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Sagittal airway changes: rapid palatal expansion versus Le Fort I osteotomy during maxillary protraction

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SUMMARY The purpose of the present study was to evaluate upper airway changes related to craniofacial changes induced by a facemask (FM) combined with Le Fort I osteotomy without down-fracture in Class III maxillary retrusion subjects (group 1) when compared with a similar group of subjects treated with traditional rapid palatal expansion and FM therapy. Pre- (T1) and post- (T2) protraction cephalometric radiographs of group 1 (10 females and 6 males; mean age 12.75 ± 1.91 years) and group 2 (7 females and 9 males; mean age 12 ± 1.7 years) were traced. The treatment duration was 149 ± 14 days (approximately 5 months) and 270 ± 46 days (approximately 9 months) for groups 1 and 2, respectively. A paired *t*-test for intergroup comparisons of values at T1, an independent samples *t*-test for intragroup comparisons of values at T1 and T2, and a non-parametric Mann–Whitney *U*-test for intergroup comparisons were used. To evaluate the relationship between changes in upper airway dimension and craniofacial morphology, a multiple-regression analysis was performed.

Significant maxillary protraction along with clockwise rotation of the mandible was achieved in both groups. Counter-clockwise maxillary rotation was significant in group 1 ($P < 0.05$) but not in group 2. While nasopharyngeal measurements (PNS–ad1, PNS–ad2) showed significant increases ($P < 0.05$) as a result of treatment in both groups, oropharyngeal measurements did not change. Maxillary protraction, which was achieved in both groups but in a shorter period of time in group 2, improved nasopharyngeal but not oropharyngeal airway dimensions.

Introduction

The human facial form is determined largely by the relative positioning of the maxilla and mandible before, during, and after pubertal growth. Harmonious positioning of the maxilla and mandible relative to the cranium not only facilitates the ultimate function of the jaws and teeth but also forms the anatomical basis of pleasing facial aesthetics (Bishara and Jakobsen, 1985). A dentofacial deformity is present if the maxilla and mandible are not in proportion with each other or to the rest of the cranium (Enlow, 1990).

Maxillary retrusion, without mandibular prognathism, has been reported to occur in 20–30 per cent of adult patients with Class III malocclusions (Ellis and McNamara, 1984). A Class III malocclusion is difficult to treat particularly in the mixed and late primary dentitions, mainly because of the uncertainty of a stable result after growth. Maxillary protraction has become a common technique for early correction of maxillary retrognathic Class III malocclusions (Macey-Dare, 2000; Baccetti *et al.*, 2007). The skeletal and dentoalveolar effects of maxillary protraction with/without rapid palatal expansion (RPE) have been well documented: maxillary growth and forward movement of the maxillary dentition, counter-clockwise rotation of the palatal plane, inhibition of anterior mandibular growth, clockwise rotation of the mandible, labial tipping of the maxillary incisors, and lingual tipping of the mandibular incisors (Kim *et al.*, 1999; De Toffol *et al.*, 2008). The combination of these changes not only facilitates the ultimate function of the jaws and teeth but also improves facial aesthetics.

Although traditional protraction devices are used to promote forward growth of the retruded maxilla at an early age, it has been claimed that only little advancement is obtained in a relatively long period of time (9–12 months), which is not well tolerated by young patients, and intrinsic maxillary growth potential is insufficient; therefore, mid-face retrusion very often recurs (Ishii *et al.*, 1987; Tindlund and Rygh, 1993; Kapust *et al.*, 1998; Yüksel *et al.*, 2001). With the introduction of distraction into the field of craniofacial surgery, the additional advancement that is gained is claimed to outweigh the diminished growth potential. Rachmiel *et al.* (1993, 1995, 1996, 1999) and Molina *et al.* (1998) reported that the values related to the treatment effects of surgically assisted protraction of the maxilla with a facemask (FM) changed from 3 to 12 mm in a short time period compared with conventional FM therapy. Maxillary distraction osteogenesis (MDO) has also become an accepted alternative in the treatment of patients with severe maxillary hypoplasia in craniofacial syndromes and cleft-related deformities (Wiltfang *et al.*, 2002; Lauwers *et al.*, 2005; Minami *et al.*, 2007). A maxillary osteotomy with a down-fracture may induce oedema and bleeding (Yamauchi *et al.*, 2006). In patients with an abnormal bone structure, such as cleft-related patients, these risks are greater than normal (Yamauchi *et al.*, 2006). Using a Le Fort I osteotomy without a down-fracture to perform MDO eliminates the need for extensive subperiosteal elevation around the piriform aperture and dissection of the nasal mucosa, shortening surgery time, while decreasing intraoperative blood loss and other potential vascular problems (Yamauchi *et al.*, 2006). With large maxillary advancements or inferior repositioning in non-cleft and cleft patients, complications include delayed union/non-union, increased relapse, poor stabilization, and impaired post-operative healing (Van Sickels and Tucker, 1990). In contrast to conventional orthognathic surgery, distraction osteogenesis can be used in growing children for whom expansion and new generation of tissues is necessary (Meyer *et al.*, 1999).

