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Geometric morphometric analysis of the pharyngeal airway during treatment of Class III malocclusion

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Introduction: The pharyngeal airway is important during diagnosis and treatment planning in orthodontics. This study aimed to compare the changes in the shape of the pharyngeal airway in patients with Class III malocclusion treated with a facemask (FM) with a removable maxillary appliance and modified tandem traction bow appliance (MTTBA). **Methods:** This study consisted of pretreatment and posttreatment lateral cephalograms of 35 subjects with skeletal and dental Class III malocclusion. In the first group, 20 patients (12 males, 8 females; mean age, 10.2 years) were treated with MTTBA. The mean treatment time was 12 months. In the second group, 15 patients (10 males, 5 females; mean age, 10.3 years) were treated with FM. The mean treatment time was 11.7 months. Nineteen pharyngeal landmarks were considered from the image corresponding to the midsagittal plane and marked using tpsDig software (version 2.04; Stony Brook, NY). Pharyngeal airway shape difference between the groups was assessed by performing a Generalized Procrustes analysis. The shape deformation of the pharyngeal airway from the pre- to posttreatment periods was evaluated using the thin-plate spline method. **Results:** There were no differences between MTTBA and FM groups according to airway shape for pretreatment and posttreatment periods. However, there were some deformities using the enlargement of the nasopharyngeal area in the FM group and oropharyngeal area in the MTTBA group according to pretreatment periods. **Conclusions:** There were no differences between the groups according to the mean pharyngeal airway shapes when the posttreatment periods of the FM and MTTBA groups were examined. (Am J Orthod Dentofacial Orthop 2022;162:374-85)

In the treatment of subjects with Class III malocclusion characterized by maxillary deficiency during the growth period, a facemask (FM) is often applied with different intraoral anchorage units for the forward movement of the maxilla and correction of maxillomandibular relationship.[1-4] Chun et al[5] introduced the tandem traction bow appliance, as an appliance more aesthetically acceptable, easy to use, and does not affect oral hygiene adversely, compared with other appliances used in the treatment of Class III anomalies. Atalay and Tortop[6] modified the appliance and reported that the modified tandem traction bow appliance (MTTBA) was effective for patients with Class III malocclusion because of maxillary retrusion or a combination of maxillary retrusion and mandibular protrusion. The MTTBA consisted of 2 splints and a traction bow. A headgear face-bow with short outer arms attached to the activator tubes embedded in the posterior region of the mandibular splint was used as the traction bow.[6]

In a study comparing the effects of MTTBA appliance and FM, it was concluded that both appliances were effective in correcting Class III malocclusion, but the changes obtained after FM treatment in ANB and overjet were higher.[7]

When the craniofacial complex is evaluated as a whole, it has been reported that skeletal changes obtained by orthopedic appliances have positive effects on the tongue, soft-tissue positions, and airway dimensions.[4,8,9] The pharyngeal airway, particularly the upper pharyngeal airway, is important in diagnosis and orthodontic treatment planning. Several reports in the literature have evaluated the pharyngeal airway dimension changes in Class III treatment with FM, chincup, or orthognathic surgical treatment.[3,4,8-11]

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By combining progress in imaging and software in the medical field, the geometric changes in the form of a structure can be analyzed using landmarks which are the points that have anatomic significance. The geometric shapes can be formed by the landmark points' coordinates. Statistical shape analysis, a modern geometric morphometric method that uses the shape of organs or organisms as input data, has recently become popular.[12] In several medical studies, morphometric methods are frequently used to examine the structures and geometric properties of organs or organisms related to diseases.[13-17]

Several researchers have applied morphometric methods to orthodontics, such as palatal, profile, craniofacial shapes, and so on.[18-21] However, 2 studies have evaluated the pharyngeal airway shape.[22,23] One of them evaluated the airway shape in subjects with different vertical craniofacial features,[23] and the other determined its shape in skeletal Class II and Class III anomalies.[22] However, no data were reported about the effect of Class III treatment on the pharyngeal airway with a landmark-based geometric morphometric analysis. Therefore, this study was conducted to investigate the shape differences of the pharyngeal airway regarding the pretreatment and posttreatment effects of FM with a removable maxillary appliance and MTTBA.

MATERIAL AND METHODS

This retrospective study was performed using the lateral cephalograms of 20 (12 males, 8 females) patients treated with MTTBA (mean age, 10.20 ± 1.33 years, and 15 [10 males, 5 females]) patients treated with FM (mean age, 10.34 ± 1.39 years). All lateral cephalometric radiography scans were obtained at the pretreatment (T1) and posttreatment phases (T2). Informed consent was obtained from all participants, and the Ethics Committee of Gazi University approved this study and the study protocol (2013/25901600-1409).

Inclusion criteria were as follows: skeletal Class III malocclusion characterized by maxillary retrusion or maxillary retrusion with the combination of mandibular protrusion, aged between 7-13 years, Angle Class III malocclusion, anterior crossbite, SN/GoGn angle between 26°-38°, the maxillary incisors were erupted and treated with either FM or MTTBA.

Patients with congenitally missing teeth, cleft lip and palate, or craniofacial syndromes were excluded. In addition, the patients who were reported as having pseudo-Class III malocclusion with an anterior shift in their clinical evaluation form were excluded.

