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ORIGINAL ARTICLE

Soft tissue evaluation after maxillary protraction with RPE or with the ALT-RAMEC protocol

A controlled 3D study

Elvan Onem Ozbilen[1] · Mustafa Onur Ari[2] · Hanife Nuray Yilmaz[1] · Sibel Biren[3]

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Abstract

Purpose To evaluate soft tissue changes following maxillary protraction with different expansion protocols using three-dimensional (3D) stereophotogrammetry.

Methods Pretreatment (T0) and postprotraction (T1) stereophotogrammetry and lateral cephalometric images of skeletal class III patients were included in this retrospective study. In all, 32 patients were treated either with a combination of rapid palatal expansion and facemask (RPE/FM; $n=16$; mean age: 9.94 ± 0.68 years) or with alternate rapid maxillary expansion and constriction together with a facemask (Alt-RAMEC/FM; $n=16$; mean age: 9.74 ± 1.35 years). As a control group 16 untreated patients were recruited (mean age: 9.46 ± 0.8 years). For superimpositioning of the 3D images taken at T0 and T1, the face was divided into defined regions and 3D and differences between the groups were evaluated using 3-matic software (Materialise Europe, Leuven, Belgium). Cephalometric analyses were also performed.

Results While the increases in the cephalometric parameters SNA and ANB were significantly greater in the treatment groups, the value for SNB also increased in the control group ($p<0.05$). The results of the stereophotogrammetry analyses demonstrated that the mean changes in the RPE/FM and in the Alt-RAMEC/FM groups were significantly different for the midface compared to the control group (0.33 ± 0.26 mm, 0.3 ± 0.31 mm, 0.1 ± 0.18 mm). The maximum positive, negative, and mean changes were also significantly different between the treatment and control groups for the upper lip ($p<0.05$). For the lower lip and the chin significant backward movements in the RPE/FM as well as in the Alt-RAMEC/FM group (–1.06 ± 1.26 mm, –0.68 ± 0.45 mm) were observed, while the control group (0.09 ± 0.53 mm) presented changes in the opposite direction. Regarding soft tissue changes, no significant differences were found between the RPE/FM and Alt-RAMEC/FM groups.

Conclusion Both treatment protocols improved the soft tissue profile due to a forward movement of the midface and the upper lip, and a backward movement of the lower lip and chin, compared to the control group.

Keywords Alternate rapid maxillary expansion and constriction · Facemask · Rapid palatal expansion · Facial esthetics · 3D stereophotogrammetry

✉ Assistant Prof. Elvan Onem Ozbilen, DDS Specialist in Orthodontics
elvanonem89@gmail.com

[1] Department of Orthodontics, Faculty of Dentistry, Marmara University, 9/34854 Maltepe/Istanbul, Turkey

[2] Private Practice, Istanbul, Turkey

[3] Department of Orthodontics, Faculty of Dentistry, Istanbul Kent University, Istanbul, Turkey

Untersuchung des Weichgewebes nach Oberkieferprotraktion mit RPE oder dem ALT-RAMEC-Protokoll

Eine kontrollierte 3-D-Studie

Zusammenfassung

Zielsetzung Evaluierung von Weichgewebeveränderungen nach einer Oberkieferprotraktion mit verschiedenen Expansionsprotokollen mittels dreidimensionaler (3-D) Stereophotogrammetrie.

Methoden In diese retrospektive Studie wurden sowohl vor (T0) als auch nach der Protraktion (T1) Stereophotogrammetrie- und laterale Fernröntgenseitaufnahmen von Patienten der skelettalen Klasse III aufgenommen. Insgesamt wurden 32 Patienten entweder mit einer Kombination aus schneller Gaumennahterweiterung und Gesichtsmaske (RPE/FM; $n=16$; Durchschnittsalter: 9,94 ± 0,68 Jahre) oder mit abwechselnder schneller Gaumennahterweiterung und -konstriktion in Kombination mit einer Gesichtsmaske (Alt-RAMEC/FM; $n=16$; Durchschnittsalter: 9,74 ± 1,35 Jahre) behandelt. Als Kontrollgruppe wurden 16 unbehandelte Patienten rekrutiert (mittleres Alter: 9,46 ± 0,8 Jahre). Für die Überlagerung der bei T0 und T1 aufgenommenen 3-D-Bilder wurde das Gesicht in bestimmte Regionen eingeteilt und die 3-D- und Unterschiede zwischen den Gruppen mit der Software 3-matic (Materialise Europe, Leuven, Belgien) wurden ausgewertet. Ferner wurden kephalometrische Analysen durchgeführt.

