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Determining the short-term effects of different maxillary protraction methods on pharyngeal airway dimensions

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Abstract

Objective: This study sought to evaluate the effects of different maxillary protraction methods on the pharyngeal airway in Class III patients with maxillary retrognathia.

Setting and Sample Population: A total of 59 individuals (31 females and 28 males) with a mean age of 11.38 ± 1.24 years were included in this study.

Material and Methods: Fifty-nine treated maxillary retrognathic patients who underwent different protraction methods were evaluated. Twenty patients treated with RME (Rapid Maxillary Expansion) made up the first group, and 20 patients treated with 5-week Alt-RAMEC (Alternate Rapid Maxillary Expansion and Constriction) protocol comprised the second group. Lastly, 19 patients on whom face masks with miniplates were applied were included in the skeletal anchorage (SA) group. Sixteen linear and four areal pharyngeal airway measurements were made on lateral cephalograms before and after treatment. Differences between the groups were assessed using analysis of variance (ANOVA) tests.

Results: The mean maxillary protraction levels were determined as 2.7, 3.69 and 4.01 mm in the RME, Alt-RAMEC and SA groups, respectively. In the nasopharynx, AD1-PNS, AD2-PNS, PNS-Ba and PNS-Ho measurements revealed a significant increase in the SA group compared to the other groups ($P < .05$). In the oropharynx, PNS-Ep measurement increased significantly in the RME group ($P < .05$). In the total pharyngeal airway area, an increase was detected in the SA, Alt-RAMEC, and RME groups.

Conclusion: The most effective protraction method in terms of pharyngeal airway dimensions, especially in the nasopharynx, is the application of the face mask with skeletal anchorage. A greater increase in vertical airway length (PNS-Ep) was observed with RME.

KEYWORDS

Alt-RAMEC, face mask, maxillary protraction, pharyngeal airway, skeletal anchorage

1 | INTRODUCTION

Skeletal Class III malocclusion can be defined as a craniofacial disharmony characterized by maxillary retrognathia, mandibular prognathia or a combination of both jaw relationships.[1] The prevalence of Class III malocclusion was reported to be less than 8% in the UK population, between 4% and 14% in the Asian population and between 10% and 12% in the Turkish population.[2-5] Maxillary protraction therapy of skeletal Class III malocclusion has been commonly used for maxillary deficiency over the past several decades.

Class III malocclusion treatments using face masks have been well documented to be successful in correcting skeletal Class III malocclusions due to maxillary deficiency.[6-10] Face masks produce a mechanical force on the maxilla through elastics, thereby stimulating cell activation and bone apposition in the circummaxillary sutures.[11,12]

The face mask has been applied by several different appliances or by many different methods since it was used in skeletal Class III treatments. One of the aims of these different methods is to decrease relapse by increasing skeletal effect and to increase patient comfort and cooperation. In this regard, it has been reported that rapid palatal expansion with a face mask (RME/FM) used in the treatment of Class III malocclusion is successful in eliminating transverse and sagittal maxillary deficiency.[6-8] Later, the alternate rapid maxillary expansion and constriction (Alt-RAMEC) protocol was introduced by Liou,[13,14] and some authors have reported that protocol increased skeletal effects in maxillary protraction. Recently, skeletal anchorage (SA) treatments with titanium miniplates have been applied by researchers to increase maximum skeletal effect and prevent undesirable dental effects during maxillary protraction.[15-19]

It is thought that maxillary protraction has effects on skeletal, dentoalveolar and soft tissues as well as pharyngeal airway dimensions within surrounding craniofacial structures. For this purpose, several studies have examined the change in pharyngeal airway dimensions with a face mask. However, there is no consensus among researchers on this subject. Most studies have found increased pharyngeal airway dimensions,[20-29] but some researchers have reported that maxillary protraction did not change any significant pharyngeal airway dimensions.[30-32]

The most popular methods for evaluating pharyngeal airway dimensions in the literature are cephalometric radiographs and CBCT (cone beam computed tomography). Although almost all of the pharyngeal airway studies related to Class III malocclusion are performed with cephalometric radiographs[21,24] due to the radiation dose of CBCT, its high cost, and not being suitable for routine use; cephalometric radiographs are also used during exposure on head posture, swallowing, breathing, etc situations can affect radiographs.

Although the effects of different protraction methods on the pharyngeal airway have been revealed in relevant studies, to the best of our knowledge, there is no study evaluating the effects of face mask treatment on pharyngeal airway dimensions with RME, modified Alt-RAMEC protocol and skeletal anchorage. The aim of our study was to compare the variation in pharyngeal airway dimensions with different maxillary protraction methods.

2 | MATERIAL AND METHODS

Ethical approval for this retrospective study was obtained from the local ethics committee (Clinical Research Ethics Committee, Suleyman Demirel University). In addition, informed consent was obtained from the parents of the patients included in the study. The study consisted of patients presenting with skeletal Class III malocclusion characterized by maxillary retrognathia and treated with either RME, Alt-RAMEC or SA with face mask treatment.