A number of studies have been published that investigated the effects of mid-face advancement on upper airway dimensions (Hiyama *et al.*, 2002; Sayınsu *et al.*, 2006; Kilinç *et al.*, 2008; Oktay and Ulukaya, 2008; Kaygısız *et al.*, 2009; Baccetti *et al.*, 2010). However, there are conflicting results. Significant changes of both oro- and nasopharyngeal area dimensions have been reported by Kilinç *et al.* (2008) and Oktay and Ulukaya (2008), while Sayınsu *et al.* (2006) and Kaygısız *et al.* (2009) demonstrated significant improvement only in nasopharyngeal airway dimensions. On the other hand, Hiyama *et al.* (2002) and Baccetti *et al.* (2010) did not show any significant changes in the sagittal oro- and nasopharyngeal airway dimensions. In all these studies, Class III maxillary retrognathic patients were treated with a traditional maxillary protraction mask with/without RPE.

The purpose of the present study was to evaluate upper airway changes related to craniofacial changes induced by an FM combined with a Le Fort I osteotomy without down-fracture in Class III maxillary retrusion subjects when compared with a similar group of subjects treated with traditional RPE-assisted FM therapy.

Table 1 Comparison of pre-protraction craniofacial and upper airway measurements of groups 1 and 2 (paired *t*-test).

	Pre-protraction (T1)				
	Group 1 (Facemask + osteotomy)		Group 2 (Facemask + rapid palatal expansion)		
	Mean	SD	Mean	SD	*P*
Airway					
SPPS	12.39	2.83	11.46	3.39	
MPS	11.70	3.13	10.41	2.74	
IPS	11.41	3.17	9.81	4.05	
apw3–ppw3	13.29	4.79	12.09	4.54	
PNS–ad1	20.88	5.56	22.12	5.87	
PNS–ad2	16.52	4.22	15.93	5.16	
Head posture					
SN–CVT	109.22	10.56	102.72	9.34	
SN–OPT	105.38	9.50	98.70	9.55	
PL–CVT	99.91	11.10	92.47	8.10	*
PL–OPT	95.56	9.03	88.61	7.95	*
Hyoid position					
H–mp	17.28	6.23	14.89	6.23	
H–Rg	40.88	5.74	39.10	7.58	
L3i–Rgn-H	10.20	8.85	7.38	5.40	
Craniofacial					
SNA	75.44	4.92	78.44	3.28	
SNB	78.84	3.56	79.31	3.83	
ANB	−2.91	2.52	−1.13	1.82	*
Maxillary depth	83.25	6.00	86.66	2.98	
Maxillary height	63.56	3.49	62.06	2.71	
NIA	−6.84	5.20	−4.03	2.78	
SN–PP	10.16	4.93	10.00	3.37	
SN–MP	36.03	4.34	35.84	4.40	

*$P < 0.05$.

Subjects and method

Thirty-two growing Class III patients characterized by an Angle Class III dental relationship with an anterior crossbite and skeletal Class III relationship with maxillary retrognathism referred to the Department of Orthodontics, Marmara University, were recruited for this study.

Sixteen patients (10 females and 6 males; mean age 12.75 ± 1.91 years) with moderate to severe maxillary retrognathism [N-perpendicular-A (Nper-A) point ≤ −5 mm; SNA: 75.44 ± 4.9, maxillary depth: 83.25 ± 6, Nper-A: −6.84 ± 5.2; Table 1] were treated with FM therapy associated with an incomplete Le Fort I osteotomy without down-fracture as recommended by Yamauchi *et al.* (2006; group 1). In this group, two patients had a bilateral cleft lip and palate (CLP), one patient a unilateral CLP, and one a cleft palate.

The other 16 patients (7 females and 9 males; mean age 12 ± 1.7 years) with comparatively mild retrognathism (Nper-A point > −5 mm; SNA: 78.44 ± 3.2, maxillary depth: 86.66 ± 2.9, Nper-A: −4.03 ± 2.7; Table 1) were treated with traditional RPE-assisted FM therapy (group 2). Before treatment, the procedures were explained to both the patient and parents in detail and written informed consent form was obtained from the parents.

