

Soft tissue changes during orthopedic therapy: An in vivo 3-dimensional facial scan study

Federica Pellitteri, Paolo Albertini, Luca Brucculeri, Francesca Cremonini, Daniela Guiducci, Virginia Falconi, and Luca Lombardo

Ferrara, Italy

Introduction: The aim was to compare the soft tissue changes in pretreatment and posttreatment facial scans of patients who had undergone various orthopedic treatments vs a control group of untreated growing patients.

Methods: Facial scans were performed before (T0) and after (T1) orthopedic treatment in 15 patients prescribed rapid palatal expander (RPE), 15 cervical headgear (HG), and 15 facemasks (FM), as well as 6 months apart in 15 untreated growing patients. After best-fit scan alignment using Geometric Control X software (3D Systems Inc, Rock Hill, SC), a 3-dimensional (3D) analysis of soft tissue changes was performed, comparing 3D reference points (total 22) and 8 areas on T0 and T1 scans. Kruskal-Wallis nonparametric tests and pairwise comparison with Bonferroni's correction were applied to identify any statistically significant differences among groups ($P < 0.05$). All analyses were conducted with SPSS software (version 28; IBM, Armonk, NY). **Results:** At T1, reduced soft tissue projection was found at the nose and upper lip in the HG group, the lower lip in the HG and RPE groups, and the chin in the FM and RPE groups. The RPE group displayed a statistically significant increase in facial divergence, confirmed by gnathion position (RPE vs FM [$P = 0.018$] and RPE vs control [$P = 0.046$]), as well as an increase in the soft tissue projection of both cheeks (left cheek in range of 1-2 mm [$P = 0.030$] and range of 0 to -1 mm [$P = 0.022$]; right cheek in range of 1-2 mm [$P = 0.003$] and range -1 to -2 mm [$P = 0.001$]). There were no clinically significant differences among groups in mandibular right and left body areas. **Conclusions:** The 3D facial analysis revealed significant differences in soft tissues among orthopedic treatments, especially at the upper and lower lip and chin areas, as compared with untreated patients. (Am J Orthod Dentofacial Orthop 2025;167:154-65)

Soft tissue assessment is essential in medicine, and dentistry in particular. Various means of quantitatively and qualitatively describing soft tissue profiles have been proposed, but in orthodontics, the most commonly used method is facial photography. Although this enables the determination of the facial size (length and width), shape, and profile, a 2-dimensional (2D) image of the facial surface is unable to provide any information on depth or volume, making it unsuitable for assessment of facial deformity or asymmetry.¹ This is better achieved by noninvasive optical scanning

3-dimensional (3D) approaches, such as cone-beam computed tomography and 3D face scanners.²⁻⁴ Face scanners capture a series of 3D images of the patient's face and convert them into high-precision digital models, allowing a more accurate description of facial morphology, proportions, and asymmetry.¹ Moreover, face scanners allow volumes and areas to be measured in 3 dimensions during the patient's entire treatment and growth.

To determine the most appropriate treatment plan for each patient, orthopedic therapy, in particular, must be grounded on an accurate evaluation of a young patient's skeletal and dental relationships and facial soft tissues. Indeed, the soft tissues, especially the lips, cheeks, chin, and nose, significantly influence the esthetics of the face and the relationship with the underlying dental and skeletal structures.^{1,5} Therefore, orthodontic/orthopedic treatment planning must take into account not only skeletal but also soft tissue changes.⁵ Imbalances in the growth of ≥ 1 part of the craniofacial structures can lead to esthetic and

From the Department of Orthodontics, University of Ferrara, Ferrara, Italy.

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Address correspondence to: Federica Pellitteri, Department of Orthodontics, University of Ferrara, Via Luigi Borsari, 46, Ferrara, Italy 44121; e-mail, federica.pellitteri@hotmail.it.

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functional problems and consequently compromise the harmonic development of a young patient's soft tissue.⁵

With this in mind, this study aimed to map the soft tissue changes occurring in patients undergoing orthopedic treatment, comparing facial scans taken before and after treatment with either rapid palatal expander (RPE), facemask (FM) or headgear (HG), using a group of untreated growing patients as control.

MATERIAL AND METHODS

After approval by the University of Ferrara Institutional Review Board (approval No. 10/2023) and informed consent release, a sample of young white patients who had undergone an orthopedic treatment to correct skeletal malocclusion using RPE, cervical HG, or FM were retrospectively selected.

The inclusion criteria were (1) growing patients, (2) transverse maxillary constriction, (3) Class II skeletal relationship ($ANB > 5^\circ$), and (4) Class III skeletal relationship (ANB less than -3°)

Complete initial records were taken for correct diagnosis, specifically intraoral photographs, panoramic radiographs, lateral cephalograms, and dental scans. Patients were prescribed orthopedic treatment for the correction of skeletal malocclusion by means of RPE, with or without sagittal correction via cervical HG in patients with skeletal Class II malocclusion or FM in patients with skeletal Class III malocclusion. The patients were all treated by the same operator, and the expanders all had the same design. Specifically, they were 4-arm expanders whose anterior arms extended to the mesial part of the deciduous canine, and posterior arms were fused to standard bands, with anchorage on the deciduous second molars featuring a Leone expansion screw (Leone, 0019; Sesto Fiorentino, Firenze, Italy) with 45 maximum turns and 0.2 mm each turn. All RPE and FM treatments were performed with appliances anchored on the deciduous second molars, whereas HG treatments, which are indicated during peak growth, were performed with appliances bonded on the permanent maxillary first molars. Only patients with Class II Division 1 malocclusion with sufficient overjet to allow mandibular advancement were selected for the patients with HG. To equalize the groups, patients who did not have decreased or increased lower third height were selected for all groups: RPE, HG, FM, and control. Patients were selected according to FMA angle ($26^\circ \pm 5^\circ$), with no extreme hypodivergent or hyperdivergent values. The average FMA value of the group was 25.7° with a minimum value of 23.6° and a maximum value of 29.8° .

