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Effects of reverse headgear on pharyngeal airway in patients with different vertical craniofacial features

Burcu BALOŞ TUNCER
Çağrı ULUSOY
Cumhur TUNCER
Çağrı TÜRKÖZ
Selin KALE VARLIK

Gazi University, Faculty of Dentistry, Department of Orthodontics, Ankara, Turkey.

Abstract: The aim of this study was to investigate the effects of reverse headgear (RH) on pharyngeal airway morphology in two groups of Class III patients with different vertical craniofacial features in comparison with an untreated Class III group. Seventeen subjects (9 males, 8 females; mean age 11.3 ± 0.98 years) with optimum vertical growth and 17 subjects (10 males, 7 females, mean age 11.5 ± 1.1 years) with a vertical growth pattern treated with a removable intra-oral appliance and a Delaire type facemask were included. An untreated Class III control group of 11 subjects (8 males, 3 females, mean age 9.1 ± 1.1 years) was included to compare the treated groups. The paired t-test for intragroup and one-way ANOVA for intergroup comparisons were performed. The relationships between changes in the craniofacial morphology and airway were assessed by Spearman correlation analysis. The airway dimensions at the adenoid side and soft palate were increased in the treatment groups compared to the control group ($p < 0.05$). The nasopharyngeal area demonstrated a significant difference in normodivergent and control subjects ($p < 0.05$). No significant difference was found in the airway morphology due to different vertical features. The effect of RH treatment on the sagittal airway dimensions revealed no significant difference between different vertical craniofacial features in the short term.

Keywords: Orthodontics; Extraoral Traction Appliances; Airway Management.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Corresponding Author:
Çağrı Ulusoy
E-mail: culusoy77@yahoo.com

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Introduction

Maxillary advancement by reverse headgear (RH) has been a major treatment option in young skeletal Class III patients,[1,2] providing enhancement of maxillary growth and restraint and/or redirection of mandibular growth.[3] The beneficial effects of RH on the upper airway dimensions have been demonstrated in previous studies.[4,5,6] Airway analysis often included cephalograms,[7] and their reliability was found to be adequate.[8]

Studies have shown an association between craniofacial morphology and airway dimensions,[9,10] and there is limited knowledge due to the effect of a steep mandibular plane angle on airway size.[11,12,13] Reduction in airway space after mandibular setback surgery in Class III patients was declared to be a causative factor in airway obstruction.[14] Reduced airway dimensions are proposed to be related to an increased mandibular plane angle.[15,16] Hence, there was an interest in whether different vertical craniofacial features evoke differences in airway dimensions. Thus, the aim of this study was to investigate the effects of RH treatment on airway morphology in Class III patients, demonstrating different vertical facial patterns (normodivergent versus hyperdivergent) in comparison with an untreated Class III control group.

Methodology

Materials for this retrospective study were selected from the files of the Department of Orthodontics, Gazi University, Dentistry Faculty. The study was approved by the Ethical Committee of Gazi University (protocol number: 2014/12544). Patients were included based on the following criteria: (1) RH treatment, (2) skeletal (ANB < 0°) and dental Class III malocclusion with maxillary retrusion (SNA < 82°), (3) anterior crossbite, (4) optimal or high mandibular plane angle (SN/GoGn:26-38°or > 38°), (5) no congenital anomalies, (6) presence of good quality cephalograms. Of the 102 patients who fit the above criteria, patients with chronological ages between 9-12 years who were in the prepubertal period (between the PP_2 and MP_{3cap} developmental stages) were chosen.[17] Sample size was calculated with a statistical power of 0.80, and the number of patients per group was required to be at least 10. The final treatment groups included 34 patients (15 males, 19 females).

The Reverse Headgear normodivergent (RH-ND) group consisted of 17 subjects (9 males, 8 females; mean age 11.3 ± 0.98 years) demonstrating optimum vertical growth (SN/GoGn: 26-38°) who were treated with a removable intra-oral appliance with a thickness to open the bite to an edge-to-edge incisal position, with hooks between the lateral incisors and canines, and a Delaire type facemask (Figure 1). The mean treatment time was 9.7 ± 2.8 months.

The Reverse Headgear hyperdivergent (RH-HD) group consisted of 17 children (10 males, 7 females, mean age 11.5 ± 1.1 years) with increased vertical growth (SN/GoGn > 38°) who were treated with the same appliance for 10.6 ± 1.2 months. Both groups revealed a protraction force of 400-450 g per side delivered by elastics from the hooks, approximately 30° below the occlusal plane.[18] Patients were asked to wear the appliances 14-16 hours per day. All were treated at least to a positive dental overjet before discontinuing treatment.

