European Journal of Orthodontics 28 (2006) 383–392
doi:10.1093/ejo/cjl008
Advance Access publication 26 May 2006

Evaluation of maxillary protraction and fixed appliance therapy in Class III patients

Ayça Arman*, T. Ufuk Toygar** and Eyas Abuhijleh***
Departments of Orthodontics, Faculties of Dentistry, *Başkent University and **Ankara University, Turkey, and ***Growth and Development Department, Orthodontic Division, Ajman University, Al Fujirah, United Arab Emirates

SUMMARY The aim of this study was to examine the dentofacial changes in Class III patients treated with fixed appliances subsequent to rapid maxillary expansion (RME) and facemask therapy. The material consisted of the cephalograms and hand-wrist films of 14 (9 girls, 5 boys) skeletal Class III and 15 (10 girls, 5 boys) untreated subjects obtained at the beginning of treatment/observation (T_1), immediately after orthopaedic therapy (T_2), and at the end of the observation period (T_3). The mean pre-treatment/control ages were approximately 11.5 years and the observation period was 3 years (T_2–T_1: 1 year, T_3–T_2: 2 years). The cephalometric films were analysed according to the structural superimposition method of Björk. All tracings were double-digitized and the measurements were calculated by a computer program. Intragroup changes and intergroup differences were statistically analysed.

Forward movement of the maxilla ($P < 0.01$), backward movement and rotation of the mandible, an increase in the ANB angle ($P < 0.001$), lower face height and overjet ($P < 0.001$), a decrease of overbite, and an improvement in the sagittal lip relationship ($P < 0.01$) presented significant intergroup differences between T_2 and T_1. During the second phase of treatment (T_3–T_2), although not statistically significant, forward movement of the maxilla was less than in the control subjects. Overall changes during the observation period (T_3–T_1) revealed that correction was mainly due to favourable changes in the mandibular and dentoalveolar components of the discrepancy, while those in maxillary position were not different from the control group. The soft tissue profile improved significantly ($P < 0.001$) in the treatment group. Comparison with the Class I controls at the end of the observation period confirmed that some Class III characteristics still remained in the treated patients.

Introduction

A Class III incisor relationship is one of the most difficult malocclusions to correct orthodontically, mainly because of the uncertainty of a satisfactory and stable outcome after growth.

There has been controversy among orthodontists regarding treatment of skeletal Class III malocclusion in growing children, since it is difficult to provide precise criteria as to whether the treatment could be completed by an orthodontic/orthopaedic approach alone or whether a subsequent surgical approach would be required after growth has ceased.

A number of clinicians consider that mandibular prognathisim has a genetic potential that cannot be altered merely by orthopaedic treatment and suggest a surgical approach (Proffit, 1986; Kajiyama *et al.*, 2000; McIntyre, 2004). On the other hand, successful orthopaedic treatment can prevent the problem from becoming more severe, can eliminate or reduce the need for a comprehensive surgical approach and will improve the psychosocial well being and appearance of the patient during the teenage years which are the most formative years of their lives. Regardless of treatment choice, a functional and aesthetic treatment result that is stable over the long term is the desired outcome.

Early treatment is commonly indicated for Class III malocclusions, since if left untreated they will ultimately comprise a substantial percentage of patients seeking orthognathic surgery as adults. Therapeutic regimes designed to influence facial morphology during growth include functional approaches (Fränkel and Fränkel, 1989; McNamara and Brudon, 1993), chincup therapy (Sugawara *et al.*, 1990; Deguchi *et al.*, 2002), extraoral traction to the mandibular dentition (Battagel and Orton, 1995), and reverse headgear or facemasks (Tanne and Sakuda, 1991; Merwin *et al.*, 1997; Turley, 2002).

The Class III malocclusion can exhibit a variety of skeletal and dental components, including a large or protrusive mandible, retrusive maxilla, protrusive mandibular dentition, retrusive maxillary dentition and combinations of these components (Campbell, 1983; Ellis and McNamara, 1984; Guyer *et al.*, 1986; McNamara and Brudon, 1993). Although most Class III patients have excess mandibular development, there is also some degree of maxillary deficiency. This has been reported to be sufficient to make the maxilla a significant part of the problem such that two-thirds of Class III individuals present a combination of maxillary retrusion and mandibular protrusion (Ellis and McNamara, 1984; Guyer *et al.*, 1986).

Animal experiments have shown that sutural growth of maxilla can be stimulated by protraction forces (Nanda, 1978; Jackson *et al.*, 1979). Therefore, maxillary protraction has been considered as the treatment of choice for the majority of subjects with a Class III malocclusion.

A number of studies have been performed documenting the initial and short-term response to maxillary expansion and protraction (Baccetti *et al.*, 1998; Nartallo-Turley and Turley, 1998; Cha, 2003; Arman *et al.*, 2004). A few of these have evaluated the long-term craniofacial modifications after orthopaedic correction (Shanker *et al.*, 1996; Gallagher *et al.*, 1998; Ngan *et al.*, 1998; MacDonald *et al.*, 1999; Baccetti *et al.*, 2000; Lerpitayakun *et al.*, 2001; Hägg *et al.*, 2003; Westwood *et al.*, 2003).