In patients assigned to the HG or FM group that had undergone previous palatal expansion, scans taken after the end of transverse correction, before the sagittal correction stage, were taken as pretreatment (T0). The control group comprised patients with skeletal Class I relationship ($2.0^\circ \pm 2.4^\circ$) and correct transverse maxillary dimensions. Patients at the end of growth or with any facial scars, cosmetic surgery, or skin blemishes were excluded.

Facial scans were performed T0 and posttreatment (T1) to map the soft tissue changes. Specifically, in the RPE group, the T0 facial scan was performed the day the appliance was bonded, and the T1 on the day the device activation phase was completed and correct transverse dimensions were achieved. In the FM and HG groups, the T0 scan was performed on the day of delivery of the extraoral appliance, and the T1, when overcorrected dental Class I malocclusion was achieved. For the control group patients, T0 was taken as an initial appointment, and T1 after 6 months. All facial scans were taken using the EinScan H face scanner (70565; Shining 3D Technology GmbH, Stuttgart, Germany), a structured light scanning system. All participants were asked to sit in a chair against a backrest to prevent forward or backward movement of their bust and head and maintain the correct natural head position⁶⁻⁸ with arches in occlusion, relaxed lips, and closed eyes. A careful quality control assessment was performed to check for differences in head posture or facial expression that could influence the measurements in this study. Patients with longer hair were asked to tie it back to enable scanning of all parts of the face, including the ears.

The raw images obtained from the facial scans were processed by the EinScan H face scanner's dedicated software, with the files being exported in object file wavefront 3D and jpeg to obtain both the shape and texture of the scan. Afterward, Geometric Control X software (3D Systems, Rock Hill, SC) was used to superimpose the T0 (the "reference mesh") and T1 (the "measured model") scans through best-fit alignment, automatically excluding areas with a variation of 0.005 mm excluding areas with a variation of 0.005 mm per current software defaults, using the same spatial coordinates of the points for each triangle of the meshes. A 3D analysis of 22 reference points and 8 areas of the face was used to compare the reference mesh and measured model in each group and differences in soft tissue projection between each group and the control. First, the positions of the 22 reference points (nasion; right and left endocanthion; right and left zygomaticus; pronasion; right and left alare; right, central, and left subnasal; right and left midlabial point; upper lip; upper

stomion; lower stomion; right and left labial commissure; lower lip; sublabial; pogonion'; and gnathion') were identified on T0 and T1 scans, and the linear distance between them on the superimposition was measured in millimeters (Fig 1; Table I). Measurements are performed directly by the Geomagic Control X program thanks to its 3D linear measurement function, which allows, through the application of a single point, the shortest distance between the 2 scans at that specific point to be measured, regardless of the scan orientation. When the reference scan (T0) is covered by the final scan (T1) (thus indicating an increase in volume at that point), the sign of the measurement is positive. When there has been a decrease in volume at the analyzed point, with it being further back on the final scan (T1) than on the reference scan (T0), the sign is negative. Fifteen days later, point placement and measurements were repeated by the same operator to verify intraoperator repeatability.

The second analysis consisted of outlining 8 areas on the reference mesh: nose, upper lip, lower lip, chin, right cheek, left cheek, mandibular right body, and mandibular left body (Fig 2, A and B), and then using the software to conduct a 3D comparison by automatically analyzing the percentage overlap in each surface area; the tolerance range was set between +3 mm and -3 mm, and the following 8 discrepancy ranges were considered: 0-1 mm; 1-2 mm; 2-3 mm; >3 mm; from 0 to -1 mm; from -1 to -2 mm; from -2 to -3 mm; and less than -3 mm.

Statistical analysis

Power analysis was conducted to verify the correct minimum sample size, and interclass correlation coefficient tests were applied to the analysis of the 22 reference points, which was repeated twice to verify intraoperator repeatability. For analysis of the landmark areas, it was not necessary to calculate the repeatability index, as the measurements were made after the best-fit alignment and the percentage of the area within each tolerance range calculated by the Geomagic Control X software.

The Kruskal-Wallis nonparametric test based on median values was used to analyze both points and areas and test the equality of distributions among the 4 groups (control, RPE, FM, and HG). The null hypothesis was that all the distributions identified in each group would be equal to each other, against the alternative hypothesis that there would be at least 1 pair of distributions identified in the groups different from each other.

For the tolerance ranges less than -3 mm and >3 mm, significance tests were not performed, as the medians of the overlapping surfaces within these ranges were all 0%. When significant differences were identified, pairwise tests with Bonferroni's correction were performed to assess between which pairs.