Treatment protocol in group 1

For each patient, a continuous wire framework was bent from 1.1 mm stainless steel wire starting from the buccal side of the upper canines and touching the buccal and palatal surfaces of the posterior teeth and the lingual surfaces of the anterior teeth. The wire was sandblasted and covered with acrylic on the posterior segments. After cementation of the acrylic cap splint with fluoride-releasing glass ionomer cement (Unitek Multi-Cure Glass Ionomer Band Cement; 3M-Unitek, Monrovia, California, USA; Figure 1), an incomplete Le Fort I osteotomy without down-fracture was performed by the same surgeon (TK). A Petit type FM (Ormco Corp., Glendora, California, USA) was applied on the fifth to seventh day post-surgery with a total force value ranging from 1700 to 2000 g. The direction of the elastics was approximately 30 degrees below the occlusal plane (Ngan *et al.*, 1996). The patients were instructed to wear the FM 24 hours a day (except during meal times) until a Class II canine relationship was achieved (Westwood *et al.*, 2003). They then wore the FM only at night for 3 months for retention purposes. The maxillary splints were removed at the end of the retention period and treatment continued with fixed appliances. RPE was not performed for any of the patients in this group.

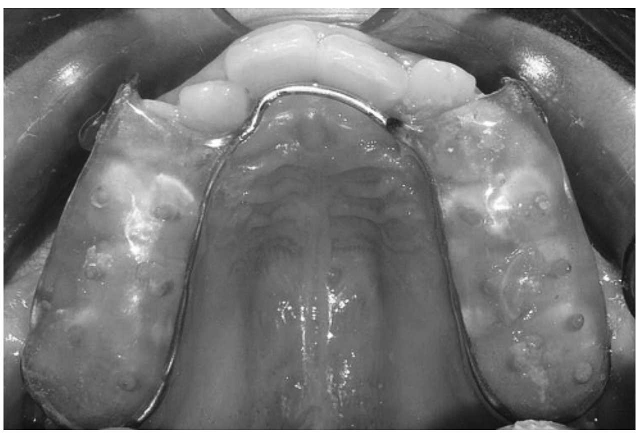

Figure 1 The acrylic cap splint without an expansion screw used for patients in group 1 (facemask/osteotomy).

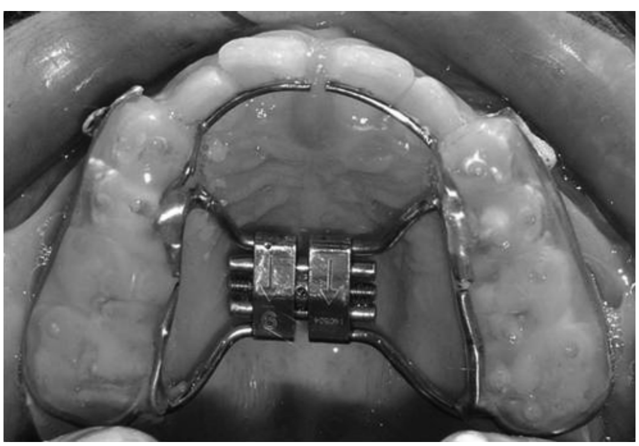

Figure 2 The acrylic cap splint-type rapid palatal expander used for patients in group 2 (facemask/rapid palated expansion).

Treatment protocol for group 2

An acrylic cap splint-type RPE (A0620-13, Leone, Firenze, Italy), which had hooks between the upper lateral incisors and canines, was fabricated for each patient and cemented with fluoride-releasing glass ionomer cement (Unitek Multi-Cure Glass Ionomer Band Cement, 3M-Unitek). A lingual wire (0.9 mm) was welded to the anterior arms of the hyrax to support the upper incisors during protraction (Figure 2). In this group, RPE was performed by activating the palatal screw twice a day for 7 days for the purpose of sutural disarticulation. At the end of 1 week of RPE and following the occurrence of a diastema between the upper central incisors, a Petit type FM was applied with 1000 g of total force. As in group 1, the direction of the elastics was approximately 30 degrees below the occlusal plane. The patients were instructed to wear the appliance for 16 hours a day until a Class II canine relationship was achieved (Westwood *et al.*, 2003). The maxillary splints in this group were removed after the achievement of a Class II canine relationship and the treatment continued with fixed appliances.

Cephalometric measurements

Lateral cephalograms, in natural head posture, were taken pre- (T1) and post- (T2) protraction. One experienced orthodontist (BC) traced the lateral cephalograms of each patient. The values at T1 and T2 and the differences between the two values were evaluated for each variable. Reference points and cephalometric variables in this study are shown in Figure 3. The skeletal changes were evaluated by SNA, SNB, ANB, maxillary depth, maxillary height, Nper-A, SN–PP, and SN–MP. The other variables used to evaluate the sagittal upper airway dimension, head posture, and hyoid position were SPPS, MPS, inferior pharyngeal space (IPS), apw3–ppw3, SN–CVT, SN–OPT, PL–CVT, PL–OPT, PNS–ad1, PNS–ad2, H–mp, H–Rs, and L3i–Rgn-H (Solow and Tallgren, 1976; Hellsing, 1989; Hiyama *et al.*, 2002; Sayınsu *et al.*, 2006).

