Dental Research Journal

Original Article

Assessment of the effect of maxillary protraction appliance on pharyngeal airway dimensions in relation to changes in tongue posture

Shahla Momeni Danaei[1], Shabnam Ajami[1], Hamideh Etemadi[2], Niloofar Azadeh[2]

[1]Department of Orthodontics, Orthodontic Research Center, Shiraz University of Medical Sciences, [2]Department of Orthodontics, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran

ABSTRACT

Background: Literature is controversial in regard with alterations in pharyngeal airway dimensions subsequent to maxillary protraction. The correlation between maxillary protraction and sagittal airway dimension was investigated in association with tongue and soft palate position in skeletal Class III children. The results were compared with those of an untreated Class III and a Class I malocclusion control group.

Materials and Methods: In this cross-sectional study pre- and post-treatment cephalometric radiographs of 19 Class III patients (6 males, 13 females; mean age, 7.93 ± 0.96 years) treated with facemask were analyzed. The correlation between treatment changes in craniofacial morphology and those in the upper airway, tongue, and soft palate was evaluated. These results were compared with those of a group of 16 Class I malocclusion patients (1 male, 15 females; mean age, 7.31 ± 0.7 years) and a group of 15 untreated Class III patients (4 males and 11 females; mean age, 7.46 ± 0.1 years). A paired *t*-test, the Shapiro–Wilk test and Mann–Whitney U-test was used. The level of significance was established as $P < 0.05$.

Results: Nasopharyngeal airway measurements PNS-ad1 and PNS-ad2 significantly increased by 2 mm and 2.1 mm, respectively. Statistical analysis revealed that maxillary protraction had a positive relationship with PNS-ad1 and PNS-ad2.

Conclusion: Nasopharyngeal airway dimensions can be improved in the short term with maxillary protraction in skeletal Class III children.

Key Words: Advancement, airway, maxillary, soft palate, tongue

Received: June 2017
Accepted: October 2017

Address for correspondence:
Dr. Niloofar Azadeh, Department of Orthodontics, Faculty of Dentistry, Shiraz University of Medical Sciences, Ghasrodasht Avenue, Shiraz 71956-15878, Iran.
E-mail: niloofarazadeh@yahoo.com

INTRODUCTION

Orthopedic and dentoalveolar effects of maxillary protraction have been broadly discussed in the literature.[1-4]

The relationship between forward displacement of maxilla and dimensions of pharyngeal airway has been proposed and investigated;[5-12] the issue, however, is very controversial.

Several studies confirmed the existence of a positive correlation between maxillary protraction and the improvement of pharyngeal airway dimensions.[5-7] Other studies investigated the synergistic effect of maxillary protraction and expansion and concluded that the treatment could positively improve naso- and/or oro-pharyngeal airway dimensions in short term.[8,9]

Access this article online

Website: www.drj.ir
www.drjjournal.net
www.ncbi.nlm.nih.gov/pmc/journals/1480

How to cite this article: Danaei SM, Ajami S, Etemadi H, Azadeh N. Assessment of the effect of maxillary protraction appliance on pharyngeal airway dimensions in relation to changes in tongue posture. Dent Res J 2018;15:208-14.

Kaygısız *et al*. showed long-term improvements in nasopharyngeal airway dimensions after treatment with reverse-pull headgear,[10] Pamporakis *et al*. demonstrated an insignificant increase in the volume of upper and lower airway following treatment,[11] and Baccetti *et al*. showed no significant short- or long-term changes in sagittal oropharyngeal and nasopharyngeal airway dimensions after maxillary protraction.[12]

The position of hyoid bone, soft palate, and tongue posture are considered as important variables that control airway dimensions.[7,13]

The association of tongue posture with characteristics of the maxilla and mandible has been investigated. It has been shown that Class III participants have a significantly lower tongue posture as compared to Class I participants,[14] and upper airway obstruction has been associated with this low tongue posture.[15]

In addition, a higher tongue posture has been shown by Ozbek *et al*.[16] and Iwasaki *et al*. following rapid maxillary expansion.[15]

It can be hypothesized that facemask therapy, through anterior repositioning of the maxilla, may alter tongue posture and consequently the airway dimensions as RME does.

Moreover, due to anatomic attachment of maxillary bone and soft palate, it can be presumed that positional changes in the maxilla could also affect position of the soft palate.