The inclusion criteria were an absence of any craniofacial anomaly, systemic disorder or airway pathologies and the presence of a negative overjet, a maxillary deficiency and a concave profile and a decreased SNA angle and negative ANB angle identified in the cephalometric analysis. Patients exhibiting a functional Class III anomaly and patients treated with different RME appliances (eg banded hyrax appliance, full coverage appliance, fan-type expanders), different Alt-RAMEC protocols, cephalometric radiographs with adequate imaging quality and patients with incorrect head posture during radiographic exposure were excluded. Lateral cephalometric radiographs and patient anamnesis forms were examined for airway pathologies. For airway obstruction, patients with obstruction greater than 5 mm in the upper airway measurement determined by McNamara[33,34] on lateral cephalometric radiographs were excluded from the study.

The sample size was calculated based on a significance level of $P = .05$ to detect a clinically meaningful difference of 1 mm ($\pm$0.98 mm)[25] for the upper pharyngeal dimension between the groups by a power analysis using G*Power (Franz Faul, Universität Kiel). A total of at least 52 patients were required in the groups to reach 80% power. Finally, 59 patients (20 in the RME group, 20 in the Alt-RAMEC group and 19 in the SA group) whose pre-treatment skeletal maturity stages were either pre-peak or peak (CS2, CS3 or CS4) according to cervical vertebral maturation (Lamparski method) were included in this study.

Lateral cephalometric radiographs obtained at the beginning of treatment (T0) and at the end of the face mask treatment (T1) were compared to determine the changes in the pharyngeal airway dimensions after maxillary protraction.

2.1 | Treatment protocols

In accordance with the information in the anamnesis forms and hospital records of the patients, those who were suitable for the treatment protocols that we compared in our study were selected.

The RME group included patients (unilateral 400-500 g) with a Petit-type face mask after expansion (the hyrax screw was opened twice per day for 1 week) with an acrylic-bonded RME appliance before the face mask.

The Alt-RAMEC group included patients who underwent the 5-week Alt-RAMEC protocol with an acrylic-bonded RME appliance before the face mask. Although the researchers recommended at least 7-9 weeks in the original Alt-RAMEC protocol, patients who underwent a more frequent 5-week protocol in our clinic were preferred because their effects on airway dimension were similar in the literature.[21]

In the SA group, patients (unilateral 400-500 g) treated with Petit-type face masks from miniplates surgically placed in the apertura piriformis area were included.

In the face mask treatments in our clinic, patients are routinely checked at 1-month intervals and are required to wear devices for at least 18-20 hours a day until at least a 2-mm positive overjet is obtained. All patients included in the study were treated by two clinicians at the same clinic between 2018 and 2020. Total orthopaedic treatment durations were 0.95 ± 0.41 years, 0.52 ± 0.17 years and 0.56 ± 0.22 years in the RME, Alt-RAMEC and SA groups, respectively (Figure 1).

2.2 | Cephalometric analysis

Skeletal, dentoalveolar and linear pharyngeal measurements used in the study were determined using the Dolphin Imaging (Premium software, version 11.5.06.24, Dolphin Imaging and Management Solutions, Chatsworth, Calif) computerized cephalometric analysis programme. Areal pharyngeal measurements were performed with the SketchAndCalc™ software program (SketchAndCalc Area Calculation software, Axiom Welldone ©, https://www.sketchandcalc.com/) on digital lateral cephalometric radiographs after digital calibration.

The 42 landmarks used in our study are depicted in Figure 2. The cephalometric analysis used 15 craniofacial, 7 nasopharyngeal, 7 oropharyngeal, 2 hypopharyngeal (Figure 2) and 4 area measurements (Figure 2). To minimize methodological errors, all lateral cephalograms were digitized by one examiner.

In each film, a horizontal reference line (HRL) was constructed passing through the tuberculum sella (T) and wing points (W), and a perpendicular line was constructed passing through the tuberculum sella as a vertical reference line (VRL). For the total protraction degree of the maxilla, the distance of point A from these lines was determined as a reference.

The protraction rates of the protraction methods in this study and the skeletal and dental effects of the treatment changes in these methods were calculated. The rate of protraction was found by calculating the amount of protraction by looking at the amount of sagittal movement of point A (A-VRL) and dividing it by the total protraction duration. The method used by Pancherz[35] in Class II malocclusions was modified to calculate skeletal and dental effects. The skeletal effect of the treatment changes in the three different methods was found by summing the sagittal movement of point A relative to the fixed reference plane (A-VRL) and adding the backward movement values of the Pg point (Pg-VRL). The dental effects were calculated by subtracting the skeletal effect in the total overjet correction.

