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Effects on the sagittal pharyngeal dimensions of protraction and rapid palatal expansion in Class III malocclusion subjects

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SUMMARY This study examined the effects of rapid palatal expansion (RPE) and maxillary protraction headgear therapy in 18 patients with a skeletal Class III malocclusion (11 girls and seven boys; mean age 10.9 years) on upper airway dimensions compared with an untreated control group (nine girls and eight boys; mean age 10.9 years). Pre- and post-treatment cephalometric radiographs were traced and analysed at similar time intervals. The average treatment time was 6.94 ± 0.56 months. Wilcoxon's test was used for intragroup comparisons and the Mann–Whitney *U*-test for intergroup comparisons.

A significant increase occurred in the maxillary forward position. Mandibular forward movement and downward and backward rotation were inhibited. In addition, the upper incisors were proclined ($P < 0.001$), and the lower incisors were significantly retroclined ($P < 0.05$). When the treatment and control groups were compared, the upper airway linear measurements (pns-ad^1, pns-ad^2, APW-PPW, APW′-PPW′) and the nasopharyngeal area had increased in the treatment group.

These results demonstrated that maxillary expansion together with protraction of the maxilla improved naso- and oropharyngeal airway dimensions in the short term.

Introduction

Class III malocclusions are considered to be among the most challenging malocclusions to treat. Studies on the multifactorial aetiology of Class III malocclusions have shown that true maxillary skeletal retrusion is as frequent as mandibular prognathism and that 32–63 per cent of patients with a skeletal Class III malocclusion have a retruded maxilla or a combination of a retruded maxilla and excessive mandibular growth (Sanborn, 1955; Jacobson *et al.*, 1974; Ellis and McNamara, 1984; Guyer *et al.*, 1986; Williams and Andersen, 1986). Enlow (1982) described the typical Class III individual as having a middle cranial fossa that is aligned in a backward and upward manner, resulting in the nasomaxillary complex being in a more retrusive position. The ramus is often rotated forward with upward and backward displacement of the middle cranial fossa and a vertically short nasal region (Sanborn, 1955; Jacobson *et al.*, 1974; Enlow, 1982; Ellis and McNamara, 1984; Guyer *et al.*, 1986; Williams and Andersen, 1986).

It has been almost 100 years since Class III malocclusions characterized by maxillary retrusion were being treated with protraction headgear (Postpeschnigg, 1875) that applies continuous and directional anterior force. A number of animal studies have shown that continuous protraction force causes significant anterior displacement concurrently with histological changes in the maxillary and circummaxillary sutures (Kambara, 1971; Jackson *et al.*, 1979).

Maxillary displacement can be easily achieved using rapid palatal expansion (RPE). Using both appliances (RPE + protraction headgear) combined can weaken the sutural junctions of the maxilla with the other nine bones of the craniofacial structure and allows the protraction force to work effectively (Haas, 1970; Bell, 1982). Palatal expansion with protraction headgear is an accepted and routine part of the treatment of Class III malocclusions (Turley, 2002).

The changes in the upper airway dimensions and craniofacial structures related to RPE and maxillary protraction protocols have not been compared with an untreated Class III control group, although the severe maxillary hypoplasia seen in craniofacial anomalies is thought to constrict the upper airway, including the nasal cavity and velopharynx (Handler, 1985; Hui *et al.*, 1998). A positive effect of midface distraction on alleviating upper airway obstruction in the midface hypoplasia seen with achondroplasia was recently reported (Elwood *et al.*, 2003), and the change in respiratory function induced by RPE has also been documented (Basciftci *et al.*, 2002; Doruk *et al.*, 2004). A maxillary protraction appliance used in combination with a chin cap alters the upper airway dimensions during maxillary protraction (Hiyama *et al.*, 2002). Thus, the aim of this study was to determine the effects of RPE and maxillary protraction headgear on the upper airway dimensions (naso- and oropharyngeal airway) compared with an untreated control group.