Ergebnisse Während die Anstiege der kephalometrischen Parameter SNA und ANB in den Behandlungsgruppen signifikant ausgeprägter waren, stieg der Wert für SNB auch in der Kontrollgruppe an ($p<0,05$). Die Ergebnisse der stereophotogrammetrischen Analysen zeigten, dass die mittleren Veränderungen in der RPE/FM- und in der Alt-RAMEC/FM-Gruppe für das Mittelgesicht im Vergleich zur Kontrollgruppe signifikant unterschiedlich waren (0,33 ± 0,26 mm, 0,3 ± 0,31 mm, 0,1 ± 0,18 mm). Die maximalen positiven, negativen und mittleren Veränderungen waren ebenfalls signifikant unterschiedlich zwischen den Behandlungsgruppen und der Kontrollgruppe für die Oberlippe ($p<0,05$). Für Unterlippe und Kinn wurden sowohl in der RPE/FM- als auch in der Alt-RAMEC/FM-Gruppe signifikante Rückwärtsbewegungen (-1,06 ± 1,26 mm, -0,68 ± 0,45 mm) beobachtet, während die Kontrollgruppe (0,09 ± 0,53 mm) Veränderungen in entgegengesetzter Richtung aufwies. Hinsichtlich der Weichgewebeveränderungen wurden keine signifikanten Unterschiede zwischen der RPE/FM- und der Alt-RAMEC/FM-Gruppe festgestellt.

Schlussfolgerung Beide Behandlungsprotokolle verbesserten die Weichgewebeparameter durch eine Vorwärtsbewegung des Mittelgesichts und der Oberlippe sowie durch eine Rückwärtsbewegung der Unterlippe und des Kinns, verglichen mit der Kontrollgruppe.

Schlüsselwörter Abwechselnde schnelle Gaumennahterweiterung und -konstriktion · Gesichtsmaske · Schnelle Gaumennahterweiterung · Ästhetik des Gesichts · 3-D-Stereofotogrammetrie

Introduction

Among all malocclusions, class III is very often associated with an unacceptable profile, which might be challenging for the psychology and social lives of the affected individuals. Treating these patients will not only improve occlusal function, but also esthetics and social well-being [1]. Two-thirds of skeletal class III malocclusions have maxillary retrognathism, either alone or combined with mandibular prognathism in etiology [2, 3]. Maxillary protraction (MP) was proved to be an effective method in the treatment of class III malocclusion [3, 4], and the induced treatment effects have been reported as the acceleration of maxillary forward growth with a counterclockwise rotation, mandibular backward movement with a clockwise rotation, forward movement of the maxillary dentition, and backward movement of the mandibular dentition [4, 5].

Weakening of the circummaxillary sutures with rapid palatal expansion (RPE) is suggested to enhance the treatment effects of MP [6, 7]. For sutural mobilization, however, it is claimed that 12–15 mm expansion is necessary, but such expansion is usually excessive and may irritate the tissues [8]. To overcome these problems and to enhance maxillary forward movement with sutural mobilization, a different protocol, involving alternate rapid maxillary expansion and constriction (Alt-RAMEC), has been proposed [8]. In the Alt-RAMEC protocol, repetitive opening and closing of the expansion screw for seven to nine consecutive weeks was reported to result in greater maxillary forward movement after protraction in cleft palate patients [8]. Although there are conflicting results in noncleft palate patients [9, 10], recent studies have reported more favorable skeletal outcomes for that protocol [11–15].

Most studies have focused on skeletal changes following MP, either with conventional RPE or with the Alt-RAMEC protocol. However, skeletal correction should not be the only aim of orthodontic treatment. Alterations in the soft tissues to improve facial esthetics is also one of the primary aims for greater success [16]. A few studies have reported improved soft tissue profiles following RPE ± MP [17–19]. Kilic et al. [16] concluded in their cephalometric study that following MP, the soft tissues around the maxilla and the upper lip moved forward, and the soft tissues around the mandible moved backward and downward significantly. Kilicoglu and Kirlic [20] reported an improvement in the facial profile with a more pronounced upper lip and the soft tissue pogonion moving backwards. Moshkelgosha et al. [21] evaluated the facial soft tissue profile in two-dimensional (2D) photographic images and reported significant increases in the upper lip and nasal prominence. However, the lower lip did not show significant changes.

When the soft tissue changes were compared between patients treated with the RPE/MP or the Alt-RAMEC/MP protocol, two studies observed that the increase in H angle, the anterior movement of the upper lip, and the decrease in lower lip position in relation to the vertical line were more pronounced in the Alt-RAMEC/MP group [12, 22]. On the contrary, Liu et al. [14] compared patients being treated with MP, RPE/MP or Alt-RAMEC/MP in a recently published study and found no significant differences with regard to soft tissue parameters. Although all these studies reported improvements in the soft tissue profile, the evaluation was based on 2D images, which are limited due to the complex morphology of the human face and anatomical superimpositions. To overcome these problems and for more accurate results, three-dimensional (3D) imaging techniques, such as cone-beam computed tomography (CBCT), laser scanners, and 3D stereophotogrammetry can be used for soft tissue evaluation [23–28]. Among these methods, 3D stereophotogrammetry was found to be preferable to the others due to the short acquisition time, non-invasiveness, lack of radiation, ease of use and archiving together with the proven accuracy, reliability, and validity [23, 25, 29–31] . Furthermore, it is advantageous over conventional photography due to the reduced number of variables (because of the fixed nature of the system, lighting conditions and camera angulations, distances are more standardized) and its ability to reproduce 1:1 surface imaging [32].