The aim of this study was to examine the dentofacial changes in Class III patients treated with fixed appliances following rapid maxillary expansion (RME) and maxillary protraction via facemask therapy, and to compare the treatment outcomes with an untreated control sample.

Subjects and methods

The material consisted of the cephalograms and hand-wrist films of 14 subjects (9 girls, 5 boys) treated in the Department of Orthodontics, Ankara University, and 15 untreated control subjects (10 girls, 5 boys) from a previously collected longitudinal growth study. The initial radiographs (T_1) were obtained before appliance insertion, the second (T_2) after achieving a positive overjet and/or Class I occlusion, and the third (T_3) after the removal of the fixed orthodontic appliances. The patients included in the treatment group were selected according to the following criteria:

1. Skeletal Class III (ANB < 0 degrees, Wits < −2 mm), due to maxillary retrusion, or a combination of maxillary retrusion and mandibular protrusion;
2. Retrusive nasomaxillary area and/or upper lip position;
3. Angle Class III malocclusion with anterior crossbite;
4. Normally or anteriorly directed vertical growth patterns according to S-N. MP angle (< 40 degrees) and mandibular rotation prediction criteria of Björk (Skieller *et al.*, 1984);
5. Normal or increased overbite (overbite > 1 mm);
6. No congenitally missing or extracted teeth at the beginning of treatment.

The control subjects, matched according to skeletal maturation stage and chronological age, displayed Class I or Class III skeletal relationships (ANB: minimum −1.9 degrees, maximum 4.7 degrees), and normal vertical growth patterns with acceptable occlusions demonstrating no orthopaedic treatment need. The mean chronological age was approximately 11.5 years and all subjects were between $PP_{2=}$ and MP_{3cap} developmental stages (Helm *et al.*, 1971) at the beginning of the treatment/observation period. The mean chronological ages at T_1, T_2, and T_3 and the duration of the observation periods are shown in Table 1.

Treatment was initiated with a bonded RME appliance activated with a semi-rapid protocol (RME of 5–7 days, followed by slow maxillary expansion) until the desired expansion was achieved (İşeri and Özsoy, 2004). Protraction elastics delivering a force of 400–600 g per side were attached near the maxillary canines with a downward and forward pull of 20–30 degrees to the occlusal plane. At this first orthopaedic phase of treatment, the patients were instructed to wear their facemasks at least 14 hours per day until a positive overjet was achieved (T_2–T_1: 1.1 years). In 11 patients the overjet was overcorrected to more than 2.5 mm.

Following the maxillary protraction phase, a second phase of orthodontic treatment with edgewise appliances was used for final detailing of the occlusion (T_3–T_2: 1.8 years). The patients were treated without extractions and all used Class III elastics and facemasks or chincups during the fixed appliance phase. As the patients were still in their active growth period at the end of the treatment period, some of them continued to wear their chincups in addition to their intraoral appliances for retention and control of late mandibular growth.

Cephalometric analysis

The cephalometric records were obtained under standardized conditions. The cephalograms were traced and the reference points were marked (Figure 1). Horizontal (HR) and vertical reference (VR) planes were transferred from the T_1 tracing to the T_2 and T_3 tracings according to the structural superimposition method (Björk and Skieller, 1983). The second (T_2) and third (T_3) films were superimposed on the first and were orientated to obtain maximal coincidence of the anatomic reference structures. These reference structures were (1) The contours of the anterior wall of sella turcica,

Table 1 Mean chronological ages at beginning of the observation period (T_1), after orthopaedic (RME and maxillary protraction) therapy (T_2), at the end of the observation period (T_3), and duration for each observation period (years).

Observation period	Treatment group (n = 14)		Control group (n = 15)		*t*-test
	$\bar{X}$	$S_{\bar{X}}$	$\bar{X}$	$S_{\bar{X}}$	
T_1	11.5	0.31	11.9	0.54	NS
T_2	12.5	0.33	12.9	0.51	NS
T_3	14.3	0.35	14.9	0.46	NS
T_2–T_1	1.1	0.09	1.0	0.12	NS
T_3–T_2	1.8	0.15	2.0	0.23	NS
T_3–T_1	2.9	0.09	3.0	0.23	NS

$\bar{X}$, mean; $S_{\bar{X}}$, standard error of mean; NS, non-significant.