2.3 | Statistical analysis

Descriptive statistics were calculated for all measurements at T0 and T1 for all treatment groups. All statistical analyses were performed using the SPSS software package program (SPSS Inc, version 21.0). Changes in the pharyngeal airway dimensions with treatment at T0 and T1 for all groups were evaluated with repeated measurements and pairwise comparisons. One-way analysis of variance (ANOVA) and Tukey post hoc tests were used to compare the changes in the groups and initial values. Statistical significance was tested at $P < .05$, $P < .01$ and $P < .001$. In order to detect the method error in the measurements, remeasurements were made in 40 cephalometric radiographs 2 weeks later by the same researcher. Repeatability coefficients were found to be high ($r \geq .913$), which revealed no statistically significant error.

3 | RESULTS

In terms of treatment durations, gender distribution and chronological age, no statistically significant differences were found among any of the groups (Table 1). The mean chronological age between groups in the SA group was the highest (SA group: 12.01 ± 0.91 years; RME group: 10.50 ± 1.02 years; Alt-RAMEC group: 11.67 ± 1.17 years). Upper canine teeth eruption has been considered as a chronological age advantage associated with the safe placement of orthodontic miniplates.

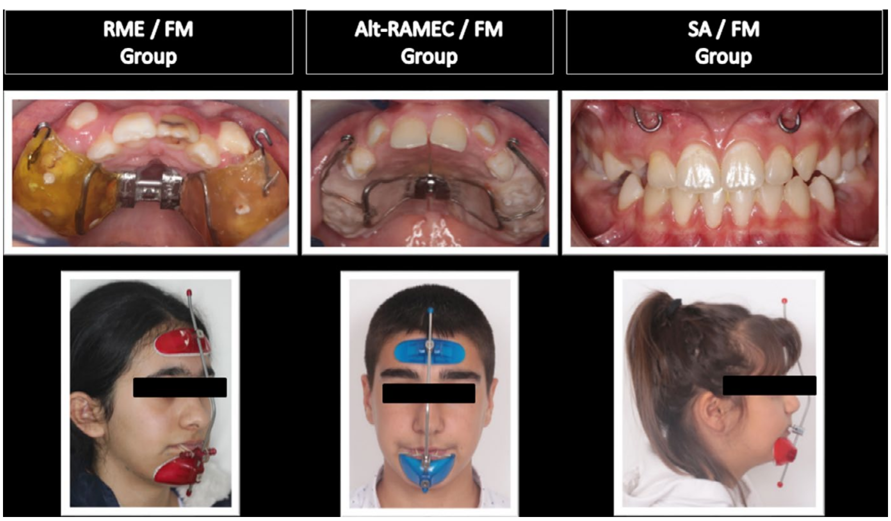

FIGURE 1 Intraoral appliances and face mask used in groups

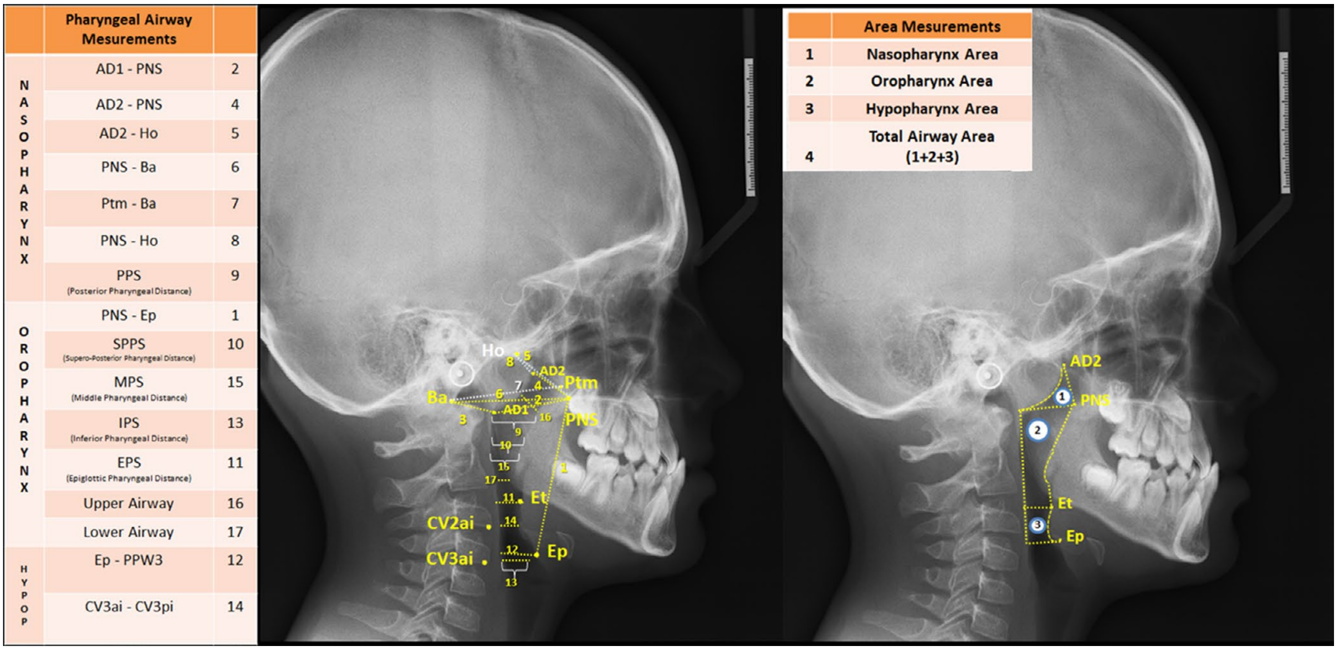

FIGURE 2 Landmarks and pharyngeal airway and area measurements used in the study

TABLE 1 Comparison of the chronological ages, gender distributions and treatment time between the groups

	Gender distribution (male/female)	Chronological age (y) Mean ± SD	Treatment time (y) Mean ± SD
Group 1 RME Group (N = 20)	10/10	10.50 ± 1.02	0.95 ± 0.41
Group 2 Alt-RAMEC Group (N = 20)	9/11	11.67 ± 1.17	0.52 ± 0.17
Group 3 SA Group (N = 19)	9/10	12.01 ± 0.91	0.56 ± 0.22
P	.864[a]	.906[b]	.513[b]

Abbreviations: N, number; SD, standard deviation.