To the best of our knowledge, only three studies assessing the soft tissue changes following treatment using expansion and MP with 3D stereophotogrammetry exist [15, 27, 28]. Therefore, the aim of the present study was to compare soft tissue changes in the different regions of the face following MP with two different expansion methods (RPE and Alt-RAMEC) in an untreated class III control group using 3D stereophotogrammetry and surface-based 3D analyses.

Materials and methods

The present controlled retrospective study was approved by the Ethical Committee of Marmara University, Faculty of Dentistry (21 December 2020, 2020/87, Istanbul, Turkey) and was conducted in accordance with the Declaration of Helsinki of 1975 as revised in 2013.

Sample size calculation

G*Power software v3.1.9.2 (Heinrich Heine University, Düsseldorf, Germany) was utilized for sample size calculation based on a previous study [30], considering the large effect sizes for the average changes in the morphological regions that were observed between the groups in that study. The calculation indicated that a minimum of 16 patients was required in each group (power: 0.85; α: 0.05; effect size: 0.5).

Eligibility criteria

The study sample was randomly derived from the archive of Marmara University, Department of Orthodontics. The inclusion criteria were as follows: (1) anterior crossbite, (2) skeletal class III malocclusion with maxillary deficiency (N⊥A < –1 mm, SNA < 80°, maxillary depth < 90°, ANB < 2°), (3) no systemic/genetic diseases, (4) no previous orthodontic treatment, and (5) availability of complete records.

Orthodontic procedure

The RPE/FM group consisted of 16 patients (mean age: 9.94 ± 0.68 years). A bonded hyrax with an acrylic bite-block (Leone A0620, Sesto Fiorentino-Firenze, Italy) was used for RPE. The patients were instructed to activate the screw twice daily (0.5 mm/day) until the sufficient maxillary expansion (7–14 days of expansion) was achieved. Following RPE, a petit-type facemask (FM; Ormco™, Brea, CA, USA) was prescribed with a force vector of 30° to the occlusal plane and with 400 g/side for a minimum of 16 h/day until a class II dental relationship was obtained.

The Alt-RAMEC/FM group consisted of 16 patients (mean age: 9.74 ± 1.35 years). For the Alt-RAMEC protocol, a double-hinged expansion screw (US patent number: 633477B1, Bestdent, Kaohsiung, Taiwan) with an acrylic bite-block was used. The patients were instructed to activate the screw at a rate of 1 mm/day in the first week. During the following week, the screw was closed at the same rate. The expansion and constriction procedures were continued for 9 weeks [8]. Following the Alt-RAMEC protocol, FM treatment was prescribed as in the first group. Pretreatment (T0) and postprotraction (T1) lateral cephalograms and

Table 1 Definition of the planes and the morphological regions
Tab. 1 Definition der Ebenen und der morphologischen Regionen

Planes	*Definition*
Exocanthion	A plane passing through the right and left exocanthion points and parallel to the Frankfurt horizontal plane (FHP)
Lip	A plane passing through the right and left chelion points and parallel to the FHP
Subnasal	A plane passing through the soft tissue subnasal point and parallel to the FHP
Menton	A plane passing through the soft tissue menton point and parallel to the FHP
Right chelion	A plane passing through right chelion point and parallel to the midsagittal plane (MSP)
Left chelion	A plane passing through the left chelion point and parallel to the MSP
Morphological regions	*Definition*
Total face	The whole face except the hair, ears, and neck region
Zygoma	The region between the exocanthion plane and the subnasal plane
Midface	The region between the exocanthion plane and the lip plane
Upper lip	The region between the subnasal plane, the lip plane, right and left chelion plane
Lower lip and chin	The region between the lip plane, the menton plane, right and left chelion plane

3D stereophotogrammetric images without the acrylic bite-blocks were obtained from the department archives for both study groups. According to the information obtained from the patient files, no other active treatment was performed between the T0 and T1 records of the patients.

The control group also consisted of 16 patients (mean age: 9.46 ± 0.8 years) whose treatment could not start immediately for various reasons, such as poor oral hygiene, dental treatments or not having the sufficient number of teeth for anchorage. The lateral cephalograms and 3D stereophotogrammetric images of this group were also performed as a routine examination procedure in the department. Informed consent was obtained from all patients included in the treatment and control groups.

The numbers of the male and the females included in the present study were not the same for each group; however, mostly males were present in the groups.

Data collection and measurements

Lateral cephalograms were analyzed using NemoStudio NX-Pro 10.4.2 (Software Nemotec, Madrid, Spain). For skeletal changes SNA, SNB, ANB angles, and Frankfurt–mandibular plane angle (FMA) differences were calculated between T0 and T1. For the 3D stereophotogrammetric images the 3dMDface system (3dMD Inc., Atlanta, GA, USA) was used. The 3dMDface system simultaneously captures the image with two modular units of six cameras, positioned at predetermined distances and angles. The system was calibrated prior to each acquisition and each patient was seated on a height-adjustable chair while looking into a mirror to ensure natural head posture for standardization. Following image acquisition, the images were processed using the 3dMDvultus version 2.1 software (3dMD Inc.). The ears, hair, and neck regions were removed. For initial superimposition, T0 and T1 3D images were brought closer using global registration, and the forehead and dorsum of the nose were hand-selected and superimposed using the iterative closest point method. Following superimposition, the 3D images were converted to stereolithography (.stl) format and transferred into the 3-matic software (Materialise Europe, Leuven, Belgium) for further evaluation.