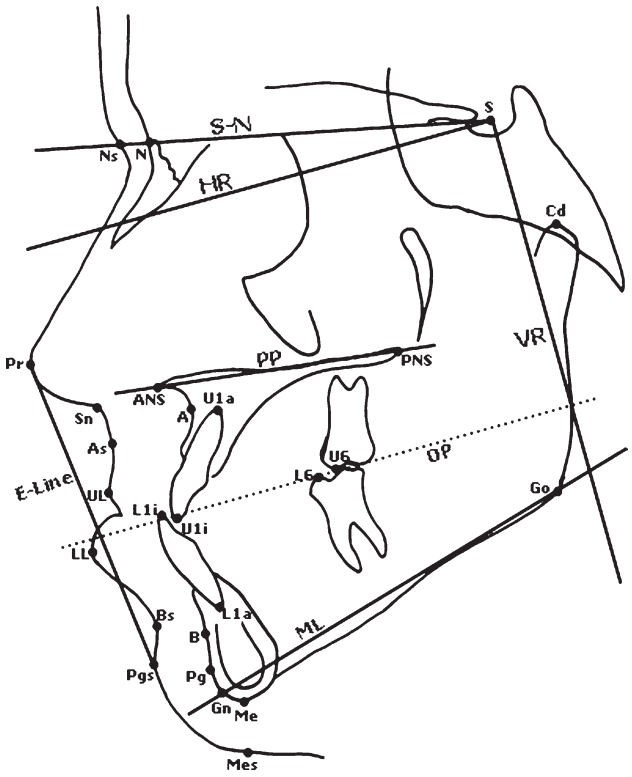

Figure 1 Reference landmarks and reference planes used in the study. S, sella; N, nasion; ANS, anterior nasal spine; PNS, posterior nasal spine; A, subspinale; U1i, incisal edge of the maxillary central incisor; U1a, apex of the maxillary central incisor; U6, mesial cusp tip of the maxillary first molar; L1i, incisal edge of the mandibular central incisor; L1a, apex of the mandibular first central incisor; L6, mesial cusp tip of the mandibular first molar; B, supramentale; Pg, pogonion; Gn, gnathion; Me, menton; Go, gonion; Cd, condylion; Ns, soft tissue nasion; Pr, pronasale; Sn, subnasale; As, soft tissue point A; UL, upper lip; LL, lower lip; Bs, soft tissue point B; Pgs, soft tissue pogonion; Mes, soft tissue menton; VR, vertical reference plane constructed perpendicular to the occlusal plane (OP) on the first tracing (T_1) from point sella (S) of T_1; HR, horizontal reference plane drawn perpendicular to VR from sella (S) and parallel to OP at T_1; S-N, sella (S)-nasion (S) line; PP, palatal plane passing through ANS and PNS; OP, occlusal plane constructed between the midpoints of U6 and L6, U1i and L1i; ML, mandibular plane constructed between Go and Gn points; E-line (E), Ricketts' aesthetic line constructed between Pr and Pgs.

(2) the anterior contours of the median cranial fossa, (3) the intersection of the anterior contour of sella and tuberculum sella, (4) the inner surface of the frontal bone, (5) the contours of the ciribriform plate, (6) the contours of the bilateral frontoethmoidal crests, and (7) the contour of the median border of the cerebral surfaces of the orbital roofs. Control of the superimposition was made by checking the changes of the frontoparietal suture, occipital bone, and points articulare and pterygomaxillare.

VR was constructed perpendicular to the occlusal plane of the first tracing (OP_1) from point sella (S_1) of the first tracing (T_1) and HR was drawn perpendicular to VR from S_1. The co-ordinates of the reference landmarks were recorded using a Hipad Digitiser (Houston Instruments, Houston Texas, USA) with a resolution of 0.125 mm and with a double-digitizing procedure. The PorDios (Purpose on request Digitizer input–output system, Institute of Orthodontic Computer Science, Århus, Denmark) cephalometric analysis program was used to perform the calculations.

Statistical method

Paired *t*-tests were used to analyse changes within the groups and independent *t*-tests to compare treatment changes with the control group.

Method error

All measurement calculations (landmark identification, superimposition, and digitization) for the 15 subjects were carried out by the same investigator 1 month after the first measurements were made. Intraclass correlation coefficients were found to be within 0.92–0.99 and the method was found to yield sufficient reliability.

Results

The craniofacial morphology of all subjects and the statistical evaluation of intergroup differences at T_1, T_2, and T_3 are shown in Table 2. The changes in measurements, statistical analysis of intra- and intergroup differences from T_1 to T_2 are shown in Table 3, and the mean changes from T_2 to T_3 in Table 4. Evaluation of overall treatment/control changes (T_1–T_3) are presented in Table 5.

Skeletal measurements

The midface length (Cd-A), sagittal position of point A (A-VR), effective mandibular length (Cd-Gn), mandibular prognathism (SNB), gonial angle, intermaxillary relationship [(ANB, (A-VR)-(B-VR)], and facial convexity angle (N.A.Pg) was significantly different between the groups at T_1 (Table 2).

Throughout the maxillary protraction phase, the increase in lower anterior face height (ANA-Me) was more pronounced in the treatment group than in the controls (Table 3). The maxilla displaced anteriorly (SNA, A-VR), the midface length (Cd-A) increased significantly in the treatment group, and the increase in SNA angle was statistically different from the controls. The mandible was positioned backward (SNB, B-VR) significantly in the treatment group, and change in the SNB angle was statistically different from the controls (Table 3). Posterior rotation of the mandible (S-N.MP) was significant in the treatment group. The intermaxillary relationship improved significantly with a concomitant increase in the facial convexity angle in the treatment group (Table 3).

In the post-protraction period (T_3–T_2), an increase in SNB angle was observed in the control group which was different from the treatment group (Table 4).

Table 2 Mean values of measurements at the beginning of the observation period (T_1), after orthopaedic therapy (T_2) and at the end of the observation period (T_3) and comparison of the treatment and control groups (independent *t*-test).