All analyses were conducted with SPSS software (version 28; IBM, Armonk, NY), and the significance level was set at $P < 0.05$.

RESULTS

Power analysis yielded a minimum sample of 15 subjects per group, with a power ($1 - \beta$) equal to 0.80 and first-rate error type (α) equal to 0.05.⁵ Hence, a total of 45 patients were included in the study: 15 patients in the RPE group, 7 females and 8 males (10.5 ± 1.2 years), 15 patients in the FM group, 7 females and 8 males (9.9 ± 0.8 years), 15 patients in the HG group, 9 females and 6 males (11.5 ± 0.4 years) and 15 patients in the control group, 10 females and 5 males (10.8 ± 0.6 years).

The mean treatment duration for each group, defined by the time interval between scan T0 and T1, was 44 ± 6 days in the RPE group, 7 ± 1 months in the HG group, 9 ± 1 months in the FM group and 6 months ± 19 days for the control group.

The RPE group was given an average of 41 rotations, with a maximum value of 45 and a minimum value of 32. The expansion screw used achieves 0.2 mm of expansion with each turn, so the average transverse expansion achieved was 8.2 mm. The ANB angle for the HG group was 6.1° , with a maximum value of 7.2° and a minimum value of 5.5° . For the FM group, the average ANB angle was -3.4° , with a maximum value of -3.7° and a minimum value of -3.0° .

The placement of 22 reference points on patients' facial scans was performed twice by the same operator 15 days apart to take into account positioning errors (Fig 3). Interclass correlation coefficient testing yielded a figure of 0.90, significantly different from 0 ($P < 0.05$), for every 3D reference point, indicating excellent repeatability. Therefore, only the first set of measurements was used in the comparative analysis.

The Kruskal-Wallis test indicated a statistically significant difference ($P < 0.05$) among the 4 groups at the following points: pronasion; right and left alare; right, central and left subnasal; right and left midlabial point; upper and lower lip; upper stomion; pogonion; and gnathion (Table II). To assess which pairs were statistically different from each other (Table III), pairwise

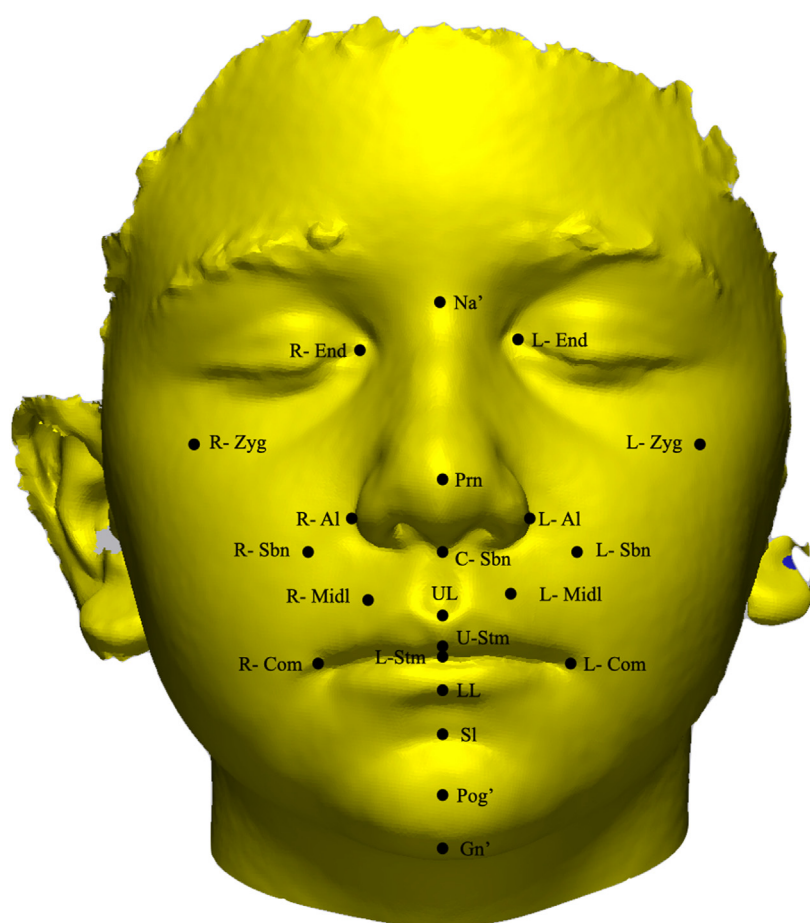


Fig 1. Definition of 3D reference landmarks for analysis of points.

comparison and Bonferroni adjustment were used, which yielded the following:

1. HG vs control: pronasion ($P = 0.012$); central subnasal ($P = 0.026$); upper lip ($P = 0.018$); and upper stomion ($P = 0.003$).
2. HG vs RPE: right ($P = 0.019$) and left ($P = 0.001$) alare; left subnasal ($P = 0.045$); left midlabial ($P = 0.019$) and pogonion ($P = 0.044$).
3. HG vs FM: right ($P = 0.017$), central ($P = 0.001$), and left ($P < 0.001$) subnasal; right ($P < 0.001$) and left ($P < 0.001$) midlabial; and pogonion ($P = 0.011$).
4. Control vs FM: left subnasal ($P = 0.033$) and lower lip ($P = 0.050$).
5. Control vs RPE: gnathion ($P = 0.046$), lower lip ($P = 0.050$), and upper stomion ($P = 0.009$).
6. RPE vs FM: Gnathion ($P = 0.018$).