Few of the previous studies[9,12] included a suitable control group with normal growth of the airway to investigate this matter; therefore, the purpose of this study was to assess the association of tongue posture and pharyngeal sagittal dimensions in Class III patients treated with facemask in comparison with an untreated Class III and a treated Class I group.

MATERIALS AND METHODS

Sample size and inclusion and exclusion criteria

This was a before-after cross-sectional retrospective study of 34 patients who were diagnosed as having skeletal Class III deformity, defined as maxillary retrusion with normally positioned mandible (SNA <77, 76≤ SNB ≤80, ANB <1)[17] and 16 patients with skeletal Class I relationship, Class I molar relationship, and a mild malocclusion. There were 39 female and 11 male patients with average age of 7.56 ± 0.58 years in the range of 5–9 years old at the treatment onset. The participants were selected from the files of a private clinic and orthodontic department of Shiraz University of Medical Sciences. The records of all patients were retrospectively selected on the basis of the following criteria:

1. Availability of before (T1) and after (T2) treatment lateral cephalograms. T2 was defined as 9–12 months after T1. Only cephalograms taken at rest and in the natural head position that included the second and fourth cervical vertebrae were included in the study
2. Patients having one or more of these criteria were excluded from the study: History of trauma to the face and jaws, apparent facial asymmetry, presence of any syndrome related to orofacial region, cleft lip and/or palate, obstructive sleep apnea or even habitual snoring, chronic upper respiratory tract infections and diseases, previous history of adenoidectomy/tonsillectomy, and vertical growth pattern. The data for excluding these criteria were gathered from patient's medical and dental history and cephalograms
3. The patients having these criteria were included in the study: Participants aged between 5 and 9 years, anterior crossbite, straight or concave profile, Class III molar relation, and existing scleral show.

Patients were divided into three groups:

Group 1: Sixteen patients (1 male and 15 females; mean age, 7.31 ± 0.7 years) with skeletal Class I relationship, Class I molar relationship, and a mild malocclusion. These patients were treated with either removable or fixed appliances.

Group 2: Fifteen patients (4 males and 11 females; mean age, 7.46 ± 0.1 years) with anterior crossbite, a Class III molar relationship, maxillary skeletal retrusion with no congenital anomalies, or mandibular deviation.

Group 3: The same diagnostic criteria for Group 2 were used. Of these, nineteen patients (6 males and 13 females; mean age, 7.93 ± 0.96 years) who had been successfully treated using a maxillary protraction appliance (delaire-type facemask) and no maxillary expansion were chosen.

Radiography

All cephalograms chosen had been taken at one radiographic clinic with the same equipment (cephalometer PM 2002 EC Proline, KV 85; Planmeca, Helsinki, Finland) in which the film distance to the X-ray tube have had been fixed at 150 cm and the film distance to the midsagittal plane of the patients' head have had been fixed at 15 cm as suggested by the manufacturer.

Lateral cephalograms

The cephalograms were hand traced on a 0.003-inch thick, 8 × 10-inch matte acetate tracing paper (Truvision, Ortho Technology Inc., Tampu, Florida, USA; distributed by Emergo Europe, Molenstraat, Netherlands) with HB pencil.

Skeletal landmarks are depicted in Figure 1 and determined according to Jacobson.[18] Soft-tissue landmarks and airway, soft palate, and tongue measurements are defined in Table 1.

Statistical analysis

To estimate the reliability of a single measurer, measurements were retaken in 3 weeks. A paired *t*-test with a significance level of ≤0.01 was conducted on two measurements to check for any significant differences in the measured items recorded in two different measurements. After no significant difference was confirmed, the mean values of the two measurements were adopted for statistical analyses. All statistical analyses were performed using SPSS version 12.0 for Windows (SPSS Inc., Chicago, IL, USA). The result of the Shapiro–Wilk test confirmed that the variables followed normal distribution ($P > 0.05$). The mean and standard deviation at the first encounter (T1), at treatment completion (T2), and of the difference between them (T2–T1) were statistically analyzed using paired *t*-test. A Mann–Whitney U-test was used to assess the significance of the differences in every parameter between the groups. The level of significance was established as $P < 0.05$.