Statistical analysis

Statistical calculations were performed with GraphPad Prisma Version 3.0 software for Windows (San Diego, California, USA). In addition to standard descriptive statistical calculations (mean and standard deviation), a paired *t*-test was used to perform intergroup comparisons of values at T1 (Table 1). An unpaired *t*-test was used for intragroup comparisons of values at T1 and T2 (Table 2) and a non-parametric Mann–Whitney *U*-test to compare treatment changes between groups (Table 3). To evaluate the relationship between changes in the upper airway dimension and craniofacial morphology, multiple-regression analysis was performed (Tables 4 and 5). The results were evaluated within a 95 per cent interval. The statistical significance level was established as $P < 0.05$.

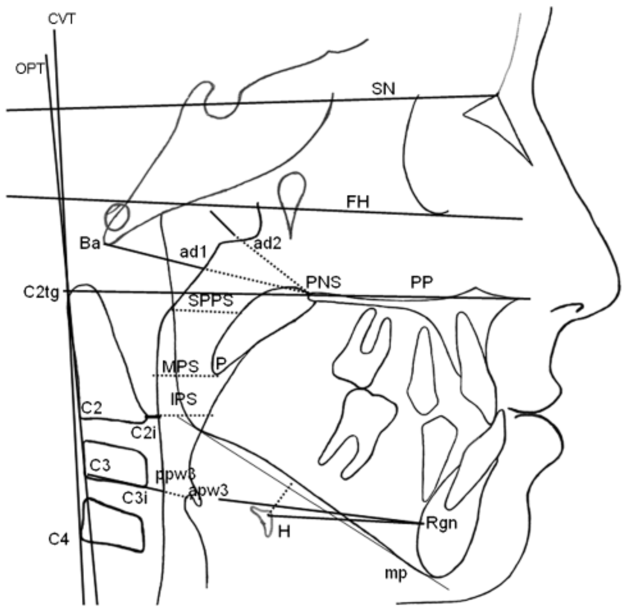

Figure 3 Diagrammatic represantation of head posture, hyoid position, and airway variables. ad1, the point where posterior nasal spine (PNS)-basion (Ba) line intersects the posterior pharyngeal wall; ad2, the point where a line perpendicular to sella (S)-Ba plane passing through PNS intersects the posterior pharyngeal wall; SPPS, the anteroposterior width of the pharynx measured between the posterior pharyngeal wall and the dorsum of the soft palate on a line parallel to the Frankfort horizontal plane that runs through the middle of the line from PNS to P; MPS, the anteroposterior width of the pharynx measured between the posterior pharyngeal wall and the dorsum of the tongue on a line parallel to the FH plane that runs through P; IPS, the anteroposterior width of the pharynx measured between the posterior pharyngeal wall and the dorsum of the soft palate on a line parallel to the FH plane that runs through C2i; ppw3, the point where the line connecting C3 and C3i intersects the posterior pharyngeal wall; apw3, the point where the line connecting C3 and C3i intersects the anterior pharyngeal wall; SN-CVT, the angle formed by the SN plane and the line through C2tg and C4 (CVT); SN-OPT, the angle formed by the SN plane and the line through C2tg and C2(OPT); Rgn, The most posterior point on the symphysis of the mandible.

To determine the method error, 10 randomly selected cephalograms were retraced and remeasured by the same author after an interval of 3 weeks. Inter-rater correlation coefficients were found to be within 0.91 and 0.95.

Results

The treatment duration for group 1 was found to be significantly less than that of group 2 ($P < 0.01$). In group 1, a Class II canine relationship was achieved in 65 ± 24 days (approximately 2.5 months); however, the patients continued to wear the FM for a further 87 ± 27 days (approximately 3 months) as retention. Therefore, the overall treatment duration for group 1 was 149 ± 14 days (approximately 5 months). In group 2, a Class II canine relationship was achieved in 270 ± 46 days (approximately 9 months).

When the initial craniofacial and airway measurements of groups 1 and 2 were compared, significant differences were found in palatal plane inclination (PL–CVT, PL–OPT) and sagittal jaw discrepancy (ANB) measurements (Table 1). Before treatment, the Class III skeletal relationship was more pronounced for patients in group 1 than in group 2 (ANB = −2.91 and 1.13 degrees, respectively; $P < 0.05$; Table 1). The palatal planes of the patients in group 1 were also more anteriorly inclined than in group 2 (PL–CVT = 99.91 and 92.47 degrees; PL–OPT = 95.56 and 88.61 degrees, respectively; $P < 0.05$; Table 1).