Parameter	Treatment group (T_1)		Control group (T_1)		*t*-test	Treatment group (T_2)		Control group (T_2)		*t*-test	Treatment group (T_3)		Control group (T_3)		*t*-test
	$\bar{X}$	$S_{\bar{X}}$	$\bar{X}$	$S_{\bar{X}}$		$\bar{X}$	$S_{\bar{X}}$	$\bar{X}$	$S_{\bar{X}}$		$\bar{X}$	$S_{\bar{X}}$	$\bar{X}$	$S_{\bar{X}}$	
Skeletal															
Face heights															
N-Me (mm)	119.99	2.61	115.28	1.58		124.55	2.63	118.53	1.91		129.52	2.84	120.75	1.89	*
ANS-Me (mm)	67.17	1.84	64.75	1.52		70.87	1.92	66.54	1.72		73.92	2.17	68.70	1.62	
S-Go (mm)	73.74	1.62	71.62	1.15		76.05	1.65	74.34	1.58		80.03	2.11	76.87	1.60	
Maxillary skeletal															
Cd-A (mm)	78.51	1.02	82.73	1.28	*	81.81	1.05	84.22	1.38		85.24	0.80	86.85	1.39	
SNA (°)	76.19	0.74	78.67	1.12		78.02	1.13	78.81	1.22		77.28	0.89	79.60	1.19	
A-VR (mm)	68.98	0.88	73.46	1.16	**	71.09	1.04	71.78	3.44		72.36	0.90	76.07	1.43	*
S-N.PP (°)	35.75	1.27	33.90	1.52		37.00	1.31	33.57	1.79		36.70	1.75	31.92	1.92	
HR.PP (°)	10.30	0.81	10.19	0.80		10.62	0.95	4.85	5.50		11.32	0.99	10.45	1.14	
Mandibular skeletal															
Cd-Gn (mm)	116.47	2.04	110.30	1.53	*	119.55	1.88	113.53	1.84	*	126.49	2.01	118.14	1.57	**
SNB (°)	80.18	0.79	76.73	1.16	*	79.07	0.64	77.18	1.31		78.94	0.76	78.28	1.37	
B-VR (mm)	79.72	1.34	75.56	1.18	*	78.47	1.23	76.26	2.17		80.83	1.15	79.14	1.52	
S-N.MP (°)	35.75	1.27	33.90	1.52		37.00	1.31	33.57	1.79		36.70	1.75	31.92	1.92	
HR.MP (°)	16.82	0.98	14.48	0.83		18.04	1.09	19.28	5.08		17.14	1.25	13.62	1.05	*
Gonial Angle (°)	126.02	1.43	120.06	1.31	**	125.57	1.70	119.89	1.56	*	125.78	2.06	118.87	1.41	**
Maxillomandibular															
ANB (°)	−3.99	0.62	1.94	0.49	***	−1.05	0.92	1.63	0.54	*	−1.67	0.70	1.33	0.68	**
(A-VR)-(B-VR) (mm)	−10.74	0.81	−2.10	0.63	***	−7.37	0.94	−4.48	2.07		−8.47	0.85	−3.06	0.98	***
N.A.Pg (°)	−9.82	1.59	2.15	1.16	***	−4.11	2.10	1.40	1.32	*	−6.51	1.70	0.19	1.57	**
Dentoalveolar															
Overjet (mm)	−3.15	0.52	3.05	0.32	***	2.96	0.49	2.88	0.29		3.07	0.40	3.69	0.21	
Overbite (mm)	1.58	0.72	2.31	0.46		−0.29	0.67	2.43	0.42	**	0.84	0.41	2.49	0.45	*
U1i-NA (mm)	4.98	0.52	4.13	0.52		6.14	0.84	4.34	0.52		7.28	0.80	4.95	0.66	
U1.NA (°)	24.50	0.96	22.96	1.49		27.10	1.95	22.42	1.41		27.48	1.87	24.75	1.58	*
L1i-NB (mm)	2.61	0.55	4.06	0.50		1.59	0.53	4.07	0.53	**	1.86	0.76	3.57	0.50	
L1.NB (°)	18.78	1.91	24.95	1.66	*	14.67	1.41	24.42	1.60	***	16.06	2.05	23.87	1.54	**
S-N.OP (°)	18.86	1.08	19.59	1.09		17.41	1.17	18.37	1.02		16.74	1.10	16.42	0.95	
Soft tissue															
Ns-Mes (mm)	128.49	2.53	123.74	1.66		133.04	2.43	125.83	3.50		138.49	2.80	129.10	1.93	**
Sn-Mes (mm)	70.18	1.68	70.26	1.40		74.10	1.55	70.67	3.21		77.31	2.08	74.45	1.74	
Ns.Sn.Pgs (°)	6.87	1.33	15.91	1.25	***	11.64	1.55	15.80	1.41		10.23	1.60	16.00	1.72	*
As-VR (mm)	86.01	1.00	88.93	1.18		88.48	1.09	87.47	4.41		90.86	1.03	92.95	1.52	
UL-VR (mm)	89.76	1.03	91.91	1.29		92.00	1.14	91.71	4.31		94.90	1.16	97.17	1.63	
UL-E (mm)	−6.93	0.76	−3.27	0.55	***	−5.54	0.91	−3.22	0.78		−6.39	0.95	−4.07	0.58	*
LL-VR (mm)	93.55	1.09	92.00	1.23		93.39	1.16	92.22	3.46		96.44	1.18	96.79	1.60	
LL-E (mm)	−2.15	0.85	−1.27	0.55		−2.54	0.69	−1.14	0.69		−3.26	0.96	−4.07	0.55	
Bs-VR (mm)	89.99	1.34	86.72	1.08		88.97	1.29	86.71	2.59		91.70	1.21	90.48	1.46	
(UL-VR)-(LL-VR) (mm)	−3.79	0.33	−0.09	0.34	***	−1.39	0.38	−0.52	1.00		−1.53	0.32	0.39	0.42	**