Materials and methods

Lateral cephalometric radiographs of 18 patients (11 girls, seven boys) treated at the Department of Orthodontics, Faculty of Dentistry, Dicle University, Diyarbakir, Turkey, and 17 untreated control subjects (nine girls and eight boys) were examined. The first radiograph (T1) was taken before appliance therapy and the second (T2) after achieving a positive overjet but before a second phase of fixed appliance treatment. The records included in the treatment group were selected retrospectively. The criteria used were the presence of a skeletal Class III malocclusion with maxillary skeletal retrusion, the absence of other congenital anomalies, an anterior crossbite with a Class III molar relationship, and no mandibular displacement.

The control subjects, selected from the clinic archive, had been used in two previous studies (Kama *et al.*, 2006; Özbaş, 2006). The control subjects were matched according to the skeletal maturation stage and chronological age and had a Class III skeletal malocclusion with maxillary skeletal retrusion. The control period was 9.82 ± 0.48 months [mean ± standard deviation (SD)]. The mean ages at T1 for the treatment and control groups are shown in Table 1. To evaluate the maturation stage, hand–wrist radiographs were used. All the treatment and control subjects were between PP_2 and MP_{3cap} developmental stages at T1.

The treatment groups were treated successfully with protraction headgear and RPE. Expansion was achieved using a banded Hyrax expansion appliance. The first permanent molars and first premolars or the first primary molars were banded. After obtaining alginate impressions, a Hyrax screw was soldered to the bands on the models in an antero-posterior direction. Following cementation, an orthodontist first activated the appliance; the patients were then asked to activate the screw twice a day for 7 days. At the end of day 7, protraction therapy commenced. A Petit-type facemask was used with 600–700 g of force applied bilaterally. The direction of the elastics was approximately 20 degrees below the occlusal plane. The patients were instructed to wear the appliance for at least 18 hours a day. The treatment time was 6.94 ± 0.56 months (mean ± SD).

Cephalometric analysis

Cephalometric radiographs were obtained in the natural head position (NHP; Solow and Tallgren, 1971) at a film-focus distance of 155 cm with a midsagittal plane-to-film distance of 12.5 cm. NHP was achieved by having the subjects look into their own eyes in a mirror while standing in the orthoposition defined by Mølhave (1958).

The cephalometric radiographs were traced and the reference points (Linder-Aronson, 1970; Figure 1) were marked on the two films for each subject simultaneously by one author (JDK) to obtain maximum agreement when marking.

Area measurements: the total, nasopharyngeal (NA), and oropharyngeal areas (Figure 2) were measured using Image tool 3.0 software (UTHSCSA, University of Texas Health Science Center at San Antonio, Texas, USA).

Statistical analysis and method error

Statistical analysis was undertaken using version 6 of the Statistical Package for Social Sciences (SPSS Inc., Chicago, Illinois, USA). Wilcoxon's test was used to evaluate the treatment effects and changes during the observation period