During T1–T2, both groups showed significant increases in sagittal maxillary cephalometric measurements (SNA, maxillary depth, Nper-A; $P < 0.001$; Table 2), as well as significant improvements in maxillary/mandibular difference (ANB angle; $P < 0.001$; Table 2). Forward movement of the maxilla as a result of treatment was not significantly different between the groups (Table 3); only the increase in maxillary depth was significantly more in group 1 ($P < 0.05$, Table 3). In both groups, the significant decrease in SNB ($P < 0.05$, Table 2) resulted in a clockwise rotation of the mandible, revealed by the increase in MP–SN angle ($P < 0.01$, Table 2). Although both treatment modalities caused counter-clockwise maxillary rotation, the change was significant only in group 2 ($P < 0.05$, Table 2). However, when the groups were compared, no significant difference in changes related to palatal inclination was found (Table 3). Maxillary height did not change significantly in either group (Table 2).

While nasopharyngeal measurements (PNS–ad1, PNS–ad2) showed significant increases due to treatment in both groups ($P < 0.05$, Table 2), oropharyngeal measurements did not change (Table 2). Although the vertical position of the hyoid bone was not affected by treatment, the sagittal position showed forward movement in group 1, demonstrated by the decrease in Hy–Rgm distance ($P < 0.05$, Table 2). However, when the groups were compared, it was found that the sagittal position of the mandible was not significantly different (Table 3). No patients showed any significant change in head position (SN–CVT, SN–OPT) during active treatment (Table 2).

In the multiple-regression analysis, the measurements related to the change in upper airway dimensions (SPPS, MPS, IPS, apw3–ppw3, PNS–ad1, and PNS–ad2) were considered as dependent variables, whereas SNA, SNB, SN–MP, SN–CVT, PL–CVT, and SN–PP were selected as independent variables. For group 1, the changes in SNB and SN–MP had significantly negative effects on the IPS ($P < 0.05$, Table 4). For group 2, while the change in SNA had a significantly positive effect on IPS ($P < 0.01$, Table 4), the changes in SNB and PL–CVT showed significantly negative effects on upper pharyngeal space ($P < 0.01$ and $P < 0.05$, respectively; Table 5)

Discussion

There are contrasting findings in the literature regarding the possibility of improving sagittal airway dimensions

Table 2 Descriptive statistics and statistical comparisons of cephalometric measurements at pre- (T1) and post- (T2) protraction in groups 1 and 2 (unpaired *t*-test).

	Group 1 (Facemask + osteotomy)					Group 2 (Facemask + rapid palatal expansion)				
	T1		T2			T1		T2		
	Mean	SD	Mean	SD	*P*	Mean	SD	Mean	SD	*P*
Airway										
SPPS	12.39	2.83	12.22	1.59		11.46	3.39	12.61	3.33	
MPS	11.70	3.13	11.44	2.08		10.41	2.74	10.70	2.78	
IPS	11.41	3.17	12.22	4.30		9.81	4.05	9.96	3.44	
apw3–ppw3	13.29	4.79	13.00	4.19		12.09	4.54	11.05	3.03	
PNS–ad1	20.88	5.56	21.63	5.47		22.12	5.87	23.78	5.68	*
PNS–ad2	16.52	4.22	18.94	5.06	*	15.93	5.16	19.29	5.03	*
Head posture										
SN–CVT	109.22	10.56	109.91	8.60		102.72	9.34	104.06	7.06	
SN–OPT	105.38	9.50	104.66	8.59		98.70	9.55	99.84	6.99	
PL–CVT	99.91	11.10	101.34	9.04		92.47	8.10	95.04	5.85	
PL–OPT	95.56	9.03	95.81	8.63		88.61	7.95	90.79	5.06	
Hyoid position										
H–mp	17.28	6.23	18.16	4.96		14.89	6.23	15.02	5.86	
H–Rg	40.88	5.74	38.16	4.10	*	39.10	7.58	38.76	4.71	
L3i–Rgn-H	10.20	8.85	10.64	7.58		7.38	5.40	7.91	7.01	
Craniofacial										
SNA	75.44	4.92	78.91	3.62	***	78.44	3.28	80.22	3.33	**
SNB	78.84	3.56	77.22	3.07	*	79.31	3.83	78.25	3.89	*
ANB	−2.91	2.52	1.66	2.35	***	−1.13	1.82	2.22	1.63	***
Maxillary depth	83.25	6.00	87.00	4.45	***	86.66	2.98	88.47	3.34	***
Maxillary height	63.56	3.49	62.44	3.12		62.06	2.71	61.44	3.46	
NIA	−6.84	5.20	−3.37	4.76	***	−4.03	2.78	−1.69	3.56	***
SN–PP	10.16	4.93	8.44	3.81		10.00	3.37	8.34	3.07	*
SN–MP	36.03	4.34	38.44	4.08	**	35.84	4.40	37.41	4.83	**

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

by means of maxillary protraction (Hiyama *et al.*, 2002; Sayınsu *et al.*, 2006; Kilinç *et al.*, 2008; Oktay and Ulukaya, 2008; Kaygısız *et al.*, 2009; Baccetti *et al.*, 2010).