$\bar{X}$, mean; $S_{\bar{X}}$, standard error of mean; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

During the overall observation period (T_1–T_3) the increase in anterior face heights (N-Me, ANS-Me) was more significant in the treatment group (Table 5). The midface length (Cd-A) increased and the maxilla moved forward (SNA, A-VR) similarly in both groups. The changes in the position (SNB, B-VR) and rotation of the mandible (S-N.MP) showed significant intergroup differences. Both the ANB angle (2.32 degrees) and modified Wits appraisal [(A-VR)-(B-VR), 2.27 mm] increased significantly in the treatment group compared with the controls (Table 5).

Final evaluation of the skeletal parameters at T_3 revealed that anterior face heights, sagittal position of point A, effective mandibular length, mandibular rotation according to HR (HR.MP), gonial angle, intermaxillary relationship, and facial convexity still significantly differed from the control group (Table 2).

Dentoalveolar measurements

Significant intergroup differences for overjet and lower incisor inclination (L1.NB) were found at T_1 (Table 2).

Table 3 Changes in the treatment/control groups during the orthopaedic phase (RME and maxillary protraction) of the therapy (T_2–T_1), significance of changes in each group (paired *t*-test) and comparison of changes in the treatment/control groups (independent *t*-test).

Parameter	Treatment group (T_2–T_1)			Control group (T_2–T_1)			Independent *t*-test
	$\bar{X}$	$S_{\bar{X}}$	Paired *t*-test	$\bar{X}$	$S_{\bar{X}}$	Paired *t*-test	
Skeletal							
Face heights							
N-Me (mm)	4.56	0.79	***	3.25	0.64	***	
ANS-Me (mm)	3.70	0.53	***	1.80	0.52	**	*
S-Go (mm)	2.31	0.67	**	2.72	0.85	**	
Maxillary skeletal							
Cd-A (mm)	3.31	0.84	**	1.49	0.59	*	
SNA (°)	1.83	0.60	**	0.14	0.25		*
A-VR (mm)	2.11	0.61	**	−1.68	2.87		
S-N.PP (°)	−0.28	0.41		0.22	0.44		
HR.PP (°)	0.32	0.30		−5.34	5.07		
Mandibular skeletal							
Cd-Gn (mm)	3.07	0.52	***	3.23	0.75	***	
SNB (°)	−1.11	0.29	**	0.45	0.31		***
B-VR (mm)	−1.25	0.40	**	0.70	1.38		
S-N.MP (°)	1.25	0.53	*	−0.33	0.48		*
HR.MP (°)	1.22	0.50	*	4.80	5.03		
Gonial angle (°)	−0.45	0.90		−0.17	0.46		
Maxillomandibular							
ANB (°)	2.94	0.66	***	−0.31	0.25		***
(A-VR)-(B-VR) (mm)	3.36	0.71	***	−2.38	1.76		**
N.A.Pg (°)	5.70	1.25	***	−0.75	0.55		***
Dentoalveolar							
Overjet (mm)	6.11	0.77	***	−0.16	0.26		***
Overbite (mm)	−1.87	0.54	**	0.12	0.20		***
U1i-NA (mm)	1.17	0.48	*	0.21	0.32		
U1.NA (°)	2.60	1.35	*	−0.53	0.61		*
L1i-NB (mm)	−1.03	0.38	*	0.01	0.21		*
L1.NB (°)	−4.11	1.40	*	−0.53	0.63		*
S-N.OP (°)	−1.45	0.50	*	−1.22	0.59		
Soft tissue							
Ns-Mes (mm)	4.55	0.79	***	2.09	2.37		
Sn-Mes (mm)	3.91	0.72	***	0.41	2.23		
Ns.Sn.Pgs (°)	4.77	0.89	***	−0.11	0.60		***
As-VR (mm)	2.47	0.57	***	−1.46	3.94		
UL-VR (mm)	2.24	0.64	**	−0.21	3.84		
UL-E (mm)	1.39	0.60	*	0.05	0.61		
LL-VR (mm)	−0.16	0.54		0.22	2.89		
LL-E (mm)	−0.39	0.54		0.14	0.48		
Bs-VR (mm)	−1.02	0.49		−0.01	1.95		
(UL-VR)-(LL-VR) (mm)	2.40	0.60	**	−0.43	1.02		*

$\bar{X}$, mean; $S_{\bar{X}}$, standard error of mean; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

The significant outcomes of RME and maxillary protraction therapy (T_1–T_2) were an increase in overjet (6.11 mm) and a decrease in overbite (Table 3). The proclination of the upper incisors (U1.NA) and retrusion of the mandibular incisors (L1.NB) in the treatment group were significantly different from the controls. The decrease in the occlusal plane angle (S-N.OP) was significant in the treatment group (Table 3).