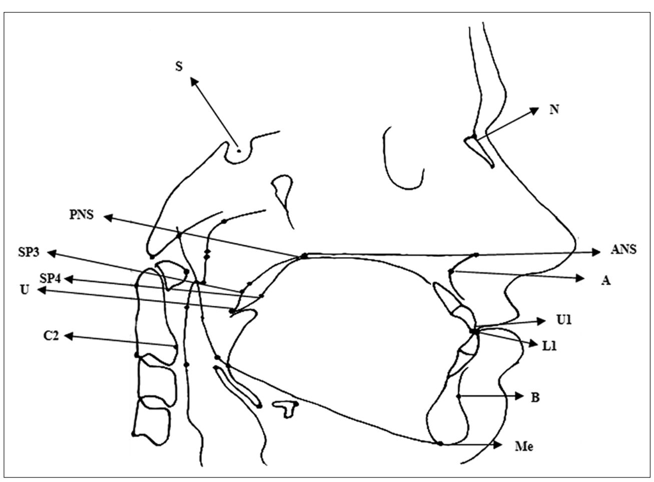

Figure 1: Skeletal and soft-tissue landmarks.

RESULTS

Among the airway parameters, minimum lingual airway (MLA), AD1 to PNS, and AD2 to PNS significantly increased after treatment only in the treated Class III malocclusion group. In addition, both VRL to U and VRL to EP increased significantly after treatment in the treated Class I group ($P < 0.05$).

Soft palate measurements showed no significant changes with treatment. [Table 2]

However, the partial length of tongue in the anterior region of the tongue (Tg6) decreased significantly after treatment in treated Class I malocclusion group; tongue height (TGH) increased significantly in the untreated Class III malocclusion group, and the distance of root part of tongue from the posterior pharyngeal wall (Pt-Pw) showed a significant increase in treated Class III group.

The comparison between the three groups showed that there were no significant changes in soft palate and airway values before and after treatment but that there was a significant difference between before and after values of TGH and Pt-Pw. Comparison between each of the two groups showed that this significance was due to the difference between the 2nd and the 3rd group.

DISCUSSION

Growth modification and orthognathic surgery cause not only tooth movement but also changes in the skeletal dimension; it can, therefore, be hypothesized that size and position of the adjacent soft tissues are also altered. The results of this study confirmed the significant effect of skeletal change caused by an MPA on changes in the size of the airway, tongue, and soft palate during treatment.

Among the airway parameters, minimum airway dimension behind the base of the tongue (MLA), airway dimension at the level of basion-PNS plane (AD1 to PNS) and airway dimension at the level of PNS-So (AD2 to PNS) significantly increased after treatment only in the treated Class III malocclusion group. In addition, both VRL to U and VRL to EP increased significantly after treatment in the treated Class I malocclusion group.

Soft palate measurements showed no significant changes with treatment.