In the 3-matic software, the midsagittal plane (MSP) was first defined as a vertical reference plane, which is the sym-

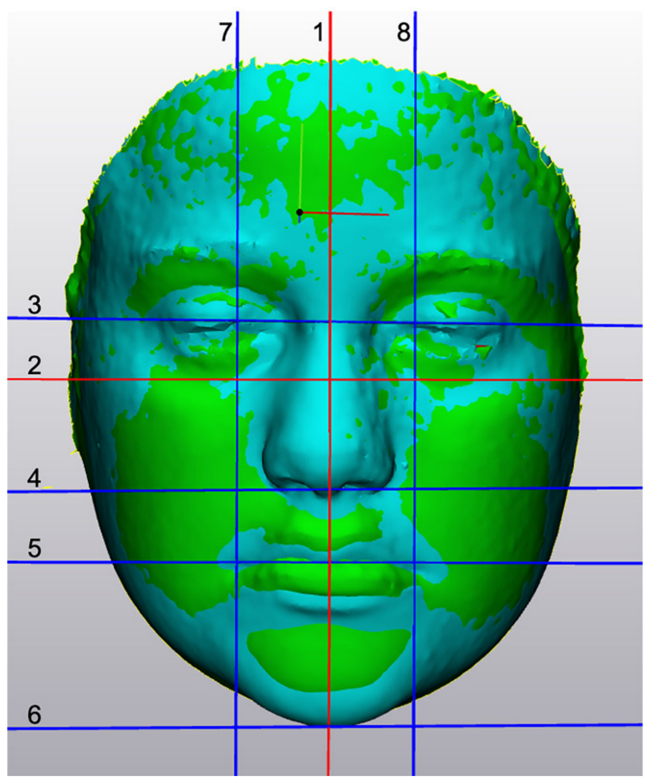

Fig. 1 Planes: (1) midsagittal, (2) Frankfurt horizontal, (3) exocanthion, (4) subnasal, (5) lip, (6) menton, (7) right chelion, (8) left chelion
Abb. 1 Ebenen: (1) mittsagittal, (2) Frankfurter Horizontale, (3) Exochantion, (4) Subnasale, (5) Lippe, (6) Menton, (7) rechtes Chelicon, (8) linkes Chelicon