[a]Results of Pearson chi-square test.
[b]Results of ANOVA test.

Each intragroup variable of skeletal and dentoalveolar mean values and standard deviations assessed at pre-treatment (T0) and post-treatment (T1) are presented in Table 2.

Although there were statistically significant increases in all values except the A-HRL measurement (SNA°, Co-A and A-VRL values) following maxillary protraction, there was a significant difference in the SNA° and A-VRL values between the groups associated with these variables. Following the face mask treatment, the mean maxillary protraction (A-VRL) was 2.7 mm in the RME group, 3.69 mm in the Alt-RAMEC group and 4.01 mm in the SA group ($P < .01$). Analysis of the SN/GoGn angle, one of the vertical dimensional parameters, revealed a significant difference between the groups. The mean SN/GoGn angle increased in all groups following maxillary protraction ($P < .001$). The lowest increase was determined in the SA group (1.36° ± 0.49°). In addition, the vertical plane angle had increased minimally and mostly remained stable in the SA group and displayed a significant difference among the groups ($P < .05$).

While there was no statistically significant difference in the initial values of pharyngeal airway measurements of the patients in all groups (Table 3), a difference was found in the craniofacial values of A-HRL, convexity, overbite and SN/GoGn measurements (Table 2). The mean values of the pharyngeal airway parameters for the treatment periods and intragroup changes are depicted in Table 3, and the comparisons of the changes in all groups are shown in Table 4. Analysis of changes in pharyngeal airway measurements in the groups revealed significant changes in AD1-PNS, AD2-PNS, PNS-Ba and PNS-Ho measurements (nasopharynx) in upper and lower airway measurements taken as reference by McNamara and PNS-Ep measurements (oropharynx) ($P < .05$). Hypopharyngeal

TABLE 2 Comparison of initial and intragroup values at different maxillary protraction methods