The MTTBA consisted of 2 splints in the maxilla and mandible and a face-bow with short outer arms that attached to the mandibular splint, and a traction bow. The vertical opening was 5-6 mm at the molar region, and sagittal activation was not done. A traction bow was attached to the activator tubes embedded in the posterior region of the mandibular splint. Maxillary splint had labial hooks between the maxillary central and lateral incisors.[6] Approximately 400-500 g of force was applied symmetrically via elastics with an angle of 35°-40° to the occlusal plane (Fig 1). The mean treatment period (T2 − T1) was 12 months.

The FM appliance consisted of a maxillary intraoral removable appliance and Delaire-type FM. Approximately 350-400 g of force was applied from the anterior hooks of the maxillary removable appliance to the FM bow with extraoral elastics (Fig 2). The mean treatment period (T2 − T1) was 11.7 months.

Data from the regions marked in the pharyngeal airway were collected from 2-dimensional (2D) digital images. Nineteen pharyngeal landmarks were considered from the image corresponding to the midsagittal plane and marked using tpsDig software (version 2.04; Stony Brook, NY) (Fig 3). Reference planes were drawn parallel to the SN plane for the true placement of landmarks. The landmarks were chosen on the basis of reliability and anatomic coverage to maximize the pharyngeal airway explanations. The identifications of the markings are shown in Table I.

Statistical analysis

In this study, the following software was used for statistical analysis: R (version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria), PAST (version 3.0; PAleontological Statistics, University of Oslo, Oslo, Norway), and SPSS (version 21.0; IBM Corp, Armonk, NY). To check data normality, the Shapiro-Wilk test was applied. Data were presented as mean ± standard deviation and median (interquartile range). Pearson chi-square, independent samples *t* tests, and Mann-Whitney U tests were used for statistical comparisons of gender, age, and cephalometric variables between the groups. Type I error rate was set at $\alpha = 5\%$.

Geometric morphometric analysis was used in this study. The Generalized Procrustes analysis,[12] the approach that obtains the minimum sum of squared differences between the landmarks, was used to obtain the mean pharyngeal airway shape in the pretreatment and posttreatment periods and related tangent coordinates using lateral cephalometric images of patients for each group. Box's M procedure was used to test the variance-covariance matrices' homogeneity. The James F_J test was considered for shape comparisons if variance-covariance matrices were unequal. Otherwise,

Fig 1. Intraoral and extraoral photographs of MTTBA.

Fig 2. Intraoral and extraoral photographs of FM.

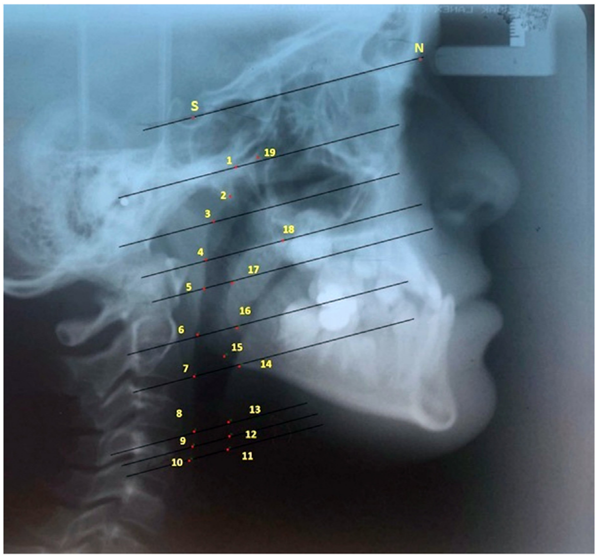

Fig 3. Landmark markings on the pharyngeal airway.

the shape comparisons were performed with the Hotelling's T^2 test between the groups.[24] Principal coordinate analysis (PCoA), a type of ordination method known as metric multidimensional scaling, was applied to tangent coordinates obtained by the Procrustes analysis. The PCoA routine finds the eigenvalues and a matrix's eigenvectors containing the similarities or distances among all landmark points. Euclidean distance is used in PCoA. The eigenvalues, giving a measure of the variance accounted for by the corresponding eigenvectors (coordinates), were computed. The percentages of variance accounted for by these components were also reported. Then, the classification and changes of patients in MTTBA and FM groups were examined for pretreatment and posttreatment time points using PCoA. The shape deformations of the pharyngeal airway from the pre- to posttreatment periods were evaluated using the thin-plate spline (TPS) method, derived from a mathematical model used in computer graphics and applied to morphometrics by Bookstein.[25] The points exhibiting