In the present study, changes in craniofacial morphology and upper airway dimensions of growing Class III maxillary retrognathic patients treated with two different treatment modalities were analysed. While a maxillary osteotomy without down-fracture was performed along with maxillary protraction FM therapy in group 1, traditional RPE-assisted maxillary protraction was used in group 2. The treatment changes that occurred in these two groups were compared and the relationship between changes in craniofacial morphology and upper airway dimensions was evaluated.

Maxillary advancement reported in the literature is approximately 1.5–2 mm during 6–12 months of FM wear, which requires patient compliance (Ishii *et al.*, 1987; Tindlund and Rygh, 1993; Kapust *et al.*, 1998; Kim *et al.*, 1999; Alcan *et al.*, 2000; Yüksel *et al.*, 2001). However, resistance to maxillary protraction by the craniofacial skeletal architecture can be reduced using osteotomic cuts, which allows orthopaedic advancement with almost exclusively skeletal effects in a relatively short period of time (Pelo *et al.*, 2007). In agreement with Kim *et al.* (1999), in the current study, maxillary advancement of 3.47 mm was found in the Le Fort I osteotomy-assisted FM group in 5 months compared with 1.78 mm in the RPE/FM group in 9 months. Since SNA has been shown to be stable throughout growth (Bishara and Jakobsen, 1985; Nelson *et al.*, 2003), the change in parameters related to sagittal maxillary position (SNA, maxillary depth, Nper-A) indicates a positive treatment effect on maxillary growth.

In group 1, four patients had a CLP. The effect of maxillary protraction post-operatively between the CLP patients and the non-cleft patients might have been different. Sarnas and Rune (1987) reported that the mean net effect in anterior displacement of the maxilla (SNA) was larger in CLP patients than in the non-cleft patients. However, Jia *et al.* (2006, 2008) showed that the amount of maxillary anterior movement in operated unilateral CLP patients was similar to that of non-cleft patients after maxillary protraction performed before puberty. Therefore, these four patients were not excluded from the group.

In the present study, maxillary protraction did not cease when a Class I canine relationship was achieved but continued until the canines were in a Class II relationship. Although maxillary anterior movement was not found to be different between cleft and non-cleft patients, its tendency to relapse in cleft patients compared with non-cleft patients has been reported to be greater (Houston *et al.*, 1989). Relapse of maxillary protraction is also important for non-cleft patients. Several investigators found that growth of the maxilla after protraction was not normalized but returned to its original Class III growth pattern after treatment (Shanker *et al.*, 1996; Baccetti *et al.*, 1998; MacDonal *et al.*, 1999). Therefore, to overcome the possible relapse effects on treatment, the recommendations of Westwood *et al.* (2003) were followed and all patients were overcorrected towards a Class II occlusal relationship.

Table 3 Comparison of intergroup changes (non-parametric Mann-Whitney *U*-test). SD, standard deviation.

	Group 1 (T2–T1)		Group 2 (T2–T1)			
	Mean	SD	Mean	SD	MW	*P*
Airway						
SPPS	−0.17	2.91	+1.14	3.25	90.5	
MPS	−0.26	2.90	+0.29	1.76	124.5	
IPS	+0.81	3.81	+0.15	2.18	125.5	
apw3–ppw3	−0.29	4.15	−1.04	3.51	118	
PNS–ad1	+0.75	4.27	+1.66	2.92	112	
PNS–ad2	+2.42	2.52	+3.36	5.73	125.5	
Head position						
SN–CVT	+0.69	7.98	+1.34	6.27	122.5	
SN–OPT	−0.98	5.99	−2.38	4.09	118.5	
PL–CVT	+1.44	9.33	+2.58	5.04	116.5	
PL–OPT	+0.25	7.33	+2.18	5.52	97.5	
Hyoid position						
H–mp	+0.87	5.76	+0.13	3.98	116.5	
H–Rg	−2.72	4.32	−0.34	4.86	93	
L3i–Rgn-H	+0.44	10.01	+0.53	5.35	110.5	
Craniofacial						
SNA	+3.47	2.96	+1.78	1.81	85.5	
SNB	−1.63	1.69	−1.06	1.22	100.5	
ANB	+4.56	2.06	+3.34	1.09	79	
Maxillary depth	+3.75	3.13	+1.81	0.93	75.5	*
Maxillary height	−1.13	2.25	−0.63	1.42	100	
NIA	+3.47	2.77	+2.34	1.58	89	
SN–PP	−1.72	3.36	−1.66	1.81	126.5	
SN–MP	+2.41	2.48	+1.56	1.56	102.5	

*$P < 0.05$.

Maxillary height did not show any significant changes in the present study. However, in both groups, point A moved upward insignificantly (1.13 and 0.63 mm, respectively). This insignificant vertical movement of point A was slightly more in group 1 than in group 2. This might have been due to counter-clockwise rotation of the maxilla with the protraction forces.