	RME group			Alt-RAMEC group			Skeletal anchorage (SA) group			
	Pre-treatment	Post-treatment		Pre-treatment	Post-treatment		Pre-treatment	Post-treatment		
	Mean ± SD	Mean ± SD	*P′*	Mean ± SD	Mean ± SD	*P′*	Mean ± SD	Mean ± SD	*P′*	*P*†
Skeletal dentoalveolar measurements										
SNA (°)	76.8 ± 3.04	78.83 ± 3.51	***	76.78 ± 2.5	80.5 ± 2.77	***	76.61 ± 2.77	80.01 ± 0.58	***	NS
Co-A (mm)	74.61 ± 3.93	77.95 ± 4.2	***	72.04 ± 3.34	76.55 ± 4.3	***	74.33 ± 4.78	77.85 ± 4.45	***	NS
A-HRL (mm)	54.11 ± 0.92	52.86 ± 3.66	NS	52.12 ± 0.83	53.96 ± 3.63	NS	51.3 ± 0.56	52.33 ± 3.61	NS	*
A-VRL (mm)	49.76 ± 5.1	52.46 ± 0.5	***	50.91 ± 3.76	54.6 ± 0.52	***	49.88 ± 1.93	53.89 ± 0.57	***	NS
SNB (°)	79.43 ± 2.91	76.42 ± 3.14	***	80.04 ± 2.81	77.22 ± 2.36	***	78.8 ± 2.79	76.15 ± 0.88	***	NS
Co-Gn (mm)	102.44 ± 4.67	103.39 ± 5.82	NS	101.9 ± 4.67	102.54 ± 5.18	NS	103.8 ± 6.73	104.36 ± 6.8	NS	NS
ANB (°)	−2.6 ± 1.65	2.35 ± 1.77	***	−3.21 ± 1.4	3.28 ± 1.57	***	−2.08 ± 0.65	3.99 ± 0.8	***	NS
Wits (mm)	−6.83 ± 2.93	−3.07 ± 3.24	***	−7.33 ± 2.62	−2.46 ± 2.5	***	−6.2 ± 1.47	−1.43 ± 0.83	***	NS
Convexity (mm)	−3.57 ± 1.71	5.21 ± 1.83	***	−5.34 ± 2.04	3.96 ± 4.24	***	−3.29 ± 2.71	7.12 ± 3.85	***	*
U1/PP (°)	110.35 ± 4.66	115.53 ± 5.7	***	111.58 ± 3.87	115.6 ± 5.61	***	113.72 ± 3.6	115.7 ± 4.19	NS	NS
IMPA (°)	84.81 ± 6.13	82.32 ± 7.52	***	85.35 ± 6.6	83.07 ± 7.66	***	87.4 ± 6.53	85.04 ± 6.58	***	NS
Overjet (mm)	−2.05 ± 1.75	4.37 ± 1.55	***	−1.74 ± 1.55	5.2 ± 1.43	***	−1.5 ± 0.95	5.38 ± 1.05	***	NS
Overbite (mm)	3.03 ± 2.77	1.06 ± 2.58	***	2.32 ± 1.1	0.94 ± 1.9	***	1.55 ± 0.87	1.17 ± 1.43	*	*
SN/GoGN (°)	32.26 ± 4.35	34.67 ± 5.07	***	32.6 ± 4.63	34.56 ± 4.64	***	34.6 ± 2.95	35.96 ± 1.96	***	*
SN/PP (°)	10.7 ± 2.92	9.79 ± 3.6	***	10.52 ± 4.44	9.84 ± 3.97	***	10.95 ± 1.27	10.64 ± 1.22	*	NS
Protraction amount (mm)	2.7 ± 1.03			3.69 ± 1.05			4.01 ± 1.46			
Protraction rate (mm/mo)	0.23 ± 0.11			0.59 ± 0.15			0.58 ± 0.19			
Skeletal-dental effects	%79.66 Skeletal %20.34 Dental			%84.97 Skeletal %15.03 Dental			%87.35 Skeletal %12.65 Dental			

Note: P′, Intragroup changes with paired *t* test; $P^{\dagger}$, Comparison of initial values with ANOVA test.

Abbreviations: NS, not significant; SD, standard deviation.

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$.

measurements demonstrated a significant change in all groups (*P* > .05).

The findings revealed no significant difference between the groups in terms of nasopharyngeal and oropharyngeal measurements (*P* > .05) (Table 4). In the nasopharynx, AD1-PNS, AD2-PNS, PNS-Ba and PNS-Ho measurements displayed a significant increase in the SA group compared to the other groups (*P* < .05). In the oropharynx, PNS-Ep, MPS, upper airway and lower airway measurements taken as references by McNamara displayed significant differences among the three groups (*P* < .05). Whereas a significant increase was observed in the SA group compared to the other groups in the upper airway and lower airway measurements taken as a reference by McNamara, vertical airway length measurement (PNS-Ep) increased significantly in the RME group (*P* < .05). The findings indicated no significant difference between the groups in terms of hypopharyngeal measurements (*P* > .05).

When the areal pharyngeal airway measurements were evaluated, a significant change was found with three different protraction methods (*P* < .05). Whereas an increase was observed with all three treatment methods in the nasopharynx and oropharynx area, the highest increase was found in the SA group. In the area of the hypopharynx, a decrease was detected for all three groups, although it was not significant (*P* > .05). In the total pharyngeal airway area, the highest increase was detected in the SA, Alt-RAMEC, and RME groups.

TABLE 3 Comparison of initial and intragroup values in pharyngeal airway measurements