Table I. Definitions of landmarks used in this study

Landmark no.	Description[†]
1	Superior point of adenoid tissue
2	Apex of adenoid tissue
3	Inferior point of adenoid tissue
4	The point at which the line from the most anterior point of the first cervical vertebra intersects the posterior pharyngeal wall
5	The point at which the line from the midpoint of the velum palatinum intersects the posterior pharyngeal wall
6	The point at which the line from the apex of the velum palatinum intersects the posterior pharyngeal wall
7	The point at which the line from the anterior inferior point of the second cervical vertebra intersects the posterior pharyngeal wall
8	The point at which the line from the superior point of the hyoid bone intersects the posterior pharyngeal wall
9	The point at which the line from the midpoint of the hyoid bone intersects the posterior pharyngeal wall
10	The point at which the line from the inferior point of the hyoid bone intersects the posterior pharyngeal wall
11	The point at which the line from the inferior of the hyoid bone intersects the anterior pharyngeal wall
12	The point at which the line from the midpoint of the hyoid bone intersects the anterior pharyngeal wall
13	The point at which the line from the superior point of the hyoid bone intersects the anterior pharyngeal wall
14	The point at which the line from the anterior inferior point of the second cervical vertebra intersects the anterior pharyngeal wall
15	The point at which the line from the gonion intersects the anterior pharyngeal wall
16	The point at which the line from the apex of the velum palatinum intersects the anterior pharyngeal wall
17	The point at which the line from the midpoint of the velum palatinum intersects the anterior pharyngeal wall
18	The point at which the line from the posterior nasal spine intersects the anterior pharyngeal wall
19	The most superior point of the pterygomaxillary fissure

[†]All the lines were constructed parallel to SN.

the greatest reductions or enlargements labeled as deformations were established through the TPS analysis.

All of the measurements and digitization were made by one researcher (M.K). This researcher was previously trained and calibrated by one experienced professor (T.T), a specialist in orthodontics, and had more than 25 years of clinical and research experience identifying landmarks. To determine the reliability of the method, 20 lateral cephalograms (10 for the MTTBA group; 10 for the FM group) were randomly selected and redigitized by the same researcher 2 weeks after the first digitization. Based on the generalizability theory, the intrarater reliability coefficient was calculated for a 2-facet crossed design (landmark pairs-by-rater-by-subject, $l \times r \times s$). According to generalizability theory, the reliability for relative (norm-referenced) interpretations is the generalizability coefficient (G), calculated for both groups. Strong repeatability was assessed for both groups (MTTBA group, G = 0.9713; FM group, G = 0.9785).

RESULTS

There were no differences between MTTBA and FM groups according to age and sex ($P = 0.464$ and $P = 0.686$, respectively). Analysis of the pretreatment parameters showed that craniofacial characteristics did not differ between the groups (Table II). Intergroup comparisons of the skeletal parameters revealed no significant differences between the treatment changes of FM and MTTBA groups except for the ANB angle (Table III). An increase in ANB angle was significantly greater in the FM group than in the MTTBA group ($P < 0.05$).

According to the MTTBA and FM groups, the mean shapes obtained in the pretreatment and posttreatment periods are shown in Figure 4. There were no differences between the MTTBA and FM groups according to airway shape for the pretreatment and posttreatment periods ($P = 0.459$ and $P = 0.310$, respectively).

The deformations of the mean pharyngeal airway shapes of the groups according to the pretreatment period were examined (Fig 5). In the pretreatment period, when the deformations of the FM group were examined according to the mean shape of the MTTBA group, a red zone (expansion) was observed at the landmarks 13, 14, and 15 (on the anterior pharyngeal wall from the gonion to the superior point of the hyoid bone). However, in the mean shape of the FM group, a dark blue zone (narrowing) was observed at the landmarks 6, 15, and 16 (between the apex of the velum palatinum and gonion), and the dark blue zone was surrounded by the landmarks 1, 2, 3, and 18 (the region between the adenoid tissue and posterior nasal spine).

During the posttreatment period, when the mean pharyngeal airway shape of the MTTBA group was used as a reference, the red zone (expansion) was surrounded by landmarks 6, 15, and 16 (between the apex of the velum palatinum and gonion); the dark blue zone (narrowing) of landmarks 14 and 15 (on the anterior pharyngeal wall from gonion to the anterior inferior point of the second cervical vertebra), and the dark blue zone (narrowing) surrounded by landmarks 4, 5, 16, and 17 (the region between the most anterior point of the first cervical vertebra and midpoint of the velum palatinum on the posterior pharyngeal wall, and

Table II. Pretreatment values and statistical differences between the groups

	MTTBA		FM		
Variables	*Mean ± SD (Min, Max)*	*Median (IQR)*	*Mean ± SD (Min, Max)*	*Median (IQR)*	*P value**
SNA, °	77.18 ± 3.25 (71.50, 84.00)	77.25 (4.40)	78.43 ± 3.24 (74.00, 84.50)	78.00 (6.00)	0.265†
SNB, °	80.05 ± 3.00 (75.00, 86.00)	80.75 (4.80)	80.30 ± 4.32 (72.00, 86.50)	81.00 (8.00)	0.841†
ANB, °	−2.85 ± 1.40 (−6.00, −1.00)	−3.00 (1.50)	−2.40 ± 1.99 (−4.50, 3.00)	−3.00 (2.50)	0.934‡
CoA, mm	82.63 ± 3.48 (77.00, 89.50)	83.00 (4.90)	80.30 ± 5.04 (70.50, 90.00)	80.00 (6.00)	0.115†
CoGn, mm	112.38 ± 5.20 (101.00, 121.50)	112.00 (7.60)	112.23 ± 6.15 (103.00, 127.50)	113.00 (6.00)	0.942†
SN/GoGn, °	32.93 ± 3.47 (27.00, 38.00)	32.75 (6.50)	34.10 ± 4.64 (25.00, 44.50)	33.00 (6.50)	0.397†

SD, standard deviation; *Min*, minimum; *Max*, maximum; *IQR*, interquartile range.
**P* <0.05; †Independent samples *t* test; ‡Mann-Whitney U test.