Rotation of the maxilla is determined by the point of application and the line of action of the protraction force relative to its centre of resistance (Ishii *et al.*, 1987; Tindlund and Rygh, 1993). The future position of the completely osteotomized dentomaxillary complex is controlled by the point of application and line of action of the distraction force relative to its centre of mass. This is in contrast to a constrained body where the biological response is determined by the point of application and line of action of the applied forces relative to its centre of resistance (Lee *et al.*, 1997). Ahn *et al.* (1999) drew attention to the fact that the location of the centre of mass will be affected by the size of the osseous structures, the number of teeth present, and the surgical design of the osteotomy. Based on their findings, it should also be recognized that the soft tissue envelope and attachments will provide some indeterminate anterior constraint, the forces of occlusion an inferior constraint, and the bones above the osteotomy will provide superior constraint. In the current study, the dentomaxillary complex was osteotomized in group 1. Since the dentomaxillary complex was free of its bony attchments, the location of the centre of mass was different in group 1 than the location of the centre of resistance of the non-osteotomized dentomaxillary complex in group 2. However, the direction of the elastic pull was the same in both groups, approximately 30 degrees below the occlusal plane, as recommended by Ngan *et al.*

Table 4 Results of multiple-regression analysis for group 1 (facemask + osteotomy).

Group 1	ΔSPPS		ΔMPS		ΔIPSF		ΔAPW3–PPW3		ΔPSN–ad1		ΔPNS–ad2	
SNA	−0.190	−0.193	−0.086	−0.087	0.371	0.288	0.632	0.451	0.287	0.199	0.032	0.037
SNB	0.384	0.223	−0.451	−0.263	−3.227	−1.430*	−1.984	−0.808	−1.14	−0.451	0.401	0.268
Maxillary depth	0.259	0.201	−0.040	−0.031	−0.130	−0.077	0.582	0.316	0.477	0.252	0.381	0.340
SN–MP	0.450	0.384	0.191	0.164	−1.494	−0.975*	−1.087	−0.651	0.149	0.087	0.521	0.513
SN–CVT	0.209	0.573	0.308	0.848	0.042	0.088	0.442	0.85	−0.12	−0.224	−0.333	−1.053
PL–CVT	−0.095	−0.305	−0.189	−0.608	−0.055	−0.135	−0.129	−0.289	0.236	0.515	0.365	1.352
SN–PP	−0.336	−0.388	−0.222	−0.257	−0.704	−0.621	−0.537	−0.435	−0.774	−0.61	−0.136	−0.181
R	0.704		0.601		0.79		0.863		0.557		0.598	
R^2	0.495		0.361		0.624		0.745		0.311		0.358	

*$P < 0.05$.

Table 5 Results of multiple-regression analysis for group 2 (facemask + rapid palatal expansion).

Group 2	ΔSPPS		ΔMPS		ΔIPSF		ΔAPW3–PPW3		ΔPSN–ad1		ΔPNS–ad2	
SNA	0.711	0.395	0.127	0.130	−0.838	−0.694**	−0.083	−0.043	0.584	0.361	−2.774	−0.876
SNB	−0.509	−0.191	0.724	0.502	1.437	0.805**	0.003	0.001	−0.870	−0.365	1.905	0.407
Maxilla	−1.416	−0.619	0.108	0.087	−0.019	−0.012	0.178	0.072	1.006	0.489	−0.818	−0.203
SN–MP	0.368	0.176	−0.448	−0.396	0.385	0.275	0.786	0.349	0.131	0.070	0.084	0.023
SN–CVT	0.676	1.303	−0.275	−0.977	−0.296	−0.851	0.271	0.484	−0.045	−0.097	−0.221	−0.243
PL–CVT	−0.602	−0.934	0.342	0.980	0.552	1.275*	0.266	0.383	0.397	0.687	0.370	0.326
SN–PP	0.072	0.040	0.498	0.513	0.106	0.088	−0.545	−0.282	−0.803	−0.499	−0.432	−0.137
R	0.759		0.782		0.926		0.878		0.799		0.662	
R^2	0.576		0.612		0.857		0.77		0.639		0.438	

*$P < 0.05$.

(1996). Therefore, the magnitude of the moment created by the protractive forces was different between the two groups causing different magnitudes of counter-clockwise maxillary rotation.

In both groups, the decrease in SNB occurred as a result of clockwise rotation of the mandible, demonstrated by the increase in SN–MP. The amount of this downward and backward mandibular rotation was not significantly different between the groups.

Maxillary protraction caused significant increases in the nasopharyngeal dimensions (PNS–ad1 and PNS–ad2). Although no significant changes were found between T1 and T2 oropharyngeal airway parameters, the results of the multiple-regression analysis showed that IPS was associated with mandibular clockwise rotation in group 1 and with maxillary counter-clockwise rotation along with mandibular clockwise rotation in group 2.