	RME group			Alt-RAMEC group			Skeletal Anchorage (SA) group			
	Pre-treatment	Post-treatment		Pre-treatment	Post-treatment		Pre-treatment	Post-treatment		
	Mean ± SD	Mean ± SD	P′	Mean ± SD	Mean ± SD	P′	Mean ± SD	Mean ± SD	P′	P†
Nasopharyngeal measurements										
AD1-PNS	21.53 ± 3.89	22.7 ± 3.41	***	20.79 ± 3.51	22.25 ± 3.66	***	19.94 ± 3.52	22.58 ± 3.96	***	NS
AD2-PNS	17.33 ± 3.31	19.34 ± 4.02	***	15.92 ± 3.76	18.16 ± 3.92	***	17.19 ± 3.49	20.67 ± 4.03	***	NS
AD2-Ho	11.60 ± 3.25	11.87 ± 3.63	NS	12.27 ± 3.32	12.5 ± 3.36	NS	13.52 ± 3.19	13.59 ± 3.22	NS	NS
PNS-Ba	39.13 ± 3.67	39.69 ± 3.44	NS	41.27 ± 4.01	42.21 ± 4.12	NS	42.51 ± 4.09	44.47 ± 4.19	***	NS
Ptm-Ba	37.25 ± 4.01	37.66 ± 3.94	NS	37.67 ± 3.58	38.14 ± 3.91	NS	37.93 ± 4.14	38.55 ± 3.97	*	NS
PNS-Ho	29.49 ± 3.71	31.76 ± 3.68	***	28.84 ± 3.68	31.35 ± 3.74	***	30.68 ± 3.66	34.42 ± 4.11	***	NS
PPS	21.44 ± 4.05	22.79 ± 3.93	***	21.54 ± 4.17	22.98 ± 4.06	***	22.79 ± 4.34	24.35 ± 4.25	***	NS
Nasopharynx area	95.31 ± 42.16	97.99 ± 39.46	**	96.2 ± 45.36	100.52 ± 43.88	***	93.22 ± 46.74	98.36 ± 48.89	***	NS
Oropharyngeal measurements										
PNS-Ep	53.86 ± 8.51	56.2 ± 8.46	**	53.63 ± 8.22	55.5 ± 8.66	**	53.34 ± 8.44	54.75 ± 7.89	*	NS
SPPS	9.91 ± 2.76	10.05 ± 2.69	NS	10.59 ± 2.84	10.71 ± 2.73	NS	10.14 ± 2.79	10.06 ± 3.07	NS	NS
MPS	13.29 ± 3.34	13.02 ± 3.16	NS	13.42 ± 3.61	13.21 ± 3.68	NS	12.85 ± 3.42	12.69 ± 3.66	NS	NS
IPS	10.32 ± 3.29	10.23 ± 3.33	NS	11.44 ± 3.75	11.37 ± 3.44	NS	11.12 ± 3.68	11.07 ± 3.91	NS	NS
EPS	12.53 ± 3.18	12.46 ± 3.21	NS	10.37 ± 3.19	10.32 ± 3.28	NS	11.82 ± 3.23	11.78 ± 3.34	NS	NS
Upper Airway	8.48 ± 2.42	9.85 ± 2.76	**	7.62 ± 2.46	9.83 ± 3.06	***	7.35 ± 2.68	9.98 ± 2.84	***	NS
Lower Airway	11.02 ± 3.16	10.94 ± 3.29	NS	10.39 ± 3.11	10.53 ± 3.28	NS	10.38 ± 3.19	10.66 ± 3.26	NS	NS
Oropharynx area	466.34 ± 184.4	466.9 ± 183.88	NS	475.44 ± 177.36	476.75 ± 183.55	NS	454.86 ± 175.17	456.51 ± 173.86	NS	NS
Hypopharyngeal measurements										
Eb-PPW3	13.59 ± 2.67	13.56 ± 2.88	NS	13.32 ± 3.11	13.28 ± 2.96	NS	13.86 ± 3.16	13.79 ± 3.22	NS	NS
CV3ai-CV3pi	12.73 ± 3.81	12.44 ± 3.75	NS	13.02 ± 3.46	12.8 ± 3.63	NS	12.62 ± 3.14	12.44 ± 3.17	NS	NS
Hypopharynx area	206.27 ± 85.61	204.29 ± 83.42	NS	209.63 ± 83.94	208.06 ± 83.89	NS	211.04 ± 84.33	209.59 ± 85.03	NS	NS
Total pharyngeal area	767.92 ± 173.15	769.18 ± 176.68	NS	781.27 ± 183.41	785.28 ± 179.54	**	759.12 ± 181.87	764.46 ± 180.98	**	NS

Note: P', intragroup changes with paired t test; $P^{\dagger}$, comparison of initial values with ANOVA test.

Abbreviations: NS, not significant; SD, standard deviation.

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$.