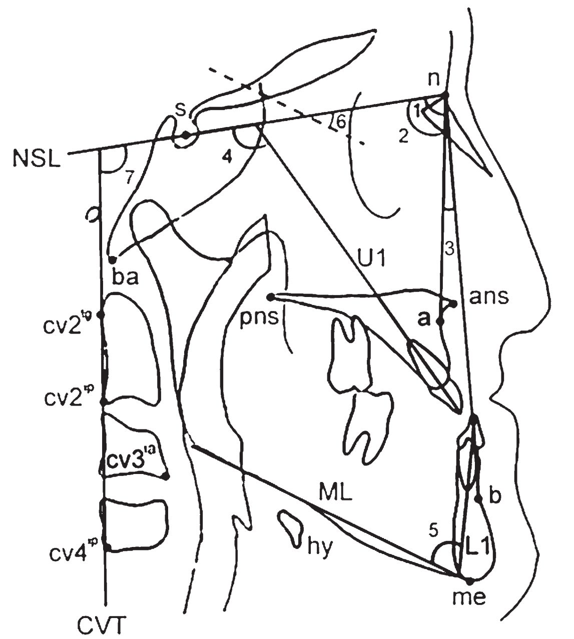

Figure 1 Reference points and angular measurements. Reference points (Linder-Aronson, 1970): Hyoid (hy), the most postero-superior point on the body of the second cervical vertebra (cv2); $cv2^{tg}$, the most postero-inferior point on the body of cv2; $cv2^{ip}$, the most postero-inferior point on the body of cv2; $cv4^{ip}$, the most antero-inferior point on the body of the fourth cervical vertebra ($cv4^{ia}$); ad^2, the intersection between a line from posterior nasal spine (pns) to the midpoint of a line joining basion (ba) and sella (s) and the posterior contour of the adenoid soft tissue shadow; ad^1, the intersection between a line from pns to ba and the posterior contour of the adenoid soft tissue shadow; APW, the anterior pharyngeal wall along the line intersecting $cv2^{ia}$ and hy; PPW, the posterior pharyngeal wall along the line intersecting $cv2^{ia}$ and hy; APW′, the anterior pharyngeal wall along the line intersecting $cv4^{ia}$ and hy; PPW′, the posterior pharyngeal wall along the line intersecting $cv4^{ia}$ and hy. Angular measurements: 1-SNA, 2-SNB, 3-ANB, 4-U1 to NSL, 5-L1 to ML, 6-NSL/ML, 7-NSL/CVT; NSL, nasion sella line; ML, mandibular plane; NSL-CVT, the angle between line NSL and the line from $cv4^{ip}$ to $cv2^{ip}$ (cervical vertebra tangent).

Table 1 Chronological age distribution (years).

	Minimum	Maximum	Mean	SD
Treatment	9.3	11.9	10.5	0.93
Control	9.9	11.8	10.9	0.82

SD, standard deviation.

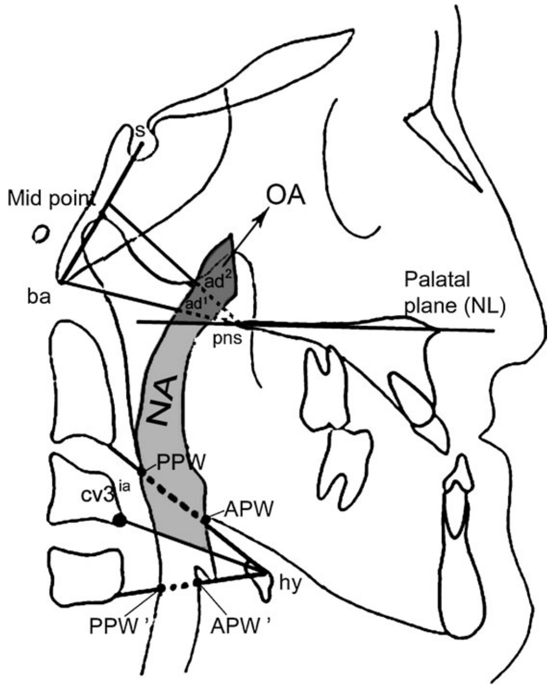

Figure 2 Upper airway distance measurements. pns-ad^1, the distance from posterior nasal spine (pns) to the posterior pharyngeal wall (ad^1) along the line from pns to basion (ba); pns-ad^2, the distance from pns to the adenoid tissue (ad^2) along the line from pns to the midpoint of a line joining ba and the centre of sella turcica (s); APW-PPW, pharyngeal depth, the linear distance on the line connecting points hy and cv2^{ia}, between the intersection point on the anterior and posterior pharyngeal walls; APW′-PPW′, pharyngeal depth, the linear distance on the line connecting points hy and cv4ip, between the intersection point on the anterior and posterior pharyngeal walls. Upper airway area measurements: the total area of the upper airway was divided into two parts; nasopharyngeal area (NA) and oropharyngeal area (OA) by an extension of the palatal plane (NL). The line from hy point to cv3^{ia} point, which intersects the anterior and posterior pharyngeal walls, was accepted as the lower border of oropharyngeal area.

in each group, and the differences between the groups were determined using a Mann–Whitney *U*-test.