Figure 1. View of intraoral appliance.

Control (CNT) group: Data on 11 untreated Class III subjects (8 males, 3 females, mean age 9.1 ± 1.1 years), which were collected for a previous study for 12 months, were used.

All cephalograms were taken in natural head position using a Trophy Instrumentarium Cephalometer (Instrumentarium Imaging Co., Tuusula, Finland) at 70KVp, 16 mAs^{-1}, under standard conditions in the occlusal position, as after a usual swallow. The radiographs were traced on acetate papers and measured manually by the same researcher. Cephalometric measurements are shown in Figure 2A, 2B. Area measurements were performed by the NETCAD for Windows Software Programme (Ulusal Co., Ankara, Turkey), an engineering drawing program. The airway area was divided by the palatal line into the nasopharyngeal area (NA) and oropharyngeal area (OA) (Figure 3). The cephalograms were scanned (Epson Co., Nagano, Japan) using standard conditions. NA and OA were digitized according to the specified points by two different researchers to obtain maximum reliability and agreement. The numerical value of the areas was calculated as units. Fifteen randomly selected

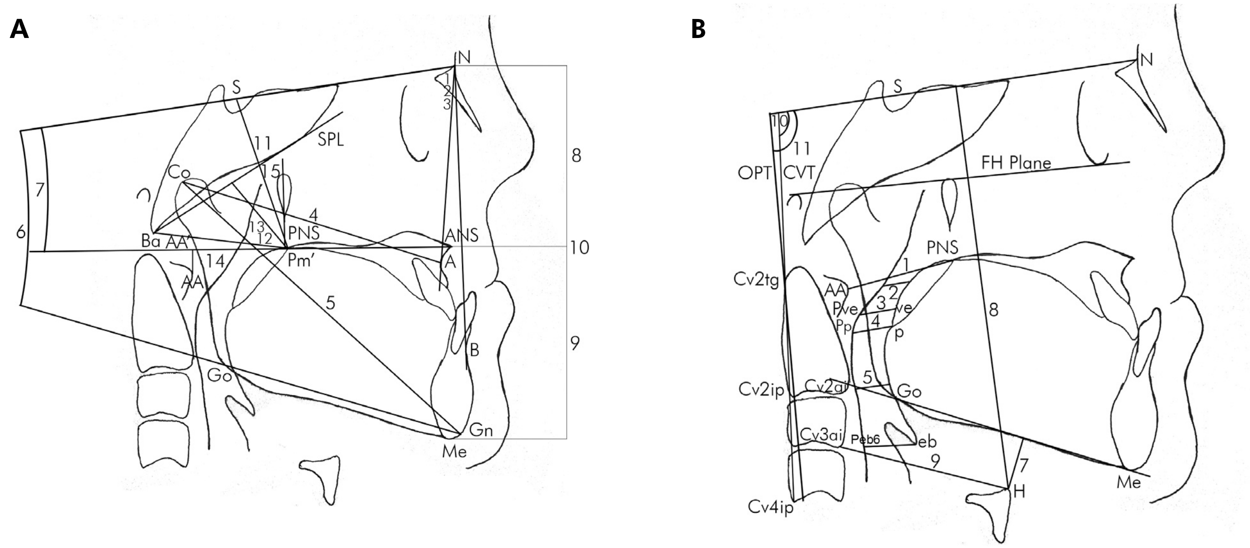

Figure 2. A: Cephalometric analysis of jaws and nasopharynx. (1) SNA; (2) SNB; (3) ANB; (4) Co-A, effective maxillary length; (5) Co-Gn, effective mandibular length; (6) SN-GoGn; (7) SN-PP, palatal plane inclination; (8) N-ANS, upper anterior facial height; (9) ANS-Me, lower anterior facial height; (10) N-Me, total anterior facial height; (11) S-PNS, nasopharyngeal height; (12) ad1-PNS, distance from PNS to lower adenoid tissue; (13) ad2-PNS, distance from PNS to upper adenoid tissue; (14) AA'-Pm', distance between the perpendicular intersections of the anterior atlas and pterygomaxillary line along the palatal line; (15) Pm'-SPL, sphenoid line tangent to lower border of sphenoid. **B:** Cephalometric analysis of oropharynx, hyoid bone and head posture. (1) AA-PNS; (2) SPS, distance from the midpoint of the line from PNS to tip of soft palate to the horizontal counterpart on the posterior pharyngeal wall along parallel line to Frankfurt horizontal (FH) plane; (3) ve-Pve, distance of velum palatinum to the horizontal counterpart on the posterior pharyngeal wall along parallel line to FH plane; (4) MPS, distance from the tip of the soft palate to the horizontal counterpart on the posterior pharyngeal wall along parallel line to FH plane; (5) IPS, distance