The Kruskal-Wallis test was used to compare the median overlap of each area in each tolerance range among groups to determine their statistical significance (Table IV). In all

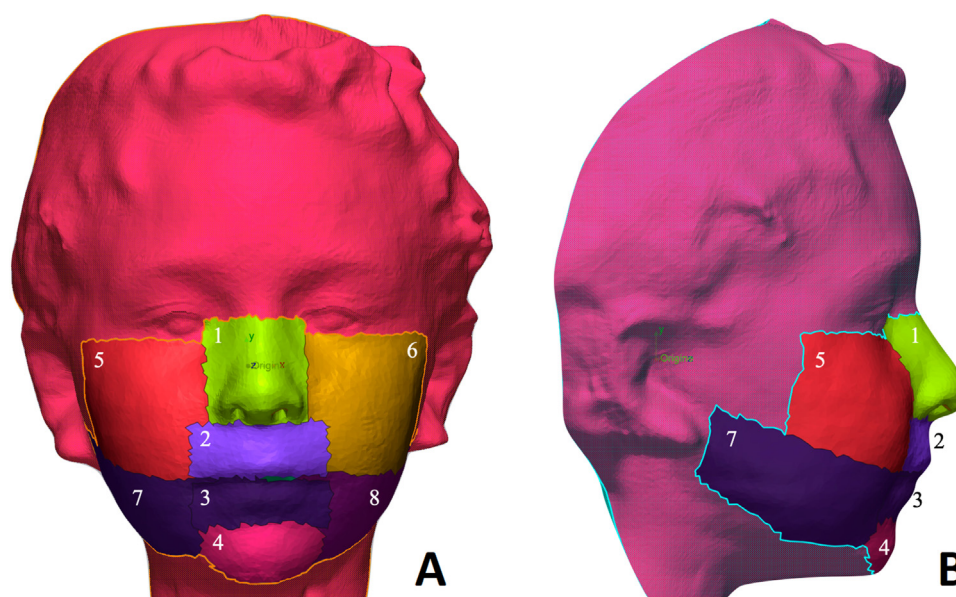
areas, there were statistically significant differences among groups in at least 1 tolerance range: the nose (range: -1 to -2 mm), the upper lip (ranges: 0 – 1 mm; 1 – 2 mm; 0 to -1 mm; and -1 to -2 mm), the lower lip (ranges: 0 – 1 mm; -1 to -2 mm; and -2 to -3 mm), the chin (ranges: 0 – 1 mm; 0 to -1 mm; -1 to -2 mm; and -2 to -3 mm), right cheek (ranges: 1 – 2 mm and 0 to -1 mm), left cheek (ranges: 1 – 2 mm and 0 to -1 mm), mandibular right body (range: 0 to -1 mm), and mandibular left body (ranges: 1 – 2 mm and 0 to -1 mm). Pairwise comparisons and Bonferroni adjustment were used to ascertain which between-group comparisons were statistically significant for each area (Table V).

DISCUSSION

The advent of face scanners has made 3D imaging systems extremely less time-consuming and more accessible for use in several research areas related to facial anatomy, maxillofacial surgery, esthetics, and orthodontics.^{4,9,10} In particular, they enable the analysis of facial

Table I. Definition of 3D reference landmarks for analysis of points

<i>Cephalometric point</i>		<i>Definition</i>
Soft tissue nasion (nasion')	Na'	The most anterior point of the soft tissue frontonasal suture, located at the level of the 3D cephalometric hard tissue nasion landmark
Right endocanthion	R-End	Point at the inner commissure of the right eye fissure
Left endocanthion	L-End	Point at the inner commissure of the left eye fissure
Right zygomaticus	R-Zyg	The most superior point on the right zygomatic arch
Left zygomaticus	L-Zyg	The most superior point on the left zygomatic arch
Pronasion	Prn	The most anterior midpoint of the nasal tip (on the right and left profile view). If a bifid nose is present, the more protruding tip is chosen
Right alare	R-Al	The most lateral point on the right alar contour
Left alare	L-Al	The most lateral point on the left alar contour
Right subnasal	R-Sbn	Point of intersection between a horizontal axis passing through the central subnasal and a vertical axis passing through the right commissure
Central subnasal	C-Sbn	Central midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip
Left subnasal	L-Sbn	Point of intersection between a horizontal axis passing through the central subnasal and a vertical axis passing through the left commissure
Right midlabial	R-Midl	The midpoint between the central subnasal and right commissure
Left midlabial	L-Midl	The midpoint between the central subnasal and the left commissure
Upper lip	UL	The midpoint of the vermilion line of the upper lip
Upper stomion	U-Stm	The midpoint of the horizontal upper labial fissure
Lower stomion	L-Stm	The midpoint of the horizontal lower labial fissure
Right labial commissure	R-Com	The point located at the right labial commissure
Left labial commissure	L-Com	The point located at the left labial commissure
Lower lip	LL	The midpoint of the vermilion line of the lower lip
Sublabial	Sl	The most posterior midpoint on the labiomental soft tissue contour that defines the border between the lower lip and the chin
Soft tissue pogonion (pogonion')	Pog'	The most anterior midpoint on the soft tissue contour of the chin is located at the level of the 3D cephalometric hard tissue pogonion landmark
Soft tissue gnathion (gnathion')	Gn'	The most anteroinferior midpoint on the soft tissue contour of the chin is located at the level of the 3D cephalometric hard tissue gnathion landmark

**Fig 2.** Eight areas on the reference mesh (T0) in frontal (**A**) and lateral (**B**) view: nose (1), upper lip (2), lower lip (3), chin (4), right cheek (5), left cheek (6), mandibular right body (7), and mandibular left body (8).