To evaluate the error in cephalometric tracing, 10 randomly selected radiographs were retraced and re-evaluated by the same author aftter a 3-week interval. The reliability coefficients for the measurements due to cephalometric errors are given in Table 2.

Results

The changes that occurred during RPE and facemask therapy are presented in Table 3. The parameters pertaining to the sagittal maxillary position (SNA) demonstrated that point A moved anteriorly. The decrease in SNB angle demonstrated counterclockwise rotation parallel with clockwise rotation of the mandible. The vertical parameter, NSL/ML, increased significantly. The upper incisors tipped labially and the lower incisors lingually.

Table 2 The reliability coefficient for the cephalometric measurements.

Parameters	Reproducibility coefficient
SNA (º)	0.9979
SNB (º)	0.9964
ANB (º)	0.9833
U1 to NSL (º)	0.9829
L1 to ML (º)	0.9947
NSL/ML (º)	0.9913
NSL/CVT (º)	0.9984
pns-ad^1 (mm)	0.9768
pns-ad^2 (mm)	0.9721
APW-PPW (mm)	0.9956
APW′-PPW′ (mm)	0.9802
NA (mm^2)	0.9816
OA (mm^2)	0.9801
TA (mm^2)	0.9804

Table 3 Descriptive variables and comparison of the changes in the treatment group (n = 18) at the start (T1) and end (T2) of rapid palatal expansion.

	Mean, T1	SD	Mean, T2	SD	*P*
SNA (º)	75.23	2.21	77.13	2.58	***
SNB (º)	78.03	2.30	76.50	2.17	***
ANB (º)	−1.80	1.96	1.63	1.74	***
U1 to NSL (º)	99.46	3.39	106.73	4.35	***
L1 to ML (º)	86.06	9.42	82.66	10.21	*
NSL/ML (º)	34.13	5.02	36.66	5.23	**
NSL/CVT (º)	108.93	11.00	111.57	7.95	*
pns-ad^1 (mm)	13.73	6.94	18.36	5.14	**
pns-ad^2 (mm)	18.00	6.27	23.60	4.23	*
APW-PPW (mm)	11.73	3.88	13.20	3.80	**
APW′-PPW′ (mm)	14.60	4.86	18.73	4.77	*
NA (mm^2)	213.99	40.05	287.29	23.80	**
OA (mm^2)	827.59	270.42	938.75	306.23	NS
TA (mm^2)	1041.58	340.38	1226.04	375.17	NS

SD, standard deviation; *P*, probability.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant.

The changes that occurred during the follow-up period in the control group are presented in Table 4. Significant increases were found for SNA, SNB, and the oropharyngeal dimensions (APW-PPW, APW′-PPW′) with growth and development.

The changes in each group differed with treatment (Table 3) or natural growth (Table 4). Comparison of the control and treated groups showed the ‘real’ effects of treatment (Table 5). The increase in SNA and decrease in SNB demonstrated that counterclockwise maxillary rotation occurred in parallel with clockwise rotation of the mandible. The vertical parameter NSL/ML increased significantly. The upper incisors tipped labially and the lower incisors lingually. With RPE and maxillary protraction, significant increases were observed in the nasopharyngeal and oropharyngeal dimensions. The head was in a more extended position relative to the cervical vertebrae, as

Table 4 Descriptive variables and comparison of the changes with growth in the control group, $n = 17$ at the start (C1) and end (C2) of the observation period.

	Mean, C1	SD	Mean, C2	SD	*P*
SNA (°)	74.80	4.00	75.90	3.19	*
SNB (°)	77.66	3.87	79.06	3.42	*
ANB (°)	−2.86	1.32	−3.16	1.93	NS
U1 to NSL (°)	100.93	6.47	101.86	6.16	NS
L1 to ML (°)	84.13	5.40	84.30	5.33	NS
NSL/ML (°)	35.43	4.23	34.06	4.37	NS
NSL/CVT (°)	107.63	8.32	107.16	6.28	NS
pns-ad^1 (mm)	14.53	2.61	15.10	2.87	NS
pns-ad^2 (mm)	20.03	3.78	20.00	3.89	NS
APW-PPW (mm)	14.30	5.14	14.50	4.39	*
APW′-PPW′ (mm)	13.73	3.28	14.60	2.97	*
NA (mm^2)	212.30	39.34	226.26	60.27	NS
OA (mm^2)	818.65	189.39	766.29	132.25	NS
TA (mm^2)	1030.96	189.42	992.56	119.55	NS

SD, standard deviation; *P*, probability.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant.