In the post-protraction phase of treatment the dentoalveolar outcomes achieved in the first phase were maintained (Table 4). The control group demonstrated significant changes, whereas no significant difference was observed in the treatment group regarding the dentoalveolar parameters during the second phase of treatment.

For the overall observation period, overjet increased (6.21 mm), and upper incisors showed significant protrusion (U1i-NA), differing from the controls (Table 5).

At the end of the observation period (T_3), overbite, upper incisor inclination (U1.NA), and lower incisor inclination (L1.NB) all showed significant differences between the groups (Table 2).

Table 4 Changes in the treatment/control groups in the post-protraction fixed appliance phase of therapy (T_3–T_2), significance of changes in each group (paired *t*-test) and comparison of changes in the treatment/control groups (independent *t*-test).

Parameter	Treatment group (T_3–T_2)			Control group (T_3–T_2)			Independent *t*-test
	$\bar{X}$	$S_{\bar{X}}$	Paired *t*-test	$\bar{X}$	$S_{\bar{X}}$	Paired *t*-test	
Skeletal							
Face heights							
N-Me (mm)	4.97	0.88	***	2.22	0.79	*	*
ANS-Me (mm)	3.05	0.54	***	2.16	0.58	**	
S-Go (mm)	3.98	1.02	**	2.53	0.78	**	
Maxillary skeletal							
Cd-A (mm)	3.43	0.74	***	2.63	0.94	*	
SNA (°)	−0.74	0.64		0.80	0.43		
A-VR (mm)	1.27	0.71		4.29	2.81		
S-N.PP (°)	−0.10	0.71		−1.60	0.46	**	
HR.PP (°)	0.70	0.60		5.60	4.97		
Mandibular skeletal							
Cd-Gn (mm)	6.95	1.02	***	4.61	1.06	***	
SNB (°)	−0.13	0.49		1.10	0.34	**	*
B-VR (mm)	2.36	0.60	**	2.88	1.34	*	
S-N.MP (°)	−0.30	0.65		−1.66	0.56	**	
HR.MP (°)	−0.90	0.54		−5.66	4.96		
Gonial angle (°)	0.21	1.00		−1.02	0.58		
Maxillomandibular							
ANB (°)	−0.62	0.52		−0.30	0.24		
(A-VR)-(B-VR) (mm)	−1.10	0.65		1.41	1.71		
N.A.Pg (°)	−2.40	0.94	*	−1.21	0.50	*	
Dentoalveolar							
Overjet (mm)	0.11	0.68		0.81	0.26	**	
Overbite (mm)	1.12	0.54		0.06	0.28		
U1i-NA (mm)	1.14	0.80		0.61	0.28	*	
U1.NA (°)	0.37	1.95		2.33	0.49	***	
L1i-NB (mm)	0.28	0.51		−0.50	0.17	*	
L1.NB (°)	1.39	1.48		−0.55	0.53		
S-N.OP (°)	−0.67	0.71		−1.94	0.57	**	
Soft tissue							
Ns-Mes (mm)	5.44	1.08	***	3.28	2.27		
Sn-Mes (mm)	3.22	0.85	**	3.78	1.90		
Ns.Sn.Pgs (°)	−1.41	1.20		0.20	0.75		
As-VR (mm)	2.38	0.76	**	5.48	3.72		
UL-VR (mm)	2.90	0.61	***	5.46	3.54		
UL-E (mm)	−0.84	0.41		−0.85	0.47		
LL-VR (mm)	3.04	0.71	***	4.56	2.65		
LL-E (mm)	−0.71	0.47		−1.03	0.36	*	
Bs-VR (mm)	2.73	0.76	**	3.78	1.85		
(UL-VR)-(LL-VR) (mm)	−0.14	0.34		0.90	0.96		

$\bar{X}$, mean; $S_{\bar{X}}$, standard error of mean; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Soft tissue measurements

The soft tissue convexity angle (Ns.Sn.Pgs), upper lip position from E-line (UL-E), and sagittal lip relationship [(UL-VR)-(LL-VR)] all showed intergroup differences at the start of the observation period (T_1; Table 2).

Soft tissue convexity increased, and the sagittal lip relationship significantly improved due to orthopaedic therapy (T_1–T_2) and showed significant intergroup differences (Table 3).

In the post-protraction phase (T_3–T_2), no statistical difference was found regarding the soft tissue changes between the treatment and control groups (Table 4).

During the overall treatment period, soft tissue total and lower face heights (Ns-Mes, Sn-Mes) and convexity (Ns.Sn.Pgs) increased more than in the control group (Table 5). The sagittal lip relationship [(UL-VR)-(LL-VR)] improved significantly in the treatment group (2.66 mm), showing difference between groups ($P < 0.01$).

Anterior soft tissue height, soft tissue convexity angle, sagittal upper lip position according to E-line, and sagittal lip relationship presented intergroup differences at the end of the observation period (T_3; Table 2).

Table 5 Changes in the treatment/control groups during the overall observation period (T_3–T_1), significance of changes in each group (paired *t*-test) and comparison of changes in the treatment/control groups (independent *t*-test).