Table 1: Soft-tissue landmarks

Landmark	Definition
PPW1	The intersection of the line ANS-PNS and the posterior pharyngeal wall[19]
PPW2	A point on the posterior wall of pharynx at the level of minimum airway dimension behind soft palate[19]
PPW3	A point on the posterior pharyngeal wall at the same level of uvula (tip of soft palate)[19]
PPW4	A point on the posterior wall of the pharynx that the airway behind the base of tongue is in minimum size anteroposteriorly[19]
APW1	A point on the anterior wall of the pharynx corresponding to the point PPW4[19]
U	Tip of the uvula or its projection on Mc-ii line[19]
V	The deepest point of vallecula on the anterior pharyngeal wall[19]
Ep	Tip of epiglottis[19]
SP2	The most posterior point on the nasal surface of the soft palate[19]
SO	Midpoint of the sella-basion line[19]
Ad1 (Linder-Anderson point 1)	Intersection of the line PNS-Ba and the posterior nasopharyngeal wall[19]
Ad2 (Linder-Anderson point 2)	Intersection of the line PNS-SO and the posterior nasopharyngeal wall[19]
E	Most inferior and anterior point on the epiglottis[20] (Lowe *et al*. 1986) [Figure 2]
ii	Incisal tip of most prominent mandibular incisor[20] (Bjork, 1960) [Figure 2]
is	Incisor tip of most prominent maxillary incisor[20] (Bjork, 1960) [Figure 2]
Mc	Point on the cervical, distal third of the last erupted permanent molar[20] (Rakosi, 1982) [Figure 2]
mc	Distobuccal cusp tip of the maxillary first Incisal tip of most prominent mandibular incisor permanent molar[20] (Bjork, 1960) [Figure 2]
O	Middle of the linear distance U-ii on Mc-ii line[20] (Rakosi, 1982) [Figure 2]
Pt	Intersection point between occlusal line and contour of the tongue[20] (Ingervall and Schmoker, 1990) [Figure 2]
TT	Tip of the tongue[20] (Lowe *et al*. 1986) [Figure 2]
Reference line	
VRL	The line which is drawn through the most anterior point of the second cervical vertebra (axis or C2) parallel to the edge of the cephalometric film
Airway, soft palate, and tongue posture measurements	
Airway	
MPA	The distance from PPW2 to SP2 (minimum airway dimension behind soft palate)
MLA	The distance from PPW4 to APW1 (minimum airway dimension behind base of the tongue)
Airway at U	The distance between PPW3 and U (the airway dimension at the level of the tip of the soft palate)
VRL to U	The distance from vertical reference line to the tip of uvula
VRL to EP	The distance from vertical reference line to the tip of the epiglottis
VRL to V	The distance from vertical reference line to the deepest point of vallecular
AD1-PNS	The distance from PNS to the pharyngeal wall along the line from basion to PNS
AD2-PNS	The distance from PNS to the adenoid tissue along the line from PNS to the midpoint of the line intersecting Ba to Sella
Soft palate	
SP length	Distance between PNS and P
SP thickness	Maximum thickness of soft palate measured on line perpendicular to PNS-U
SP depth	Distance of the points PNS and U mirrored on the horizontal line
Tongue posture: Figure 3	
Tg1	Partial length of tongue: Line through the O and ii
Tg2	Partial length of tongue: Line constructed on O at 30° Mc-ii line
Tg3	Partial length of tongue: Line constructed on O at 60° Mc-ii line
Tg4	Partial length of tongue: Line constructed on O at 90° Mc-ii line
Tg5	Partial length of tongue: Line constructed on O at 120° Mc-ii line
Tg6	Partial length of tongue: Line constructed on O at 150° Mc-ii line
Tg7	Partial length of tongue: Line constructed on O at 180° Mc-ii line
TGH	Maximum height of line perpendicular to Ep-TT line at tongue dorsum
TGL	Distance between Ep an TT
Pt-Pw	Distance of tongue from pharyngeal wall

MLA: Minimum lingual airway; TGH: Tongue height

Table 2: Mean and *P* values of parameters before and after treatment in the three groups of the study

Parameter	Group 1			Group 2			Group 3		
	Before	After	*P*	Before	After	*P*	Before	After	*P*
MPA (mm)	37.73±5.05	36.20±6.66	0.427	34.07±4.94	33.14±5.05	0.575	32.17±4.81	33.89±4.70	0.251
MLA (mm)	11.73±2.12	12.47±2.58	0.246	11.86±2.21	11.79±2.08	0.92	10.83±2.36	12.33±2.72	0.011
A at U (mm)	34.13±7.73	33.33±7.85	0.733	30.14±6.01	29.57±4.59	0.65	26.61±4.83	29.00±5.56	0.109
VRL to U (mm)	12.20±3.19	14.27±3.17	0.021	12.86±3.63	13.86±4.02	0.457	13.61±3.60	15.00±4.09	0.179
VRL to EP (mm)	11.40±2.97	13.07±3.90	0.024	12.00±1.96	13.07±3.34	0.229	11.28±2.65	12.61±2.64	0.126
VRL to V (mm)	16.93±3.99	19.73±6.66	0.224	17.43±3.41	17.07±3.79	0.64	16.83±3.26	17.78±3.70	0.446
AD1-PNS (mm)	19.20±5.10	19.13±5.03	0.953	16.36±4.78	15.43±4.05	0.432	16.78±4.12	18.78±3.73	0.038
AD2-PNS (mm)	17.87±3.80	20.67±6.44	0.091	20.29±7.18	20.93±5.23	0.69	19.83±3.71	21.83±3.91	0.044
SP length (mm)	26.47±5.73	25.93±4.92	0.604	22.36±6.65	22.86±4.42	0.782	23.39±5.19	24.78±3.64	0.145
SP thickness (mm)	8.40±0.91	8.53±1.55	0.792	8.79±1.67	8.79±1.25	1	8.28±1.41	8.67±1.71	0.31
SP depth (mm)	24.93±5.16	25.80±4.63	0.482	22.57±3.78	22.36±3.65	0.791	22.00±3.66	23.89±4.13	0.089
Tg1	20.67±6.28	25.73±15.30	0.183	21.93±7.09	21.71±5.94	0.844	18.56±5.46	19.72±7.09	0.227
Tg2	17.13±8.20	16.80±6.93	0.784	16.64±3.93	16.21±3.24	0.696	14.39±4.58	14.39±5.04	1
Tg3	12.27±3.24	13.13±8	0.625	13.073.02	13.07±2.46	1	12.44±2.36	12.72±3.25	0.633
Tg4	11.73±2.55	11.93±3.15	0.792	11.712.55	12.36±2.34	0.37	12.44±1.79	12.00±2.61	0.42
Tg5	13.47±2.97	12.87±3.74	0.58	12.71±2.23	13.57±2.65	0.189	15.00±2.47	13.89±2.52	0.126
Tg6	19.33±2.74	17.00±3.36	0.017	18.21±3.66	18.71±3.93	0.572	20.17±2.79	18.78±3.98	0.172
Tg7	29.07±6.37	27.40±7.55	0.468	30.36±5.17	28.86±7.16	0.193	31.89±4.78	32.61±6.25	0.44
TGH (mm)	25.73±3.17	24.67±4.24	0.417	24.36±4.72	26.21±5.01	0.042	27.61±3.01	26.61±3.84	0.169
TGL (mm)	64.60±4.22	63.33±4.97	0.783	63.36±4.94	59.50±8.24	0.126	61.39±3.63	62.50±5.17	0.302
Pt-Pw (mm)	20.53±2.92	21.27±3.5	0.313	22.86±3.46	22.43±3.63	0.56	20.00±2.20	21.78±2.32	0.012