from the intersection points on the anterior and posterior pharyngeal wall through Cv2ai along parallel line to FH plane; (6) eb-Peb, distance from vallecula epiglottis to the horizontal counterpart on the posterior pharyngeal wall along parallel line to FH plane; (7) H-MP, perpendicular distance from hyoid bone to the mandibular plane; (8) H-SN, perpendicular distance from hyoid bone to SN plane; (9) C3-H, distance from the anterio-inferior point of the third cervical vertebra to point H; (10) SN-CVT, downward angle between SN plane and the line through Cv2tg and Cv4ip; (11) SN-OPT, downward angle between SN plane and the line through Cv2tg and Cv2ip.

radiographs among all groups were retraced and remeasured by the same researcher 15 days after the first evaluation. Pearson correlation analysis was used to assess the reliability and reproducibility of the variables. The reliability coefficients (r^2) calculated for each parameter were between 0.91 and 0.97. Data were analyzed with SPSS for Windows, version 20.0 (SPSS Inc., Chicago, USA). The Shapiro-Wilk test was used to check the data normality. Intragroup comparisons were assessed by paired t-test, and the one-way analysis of variance (ANOVA) test was used for intergroup comparisons. The relationship between changes in the pharyngeal airway and craniofacial morphology was evaluated using Spearman correlation analysis. $p < 0.05$ was considered to be statistically significant.

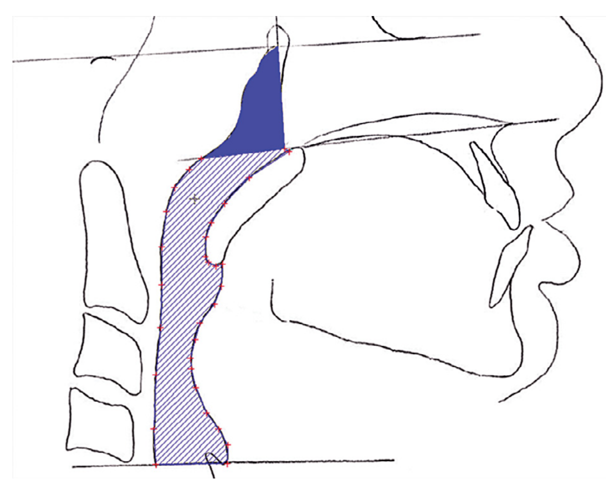

Figure 3. Nasopharyngeal (NA, blue section), oropharyngeal (OA, striped section) areas.

Results

The pre- and post-treatment and pre- and post-observation descriptive values and comparison of the changes within each group are presented in Table 1.

Treatment changes in RH-ND group: The maxilla moved forward, as revealed by the increases in SNA and Co-A ($p < 0.01$, $p < 0.001$, respectively). ANB increased significantly ($p < 0.001$). There were significant increases in Co-Gn ($p < 0.01$), N-ANS ($p < 0.05$), ANS-Me ($p < 0.001$) and N-Me ($p < 0.001$). Nasopharyngeal height, nasopharyngeal airway dimensions (NA), oropharyngeal airway dimensions (OA) and hyoid position were increased (Table 1).

Treatment changes in RH-HD group: Increases in SNA and ANB ($p < 0.01$), Co-A and Co-Gn ($p < 0.001$, $p < 0.01$) were found. The SN-PP angle decreased at

Table 1. Pre- and post-treatment and observation mean and standard deviation of variables and comparison of the changes.