Table III. Treatment changes of FM and MTTBA groups and comparison between groups

	MTTBA		FM		
Variables	*Mean ± SD (Min, Max)*	*Median (IQR)*	*Mean ± SD (Min, Max)*	*Median (IQR)*	*P value**
SNA2 → SNA1, °	1.33 ± 1.29 (−1.50, 4.00)	1.50 (1.88)	2.83 ± 2.82 (0, 10.00)	1.50 (2.50)	0.158
SNB2 → SNB2, °	−0.70 ± 1.26 (−3.50, 2.00)	−0.75 (1.25)	0 ± 3.43 (−4.00, 9.00)	−1.50 (3.00)	0.730
ANB2 → ANB1, °	2.05 ± 0.89 (0.50, 4.00)	2.00 (1.38)	3.37 ± 2.26 (0, 9.00)	3.50 (2.00)	0.021‡
CoA2 → CoA1, mm	2.23 ± 1.44 (0.50, 5.50)	2.00 (2.00)	2.77 ± 2.27 (0, 7.00)	2.00 (3.50)	0.657
CoGn2 → CoGn1, mm	2.40 ± 2.16 (−2.00, 7.00)	2.25 (3.25)	1.93 ± 1.49 (−0.50, −4.00)	2.00 (2.00)	0.521
SN/GoGn2 → SN/GoGn1, °	1.25 ± 1.28 (−1.00, 4.00)	1.00 (2.00)	1.17 ± 2.50 (−5.00, −5.00)	2.00 (3.00)	0.705

SD, standard deviation; *Min*, minimum; *Max*, maximum; *IQR*, interquartile range.
**P* <0.05; ‡Mann-Whitney U test.

the apex and midpoint of the velum palatinum on the anterior pharyngeal wall) were observed.

Our study also evaluated the shape changes of MTTBA according to pretreatment and posttreatment periods. The Procrustes mean shape obtained from landmark markings from pretreatment to posttreatment periods of the MTTBA group was shown in Figure 6, *A*. PCoA was applied to the tangent coordinates obtained after the Procrustes analysis. PCoA of the pretreatment and posttreatment periods showed a variance explanation rate for the first 2 coordinates (56.09% and 20.80%, respectively) considered in the MTTBA group was 76.89% (Fig 6, *B*). The convex hulls on the scatterplot indicate that significant differences and the variability in these periods were high.

The high level of deformations for the pharyngeal airway from pretreatment to posttreatment periods of the MTTBA were shown in the TPS graphic (Fig 6, *C*). The red-colored zone surrounded by landmarks 6, 7, 15, and 16 (expansion) was seen according to the pretreatment period (from the apex of the velum palatinum to the gonial region and anterior inferior point of the second cervical vertebra). However, the dark blue zones (narrowing) between landmarks 4 and 5 (on the posterior pharyngeal wall from the most anterior point of the first cervical vertebra to the midpoint of the velum palatinum) and between the landmarks 14 and 15 (on the anterior pharyngeal wall from the gonial region to the anterior inferior point of the second cervical vertebra) compared with the pretreatment period were observed.

The Procrustes mean shapes obtained from landmark markings from pretreatment and posttreatment periods of the FM group are shown in Figure 7, *A*. PCoA of the pretreatment and posttreatment periods showed variance explanation rate for the first 2 coordinates (24.10% and 17.47%, respectively) considered in the FM group patients was 41.57% (Fig 7, *B*). The convex hulls on the scatterplot indicate that insignificant difference in the pretreatment and posttreatment periods, and the variability in these periods was not high.

The high level of deformations for the pharyngeal airway from the pretreatment to the posttreatment period in the FM group was observed in the TPS graphic (Fig 7, *C*). According to the pretreatment period, the red-colored zone is surrounded by landmarks 1, 2, 18, and 19 (expansion; the region between the adenoid tissue, posterior nasal spine, and most superior point of the pterygomaxillary fissure). However, the dark blue regions surrounded by landmarks 6, 7, 8, 13, 14, and 15 (narrowing; the region among the apex of velum palatinum, hyoid bone, and gonion) compared with the pretreatment period were observed.