While the findings of the present study concerning the changes in nasopharyngeal dimension are in agreement with Sayınsu *et al.* (2006), Oktay and Ulukaya (2008), and Kaygısız *et al.*(2009) who also found significant increases in nasopharyngeal dimensions, they are contrary to those reported by Hiyama *et al.* (2002) and Baccetti *et al.* (2010) who did not find any changes between pre- and post-treatment airway parameters. Kilinç *et al.* (2008) compared the oro- and nasopharyngeal sagittal airway changes induced by maxillary protraction with those of untreated Class III control subjects. They reported that the nasopharyngeal dimension did not change significantly during an observation period of 9.82 ± 0.48 months in the control group. Therefore, in the current study, in both groups, the increases found in PNS–ad1 and PNS–ad2 related to nasopharyngeal airway dimension were due to maxillary protraction.

Significant changes in both oro- and nasopharyngeal dimensions have been reported following FM therapy, with (Kilinç *et al.*, 2008) and without (Kaygısız *et al.*, 2009) RPE. Although Hiyama *et al.* (2002) carried out a multiple-regression analysis, which revealed that greater maxillary forward growth was associated with a greater increase in the upper superior airway dimension, they did not find any significant changes between pre- and post-treatment airway parameters. As emphasized by Sayınsu *et al.* (2006), the related parameters were missing in their study, the upper airway measurements used (SPPS, MPS, and IPS) were not mainly related to maxillary structures, and the backward rotation of the mandible did not appear to cause any change in the related sagittal airway dimensions.

The vertical position of the hyoid bone has been considered an important parameter to evaluate and compare snoring and apnoeic patients with non-snoring and non-apnoeic patients (Nelson *et al.*, 2003). Apnoeic children and adults were found to have a significantly longer H–MP distance than control subjects (Nelson *et al.*, 2003). However, in the present study, the vertical position of the hyoid did not change significantly in either group.

Although the head has been found to be more extended after maxillary protraction (Sayınsu *et al.*, 2006; Kilinç *et al.*, 2008), head posture and upper airway dimension were not found to be correlated in the current study. This result is in agreement with the findings of Hiyama *et al.* (2002), Oktay and Ulukaya (2008), and Kaygısız *et al.* (2009) who also found no statistically significant differences in head position.

In both groups 1 and 2, maxillary protraction with an increase in nasopharyngeal airway dimension was achieved; however, treatment duration was significantly different between the groups. When a maxillary osteotomy was performed, maxillary protraction was achieved in a significantly shorter period of time.

One of the limitations of this study might be that the upper airway dimension was evaluated based on a two-dimensional cephalometric measurement (Kawamata *et al.*, 2000). Two-dimensional measurements do not render well the complex airway morphology, and anatomical information necessary for evaluation might be overlooked. Computed tomography and magnetic resonance imaging are able to depict the true three-dimensional morphology of the airway; however, their use is limited by high irradiation, cost, and restricted accessibility (Schwab, 1998). Cone beam computed tomography, with its low effective radiation dose, represents an alternative technique for comprehensive head and neck evaluation (Cattaneo and Melsen, 2008; Aboudara *et al.*, 2009).

When clinical studies are planned, every effort should be made to ensure that the data truly represent the maximum potential effect of the appliance. Although, in this study, the need for maxillary advancement in each individual was determined by the severity of the pre-treatment maxillary retrusion and was limited by the degree of downward and backward repositioning of the mandible, which contributes to the establishment of a positive overjet, since an accurate assessment of initial severity of each group was performed, determination of the true effect of the treatment modalities used was possible.

Although cephalometric records were taken at maximum intercuspation without creating any discrepancy in centric relation, estimates of the treatment changes for cephalometric parameters such as SNB and mandibular plane angle should be intrepreted with caution since the T2 records were taken before final settling of the occlusion, and the amount and direction of possible mandibular functional shift affects both the sagittal and the vertical dimensions.

Although, ideally, the treatment outcome should be compared with a matched untreated control group, this could not be established in the present study due to the difficulty in finding untreated Class III subjects (Kaygısız *et al.*, 2009). There are studies in the literature where Class I control groups have been used but the dentoalveolar and skeletal growth trends in Class III subjects may be different (Takada *et al.*, 1993). For the current study, the lack of data from a control group should not influence the results, especially since two treatment groups were compared.

Conclusions

The findings of the present study demonstrated:

1. FM with Le Fort I osteotomy without down-fracture and traditional RPE-assisted FM therapy both produced significant maxillary protraction,
2. The same amount of maxillary protraction was achieved in a shorter period of time when the FM was combined with a Le Fort I osteotomy,
3. In both groups, maxillary protraction improved naso-pharyngeal but not oropharyngeal airway dimensions.

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