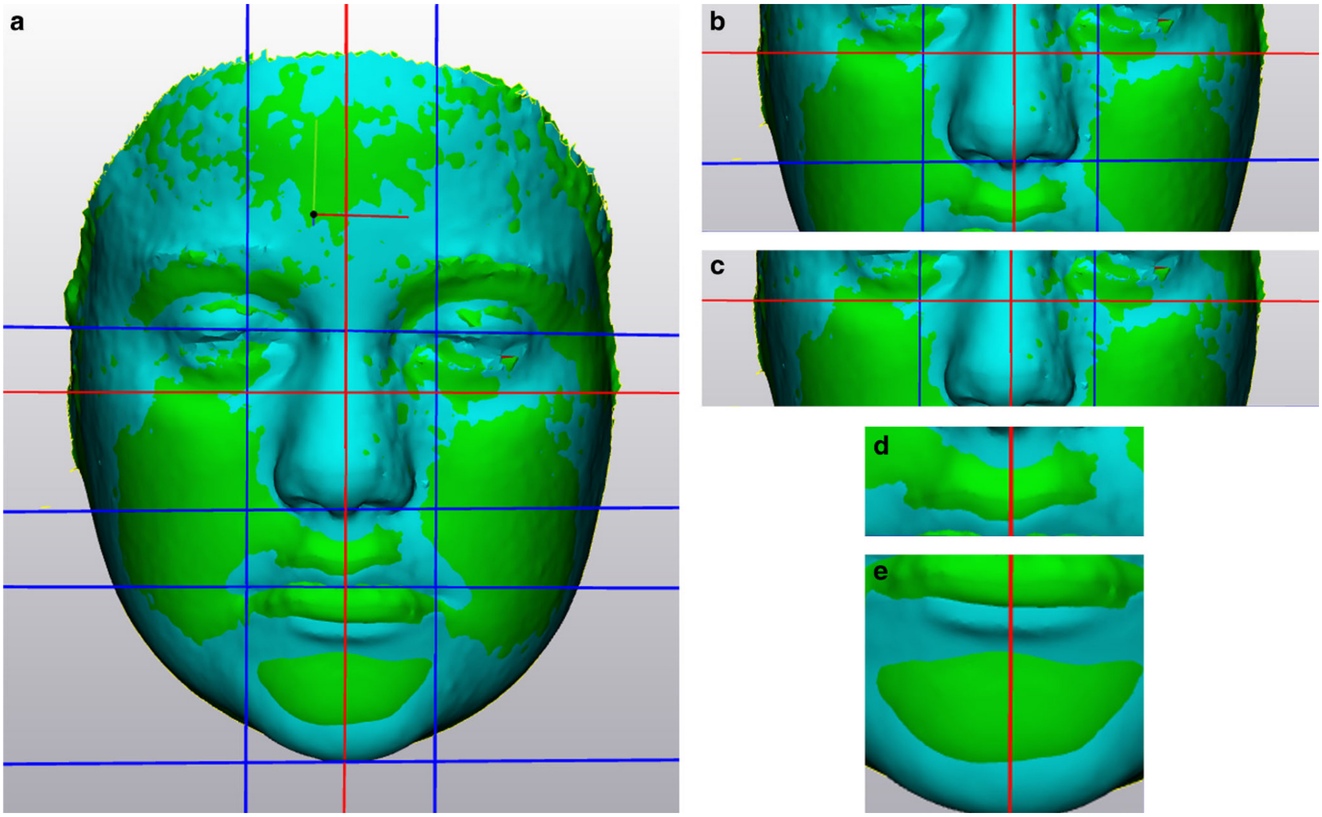

Fig. 2 **a** Total face, **b** midface, **c** zygoma, **d** upper lip, **e** lower lip and chin
Abb. 2 **a** Gesamtes Gesicht, **b** Mittelgesicht, **c** Zygoma, **d** Oberlippe, **e** Unterlippe und Kinn

metry plane of the superimposition of the T0 3D image and its mirror reflection [28]. For the horizontal reference plane, Frankfurt horizontal plane (FHP) was created as a plane passing through the right and left soft tissue orbital points perpendicular to MSP. Using these two lines, other planes were created, and the face was divided into different morphological regions, as described in Table 1 and in Figs. 1 and 2 [28, 30]. Superimposed and segmented T0 and T1 3D images were compared using the "part comparison" tool of the 3-matic software separately for each morphological region and 3D deviation analyses were performed. Following "part comparison", the software automatically created a color map and a histogram. The histogram showed maximum positive and maximum negative changes, the mean change, and the root mean square (RMS) values for the 95th percentile of the meshes. The RMS value was automatically calculated by the software by taking the square root of the mean of the squares of the data. The negative values in the histogram indicated that the regions that moved backward, and the positive values indicated that the regions that moved forward after MP. All measurements were repeated after a 1-week interval by the same operator.

Statistical analysis

IBM SPSS Statistics (version 22.0; IBM Corp., Armonk, NY, USA) was used for statistical analyses. The conformity of the parameters to the normal distribution was assessed using Shapiro–Wilks test. One-way analysis of variance (ANOVA) was performed for the comparison of the initial values. For the intergroup comparisons of T1–T0 differences for the skeletal and soft tissue parameters between the groups, one-way ANOVA for the normally distributed data and Kruskal–Wallis test for nonnormally distributed data were used followed by Bonferroni multiple comparisons. For the intragroup comparisons of skeletal values (T1–T0), paired-samples t-test was used for normally distributed data, and Wilcoxon signed-ranked test was used for nonnormally distributed data. Statistical significance was set at $p < 0.05$.

Results

The treatment periods were 10.17 ± 1.19 months and 10.49 ± 1.21 months for the RPE/FM and the Alt-RAMEC/FM groups, and the observation period was 9.57 ± 0.69

Table 2 Evaluation of the homogeneity between the initial values (T0) of skeletal parameters of the groups
Tab. 2 Evaluierung der Homogenität zwischen den Ausgangswerten (T0) der skelettalen Parameter in den Gruppen

	Group 1 RPE/FM (Mean ± SD)	Group 2 Alt-RAMEC/FM (Mean ± SD)	Group 3 Control (Mean ± SD)	*p*
SNA	79.44 ± 3.39	78.18 ± 2.45	78.19 ± 3.08	NS 0.401
SNB	80.88 ± 3.38	78.5 ± 2.73	79.38 ± 3.14	NS 0.101
ANB	–1.44 ± 1.31	–0.32 ± 1.14	–0.94 ± 1.65	NS 0.084
FMA	25.25 ± 5.86	26.2 ± 4.17	29.25 ± 4.95	NS 0.075

One-way analysis of variance, $p < 0.05$
NS not significant, *RPE/FM* rapid palatal expansion and facemask, *Alt-RAMEC/FM* alternate rapid maxillary expansion and constriction together with a facemask, *SD* standard deviation

Table 3 Evaluation of the skeletal changes during T1–T0 for each group
Tab. 3 Evaluierung der skelettalen Veränderungen während T1–T0 für jede Gruppe