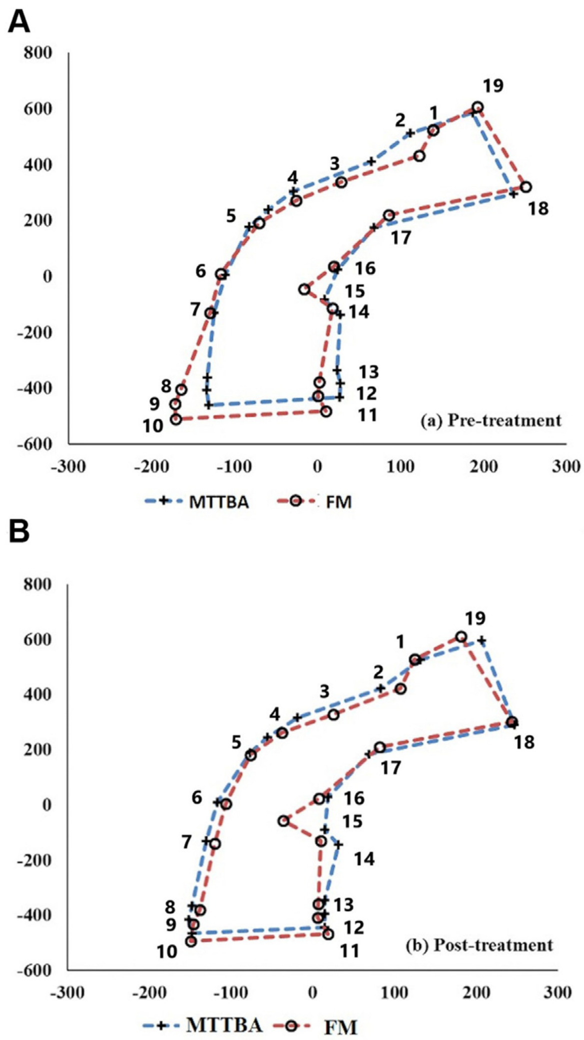

Fig 4. Procrustes mean shapes of pharyngeal airway images for **(A)** pretreatment and **(B)** posttreatment periods of MTTBA and FM groups.

DISCUSSION

The pharynx is divided into 3 sections; the nasopharynx, oropharynx, and laryngopharynx.

The nasopharynx is a part of the respiratory system because it may be regarded as the posterior portion of the nasal cavity, and the nasopharynx communicates with the oropharynx through the soft palate and posterior wall of the pharynx. The oropharynx extends from the soft palate to the superior border of the epiglottis, and it communicates anteriorly with the oral cavity by the soft palate and tongue.[26]

The reduction in the pharyngeal airway space caused difficulties in nasal breathing and mouth breathing, affecting the morphology of the face, including the mandible.[27] As a result of mouth breathing, both sleep quality and facial development during childhood might be affected. Even rarely, acute infections of the sinuses might occur.[28] Repeated anatomic partial collapse or obstruction of this region causes cessation of airflow with persistent respiratory effort, defined as obstructive sleep apnea.[29]

Orthodontists are interested in the interaction between different orthodontic treatments and pharyngeal structures. Orthodontic treatments in patients with Class III anomalies such as growth modification using certain orthopedic appliances such as the FM, Class III intermaxillary elastics and miniplates, Class III Twin-block, double-plate, MTTBA, chincup, or orthognathic surgery do not only correct anomalies but also make changes at the skeletal structures and soft tissues.[4,6,7,10,30-33] Controversial results were seen relating to the changes in the pharyngeal airway space during Class III treatments.[3,4,8,11,34] It has been reported that skeletal changes obtained by maxillary protraction positively affect the airway dimensions.[4,8,9] Although evaluating the effects of a chincup, Tuncer et al[11] found an increase in the nasopharyngeal area, and Akın et al[35] reported that it has no restrictive effect on the pharyngeal area. In both studies, these changes were explained by the movement of the hyoid bone to a more inferior position.[11,35]

During Class III treatment with MTTBA, as an alternative treatment of FM, it was reported that forward movement of the maxilla and posterior rotation of the mandible resulted in a significant increase in the oropharyngeal area in the previous research.[34] Because a facemask is one of the most common appliances used for Class III treatment, the purpose of this study was to compare the effects of MTTBA on the pharyngeal airway with the effects of FM on a morphometric basis. To the best of our knowledge, this is the first study of this kind.

In literature, there are several ways to analyze airway dimensions.[4,8,10,11,22,23,35,36] The upper airway and soft tissues provide 3-dimensional representation without radiation exposure with magnetic resonance imaging.[36] However, because of the high costs and the need to house the machine, it is not routinely used for airway assessment.[36] Lateral cephalograms have been widely used for pharyngeal airway analysis. A strong correlation ($r = 0.831$) was found between lateral cephalogram and cone-beam computed tomography (CBCT) measurements of the pharyngeal airway.[37] In contrast, Park et al[23] reported that lateral cephalograms provide only 2D representations of 3-dimensional structures, and the airway might be narrower in the anteroposterior plane and wider in the frontal plane or vice versa. CBCT images should ideally provide more accurate