Table 5 Statistical comparison of the changes between the treated ($n = 18$) and control ($n = 17$) groups at the start (T1/C1) and end (T2/C2) of treatment/observation.

	Differences (T2−T1)	SD	Differences (C2−C1)	SD	*P*
SNA (°)	1.90	0.96	1.10	1.94	*
SNB (°)	−1.53	0.87	1.37	1.98	***
ANB (°)	3.43	0.90	−0.30	1.76	***
U1 to NSL (°)	7.27	3.84	0.93	4.01	***
L1 to ML (°)	−3.40	4.13	0.17	2.04	*
NSL/ML (°)	2.53	4.38	−1.37	0.97	**
NSL/CVT (°)	2.64	2.26	−0.47	1.90	**
pns-ad^1 (mm)	4.63	5.32	0.57	0.76	***
pns-ad^2 (mm)	5.60	1.84	−0.03	1.36	*
APW-PPW (mm)	1.47	4.35	0.20	1.26	**
APW′-PPW′ (mm)	4.13	7.07	−0.87	5.73	***
NA (mm^2)	73.30	25.17	13.96	37.22	*
OA (mm^2)	111.16	373.65	−52.36	151.84	NS
TA (mm^2)	184.46	427.21	−38.40	143.56	NS

SD, standard deviation; *P*, probability.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant.

confirmed by the 2.64 degree increase in NSL/CVT. The mean increases for the nasopharyngeal airway measurements (pns-ad^1, pns-ad^2) were 4.63 and 5.60 mm, respectively, and those for the oropharyngeal airway measurements (APW-PPW, APW′-PPW′) 1.47 and 4.13 mm, respectively. A 73.3-mm^2 increase was observed in the NA (Tables 3 and 5).

Discussion

This investigation compared the pure effects of maxillary protraction treatment protocols and evaluated the differences in the skeletal and upper airway dimensions after treatment. There are studies in the literature where Class I control groups have been used; however, the dentoalveolar and skeletal growth trends in subjects with a Class III malocclusion may differ from those of 'normal' subjects. The need to use a Class III adequately matched control sample to make valid comparisons is therefore essential. Furthermore, there are examples which show that Class I control groups are not suitable for comparison with Class III treatment groups (Tindlund, 1989; Takada *et al.*, 1993; Shanker *et al.*, 1996) Therefore, to explain the basic effects of the protocol, the treatment group was compared with untreated Class III patients as a control group. For this purpose, radiographs were chosen from similar age groups and treatment/control durations.

The mean ages of the control and treatment groups were 10.9 and 10.5 years, respectively. Clinical studies have used maxillary protraction in the late-mixed to early permanent dentition stages of development in order to take maximum advantage of growth (Irie and Nakamura, 1975; Ishii *et al.*, 1987; Takada *et al.*, 1993).

In this study, an increase in SNA and a decrease in SNB were observed in the treatment group. In fact, the decrease in SNB was not related to the inhibition of mandibular growth but occurred as a result of clockwise rotation of the mandible. In the vertical plane, a significant increase in NSL/ML was observed, indicating clockwise rotation of the mandible (mean = 2.53 degrees) as an effect of combined RPE and facemask therapy. In contrast, NSL/ML decreased in the control group, although not significantly. This clearly indicates that posterior rotation of the mandible occurred as an effect of the facemask therapy.