MLA: Minimum lingual airway; TGH: Tongue height

Figure 2: Soft tissue landmark (1) ANS (SP); (2) E; (3) ii; (4) is; (5) Mc; (6) mc; (7) O; (8) Pt; (9) Pw; (10) TT; (11) U.

As for tongue measurements, however, Tg6 decreased significantly after treatment in Class I malocclusion treatment group; TGH increased significantly in the 2nd group and Pt-Pw showed a significant increase in Group 3.

In contrast, Pamporakis *et al*.[11] reported no significant changes in the upper airway dimension during treatment; Hiyama *et al*.,[5] however, associated a greater forward maxillary growth with a greater increase in the superior upper airway dimension which is in line with the results of this study.

Hiyama also mentioned the influential effects of changes in head posture on upper airway dimension. In our study, this confounding effect has been controlled by choosing cephalograms with the head in natural position.

A limitation of Hiyama's study was the absence of an untreated control group; therefore, changes in the upper airway dimensions during natural growth could not be elucidated. In our study, a group of untreated Class III patients was radiographically followed to overcome this limitation. These patients were chosen among those who prepared pretreatment radiographic records but did not begin their treatment for personal reasons and came back to seek treatment in a few months.

The results of this follow-up confirm the findings of Ozbek *et al*.[21] who demonstrated only negligible changes in the upper airway dimension during a 1.8-year observation period in untreated participants. Furthermore, in a study by Kilinç *et al*., change in the upper airway space in untreated Class III patients was trivial during the follow-up of 9.8 months.[9] Therefore, the increase in the upper airway dimension can be related to the increased maxillary growth

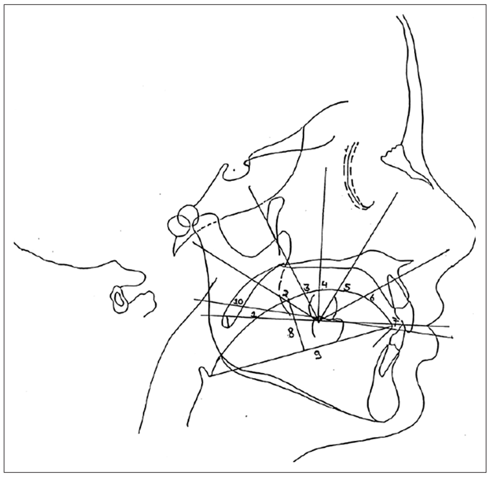

Figure 3: Soft tissue land mark (1) Tg1; (2) tg2; (3) tg3; (4) tg4; (5) tg5; (6) tg6; (7) tg7; (8) TGH; (9) TGL; (10) Pt-Pw.

induced by MPA treatment, and the increase in upper airway dimensions should not be anticipated unless patients are treated with an MPA.