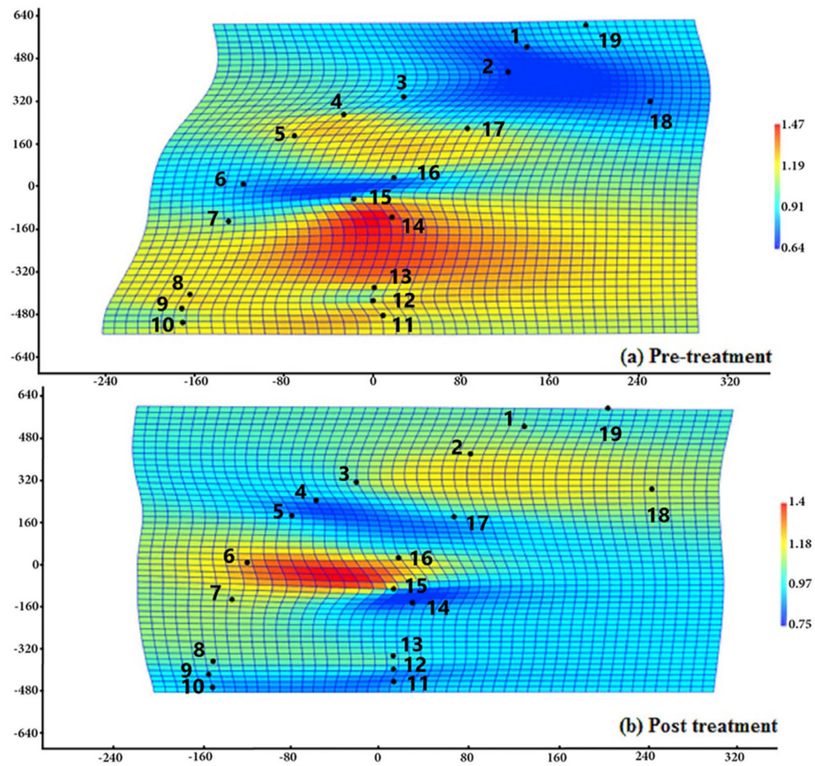

Fig 5. A TPS demonstrating the mean airway shape deformation for the FM group compared with the MTTBA group.

identification and measurements than lateral cephalograms, as these radiographs have some limitations, such as superimpositions, double projection, greater distortion, and unequal magnification.[38] However, the amount of generated radiation is the biggest controversy about the use of CBCT. Clinicians should always keep in mind that the radiation exposure should be kept *as low as reasonably achievable* principle.[38] CBCT is not taken during treatments in our department unless there are additional indications, such as impacted teeth, obstructive sleep apnea, and so on. The use of CBCT is not ethically approved to evaluate the treatment effects of the appliances used in the present study. Therefore, we evaluated pharyngeal airway shape on pretreatment and posttreatment lateral cephalometric radiographs because of the retrospective nature of this study and the ethical considerations, and economic limitations. For morphometric analysis, 2D images can be used for airway assessment.[23] Up to our knowledge, the present study is the first study that evaluates pharyngeal airway shape changes during Class III treatment.

Morphometric analysis in orthodontics could evaluate various anatomic structures and treatment effects in patients with orthodontic anomalies.[18-23] In this study, a statistical shape analysis was performed to show the pharyngeal airway changes at the pretreatment and posttreatment periods in patients with skeletal Class III anomalies. In addition to the general changes, the landmark-based shape analysis approach showed us the changes on a regional basis. All landmarks were weighted equally, and avoiding bias in the reference system was among the basic properties of geometric morphometrics.[18] In conventional cephalometric analysis, various linear and angular measurements were used and had certain inherent problems in measuring shapes.[23] It has been suggested that morphometric methods could solve these problems with less subjectivity than purely qualitative measures while describing the biological shape.[23] Therefore, pharyngeal airway shape was analyzed in this study using landmark-based morphometric analysis.

Park et al[23] reported that the nasopharyngeal airway area tends to increase with age. They found that the upper nasopharyngeal distance was greater in the hyperdivergent group. Zhang et al[39] noted that the airway was significantly smaller in a high-angle group of children with skeletal Class III malocclusion than in the optimal or low-angle group. In this study, the patients had an

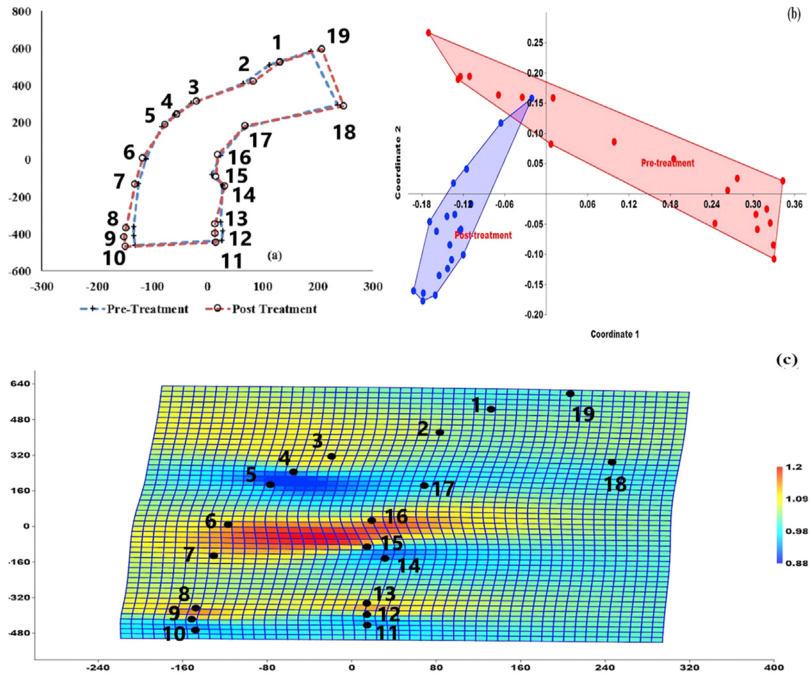

Fig 6. A, Procrustes mean shapes for the pretreatment and posttreatment periods of the MTTBA group; **B,** Scatter graphs with 95% confidence ellipses and convex hulls obtained by PCoA results of the MTTBA group; **C,** A TPS demonstrating pharyngeal airway shape deformation for posttreatment term compared with pretreatment.