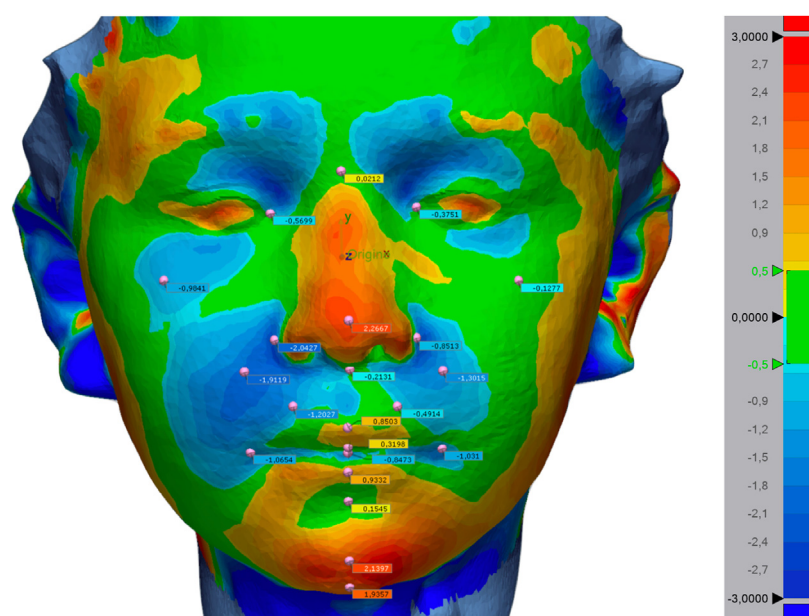


Fig 3. Example of 3D analysis of a patient showing the positioning of the 22 reference points.

features in patients with pathologies, the assessment of facial changes in growing children, the evaluation of asymmetries, and the study of soft tissue in patients undergoing orthognathic surgery.^{4,9,10} Moreover, a comparison of linear measurements on 3D face scans with direct anthropometry measurements has shown that they are reliable and repeatable, with an average error of between 0.2–1.0 mm, whereas the same measurements on a 2D photograph could lead to errors and inaccuracies because of the lack of the third dimension.^{2,9,11–13}

Soft tissue is one of the most crucial factors in treatment planning and must be analyzed carefully by the orthodontist. The soft tissues, which include the lips, cheeks, and facial muscles, play a significant role in facial appearance and smile harmony, closely related to the development of the relationship between the maxilla and mandible and the consequent dentoalveolar adaptation.¹⁴

This study aimed to analyze the 3D changes in facial soft tissues of patients undergoing orthopedic treatment compared with a control group of untreated patients, whose facial scans were performed 6 months apart from each other. The results showed that the control group did not undergo any major changes in the soft tissues. In fact, the T0 to T1 comparison showed that none of the 22 points investigated changed by >0.5 mm in the 6 months, with the exception of the pronasion, which differed by approximately 1 mm. In fact, in the analysis of the 3D reference points pronasion, right and left alare, right, middle, and left subnasal, right

and left midlabial point, upper lip, and upper stomion, the HG group was the only one to produce a decrease in soft tissue projection between T0 and T1, as an effect of posterior traction of the upper jaw. Indeed, during HG treatment, a more posterior position of the anterior border of the maxilla with respect to untreated patients has been described, with retroinclination of the maxillary incisors alongside a more flattened and extended position of the upper lip.^{1,15} However, Ge et al,¹⁶ who studied the skeletal and soft tissue effects of FM treatment in a sample of 43 patients, reported significant changes in maxillary position, with 5.04 mm skeletal advancement of the A-point and a corresponding 1.09 mm advancement of the upper lip point.¹⁶

Our analysis of areas confirms the results yielded by the analysis of points. There was a slight increase in the nose and upper lip area projection after RPE and FM treatment, whereas the HG group displaced a tendency toward a decrease in projection in both areas; however, its only statistically significant difference with respect to the control group was in the range –1 to –2 mm for the nose, and to the FM group from –2 to 2 mm for the upper lip, probably because of their opposite orthopedic effects on the maxilla.