These results are, however, not in accordance with the results of a study by Taylor *et al*. in which two periods of accelerated change (6–9 years and 12–15 years) were identified for pharyngeal soft tissues.[22]

Hiyama *et al*. attributed the increase in upper airway dimensions after maxillary protraction to a possible anterior repositioning of the tongue in the enlarged oral cavity. They explained that the change in tongue posture could have induced the soft palate to a more anterior position, which might have resulted in an increase in the superior upper airway dimension.[5]

In our study, the increase in airway space behind the soft palate was trivial; this may be attributed to the growth of soft palate that is needed to maintain velopharyngeal seal as was discussed by Akcam *et al*.[23] The space posterior to tongue, however, was increased significantly, and this is in agreement with Hiyama *et al*.'s discussion on the subject[5] and may be related to a more forward position of the tongue subsequent to facemask therapy since the distance between the base of tongue to Pt-Pw was also increased.

The increase in airway space behind tongue in treated Class I patients may also be related to a more forward position of the tongue due to the space created through protrusion of lower incisors during nonextraction treatment of these patients.

Our results were in agreement with those of Primozic *et al*. who showed that Class III participants have a significantly lower tongue posture as compared to Class I participants, with most of the difference found at the posterior regions and no significant difference at the anterior areas.[14] With maxillary protraction in our study, patients attained an increased TGH and a resultant decreased tongue-to-palate distance.

Lee *et al*. showed that after treatment with an MPA, the tongue increased in length without thickness change.[6] In our study, the thickness of tongue also remained unchanged after maxillary protraction.

Measurement of airway space after treatment with maxillary protraction appliance showed that PNS-ad1 and PNS-ad2 were, respectively, positioned 2 mm and 2 ± 0.2 mm superiorly. This is consistent with the result of studies by Lee *et al*., Sayinsu *et al*., and Kaygisiz *et al*.,[6,8,10] which showed an increase in nasopharyngeal rather than oropharyngeal space.

Contrary to our results, however, Bacceti *et al*. could not demonstrate a favorable change in the oro- and/or naso-pharyngeal airway dimensions after facemask therapy in comparison to an untreated control group. This discrepancy in results may be attributed to a longer treatment and follow-up period in their study. It could, therefore, be concluded that any improvement in airway dimensions may be lost to physiologic compensations in the future.

Akcam *et al*.[23] reported that airway space decreased in patients with the clockwise rotation of the mandible. Patients with vertical growth pattern were excluded from this study; however, the clockwise rotation of the mandible during facemask therapy was an inevitable side effect of the treatment. Therefore, it can be concluded that airway space would be more significantly increased through application of mechanics that control mandibular rotation.

In our study, the effect of deviated growth pattern in Class III individuals was controlled by simultaneous evaluation of untreated Class III patients. There was, however, limited three-dimensional evaluation of airway space because of unavailability of the costly cone-beam computed tomography (CBCT) views. In studies on upper airway space using CBCT, space area, anteroposterior width, horizontal width, and upper airway volume can be measured. Therefore, a limitation of this study was that two-dimensional views were used to evaluate a three-dimensional entity.

CONCLUSION

I. The nasopharyngeal airway dimensions can be improved in short term with maxillary protraction in skeletal Class III children
II. Pharyngeal airway space will not increase in untreated Class III patients
III. Tongue attains a more forward position after maxillary protraction and nonextraction treatment of Class I malocclusion.

Acknowledgment

The authors thank the vice-chancellery of Shiraz University of Medical Sciences for supporting this research (Grant # 8693103). This manuscript is based on the thesis by Dr. Hamideh Etemadi. The authors also thank Dr. Mehrdad Vosughi of the Center for Research Improvement of the School of Dentistry for the statistical analysis and Abdolbaghi Teyghkhorshid for help with the English in the manuscript.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