	Group 1 RPE/FM (Mean ± SD)			Group 2 Alt-RAMEC/FM (Mean ± SD)			Group 3 Control (Mean ± SD)		
	T0	T1	*p*	T0	T1	*p*	T0	T1	*p*
SNA	79.44 ± 3.39	81.25 ± 3.68	*** 0.000[a]	78.18 ± 2.45	80.17 ± 2.67	*** 0.000[a]	78.19 ± 3.08	78.88 ± 2.73	* 0.043[b]
SNB	80.88 ± 3.38	80.13 ± 3.81	NS 0.200	78.5 ± 2.73	78.33 ± 2.62	NS 0.494	79.38 ± 3.14	80.44 ± 3.41	** 0.008[b]
ANB	–1.44 ± 1.31	1.13 ± 1.63	*** 0.000[a]	–0.32 ± 1.14	1.84 ± 1.42	*** 0.000[a]	–0.94 ± 1.65	–1.56 ± 1.82	* 0.034[b]
FMA	25.25 ± 5.86	27.13 ± 5.75	** 0.004[a]	26.2 ± 4.17	26.84 ± 3.84	0.136	29.25 ± 4.95	29.56 ± 5.49	NS 0.612

NS not significant, *RPE/FM* rapid palatal expansion and facemask, *Alt-RAMEC/FM* alternate rapid maxillary expansion and constriction together with a facemask, *SD* standard deviation
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$
[a]Paired-samples t-test
[b]Wilcoxon signed rank test

Table 4 Comparison of the skeletal changes during T0–T1 periods between the groups
Tab. 4 Vergleich der skelettalen Veränderungen während T1–T0 zwischen den Gruppen

T1–T0	Group 1 RPE/FM (Mean ± SD)	Group 2 Alt-RAMEC/FM (Mean ± SD)	Group 3 Control (Mean ± SD)	*p*	Post hoc test Groups 1–2	Groups 1–3	Groups 2–3
SNA	1.81 ± 1.56	1.99 ± 0.99	0.69 ± 1.14	** 0.010[a]	NS 1.000	* 0.044	* 0.015
SNB	–0.75 ± 2.24	–0.17 ± 0.97	1.06 ± 1.12	** 0.002[b]	NS 1.000	** 0.002	* 0.027
ANB	2.56 ± 1.31	2.16 ± 0.99	–0.63 ± 1.15	*** 0.000[b]	NS 1.000	*** 0.000	*** 0.000
FMA	1.88 ± 2.22	0.63 ± 1.6	0.31 ± 2.41	NS 0.097[a]	NS 0.306	NS 0.125	NS 1.000

NS not significant, *RPE/FM* rapid palatal expansion and facemask, *Alt-RAMEC/FM* alternate rapid maxillary expansion and constriction together with a facemask, *SD* standard deviation
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$
[a]One-way analysis of variance
[b]Kruskal–Wallis, Bonferroni post hoc test for multiple comparisons

months for the control group. There was no statistically significant difference between the groups.

Intraexaminer reliability was assessed using the intraclass correlation coefficient (ICC), which ranged from 0.908–0.984 and showed a high level of agreement.

Skeletal measurements

No significant differences were found between the groups when the skeletal values of the groups at T0 were compared (Table 2).

Regarding the skeletal changes between the time points, the values for SNA, ANB, and FMA increased significantly in the RPE/FM group, whereas only the SNA and ANB values showed significant increases in the Alt-RAMEC/FM group. In the control group, the SNA and SNB angles increased significantly, while the ANB angle presented a significant decrease (Table 3).

The comparison of the changes during the T0–T1 period between the groups is summarized in Table 4. While there were statistically significant differences between the treatment and control groups for the SNA, SNB, and ANB

Table 5 Comparison of the soft tissue changes during T0–T1 periods between the groups for 95th percentile of the meshes
Tab. 5 Intergruppen-Vergleich der Weichgewebeveränderungen während der T0–T1-Zeitspannen für das 95. Perzentil der Meshes