Parameter	Treatment group (T_3–T_1)			Control group (T_3–T_1)			Independent *t*-test
	$\bar{X}$	$S_{\bar{X}}$	Paired *t*-test	$\bar{X}$	$S_{\bar{X}}$	Paired *t*-test	
Skeletal							
Face heights							
N-Me (mm)	9.53	1.03	***	5.47	0.83	***	**
ANS-Me (mm)	6.76	0.73	***	3.96	0.51	***	**
S-Go (mm)	6.29	1.10	***	5.25	0.99	***	
Maxillary skeletal							
Cd-A (mm)	6.74	0.99	***	4.12	0.95	***	
SNA (°)	1.09	0.42	*	0.94	0.38	*	
A-VR (mm)	3.38	0.69	***	2.62	0.56	***	
S-N.PP (°)	−0.38	0.67		−1.38	0.48	*	
HR.PP (°)	1.02	0.58		0.26	0.55		
Mandibular skeletal							
Cd-Gn (mm)	10.02	1.20	***	7.84	0.89	***	
SNB (°)	−1.23	0.54	*	1.55	0.42	**	***
B-VR (mm)	1.11	0.81		3.58	0.75	***	*
S-N.MP (°)	0.95	0.84		−1.98	0.68	*	*
HR.MP (°)	0.31	0.75		−0.86	0.47		
Gonial angle (°)	−0.24	1.25		−1.19	0.46	*	
Maxillomandibular							
ANB (°)	2.32	0.40	***	−0.61	0.32		***
(A-VR)-(B-VR) (mm)	2.27	0.61	**	−0.96	0.53		***
N.A.Pg (°)	3.31	0.81	***	−1.96	0.66	**	***
Dentoalveolar							
Overjet (mm)	6.21	0.58	***	0.64	0.34		***
Overbite (mm)	−0.74	0.71		0.18	0.34		
U1i-NA (mm)	2.30	0.57	***	0.82	0.39		*
U1.NA (°)	2.97	1.60		1.80	0.64	*	
L1i-NB (mm)	−0.75	0.55		−0.49	0.29		
L1.NB (°)	−2.72	1.41		−1.09	0.72		
S-N.OP (°)	−2.12	0.83	*	−3.17	0.74	**	
Soft tissue							
Ns-Mes (mm)	9.99	1.09	***	5.37	0.82	***	**
Sn-Mes (mm)	7.13	0.82	***	4.19	0.78	***	*
Ns.Sn.Pgs (°)	3.36	0.87	**	0.09	1.00		*
As-VR (mm)	4.85	0.80	***	4.02	0.79	***	
UL-VR (mm)	5.14	0.99	***	5.26	0.95	***	
UL-E (mm)	0.54	0.54		−0.80	0.47		
LL-VR (mm)	2.88	0.91	**	4.78	0.94	***	
LL-E (mm)	−1.11	0.55		−0.90	0.38	*	
Bs-VR	1.71	0.92		3.77	0.79	***	
(UL-VR)-(LL-VR) (mm)	2.26	0.46	***	0.48	0.37		**

$\bar{X}$, mean; $S_{\bar{X}}$, standard error of mean; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Discussion

The major intent of this clinical study was to evaluate the dentofacial changes induced by RME and facemask therapy after a second phase of fixed appliance therapy by comparing the overall changes with a control group. Well-designed clinical studies using control groups in order to distinguish treatment effects from normal growth and development as well as investigations comparing the effects of different therapeutic approaches in Class III malocclusions are essential (Battagel and Orton, 1995; Üçüncü *et al.*, 2000; Arman *et al.*, 2004). However, clinical trials present inevitable limitations, such as individual variations in severity of malocclusion, growth patterns, treatment protocols, patient co-operation, treatment response, and relapse potentials.

The untreated control group in the present study was closely matched for gender, chronological/skeletal age, and observation intervals. The longitudinal control material comprised subjects with acceptable occlusions and mostly skeletal Class I relationships, thus statistical differences in some of the parameters between the Class III patients and control group were noted at T_1 (Table 2).

Using a Class I control sample it was possible to demonstrate how much the treatment outcomes reached the 'normal'. As reported by Shanker *et al.* (1996), MacDonald *et al.* (1999), and Westwood *et al.* (2003) a Class III control group can be advantageous, however, these Class III control samples were mostly cross-sectional rather than longitudinal. On the other hand, it has been demonstrated that the magnitude of increase in maxillary and mandibular growth is not significantly different between skeletal Class I and III (Deguchi *et al.*, 2002).

The patients in the treatment group had a mean age of 11.5 years and all were at the pre-pubertal/pubertal stage of growth at T_1. It has been recommended that maxillary protraction be initiated at earlier ages (Campbell, 1983; McNamara and Brudon, 1993; Baccetti *et al.*, 1998; Lertpitayakun *et al.*, 2001), whereas studies comparing the effects of maxillary protraction applied in different age groups report similar skeletal response in pre-pubertal and pubertal growth peak groups (Merwin *et al.*, 1997; Yüksel *et al.*, 2001; Turley, 2002).

