn), upper lip height (sn-sto), lower lip height (sto-gn), upper vermillion height (ls-sto), lower vermillion height (sto-li) and intercanthal width (enr-enl)] were made from each of the 3D images on the 3dMD Vultus software. Three-dimensional facial image analysis was performed by a single researcher. Individual changes in soft tissue markers were evaluated using superimposed images. In the literature (22), the most stable regions for superimposition of 3-D facial images were defined as forehead, upper nasal dorsum, and zygoma, and therefore the registration protocol was performed on these regions.

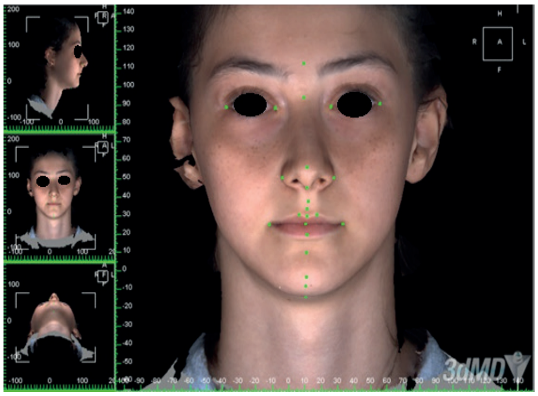

Figure 2. Facial soft-tissue measurements using 3D software

Statistical Analysis

The data were assessed in IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Released 2018, Armonk, New York, USA) statistical package program. The normal distribution of data for quantitative variables was assessed with Shapiro Wilk normality test and Q-Q graphics. Qualitative data are given as unit number (n) whereas quantitative data are given as mean ± standard deviation ($\bar{X}$ ± ss) values. Descriptive statistics are given as unit number (n), mean ± standard deviation ($\bar{X}$ ± ss) values. The comparison of measurement averages obtained from individuals at 3 different times was evaluated with one-way Repeated Measures Analysis of Variance in repeated measures. The sphericity assumption was evaluated with Mauchly's test of sphericity. Paired comparison results were presented using Bonferroni correction in post-hoc comparisons for mouth width and nasal width variables, which were found to be statistically significant as a result of one-way analysis of variance in repeated measurements. The effect size (η_p^2) for each continual measurement was calculated. $p < 0.05$ value was defined as statistically significant.

Table 1. Definitions of Soft Tissue Landmarks

Landmarks	
Nasion (n)	The point in the midline of both the nasal root and the nasofrontal suture, always above the line that connects the two inner canthi
Glabella (gr)	The most prominent midline point between the eyebrows
Endocanthion (en*)	The point located at the inner commissure of the eye fissure
Subnasale (sn)	The most posterior midpoint of the philtrum
Exocanthion (ex*)	The point located at the outer commissure of the eye fissure
Alar curvature (al*)	The most lateral point in the curved base line of each nasal wing
Labiale superius (ls)	The midpoint of the upper vermillion line
Labiale inferius (li)	The midpoint of the lower vermillion line
Gnathion (gn)	The most inferior midpoint on the soft tissue contour of the chin
Menton (me)	Most inferior point of mandibular symphisis, in midsagittal plane
Stomion (sto)	Central portion of interlabial gap
Pronasale (prn)	The most prodruded point of the apex nasi identified in lateral view of the rest position of the head
Crista philtri (cph*)	Point on left and right elevated margins of philtrum just above
Pogonion (pog)	Most anterior point on bony chin

RESULTS

In order to test the reliability and repeatability, measurements were repeated 2 weeks later on the 3D images of 10 randomly selected patients and intraclass correlation coefficients varying between 0.91 and 0.95 were obtained.

Baseline demographic features of the patients are presented in Table 2. Significant increases were observed in nasal and mouth widths following RME ($p < 0.05$).

Table 2. Demographic Characteristics of Groups

	Treatment Group
Age (y)	12.1±1.4 years
Male (n)	6
Female (n)	9
Body Mass Index (BMI)	23.2 kg/m^2

Nasal width showed a statistically significant increase immediately after RME (p <0,001) and this increase was maintained throughout the retention period (p=0,616). Similarly, there was a statistically significant increase in mouth width after RME (p=0,002). There was not a significant change during the retention period (p=0.614). Total facial height (p=0.445), upper facial height (p:0,676) and lower facial height (p=0.183) did not change with RME. Although the height of the upper lip (p=0.297), upper vermilion (p=0.885), lower vermilion (p=0.993) and lower lip (p=0.218) increased with RME, this increase was not statistically significant. Similarly, a nonsignificant increase was observed in intercanthal width in both time periods (p=0.644) (Table 3).