	Group 1 RPE/FM (Mean ± SD)	Group 2 Alt-RAMEC/FM (Mean ± SD)	Group 3 Control (Mean ± SD)	*p*	Post hoc test Groups 1–2	Groups 1–3	Groups 2–3
Total face							
Maximum negative change	–2.61 ± 1.23	–2.21 ± 1.32	–1.75 ± 0.59	NS 0.097[a]	NS 0.918	NS 0.096	NS 0.734
Maximum positive change	2.59 ± 0.72	2.31 ± 0.82	2.03 ± 0.95	NS 0.173[a]	NS 1.000	NS 0.188	NS 1.000
Mean change	0.08 ± 0.09	0.09 ± 0.13	0.12 ± 0.17	NS 0.662[a]	NS 1.000	NS 1.000	NS 1.000
RMS	0.97 ± 0.24	0.79 ± 0.25	0.67 ± 0.29	** 0.007[a]	NS 0.167	** 0.006	NS 0.560
Zygoma							
Maximum negative change	–1.52 ± 0.44	–1.38 ± 0.81	–1.11 ± 0.35	NS 0.127[a]	NS 1.000	NS 0.140	NS 0.553
Maximum positive change	1.91 ± 0.61	1.9 ± 0.43	1.61 ± 0.9	NS 0.376[a]	NS 1.000	NS 0.649	NS 0.716
Mean change	0.2 ± 0.27	0.22 ± 0.28	0.17 ± 0.25	NS 0.898[a]	NS 1.000	NS 1.000	NS 1.000
RMS	0.78 ± 0.24	0.69 ± 0.22	0.56 ± 0.29	NS 0.054[a]	NS 0.956	NS 0.051	NS 0.443
Midface							
Maximum negative change	–1.48 ± 0.45	–1.31 ± 0.56	–1.5 ± 0.86	NS 0.671[a]	NS 1.000	NS 1.000	NS 1.000
Maximum positive change	2.39 ± 0.79	2.45 ± 0.67	1.67 ± 0.99	* 0.018[a]	NS 1.000	NS 0.053	* 0.032
Mean change	0.33 ± 0.26	0.3 ± 0.31	0.1 ± 0.18	* 0.029[b]	NS 1.000	* 0.046	* 0.026
RMS	0.9 ± 0.18	0.84 ± 0.25	0.62 ± 0.3	** 0.007[a]	NS 1.000	** 0.008	NS 0.054
Upper lip							
Maximum negative change	–0.51 ± 0.44	–0.47 ± 0.34	–1.76 ± 0.87	*** 0.000[b]	NS 1.000	*** 0.000	*** 0.000
Maximum positive change	2.56 ± 1.04	2.75 ± 0.92	1.13 ± 0.93	*** 0.000[a]	NS 1.000	*** 0.000	*** 0.000
Mean change	1.06 ± 0.48	1.22 ± 0.64	–0.42 ± 0.51	*** 0.000[a]	NS 1.000	*** 0.000	*** 0.000
RMS	1.23 ± 0.52	1.43 ± 0.6	0.8 ± 0.37	** 0.004[a]	NS 0.817	NS 0.063	** 0.003
Lower lip and chin							
Maximum negative change	–2.84 ± 1.7	–2.22 ± 0.58	–1.96 ± 0.76	NS 0.179	NS 0.239	NS 0.119	NS 0.239
Maximum positive change	1.29 ± 1.03	1.06 ± 0.75	1.83 ± 1.09	NS 0.082[a]	NS 1.000	NS 0.375	NS 0.089
Mean change	–1.06 ± 1.26	–0.68 ± 0.45	0.09 ± 0.53	*** 0.000[b]	NS 1.000	** 0.002	** 0.002
RMS	1.54 ± 1.06	1.16 ± 0.49	0.96 ± 0.52	NS 0.190	NS 0.341	NS 0.102	NS 0.254

NS Not significant, *RPE/FM* rapid palatal expansion and facemask, *Alt-RAMEC/FM* alternate rapid maxillary expansion and constriction together with a facemask, *SD* standard deviation, *RMS* root mean square
$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$
[a]One-way analysis of variance
[b]Kruskal-–Wallis, Bonferroni post hoc test for multiple comparisons

parameters, there were no significant differences between the RPE/FM and the Alt-RAMEC/FM group (Table 4).

Soft tissue measurements

No significant differences were found between the RPE/FM and Alt-RAMEC/FM groups regarding soft tissue changes (Table 5).

In the comparisons of the RPE/FM group with the control group, the RMS value was significantly higher in the RPE/FM group for total face measurements. Furthermore, for the midface region the mean change and the RMS were significantly greater in the RPE/FM group (0.33 ± 0.26, 0.9 ± 0.18 mm) compared to the control group (0.1 ± 0.18, 0.62 ± 0.3 mm). In addition, the maximum positive, maximum negative, and mean changes for the upper lip region and the mean changes for the lower lip and chin region were significantly different from the control group. No significant differences were found between the two groups for the zygoma region (Table 5).

Comparing the Alt-RAMEC/FM group with the control group, none of the parameters of the total face and the zygoma region were significantly different. However, the maximum positive and the mean changes for the midface region were significantly more pronounced in the Alt-RAMEC group (2.45 ± 0.67, 0.3 ± 0.31 mm). For the upper lip region, all the measurements showed significant differences between the Alt-RAMEC and the control group. However, for the lower lip and chin region, only the mean change value was significant between these two groups (Table 5).

Discussion

In the present study, initial superimposition was performed using the forehead and the dorsum of the nose, which were shown to be stable, even if considering small changes of the head posture, and are the areas least affected by FM treatment [27]. Following initial superimposition, T0 and T1 images were matched applying the iterative closest point method as a surface registration method. The iterative closest point algorithm is a mathematical least-squares method. It has been used many times in other studies [33]. In the literature, surface-based comparison methods were suggested instead of landmark-based methods for the records of the same individuals at different time points [34, 35]. Moreover, the points used to divide the face into different morphological regions in the present study were reported to have good-to-high reliability and reproducibility [25, 26].

In the present study, the SNA and ANB angles increased significantly in both treatment groups. However, the difference between the different treatment protocols was not statistically significant. Although most of the studies in the literature reported more favorable results for the Alt-RAMEC/MP protocol [11–13], studies reporting similar results as in the present study also exist [9, 36]. The FMA increased significantly only in the RPE/FM group. Studies have shown that following MP, due to the backward–downward rotation of the mandible, the FMA increases, and this increase was more significant if using the RPE protocol than the Alt-RAMEC protocol [4, 11, 12, 15]. When the treatment and control groups were compared, significant differences were found for SNA, SNB, and ANB angles. While the increases in SNA and ANB were significantly greater in the Alt-RAMEC/FM and RPE/FM groups compared to the control group, the SNB only increased in the control group. These results were similar to previous findings [4, 11–13].