Measurement	RH-ND group					RH-HD group					CNT group				
	Pre-treatment		Post-treatment		p	Pre-treatment		Post-treatment		p	Pre-observation		Post-observation		p
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Skeletal morphology															
SNA(°)	78.1	3.5	80.5	3.7	0.002	75.4	3.2	77.1	3.0	0.004	76.1	3.8	78.5	3.7	0.003
SNB(°)	80.5	3.8	80.3	3.5	0.863	76.4	2.7	76.0	2.6	0.305	77.5	4.4	80.5	4.4	0.003
ANB(°)	-2.4	1.2	0.3	1.0	0.000	-1.1	1.0	1.1	0.9	0.000	-1.4	2.1	-2.0	2.1	0.023
CoA	83.8	4.6	88.1	4.7	0.000	83.4	6.8	88.3	7.0	0.000	77.6	3.2	79.5	3.7	0.043
CoGn	115.8	6.0	119.4	5.5	0.001	114.5	8.2	118.6	7.5	0.001	106.2	5.9	110.0	6.7	0.008
SNGoGn(°)	32.9	2.5	33.8	2.6	0.081	40.9	2.9	40.5	3.4	0.441	36.8	5.9	35.3	5.0	0.015
SN-PP(°)	7.8	3.0	6.8	2.8	0.123	9.8	3.5	8.9	3.1	0.045	7.9	2.0	8.0	3.2	1.000
N-ANS	51.6	3.5	52.5	3.5	0.040	54.0	4.4	55.5	3.4	0.004	50.5	3.7	50.4	4.0	0.878
ANS-Me	65.8	5.4	69.8	5.4	0.000	69.4	4.7	70.9	3.9	0.035	61.9	4.6	62.9	5.0	0.056
N-Me	117.4	7.3	122.3	7.4	0.000	123.4	8.0	126.3	6.3	0.011	112.4	6.8	113.3	6.5	0.180
Nasopharynx															
S-PNS	46.5	4.5	48.5	4.2	0.000	44.8	5.4	46.2	5.3	0.008	44.6	3.6	46.4	3.8	0.007
ad1-PNS	20.1	3.6	22.6	3.0	0.000	19.1	4.8	20.4	5.2	0.007	19.0	5.7	19.3	5.1	0.592
ad2-PNS	18.0	5.6	20.4	4.8	0.000	18.4	4.5	20.2	3.8	0.010	15.5	4.0	16.0	3.3	0.090
AA'-Pm'	32.2	3.8	33.3	3.4	0.014	31.3	3.2	32.5	2.9	0.009	25.7	2.8	25.3	3.6	0.347
Pm'-SPL	24.4	4.6	25.4	5.2	0.032	24.5	5.1	26.0	5.2	0.002	27.1	3.3	29.6	3.9	0.018
NA	8872	4192	10353	3086	0.010	9111	3044	9896	2620	0.309	9140	3461	8098	3545	0.155
Oropharynx															
AA-PNS	32.1	3.2	33.3	3.2	0.023	31.3	3.3	32.1	3.2	0.074	31.4	3.5	31.8	2.8	0.858
SPS	12.2	1.7	13.8	1.7	0.002	12.8	1.9	14.2	2.3	0.001	11.3	3.5	12.5	3.4	0.053
ve-Pve	9.6	2.0	11.2	2.0	0.003	10.3	1.9	11.7	2.0	0.002	9.0	3.4	9.5	3.2	0.120
p-Pp (MPS)	10.2	2.3	11.3	2.3	0.031	10.9	1.7	12.1	2.0	0.002	11.1	3.3	10.9	2.9	0.526
IPS	11.2	2.4	10.9	2.4	0.272	10.6	2.5	11.4	2.2	0.023	11.9	4.9	12.2	4.2	0.504
eb-Peb	14.4	2.9	15.4	2.3	0.073	13.6	2.4	14.4	2.7	0.062	13.3	4.3	13.1	4.4	0.507
OA	21354	4387	24362	4724	0.010	22566	5245	25238	3796	0.028	22936	9030	23347	8596	0.859
Hyoid bone															
H-MP	13.5	4.4	13.6	4.5	0.574	14.5	6.0	15.5	5.4	0.231	13.9	5.2	14.7	5.5	0.507
H-SN	101.2	9.3	104.6	8.6	0.001	102.8	9.4	99.6	8.1	0.066	93.9	6.1	96.8	7.5	0.083
C3-H	33.5	4.1	34.6	3.8	0.004	33.2	2.6	33.6	2.4	0.325	28.3	5.3	31.1	3.5	0.058
Head posture															
SNCVT (°)	103.7	9.2	103.6	9.6	0.733	105.4	5.0	105.6	6.5	0.849	105.4	8.1	104.9	8.5	0.790
SNOPT (°)	102.0	8.6	101.9	9.2	0.670	104.2	5.5	103.9	6.2	0.756	103.8	10.5	103.5	8.6	0.722

RH-ND: Reverse headgear normodivergent; RH-HD: Reverse headgear hyperdivergent; CNT: control group.
SD: standard deviation; NA: nasopharyngeal area; OA: oropharyngeal area.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.0001$; $p > 0.05$, non-significant.

a significance level of 0.05. There were increases in facial height, nasopharyngeal height, NA and OA dimensions (Table 1).