Table 3. Comparisons of pretreatment (T0), right after treatment (T1) and end of the retention phase (T2) values

Variables	T0 (n=15) $\bar{X}$ ± ss	T1 (n=15) $\bar{X}$ ± ss	T2 (n=15) $\bar{X}$ ± ss	Test statistics* p	Partial Eta Squared (η_p^2)	Pairwise Comparisons
Total facial height	110.73±6.94	111.80±8.56	111.61±7.60	F:0.834 p:0.445	0.056	-
Upper facial height	72.87±3.33	73.57±5.27	73.07±5.07	F:0.398 p:0.676	0.028	-
Lower facial height	62.37±5.97	62.92±5.84	63.64±4.79	F:1.805 p:0.183	0.114	-
Upper lip height	23.73±2.48	23.7±2.36	24.36±2.20	F:1.270 p:0.297	0.083	-
Upper vermilion height	8.83±1.82	8.65±2.05	8.82±1.49	F:0.123 p:0.885	0.009	-
Lower vermilion height	9.41±1.26	9.41±1.58	9.46±1.30	F:0.007 p:0.993	0.001	-
Lower lip height	38.82±4.27	39.85±4.42	39.75±3.32	F:1.610 p:0.218	0.103	-
Mouth width	45.14±4.94	48.21±4.40	47.44±4.42	F:11.615 p<0.001	0.453	T0-T1: p=0.002 T0-T2: p=0.016 T1-T2: p=0.614
Nasal width	33.52±3.36	36.14±2.83	35.65±3.02	F:15.834 p<0.001	0.531	T0-T1: p<0.001 T0-T2: p=0.003 T1-T2: p=0.616
Intercanthal width	93.45±3.75	93.71±4.32	94.18±5.12	F:0.448 p:0.644	0.031	-

* One-way Repeated Measures Analysis of Variance

DISCUSSION

Facial aesthetics together with an ideal occlusion in orthodontic treatment are important for patient satisfaction. For this reason, it is important for specialists to be aware of the possible effects of the mechanics applied in orthodontic treatment on soft facial tissues. Being aware of the effects of RME treatment on soft tissues helps in patient satisfaction and treatment planning. Orthodontists frequently use 2D images like posteroanterior and lateral cephalometric radiographs, panoramic and face photographs for diagnosis, treatment planning and evaluation of treatment results. Today, the development of 3D imaging technique makes it possible to measure the alterations in soft tissue position in three dimensions (23). Soft tissue images obtained from the 3dMD system provide highly accurate 3D facial surface images for diagnosis, analysis, and treatment monitoring and outcome evaluation (24). Lübbers et al. (25) evaluated the precision (repeatability and reproducibility) and the accuracy of the 3dMD system and they found the precision and the accuracy of the system sufficient and also recommended it for evaluation of the facial soft tissues. The purpose of this study was to evaluate the effects of bone-borne RME appliance on facial soft tissue profiles using 3D images. The findings of the present study can help specialists to estimate the role played by bone-aided RME in soft tissue therapy success.

Due to the adjacent anatomical relation between the maxilla and the nasal region, the nose is one of the most usually investigated anatomical regions following RME. There was a significant increase in nasal width at the end of RME treatment. Additionally, this increase remained constant throughout the 3-month retention phase. The results of our study were consistent with previous studies results (26-28). Fastuca et al. (28) evaluated soft tissue alterations after RME treatment with Haas-type expander in growing patients. They reported significant increase differences in nasal width (Alr-All). Berger et al. (29) reported a significant increase in the nose width after the expansion process and no change during the one-year retention period. Huang et al. reported a significant increase in nasal width after RME in their systematic review and meta-analysis study (30). Similarly, Altorkat et al. (19) reported a significant increase in nasal width after RME which is similar to the present study.

The changes in mouth width following RME were significant perhaps owing to lateral displacement of maxillary fragments. There was a significant increase which was stable 3 month. Similarly, Altındis et al. (18) observed a significant increase after RME with banded and acrylic expander. Kim et al. (31) evaluated immediate soft tissue changes RME and indicated a significant increase in mouth width after RME. Similar results were reported by Huang et al. (30). In opposed to present study, Baysal et al. (9) and Factuca et al. (28) observed no significant difference after RME with Haas-type expander in mouth width. This difference may be due to the different expansion appliances used in the studies.

In the present study, RME did not affect the height of the upper lip, upper vermilion, lower vermilion and lower lip. Being concordant with our study, Berger et al. (29) observed no significant change following RME and after 1 year of retention in the measures of the height of upper lip and vermilions. Similarly, Altındis et al. (18) reported no significant changes in the height of upper and lower lips and vermillion after RME therapy. However, the authors observed a significant increase only in the lower lip vermillion height. In another study conducted by Baysal et al.(9), no statistically significant alteration for the lip heights after RME was found.

Following RME, a nonsignificant increase was found in intercanthal width in the present study. These findings are in agreement with prior studies that belong to Alkhayer et al. (32), Berger et al. (29) and Baysal et al. (9). Baysal et al.(9) claimed that this insignificant increase was the result of the normal growth and development.

LIMITATIONS

One of the limitations of this study was short observation period. Furthermore, the sample size was limited even if satisfying the power analysis. Conducting the study only a single population can be considered as another limitation of the study. Although the study has some limitations, it can be deduced that soft tissue nasal and mouth width enlargement is a consequence of RME. Since this study has a single center and small sample size, its generalizability is limited.

CONCLUSION

1. After bone-borne RME treatment, statistically significant soft tissue changes were observed in mouth and nasal widths.

2.Increases obtained after RME were maintained throughout the retention period.

3.RME caused no change in the height of facial, lips and vermilions.

Competing Interests: The authors declare that they have no competing interest.

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Ethical Approval: This retrospective study was confirmed by the ethics committee of Izmir Katip Celebi University (No: 0069).

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