In maxillary protraction studies, the maxilla moves anteriorly (Björk, 1966; Iseri and Solow, 1990), increasing SNA (Turley, 1988; Shanker *et al.*, 1996; Nartallo-Turley and Turley, 1998), and the maxilla often rotates in a counterclockwise direction, with posterior nasal spine moving inferiorly more than anterior nasal spine. This vertical movement of the maxilla is accompanied by clockwise rotation of the mandible, causing the chin to move downward and backward. Lower anterior face height increases, while overbite decreases (Irie and Nakamura, 1975; Nanda, 1980; Nanda and Hicory, 1984; Ishii *et al.*, 1987; Mermigos *et al.*, 1990; McNamara and Brudon, 1993; Takada *et al.*, 1993; Turley, 1996). The results of the present study are compatible with these findings.

It has also been reported that the treatment effects of maxillary protraction include retroclination of the lower incisors and proclination of the maxillary incisors (McNamara and Brudon, 1993; Kim *et al.*, 1999). Treatment increased U1 to NSL by 7.27 degrees. The mean change in L1 to ML decreased significantly for the treatment group compared with the controls. There is a certain relationship between craniocervical angle and craniofacial morphology (Solow and Sandham, 2002). After treatment, the head was in a more extended position in relation to the cervical vertebrae, as demonstrated by a mean increase of 2.64 degrees in the NL/CVT angle. Significant increases were observed compared with the control group, supporting counterclockwise rotation of the maxillary complex.

The effects of maxillary protraction significantly increased both the naso- (pns-ad^1, pns-ad^2, NA) and oro- (APW-PPW, APW′-PPW′) pharyngeal airway dimensions. When comparing the treatment and control groups, explicit increases were seen in total and oropharyngeal areas in the treatment group. However, because of individual variations, this finding was not statistically significant.

The findings for upper airway dimensions and head posture are in agreement with previous results (Spann and Hyatt, 1971; Thach and Stark, 1979; Hiyama *et al.*, 2002). Saman *et al.* (2002) examined the oropharyngeal airway dimensions of skeletal Class III patients before and after mandibular setback surgery and found significant decreases in these dimensions with posterior relocation of the mandible or the tongue and soft palate. All of these results clearly show that treatment that changes the position of either the mandible or the tongue and soft palate will also affect the oropharyngeal airway dimensions, which are closely related to these structures.

The influence of functional appliances or RPE devices on the upper airway has been examined. In a recent review, oral devices were shown to be effective in 50–70 per cent of patients with obstructive sleep apnoea (OSA; Verse *et al.*, 2003). Mandibular distraction osteogenesis may also be of help in treating OSA in patients with mandibular hypoplasia and severe upper airway obstruction (Elwood *et al.*, 2003; Mandell *et al.*, 2004). Since mandibular growth has a definite influence on the upper airway dimensions, it has been postulated that maxillary growth could also have beneficial effects on the upper airway (Hiyama *et al.*, 2002). Although those authors found no significant changes between the pre- and post-treatment airway parameters, a multiple regression analysis revealed that greater forward maxillary growth was associated with a greater increase in the superior upper airway dimensions.

Sayınsu *et al.* (2006) investigated the effects of RPE and a protraction appliance on the sagittal airway and found an increase in nasopharyngeal, but not oropharyngeal, airway dimensions. However, they acknowledged the need for a control group to explain the pure effects of treatment. In the present study, a significant increase was observed in the post-treatment oropharyngeal dimensions (APW-PPW, APW′-PPW′), which was most likely due to less mandibular posterior rotation and a smaller decrease in SNB. Because previous studies (Hiyama *et al.*, 2002; Sayınsu *et al.*, 2006) lacked control groups, they could not assess the amount of change in this area that would be expected from growth and development regardless of orthodontic treatment.

Conclusions

This findings of the study demonstrated that RPE together with protraction of the maxilla improved the naso- and oropharyngeal airway dimensions in the short term.

The present and previous studies concerning airway dimensions were based on two-dimensional cephalometric measurements and thus have limitations. An examination of the changes that any treatment produces in the upper airway should include three-dimensional measurements using different imaging systems. Moreover, future research on this topic should monitor respiratory function.

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