Observation period changes: Both jaws came forward, declaring a significant decrease in ANB ($p < 0.05$), and increases in Co-A ($p < 0.05$) and Go-Gn ($p < 0.01$) were found. The mandibular plane angle decreased significantly ($p < 0.05$). Only nasopharyngeal height increased significantly (S-PNS, Pm'-SPL; $p < 0.05$).

Comparison of changes between groups: The increase in SNB was more prominent in the control group, showing counterclockwise rotation of the mandible during the observation period compared to the treatment groups (Table 2). The treatment groups showed significant improvements in ANB in

Table 2. Comparison of the changes between treatment and control groups.

Measurements	RH-ND group (1)		RH-HD group (2)		CNT group (3)				
	Mean	SD	Mean	SD	Mean	SD	1-2	1-3	2-3
Skeletal morphology									
SNA(°)	2.2	1.2	1.7	1.1	2.3	1.6			
SNB(°)	0.0	1.2	-0.4	0.9	2.8	1.9		***	***
ANB(°)	2.2	0.4	2.4	0.3	-0.6	1.0		***	***
CoA	4.3	1.6	4.9	2.4	1.8	1.5		*	*
CoGn	3.7	2.0	4.1	2.7	3.7	2.7			
SNGoGn(°)	0.9	0.9	-0.5	1.1	-1.5	2.3		**	
SN-PP(°)	-0.9	1.0	-1.0	1.2	0.1	1.1			
N-ANS	0.8	1.2	1.5	1.4	0.1	1.7			
ANS-Me	4.1	1.9	1.6	1.5	1.0	2.1	**	**	
N-Me	4.9	2.5	2.9	2.5	0.8	2.9		**	
Nasopharynx									
S-PNS	2.0	1.5	1.5	1.8	1.6	1.6			
ad1-PNS	2.5	1.1	1.3	1.7	0.6	2.3		*	*
ad2-PNS	2.4	1.8	1.7	1.4	0.4	1.5		*	*
AA'-Pm'	1.1	1.2	1.2	1.0	-0.4	1.4			
Pm'-SPL	0.9	1.7	1.6	1.8	2.5	1.6			
NA	1480	1262	785	974	-1041	494		*	
Oropharynx									
AA-PNS	1.2	1.1	0.8	1.1	0.6	1.4			
SPS	1.7	0.6	1.4	0.7	1.2	1.5			
ve-Pve	1.5	0.7	1.4	0.7	0.4	1.4			
p-Pp (MPS)	1.1	0.8	1.1	0.7	-0.1	1.3		*	*
IPS	-0.4	0.8	0.9	0.8	0.2	2.0			
eb-Peb	0.9	0.9	0.8	0.9	-0.4	1.9			
OA	3007	1563	2672	1570	4116	375			
Hyoid bone									
H-MP	0.2	1.5	0.9	2.0	0.8	2.3			
H-SN	3.4	3.1	-3.2	6.1	2.9	2.8			
C3-H	1.1	1.4	0.4	0.8	2.8	2.0			*
Head posture									
SNCVT (°)	-0.1	3.2	0.3	2.0	-0.5	3.5			
SNOPT (°)	-0.1	3.1	-0.3	2.0	-0.4	4.1			

RH-ND: Reverse headgear normodivergent; RH-HD: Reverse headgear hyperdivergent; CNT: control group.
SD: standard deviation; NA: nasopharyngeal area; OA: oropharyngeal area.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.0001$; $p > 0.05$, not significant.

relation to the control group ($p < 0.01$). The treatment also induced favorable increases in Co-A ($p < 0.05$). Facial height and mandibular plane angle increased in the RH-ND group in comparison to other groups. NA showed a significant difference between RH-ND and the control group ($p < 0.05$), and MPS showed a difference between the treatment and control groups ($p < 0.05$).The hyoid bone is positioned more forward in the control group in comparison to the RH-HD group ($p < 0.05$).