The increase in the width of the base of the nose is a topic covered in the literature by studies based on both 2D photographs and 3D images. However, it must be considered that these measurements are often made in 2D, even on 3D images, and most studies analyze skeletal tissue changes, often assuming that soft tissue moves

Table II. Kruskal-Wallis analysis to identify statistically significant differences in points among the 4 groups

Variables	Control			FM			RPE			HG			H3	P value
	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile		
Pronasion	0.13	0.45	1.10	−0.08	0.07	0.60	−0.12	0.24	0.66	−0.70	−0.26	0.10	9.800	0.020*
R-alare	−0.22	0.07	0.27	−0.20	0.16	0.85	0.32	0.84	1.00	−0.70	−0.24	0.39	10.665	0.014*
L-alare	−0.13	0.28	0.45	−0.17	0.15	0.84	0.45	0.60	1.15	−1.00	−0.70	−0.15	15.141	0.002*
R-subnasal	−0.65	−0.03	0.14	−0.10	0.33	0.53	−0.63	0.16	0.76	−1.05	−0.28	0.02	10.275	0.016*
C-subnasal	−0.14	0.15	0.67	−0.32	0.38	0.92	−0.51	0.04	0.47	−1.48	−0.75	−0.25	14.902	0.002*
L-subnasal	−0.40	−0.18	0.20	−0.03	0.60	0.80	−0.14	0.16	0.44	−0.72	−0.52	0.00	18.395	<0.001*
R-midlabial	−0.30	0.00	0.34	0.10	0.35	0.73	−0.75	0.14	0.46	−0.80	−0.51	−0.06	17.173	<0.001*
L-midlabial	−0.23	0.02	0.10	0.06	0.50	0.80	−0.44	0.15	0.55	−0.90	−0.63	−0.25	23.767	<0.001*
Upper lip	−0.31	0.14	0.60	−0.51	−0.07	0.87	−1.17	−0.50	−0.02	−1.12	−0.70	−0.21	13.293	0.004*
Upper stomion	0.06	0.48	1.07	−0.70	−0.04	10.26	−1.31	−0.35	0.29	−1.35	−0.75	−0.02	15.996	0.001*
Lower lip	0.26	0.61	0.92	−1.18	−0.70	0.15	−1.34	−1.00	−0.24	−0.67	−0.25	0.75	14.163	0.003*
Pogonion'	−0.24	0.02	0.24	−1.00	−0.70	0.04	−1.44	−0.43	0.02	−0.21	0.22	0.76	12.621	0.006*
Gnathion'	−0.50	0.05	0.40	−1.03	−0.25	1.14	0.44	1.21	2.51	−0.31	0.25	0.68	11.144	0.011*

R, right; L, left; C, central.

* $P < 0.05$.

Table III. Pairwise comparison and Bonferroni adjustment for analysis of points

Comparisons	Test statistic	Standard error	Standard test statistic	P value	Adjusted P value [†]
Pronasion					
HG vs control	19.633	6.376	3.079	0.002	0.012*
Right alare					
HG vs RPE	18.800	6.377	2.948	0.003	0.019*
Left alare					
HG vs RPE	24.333	6.376	3.816	<0.001	0.001*
Right subnasal					
HG vs FM	19.000	6.376	2.980	0.003	0.017*
Central subnasal					
HG vs control	18,167	6.377	2849	0.004	0.026*
HG vs FM	23,467	6.377	3680	<0.001	0.001*
Left subnasal					
HG vs RPE	17.033	6.377	2671	0.008	0.045*
HG vs FM	25.867	6.377	4057	<0.001	<0.001*
FM vs control	-17.700	6.377	-2776	0.006	0.033*
Right midlabial					
HG vs FM	26.367	6.377	4.135	<0.001	<0.001*
Left midlabial					
HG vs control	18.433	6.375	2.891	0.004	0.023*
HG vs RPE	18.833	6.375	2.954	0.003	0.019*
HG vs FM	30.733	6.375	4.821	<0.001	<0.001*
Upper lip					
HG vs control	18.933	6.376	2.970	0.003	0.018*
Upper stomion					
HG vs control	22.367	6.377	3.508	<0.001	0.003*
RPE vs control	20.333	6.377	3.189	0.001	0.009*
Lower lip					
RPE vs control	22.867	6.377	3.586	<0.001	0.002*
FM vs control	16.833	6.377	2.640	0.008	0.050*
Pogonion[*]					
HG vs FM	-19.933	6.375	-3.127	0.002	0.044*
RPE vs FM	-17.100	6.375	-2.682	0.007	0.011*
Gnathion[*]					
RPE vs FM	-18.600	6.271	-2.966	0.003	0.018*
RPE vs control	-17.029	6.382	-2.668	0.008	0.046*

Note. Each row tests the null hypothesis that the sample 1 and 2 distributions would be the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is 0.050.

* $P < 0.05$.

[†]Significance values have been adjusted by the Bonferroni correction for multiple tests.

accordingly. The results of this study actually indicate an increase in volume in the right and left Alar area after treatment with an RPE, but this was not statistically significant as compared with the other groups analyzed. Altindış et al¹⁷ concluded that RPE treatment caused slight changes in soft tissues; however, this can be considered clinically insignificant. In contrast, the systematic review proposed by Huang et al¹⁸ on soft tissue changes revealed statistically significant differences in nasal width, an average of 0.84 mm, the same increase that was found in this study (R-alar, 0.84 mm; L-alar, 0.60 mm; Table II). Moreover, Johnson et al¹⁹ concluded that the effects of RPE on the alar base or greater alar cartilage widths indicated that the actual amount of change was <1.5 mm, an increase that is not clinically

significant. In fact, a comparison of posttreatment nasal width values vs untreated norms showed no clinically significant differences in soft tissue nasal widths (<2 mm).