TABLE 4 Comparison of changes in the groups

	RME group	Alt-RAMEC group	SA group	Post hoc tests *P′*			
	Mean ± SD	Mean ± SD	Mean ± SD	1-2	1-3	2-3	*P*
Nasopharyngeal measurements							
AD1-PNS	1.17 ± 0.97	1.46 ± 1.14	2.64 ± 1.02	NS	**	**	**
AD2-PNS	2.01 ± 1.43	2.24 ± 1.61	3.48 ± 1.32	NS	**	**	**
AD2-Ho	0.27 ± 1.43	0.23 ± 1.51	0.07 ± 1.54	NS	NS	NS	NS
PNS-Ba	0.56 ± 1.49	0.94 ± 1.97	1.96 ± 1.83	*	***	**	***
Ptm-Ba	0.41 ± 1.27	0.47 ± 1.34	0.62 ± 1.57	NS	NS	NS	NS
PNS-Ho	2.27 ± 1.79	2.51 ± 1.63	3.74 ± 2.01	NS	**	**	**
PPS	1.35 ± 0.89	1.44 ± 0.97	1.56 ± 0.83	NS	NS	NS	NS
Nasopharynx Area	2.68 ± 1.88	4.32 ± 2.12	5.14 ± 2.48	**	**	NS	**
Oropharyngeal measurements							
PNS-Ep	2.34 ± 1.09	1.87 ± 1.16	1.41 ± 0.67	*	**	*	*
SPPS	0.14 ± 1.12	0.12 ± 1.19	0.08 ± 1.42	NS	NS	NS	NS
MPS	−0.27 ± 2.38	−0.21 ± 2.41	−0.16 ± 2.17	NS	*	NS	*
IPS	−0.09 ± 2.27	−0.07 ± 2.34	−0.05 ± 2.16	NS	NS	NS	NS
EPS	−0.07 ± 2.31	−0.05 ± 2.16	−0.04 ± 1.95	NS	NS	NS	NS
Upper Airway	1.37 ± 1.17	2.21 ± 1.17	2.63 ± 1.06	**	***	*	***
Lower Airway	−0.08 ± 1.57	0.14 ± 1.43	0.28 ± 0.75	***	***	**	***
Oropharynx area	0.56 ± 1.12	1.31 ± 1.09	1.65 ± 0.78	*	**	NS	**
Hypopharyngeal measurements							
Eb-PPW3	−0.03 ± 2.33	−0.04 ± 2.29	−0.07 ± 2.17	NS	NS	NS	NS
CV3ai-CV3pi	−0.29 ± 2.64	−0.22 ± 2.43	−0.18 ± 2.31	NS	NS	NS	NS
Hypopharynx area	−1.98 ± 3.16	−1.63 ± 3.12	−1.45 ± 2.74	NS	NS	NS	NS
Total pharyngeal area	1.26 ± 2.05	4.01 ± 2.11	5.34 ± 1.99	***	***	NS	***

Note: P: results of one-way ANOVA test (*P′*: Post hoc (Tukey) test).

Abbreviations: NS, not significant; SD, standard deviation.

$^{*}P < .05$; $^{**}P < .01$; $^{***}P < .001$.

4 | DISCUSSION

There are several studies in the literature on pharyngeal airway dimensions in skeletal Class III malocclusions.[20-32] In most of these studies, the pharyngeal airway characteristics of different skeletal malocclusions were compared[36] or the changes in the pharyngeal airway with the face mask[24,27,31] and chin-cup[24,37] used in Class III malocclusion treatment were examined. In studies comparing the effects of maxillary protraction on the pharyngeal airway, the changes that usually occur with a face mask versus the control group were compared.[24,25,27,29-31] Although the effects of different maxillary protraction methods on the pharyngeal airway (RME,[23,29] Alt-RAMEC[21] protocols and SA[22,23] with face masks) have been studied in separate studies, to the best of our knowledge, no study has examined them in comparison with each other in a single investigation. The main point of our study was to reveal the effects of different maxillary protraction methods on the pharyngeal airway, compare them with each other and reveal which method was more effective in terms of influencing pharyngeal airway dimensions.

In the selection criteria of the different methods that were compared in our study, it was observed that the patients treated in our clinic had an adequate sample size. As a result, RME, Alt-RAMEC and SA with face mask groups were created. Patient cooperation is required both in face mask application and in protraction using intraoral elastic. In the routine treatment protocol, patients are instructed to use a face mask all day, except for their daily activities. When most of the patient records were examined, it was observed that they used the face mask for at least 19 hours a day (average = 18.97 ± 2.08 h/d). Since it was retrospective, it was not possible to determine the usage periods of all patients. However, when the total treatment times of the patients in all three groups were examined, results demonstrated that a successful protraction occurred in a short time and that they used their face masks well.

An examination of the skeletal changes occurring in the groups with maxillary protraction before pharyngeal airway measurements revealed that the extent of protraction was the most pronounced in the SA group and the least in the RME group within a similar period of time. In addition, the skeletal effect of maxillary protraction was mostly seen in the SA group, whereas the least skeletal effect was found in the RME group. The increase in parameters in the vertical dimensions was mostly observed in the RME group due to the posterior rotation of the mandible with face mask treatment, whereas the least increase was observed in the SA group.

Among the pharyngeal airway measurements, the measurements in the nasopharynx mostly followed the skeletal parameters. In the SA group with a higher level of maxillary protraction, AD1-PNS, AD2-PNS, PNS-Ba and PNS-Ho measurements increased in parallel with the skeletal measurements. In the literature, a mean of 2.1 mm in maxillary protraction with a face mask and in AD1-PNS measurement has been associated with an average increase of 2.45 mm in AD2-PNS.[38] Our study results indicated that a similar increase was observed in the RME and Alt-RAMEC groups in AD1-PNS, AD2-PNS and PNS-Ba measurements, whereas a higher than average increase was found in the SA group. This may be due to the fact that more skeletal effects were obtained compared to other groups or comparison studies.