In the correlation analysis, the airway measurements were selected as dependent variables: SNA, SNB, SN-GoGn, H-MP, H-SN, C3-H, SN-CVT and SN-OPT were considered as independent variables. For the RH-ND group, the changes in H-MP and C3-H showed significantly positive effects on OA ($r = 0.596$, $p = 0.012$; $r = 0.484$, $p = 0.049$, respectively). In the RH-HD group, while the change in SN-GoGn had a significantly negative effect on NA ($r = -0.545$, $p = 0.024$), SN-CVT and SN-OPT have significantly positive effects on IPS ($r = 0.585$, $p = 0.014$; $r = 0.516$, $p = 0.034$, respectively). In the control group, SN-OPT showed a significantly positive effect on MPS ($r = 0.606$, $p = 0.048$).

Discussion

Recently, 3D images have become used for evaluating airway dimensions.[19] There is no doubt that 3D images would be preferable, but we believe that archives of two dimensional (2D) cephalometrics are still reliable for evaluating treatment effects, and they are reproducible and cheaper. Due to the retrospective design of this study and to ethical and economic limitations, we used cephalometric data. The ADA Council on Scientific Affairs recommended scientists to follow the "As Low As Reasonably Achievable (ALARA)" principle, which includes taking radiographs based on the patients' needs.[20] Additionally, the association between 2D and 3D measurements was demonstrated.[21]

Our results showed that both treatment groups induced significant advancement of the maxilla associated with larger amounts of maxillary growth and the inhibition of sagittal mandibular growth with respect to the control group, consistent with previous studies reporting maxillary protraction between 1-3 mm.[1,4] The mandible showed significant counterclockwise rotation and protrusion in the control group compared to the treatment groups.

No significant changes in airway parameters were found between the normodivergent and hyperdivergent groups in short term. The differences in mandibular rotation, which might implicitly cause an adverse effect on sagittal airway dimensions, exhibited no significant difference, which was consistent with a previous study.[22] Due to the counterclockwise rotation of the palatal plane in the high angle group, the expected vertical changes in the mandibular plane angle did not occur, which might explain why we were not able to find intergroup differences. Current correlation analysis showed an inverse correlation between NA and the mandibular plane angle in the RH-HD group, consistent with Freitas *et al.*,[23] who found that vertical growth patterns influenced upper airway dimensions. Confirming this point, Celikoglu *et al.*[24] found that the nasopharyngeal and oropharyngeal airway volume were significantly higher in the low-and normal-angle groups than in the high-angle group. Ucar and Uysal[16] also reported a decrease in nasopharyngeal airway space from low-angle to normal- to high-angle cases.

There are conflicting results in the literature regarding the effects of maxillary protraction with or without maxillary expansion therapy on the sagittal airway dimensions.[2,4,5,6,16] According to current results, the nasopharyngeal dimensions representing the adenoid area demonstrated significant increases in the treatment groups compared to the control group, as in previous studies.[2,5,25] This point might be related to the physiological growth pattern of the lymphoid tissue.[26] Based on the knowledge that the mean size of the adenoids continues to increase until puberty with a gradual decline afterwards,[27] the adenoid tissue was approximately at its growth peak at the ages of the treated subjects in this study. Therefore, the existence of a direct favorable effect of RH treatment on the nasopharyngeal airway dimensions could not be concluded, and the size of adenoids, which are age-dependent, should be considered when evaluating the results.

Present analysis revealed a positive correlation between head posture and oropharyngeal airway in the RH-HD and control groups, in line with a previous study.[4] Yagci *et al.*[6] also found increased airway dimensions and cranial flexion of the natural head position after expansion and protraction of the maxilla. Again, a positive correlation between the hyoid position and the oropharyngeal area in the RH-ND group was found in this study, declaring a more forward hyoid positioning after protraction. Accordingly, Muto *et al.*[28] found correlations between the pharyngeal airway and the hyoid position, jaw sizes, maxillary and mandibular prognathism, and mandibular inclination. The hyoid position represents tongue posture and function, and hyoid structures are guided to an anterio-inferior position to avoid compromising the vital airway passage as a compensatory action.[29]

Conclusion

No significant differences were found for pharyngeal airway dimensions among different vertical skeletal patterns in Class III patients after short-term maxillary protraction.

When compared with the control subjects, the nasopharyngeal airway at the adenoid region was increased after maxillary protraction, which should be considered based on age, and the oropharyngeal airway suddenly declared advancement, at the level of the soft palate.

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