The reduced projection found in the lower lip area in the HG and RPE group may be due to retroinclination of the maxillary incisors as a result of the dentoalveolar effect of those appliances. In fact, the RPE separates the 2 maxillae, creating tension between the transeptal fibers between the maxillary central incisors and promoting spontaneous closure of the diastem.²⁰⁻²³ In contrast, Miguel et al²⁴ report a 41% reduction in overjet during orthopedic HG treatment in patients with Class II malocclusion because of uprighting of the maxillary incisors.

In the chin area, there was a slight tendency for projection to increase in the HG group, likely because of the

Table IV. Statistically significant differences in the groups and tolerance range across the 8 areas, as assessed by the Kruskal-Wallis test

Ranges by area (mm)	Control			FM			RPE			HG			H_3	P value
	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile		
Nose														
–1 to –2	0.00	0.00	3.96	0.24	1.79	5.14	0.23	1.16	2.09	2.11	4.55	13.61	10.733	0.013*
Upper lip														
0–1	39.33	53.24	61.67	31.00	45.35	61.35	7.19	37.22	66.78	3.26	14.51	24.59	17.944	<0.001*
1–2	0.00	3.94	12.13	0.32	7.01	32.30	0.00	0.00	4.16	0.00	0.27	1.72	10.831	0.013*
0 to –1	8.16	39.81	51.64	15.25	26.98	33.10	16.95	33.58	54.74	37.99	61.25	67.24	11.772	0.008*
–1 to –2	0.00	0.00	3.98	0.00	0.59	4.85	0.11	6.26	17.09	8.18	15.37	32.92	17.736	<0.001*
Lower lip														
0–1	27.41	49.94	64.43	2.55	14.77	28.23	10.60	22.03	34.43	15.31	28.63	34.76	12.389	0.006*
–1 to –2	0.00	0.67	7.52	0.51	26.95	38.50	2.84	16.66	33.63	7.57	13.62	18.65	12.513	0.006*
–2 to –3	0.00	0.00	0.00	0.00	0.00	2.68	0.00	2.63	9.24	0.00	0.00	1.57	9.745	0.021*
Chin														
0–1	40.00	53.18	63.84	4.33	11.62	39.27	1.65	25.10	35.63	23.04	43.05	53.70	12.755	0.005*
0 to –1	31.10	43.57	50.21	33.47	58.31	72.82	9.91	27.68	34.62	24.28	33.04	55.08	11.217	0.011*
–1 to –2	0.00	0.00	1.23	0.00	9.24	20.35	0.00	5.14	49.88	0.00	0.32	13.43	10.823	0.013*
–2 to –3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.13	4.60	0.00	0.00	0.00	14.174	0.003*
Right cheek														
1–2	0.00	0.00	2.01	0.23	3.94	22.42	0.73	9.76	31.16	0.31	15.98	23.74	16.125	0.001*
0 to –1	43.22	52.00	79.18	10.68	21.29	55.25	7.82	21.18	36.11	15.41	22.76	40.43	16.398	<0.001*
Left cheek														
1–2	0.00	0.00	0.84	0.35	4.46	26.02	0.09	7.68	20.30	0.30	8.98	23.64	13.247	0.004*
0 to –1	22.90	52.95	75.29	12.64	17.40	52.29	13.15	19.35	36.45	22.20	29.42	51.44	10.164	0.017*
Mandibular right body														
0 to –1	47.03	52.57	67.02	21.48	38.35	53.77	12.69	35.64	56.84	9.23	19.70	49.72	10.692	0.014*
Mandibular left body														
1–2	0.00	0.00	0.22	0.45	6.39	13.97	0.00	0.66	4.83	0.00	6.99	19.55	8.623	0.035*
0 to –1	49.75	58.33	63.06	21.51	33.45	48.46	21.25	41.90	71.93	19.93	34.66	52.23	8.757	0.033*

* $P < 0.05$.

Table V. Pairwise comparison and Bonferroni adjustment for statistically significant differences in the area analysis

Range (mm) by area	Groups	Test statistic	Standard error	Standard test statistic	P value	Adjusted P value [†]
Nose						
–1 to –2	HG vs control	–20.200	6.317	–3.198	0.001	0.008*
Upper lip						
0–1	HG vs FM	20.400	6.377	3.199	0.001	0.008*
	HG vs control	25.533	6.377	4.004	<0.001	0.000*
1–2	HG vs FM	17.267	6.275	2.752	0.006	0.036*
	RPE vs FM	16.933	6.275	2.698	0.007	0.042*
0 to –1	HG vs FM	–20.333	6.377	–3.189	0.001	0.009*
–1 to –2	HG vs control	–24.267	6.317	–3.842	<0.001	0.001*
	HG vs FM	–21.167	6.317	–3.351	<0.001	0.005*
Lower lip						
0–1	FM vs control	21.300	6.377	3.340	<0.001	0.005*
–1 to –2	HG vs control	–17.533	6.352	–2.760	0.006	0.035*
	FM vs control	–18.600	6.352	–2.928	0.003	0.020*
	RPE vs control	–18.800	6.352	–2.960	0.003	0.018*
–2 to –3	RPE vs control	–16.933	5.580	–3.035	0.002	0.014*
Chin						
0–1	FM vs control	19.800	6.376	3.105	0.002	0.011*
0 to –1	RPE vs FM	20.800	6.377	3.262	0.001	0.007*
–1 to –2	FM vs control	–17.200	6.142	–2.800	0.005	0.031*
	RPE vs control	–17.600	6.142	–2.865	0.004	0.025*
–2 to –3	RPE vs FM	–16.333	4.549	–3.590	<0.001	0.002*
	RPE vs control	–12.533	4.549	–2.755	0.006	0.035*
Right cheek						
1–2	FM vs control	–17.467	6.317	–2.765	0.006	0.034*
	HG vs control	–21.467	6.317	–3.399	<0.001	0.004*
	RPE vs control	–22.000	6.317	–3.483	<0.001	0.003*
–1 to –2	RPE vs control	23.800	6.377	3.732	<0.001	0.001*
	FM vs control	19.867	6.377	3.115	0.002	0.011*
	HG vs control	17.800	6.377	2.791	0.005	0.032*
Left cheek						
1–2	HG vs control	–17.467	6.304	–2.771	0.006	0.034*
	RPE vs control	–17.667	6.304	–2.802	0.005	0.030*
	FM vs control	–20.467	6.304	–3.246	0.001	0.007*
0 to –1	RPE vs control	18.533	6.377	2.906	0.004	0.022*
Mandibular right body						
0 to –1	HG vs control	19.867	6.377	3.115	0.002	0.011*
Mandibular left body						
1–2	FM vs control	–16.267	6.142	–2.648	0.008	0.049*