SN/GoGn angle between 26° and 38° with similar chronological ages (10.20 ± 1.33 years in the MTTBA group and 10.34 ± 1.39 years in the FM group) were included. In addition, gender distribution between the groups showed no difference. When the pretreatment periods were examined, there were no differences between the groups according to the skeletal parameters and mean pharyngeal airway shapes. Therefore, this study group could be interpreted as mostly homogeneous.

Some studies evaluate airway size, area, and/or volume using cephalograms or CBCT and compare Class I, II, and III malocclusions in the literature.[3,4,8-11,22,23,33,35,39] There was only 1 study compared pharyngeal airway volume morphometrically in young adults with various sagittal skeletal discrepancies.[22] In that study, Jayaratne and Zwahlen[22] reported that total oropharyngeal airway volume was significantly greater in patients having skeletal Class III malocclusion than in Class II malocclusion.

In this study, 2 Class III treatment groups were evaluated, and a control group was not formed. Obtaining a control group from untreated patients with Class III malocclusion with similar skeletal discrepancy was difficult because of the ethical considerations considering the radiation exposure problem.[40] We also did not prefer to use an untreated historical control sample because of the secular trends in growth and maturity of children included in these collections, imbalance in the distribution of patient characteristics, and selection bias.[41]

In this study, the convex hulls on the scatterplot indicate the insignificant variability in the examinations performed during pretreatment and posttreatment periods in the FM group was very low. However, there were some deformities using the enlargement of the nasopharyngeal (landmarks 1, 2, 18, and 19) area. This low enlargement in the FM group was supported by the forward movement of the maxilla.

Although comparing the skeletal effects of the MTTBA and FM, FM showed a greater increase in ANB angle in this study. Consistent with our finding, the FM appliance caused greater increases in the ANB angle than the removable appliances used for Class III treatment in some studies.[2,7,42] Some authors declared that the increase in the upper airway dimension could be due to the increased maxillary forward growth induced by protraction treatment.[4,8] Kaygisiz et al[4] reported an improvement in the nasopharyngeal airway dimensions after FM treatment. Oktay and Ulukaya[8] reported an increase in the upper component of the airway space, especially at the nasopharynx. Hiyama et al[43] suggested that facilitating maxillary growth with maxillary

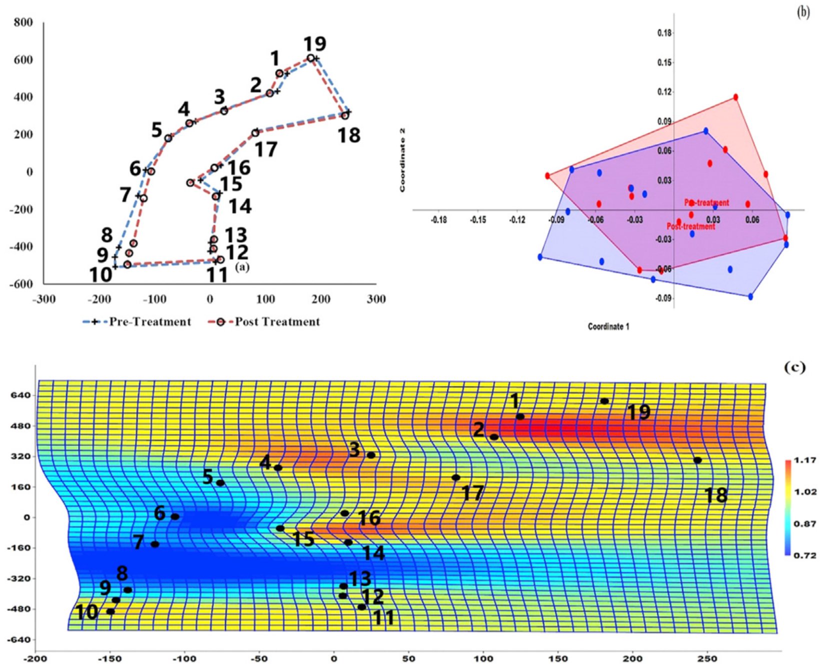

Fig 7. A, Procrustes mean shapes for the pretreatment and posttreatment periods of FM group; **B,** Scatter graphs with 95% confidence ellipses and convex hulls obtained by PCoA results of FM group patients; **C,** A TPS demonstrating the pharyngeal airway shape deformation for the posttreatment period compared with pretreatment.

protraction appliances could increase the upper airway dimensions. Hence, it causes an improvement in the respiratory function of patients with Class III malocclusion with maxillary deficiency. In a meta-analysis, Lee et al[44] showed that rapid palatal expansion (RPE) + FM treatments might increase the upper airway space in children or young adolescents. However, Mucedero et al[3] observed no significant changes in sagittal oropharyngeal and nasopharyngeal airway dimensions using FM treatment combined with RPE and bite-blocks. Pamporakis et al[45] also reported that the increase in the pharyngeal airway volume was not significant after bonded RPE + FM treatment.