Among the oropharynx measurements, MPS, IPS and EPS measurements also decreased in all three groups. Whereas this narrowing in the oropharynx of the airway was greater in the RME group, it was less in the SA group. In the RME group, the backward movement of the mandible as a result of its posterior rotation due to the use of the face mask and extrusion of the maxillary posterior teeth may have caused this effect.

Significant differences were observed between the three groups in the lower and upper airway measurements determined by McNamara. In the literature, an average 1.59 mm in upper airway measurement and an average increase of 1.02 mm in lower airway measurements was reported with maxillary protraction.[38] In our findings, an above average increase was detected in the Alt-RAMEC (2.21 mm) and SA groups (2.63 mm) in the upper airway measurements.

In summary, when craniofacial changes and airway changes in the groups were evaluated together, the amount of maxillary protraction and airway changes was parallel. The forward movement of the maxilla in the sagittal direction also led to an increase in the dimension of the upper airway, and it was observed that the increase in the nasopharynx was the highest in the SA group with the greatest skeletal change. The molar extrusion resulting from the use of a tooth-supported face mask and the pressure of the face mask on the chin cause posterior rotation of the mandible and narrow the lower airway. When the vertical skeletal changes in the groups are examined, it is seen that the most mandibular posterior rotation is in the RME group. Accordingly, lower airway values decreased more in the RME group. Vertical airway length (PNS-Ep) measurement also increased more in the RME group, where vertical skeletal dimensions increased the most. Although the Alt-RAMEC group has a similar intraoral appliance design with the RME, the force on the mandible may have decreased and posterior rotation may have been performed less than in the RME group, as the Alt-RAMEC protocol mobilizes the circummaxillary sutures more. In the SA group, although there was no support from the teeth and the protraction force could be applied over the centre of resistance, a slight posterior rotation occurred due to the force applied by the face mask to the tip of the chin. Accordingly, there was a decrease in oropharynx measurements in the SA group. In the literature, measurements were made at different levels in the oropharynx.[38] Whereas some studies have found a decrease in parallel with our findings, some of them increased, albeit minimally. This difference may be due to differences in measurements or differences in protraction methods.

Although there was no decrease in our hypopharynx measurements due to the posterior rotation of the mandible, it was observed that it was not significant and was minimal in all three groups. In some of thestudies in the literature, area measurements were also made in addition to linear measurements.[24,25,29,37] Generally, measurements were conducted on conventional cephalometric radiographs with a planimeter[39] or by drawing and photographing the area boundaries on conventional radiographs using photo analysis programmes.[29,37] In our study, area measurements were also made in order to support our linear measurements. Unlike the literature, the measurements were carried out on digital radiographs with a digital area programme. As a result of the area measurements, parallel to the linear measurements, an increase in the nasopharynx and a decrease in the oropharynx and hypopharynx were observed in all three groups. In terms of the total area, a significant increase was observed in the SA group. Although the findings of our area measurements are compatible with the literature, they have higher values in terms of mean values than the previous studies. This may be due to the fact that we used a more reliable digital area programme as a method.

Since the short-term results of maxillary protraction were examined in our study, our lack of information regarding long-term treatment results can be considered as a limitation of our study. In addition, different methods have been used in the literature to evaluate pharyngeal airway dimensions.[36] Radiological methods, such as frontal cephalometric radiographs, MRI (magnetic resonance imaging), CT (computed tomography), CBCT (cone beam computed tomography) and lateral cephalometric radiographs, were also used. Although the use of CBCT is popular in studies, its disadvantages include CBCT's radiation dose, high cost, unsuitability for routine use and other issues. For these reasons, most of the studies in the literature have been performed with cephalometric radiographs. The use of lateral cephalometric radiographs in our study can also be considered as another limitation.

5 | CONCLUSION

- In all groups, nasopharyngeal and oropharyngeal airway dimensions were improved with maxillary protraction.

- Especially in the nasopharynx, the most effective protraction method in terms of pharyngeal airway dimensions was the application of a face mask with SA.
- An increase in the total pharyngeal airway area was also detected in the SA, Alt-RAMEC and RME groups.
- The significant increase in the vertical plane angle in maxillary protraction with RME resulted in a further increase in vertical airway length (PNS-Ep).

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper (written consent is obtained from patients who apply to our clinic for treatment purposes, indicating that their radiographs or materials can be used scientific articles).

AUTHOR CONTRIBUTIONS

We declare that all authors have contributed significantly to this study and that all authors are in agreement with the manuscript.

DATA AVAILABILITY STATEMENT

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request. The used materials and method in this study was similar to a previous study mentioned below.[19]

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