Note. Each row tests the null hypothesis that the sample 1 and 2 distributions would be the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is 0.050.

* $P < 0.05$.

[†]Significance values have been adjusted by the Bonferroni correction for multiple tests.

residual growth of the mandible in these patients. In contrast, in the FM and RPE groups, there was a loss of projection, probably caused by the posterior mandibular rotation that these devices, especially the RPE, produced. This was further confirmed by the statistically significant increase in divergence of the gnathion soft tissue point, as reported by Baysal et al.⁵ In this case, the results obtained are in line with those reported by Ge et al,¹⁶ who found a significant clockwise rotation of the mandible after FM treatment, with an increase

in facial divergence and consequently a 2 mm retraction of the pogonion; at the dentoalveolar level, the inclination of the maxillary incisors increased by 8°, whereas the IMPA decreased by 4°, causing 1.06 mm retraction of the lower lip point.

The projection of the right and left cheek area, corresponding to the right and left upper jaw area, was increased after the use of each appliance, but especially FM and RPE. This is in line with the orthopedic effects of these appliances on the upper jaw. In this regard, the

control group was statistically significantly different from all the others, especially in the tolerance ranges 1–2 mm and –1 and –2 mm.

Analysis of the mandibular right and left body areas produced no clinically significant differences among the different devices. However, the HG and RPE groups showed increased volume in these areas because of mandibular advancement/growth and consequent advancement of the gonial angle. The theory that a maxilla with a reduced transverse dimension posteriorly can inhibit mandibular growth is well-known in the literature.^{25–29} Indeed, Tollaro et al,²⁶ having analyzed and classified 60 patients with Class II Division 1 malocclusion according to the presence of a reduced maxillary posterior width, concluded that such patients require preliminary expansion of the maxillary arch with subsequent monitoring of possible spontaneous sagittal repositioning. Unfortunately, the lack of studies on both 3D facial scans of growing subjects and analysis of mandibular soft tissue changes after RPE treatments make it difficult to find valid comparisons for the results obtained in this area.

Despite the significant results obtained, the study has limitations. The body mass index should be calculated for each patient at the beginning and at the end of the treatment to verify that large variations in this index could not have compromised the results of the study by altering the soft tissues of the face. Therefore, future studies should analyze the impact of body mass index changes on patient soft tissues to verify the impact a treatment, especially if lengthy, may have on a patient's face. Moreover, the possibility that conducting these treatments at different ages could alter the results obtained is a possibility to be considered. However, Johnson et al¹⁹ concluded in their study that prepubertal and postpubertal cervical vertebral maturation groups did not react significantly differently to RPE, suggesting that maturation status during adolescence plays no role in the effect that RPE has on the soft tissue around the nose and upper jaw soft tissues. Finally, it must be considered that this study is a retrospective study, whose patients are not consecutive but rather were selected to standardize the sample and not to introduce bias in the results.

CONCLUSIONS

A face-scan 3D analysis of the soft tissue changes of 45 orthopedic patients before and after treatment and in comparison with a control group suggests the following:

1. RPE causes a significant reduction in soft tissue projection at the lower lip and chin and an increase in divergence at the gnathion soft tissue point.
2. HG leads to a significant reduction in soft tissue projection at the nose and upper lip area, whereas soft tissue volume at the mandibular body increases significantly.
3. FM therapy is associated with an increase in soft tissue projection at the upper lip.

AUTHOR CREDIT STATEMENT

Federica Pellitteri contributed to conceptualization, data curation, formal analysis, investigation, methodology, project administration, software, visualization, original draft preparation, and manuscript review and editing; Paolo Albertini contributed to conceptualization, investigation, methodology, validation, visualization, original draft preparation, and manuscript review and editing; Luca Brucculeri contributed to visualization, and manuscript review and editing; Francesca Cremonini contributed to formal analysis, visualization, and manuscript review and editing; Daniela Guiducci contributed to formal analysis, visualization, and manuscript review and editing; and Luca Lombardo contributed to conceptualization, project administration, supervision, validation, visualization, and manuscript review and editing.

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