REFERENCES

1. Ngan P, Hägg U, Yiu C, Merwin D, Wei SH. Soft tissue and dentoskeletal profile changes associated with maxillary expansion and protraction headgear treatment. Am J Orthod Dentofacial Orthop 1996;109:38-49.
2. Nartallo-Turley PE, Turley PK. Cephalometric effects of combined palatal expansion and facemask therapy on class III malocclusion. Angle Orthod 1998;68:217-24.
3. da Silva Filho OG, Magro AC, Capelozza Filho L. Early treatment of the class III malocclusion with rapid maxillary expansion and maxillary protraction. Am J Orthod Dentofacial Orthop 1998;113:196-203.
4. Kapust AJ, Sinclair PM, Turley PK. Cephalometric effects of face mask/expansion therapy in class III children: A comparison of three age groups. Am J Orthod Dentofacial Orthop 1998;113:204-12.
5. Hiyama S, Suda N, Ishii-Suzuki M, Tsuiki S, Ogawa M, Suzuki S, *et al.* Effects of maxillary protraction on craniofacial structures and upper-airway dimension. Angle Orthod 2002;72:43-7.
6. Lee JW, Park KH, Kim SH, Park YG, Kim SJ. Correlation between skeletal changes by maxillary protraction and upper airway dimensions. Angle Orthod 2011;81:426-32.
7. Oktay H, Ulukaya E. Maxillary protraction appliance effect on the size of the upper airway passage. Angle Orthod 2008;78:209-14.
8. Sayinsu K, Isik F, Arun T. Sagittal airway dimensions following maxillary protraction: A pilot study. Eur J Orthod 2006;28:184-9.
9. Kilinç AS, Arslan SG, Kama JD, Ozer T, Dari O. Effects on the sagittal pharyngeal dimensions of protraction and rapid palatal expansion in class III malocclusion subjects. Eur J Orthod 2008;30:61-6.
10. Kaygisiz E, Tuncer BB, Yüksel S, Tuncer C, Yildiz C. Effects of maxillary protraction and fixed appliance therapy on the pharyngeal airway. Angle Orthod 2009;79:660-7.
11. Pamporakis P, Nevzatoğlu Ş, Küçükkeleş N. Three-dimensional alterations in pharyngeal airway and maxillary sinus volumes in class III maxillary deficiency subjects undergoing orthopedic facemask treatment. Angle Orthod 2014;84:701-7.
12. Baccetti T, Franchi L, Mucedero M, Cozza P. Treatment and post-treatment effects of facemask therapy on the sagittal pharyngeal dimensions in class III subjects. Eur J Orthod 2010;32:346-50.
13. Sheng CM, Lin LH, Su Y, Tsai HH. Developmental changes in pharyngeal airway depth and hyoid bone position from childhood to young adulthood. Angle Orthod 2009;79:484-90.
14. Primozic J, Farcnik F, Perinetti G, Richmond S, Ovsenik M. The association of tongue posture with the dentoalveolar maxillary and mandibular morphology in class III malocclusion: A controlled study. Eur J Orthod 2013;35:388-93.
15. Iwasaki T, Saitoh I, Takemoto Y, Inada E, Kakuno E, Kanomi R, *et al.* Tongue posture improvement and pharyngeal airway enlargement as secondary effects of rapid maxillary expansion: A cone-beam computed tomography study. Am J Orthod Dentofacial Orthop 2013;143:235-45.
16. Ozbek MM, Memikoglu UT, Altug-Atac AT, Lowe AA. Stability of maxillary expansion and tongue posture. Angle Orthod 2009;79:214-20.
17. McNamara JA Jr., A method of cephalometric evaluation. Am J Orthod 1984;86:449-69.
18. Jacobson A, Jacobson RL, editors. Radiographic Cephalometry from Basics to 3-D Imaging. 2nd ed. Hanover Park: Quintessence; 2006. p. 49-51.
19. Grabber TM, Vanarsdall R, Vig KW, editors. Orthodontics: Current Principles and Techniques. 4th ed. St. Louis: Mosby; 2005. p. 130-2.
20. Verma SK, Tandon P, Agrawal DK, Prabhat KC. A cephalometric evaluation of tongue from the rest position to centric occlusion in the subjects with class II division 1 malocclusion and class I normal occlusion. J Orthod Sci 2012;1:34-9.
21. Ozbek MM, Memikoglu TU, Gögen H, Lowe AA, Baspinar E. Oropharyngeal airway dimensions and functional-orthopedic treatment in skeletal class II cases. Angle Orthod 1998;68:327-36.
22. Taylor M, Hans MG, Strohl KP, Nelson S, Broadbent BH. Soft tissue growth of the oropharynx. Angle Orthod 1996;66:393-400.
23. Akcam MO, Toygar TU, Wada T. Longitudinal investigation of soft palate and nasopharyngeal airway relations in different rotation types. Angle Orthod 2002;72:521-6.