In this study, an enlargement was located cranially at the nasopharyngeal region (landmarks 1, 2, 18, and 19) in the FM group, although there was no enlargement in the MTTBA group in this zone. However, the changes in the FM group were still insignificant compared to the MTTBA group. Although posttreatment airway shapes were similar between the groups, the greater improvement in skeletal discrepancy (ANB angle) may enlarge the nasopharyngeal region in the FM group.

In this study, the convex hulls on the scatterplot indicate the significant variability in the examinations performed during the pretreatment and posttreatment periods in the MTTBA group. According to the pretreatment period, there were some deformities using the enlargement of the oropharyngeal region (landmarks 6, 7, 15, and 16). The superior boundary of enlargement was around the apex of the velum palatinum, and the inferior boundary was at the level of the gonial region and the anterior inferior point of the second cervical vertebra. So, this enlargement in the MTTBA group was located cranially in the retroglossal compartment of the oropharynx. There was only one study that evaluated the airway during MTTBA treatment using lateral cephalograms, and an increase in the oropharyngeal area was reported, which was in accordance with the current study results.[33]

In the FM group, the narrowing was observed in the zone surrounded by landmarks 6, 7, 8, 13, 14, and 15, corresponding to the retroglossal part of the oropharyngeal region compared with the pretreatment period, but this was not statistically significant. The superior boundary of this narrowing was at the level of the velum palatinum apex on the posterior pharyngeal wall, gonion on the anterior pharyngeal wall, and extending caudally to the superior point of the hyoid bone. Hart et al[46] reported a significant increase in nasopharynx volume and a significant decrease in oropharynx volume in patients with Class III malocclusion treated with 2 jaw surgery, and they suggested that these changes occurred because of downward displacement of the posterior nasal spine. A previous study that compared the skeletal effects of FM and MTTBA appliances found that changes in SN/ANS-PNS angle (−0.7° in both groups) did not differ between the groups.[7] However, this decrease was significant in the FM group at the end of the treatment. So, the insignificant changes in the oropharyngeal area in this study might be related to the maxillary rotation. Lee et al[9] also stated that FM therapy did not cause a reduction of the hypopharyngeal or oropharyngeal airway, and they pointed out that mandibular clockwise rotation and an increase in the ANB angle were the relative results. Baccetti et al[34] declared no significant changes in oropharyngeal sagittal airway dimensions by FM combined with bite-block therapy compared to untreated subjects with Class III malocclusion. Our morphometric results were also in accordance with their findings.

Ultimately, we revealed for the first time using morphometric analysis that there were no significant differences in the mean posttreatment pharyngeal airway shape between the groups. Tortop et al[7] interpreted that decreased SNB angle and increased SN/GoGn angle indicated mandibular backward rotation during MTTBA and FM treatments. Many studies have reported the clockwise rotation in the mandible during Class III treatment with functional appliances.[6,7,33,42] As the skeletal effects of the appliances used in this study on the mandibular region were similar, it is an expected situation not to find any statistically significant difference in the oropharyngeal airway region despite a slight increase in the MTTBA group.

Narrowings between the most anterior point of the first cervical vertebra to the midpoint of the velum palatinum on the posterior pharyngeal wall and between the gonial region to the anterior inferior point of the second cervical vertebra on the anterior pharyngeal wall were observed during the MTTBA treatment. In the MTTBA group, changes in the oropharyngeal airway dimensions and shape might be similar to those in the untreated patients with Class III malocclusion. However, as there is no control group in this study, this remains only a suggestion.

Deformation, enlargement, and narrowing of the airway might occur during children's normal growth pattern. No morphometric studies in the literature report how these deformations occur in these subjects. Therefore, the absence of a control group was among the limitations of this study. Another limitation of this study was that body mass index was not recorded, which may affect the airway dimensions. Furthermore, the present study's findings should be assessed within the limitations of the 2D radiography design used to assess the pharyngeal airway. The extent of generalization was limited by the age range in this study. It should be kept in mind there might be changes in this region because of relapse, so further studies are still needed to evaluate the long-term changes.

Although there were no significant differences between the appliances, as a precaution in patients with Class III malocclusion with a narrower nasopharyngeal airway, FM might be the preferred choice. Conversely, MTTBA might be an alternative treatment choice in patients with a narrower oropharyngeal airway.

CONCLUSIONS

1. Landmark-based geometric morphometric analysis can be used to evaluate the pharyngeal airway shape by considering the topographic distribution.
2. There were some significant deformations using the enlargement of the retroglossal compartment of the oropharyngeal area according to the pretreatment period in the MTTBA group.
3. When the posttreatment periods of the FM and MTTBA groups were examined, there was no difference in the mean pharyngeal airway shapes between the groups.

AUTHOR CREDIT STATEMENT

Emine Kaygisiz contributed to conceptualization, methodology, software, formal analysis, investigation, resources, data curation, original draft preparation, manuscript review and editing, visualization, supervision, and project administration; Gökhan Ocakoglu contributed to conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, original draft preparation, manuscript review and editing, and visualization; Merve Kurnaz contributed to software, validation, formal analysis, investigation, resources, data curation, original draft preparation, and manuscript review and editing; Sema Yüksel contributed to resources, manuscript review and editing, and supervision; and Tuba Tortop contributed to conceptualization, methodology, software, validation, investigation, resources, original draft preparation, manuscript review and editing, visualization, and supervision.

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