Simultaneous positive and negative soft tissue changes may occur in the face following orthodontic treatment. No significant differences were observed between the RPE/FM and Alt-RAMEC/FM groups regarding soft tissue changes in any of the morphological regions of the face, which might be explained by the nonsignificant cephalometric differences observed between groups. No previous study has compared the soft tissue effects of RPE/FM and Alt-RAMEC/FM treatments with 3D analyses. Although there are some cephalometric studies showing more favorable results for the Alt-RAMEC/MP protocol [12, 22], recent studies reported no significant difference between the two groups regarding soft tissue measurements [13, 14].

When evaluating the total face, only the RMS value was significantly different between the RPE/FM and the control group. The RMS values are squared first for calculation; therefore, the total change was calculated regardless of whether the changes were in a negative or positive direction. Since the maximum negative change in the RPE/FM group was smaller than that in the control group, the absolute value becomes greater. This may be the reason for the significant difference in the RMS value between the groups. Although there was no significant difference between the two treatment groups, the cumulative increased changes for the parameters SNB, ANB, and FMA in the RPE/FM group might be the reason for the results regarding the total face. To the best of our knowledge, there is no previous study that numerically evaluated total facial changes for a comparison of our results.

Regarding the soft tissue changes in the zygoma region, no significant changes were seen between the groups in the present study. Krneta Đokić et al. [28] defined the zygoma region as the upper face in their 3D stereophotogrammetric study and reported no significant differences in the zygoma region between the RME/FM group and class I control group, which coincides with the findings of the present study.

The 3D analyses of the midface area showed that the mean change and the RMS value were significantly greater in the RPE/FM group than in the control group, indicating more anterior displacement of the soft tissue of the midface following treatment. Although the boundaries of the midface were defined differently in the present study, the results were in agreement with the study of Krneta Đokić et al. [28]. Elnagar et al. [27] also reported anterior movement of the midface using 3D stereophotogrammetry. However, a bone-anchored MP protocol was used in their study. The findings of the present study regarding the midface changes in the RPE/FM group were also coincident with other literature findings, although 2D records were used in those [16, 17, 20, 21].

When comparing the Alt-RAMEC/FM with the control group for the midface region, the maximum positive and mean changes were significantly greater for the Alt-RAMEC/FM group supporting the significant increase in the SNA angle. There are no studies available in the literature that evaluated the changes of the soft tissues in the midface region using 3D analyses following treatment with the Alt-RAMEC/MP protocol. However, Sitaropoulou et al. [15] reported a significant forward movement in that area using a landmark-based comparison.

All the parameters regarding the upper lip region showed significant differences between the treatment groups and control group, except for the RMS value for the RPE/FM group. The anterior movement of the upper lip was in agreement with previous 2D [16, 18, 20, 21] and 3D studies [15, 27, 28]. Furthermore, the amounts of forward movement of the upper lip in the treatment groups were almost similar to the findings of Krneta Đokić et al. [28] (1.1 ± 0.8 mm). While the upper lip moved forward in the treatment groups (RPE/FM: 1.06 ± 0.48 mm; Alt-RAMEC/FM: 1.22 ± 0.64 mm), a backward movement was observed in the control group (–0.42 ± 0.51 mm).

When the lower lip and the chin region were evaluated, the mean changes were significantly different between the treatment and control groups. The direction of the movement for this region was backward in the treatment groups, whereas the movement was in an anterior direction in the control group. The backward movement of the mandible in the treatment groups might be related to the downward–backward rotation of the mandible following FM usage. Although the existing 3D and most of the 2D studies are in agreement with our results regarding the changes in the lower lip and the chin [14, 16–18, 20, 28], a few studies have reported no significant changes in this region [15, 21]. Furthermore, most of the studies reported a significant backward movement of the soft tissue pogonion [16, 18, 27, 28].

A strength of the present article is that it is the first study comparing 3D soft tissue changes following MP using two different expansion protocols together with a class III control group. As a limitation, long-term studies, however, are needed to ensure the stability of the results. Moreover, changes in body mass index of the participants were not calculated in the present study, which might affect the soft tissue volumes of the individuals.

Conclusion

Although the observed absolute soft tissue changes were rather small, they followed the skeletal changes that were achieved in patients treated according to the RPE/FM or Alt-RAMEC/FM protocol. No significant differences were found between the RPE/FM and Alt-RAMEC/FM groups regarding soft tissue changes. Compared to the control group, both treatment protocols resulted in the soft tissue with a forward movement of the midface and the upper lip, and backward movement of the lower lip and chin.

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Declarations

Conflict of interest E.O. Ozbilen, M.O. Ari, H.N. Yilmaz and S. Biren declare that they have no competing interests.

Ethical standards The present controlled retrospective study was approved by the Ethical Committee of Marmara University, Faculty of Dentistry (21 December 2020, 2020/87, Istanbul, Turkey) and was conducted in accordance with the Declaration of Helsinki of 1975 as revised in 2013. *Consent to participate:* An informed consent was obtained from all the patients included in the treatment and control groups.

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