Patient selection is extremely important for this treatment approach. The mandibular plane angle has been found to be an important factor in influencing the long-term success of RME therapy (Baccetti *et al.*, 2004). Only, patients presenting with normally directed vertical growth patterns with positive overbite values were included in the present study sample.

In addition to conventional measurements, those from reference planes constructed according to the occlusal plane on the T_1 tracing and transferred to the T_2 and T_3 tracings according to the structural superimposition method were used. The structural superimposition method should be preferred when evaluating long-term changes. Measurements that use S-N as a reference line are inherently inaccurate as these landmarks vary with growth (Arat *et al.*, 2003).

Assessment of the results demonstrates that considerable facial changes and improvements took place after one year of RME and maxillary protraction treatment. The forward movement of the maxilla (2.11 mm) was accompanied by labial movement of the maxillary incisors, an increase in the vertical measurements and mandibular plane angle, and posterior movement of the mandible. These findings are in accordance with previous studies (Shanker *et al.*, 1996; Merwin *et al.*, 1997; Gallagher *et al.*, 1998; Ngan *et al.*, 1998; MacDonald *et al.*, 1999; Baccetti *et al.*, 2000; Yüksel *et al.*, 2001; Westwood *et al.*, 2003).

Correction of the Class III relationship in the treatment group was achieved by both skeletal and dental changes. The soft tissue profile reflected the favourable skeletal and dental changes. After the orthopaedic phase of treatment (T_2) the differences between the treatment and Class I control group were reduced and the groups were more similar at this stage compared with T_1 (Table 2).

In the fixed appliance phase of the treatment (T_3–T_2), the increases in face height and backward movement of the mandible (B-VR) were different from the control group (Table 4), where significant anterior rotation of the mandible was observed. Although the treatment and control groups did not demonstrate any statistical difference regarding the maxillary and maxillomandibular changes [A-VR, SNA, (A-VR)-(B-VR)], the mean differences in these measurements were likely to be clinically significant and forward movement of the maxilla was evident and more pronounced in the control subjects in this second phase treatment (Table 4). The reason for this statistical insignificance may be the small number of subjects in the study group. Following facemask therapy, the maxilla continued to grow forward but this growth was less than the maxillary growth of the control subjects. This change can be attributed to a return of the previously existing growth pattern. Studies evaluating post-protraction changes report similar skeletal changes in treated and untreated subjects (Shanker *et al.*, 1996; Gallagher *et al.*, 1998; Ngan *et al.*, 1998; Baccetti *et al.*, 2000; Westwood *et al.*, 2003). MacDonald *et al.* (1999) demonstrated less maxillary anterior growth compared with a Class I control group but similar growth to a Class III control group during the post-protraction phase.

Overall changes during the observation period (T_3–T_1) reveal that orthopaedic and orthodontic intervention leads to significant skeletal, dentoalveolar, and soft tissue improvements. The correction was mainly due to favourable changes in the mandibular and dentoalveolar components of the discrepancy, while changes in the maxillary position were non contributory. These findings are consistent with other studies presenting similar maxillary changes in treatment and control groups in the long term (MacDonald *et al.*, 1999; Lerpitayakun *et al.*, 2001; Westwood *et al.*, 2003).

Comparison with untreated Class I controls at the end of the observation period confirmed that, despite that acceptable occlusion and appearance achieved, Class III characteristics still remained in the treated patients. Differences between the groups at this final stage were more pronounced compared with those at the end of the protraction phase, implying that skeletal improvements can be obtained during the orthopaedic phase of treatment, and mostly dental components can be maintained at the end of the treatment.

These results have important clinical implications. Treating patients with overcorrection at the orthopaedic phase may be worthwhile (Gallagher *et al.*, 1998; Westwood *et al.*, 2003). Prolonged use of a facemask or chincup together with Class III elastics can also be advisable to control the unfavourable skeletal growth pattern. A large part of the Class III correction was caused by protrusion of the upper incisors, uprighting of the lower incisors, and posterior rotation of the mandible during treatment. Changing the anchorage region of maxillary protraction using rigid skeletal anchorage via implants may be advisable to increase the maxillary skeletal effects and reduce the

undesired dentoalveolar effects of facemask therapy (Singer *et al.*, 2000; Enacar *et al.*, 2003).

This study evaluated the immediate orthopaedic effects and post-treatment outcomes of RME and maxillary protraction therapy during a three-year period. Significant relapse potentials of skeletal and dentoalveolar variables have been reported in studies of long-term effects of maxillary protraction appliances (Gallagher *et al.*, 1998; Ngan *et al.*, 1998; Hägg *et al.*, 2003). Hägg *et al.* (2003) reported a success rate of 67 per cent in a patient sample 8 years after active treatment with reverse headgear. Consequently, records at the time when facial growth is close to completion or complete should be evaluated for stability of these treatment changes.

Conclusions

Class III patients and Class I control subjects presented significant differences at the beginning of the observation period.

RME plus maxillary protraction therapy produced significant dentofacial changes from T_2 to T_1. Forward movement of the maxilla, backward movement and rotation of the mandible, improvement of the maxillomandibular relationship, an increase in lower face height and overjet, a decrease of overbite, and improvement of the sagittal lip relationship were significantly different from the control group.

At the end of the orthopaedic therapy, the treatment and control groups were more similar compared with T_1.

In the fixed appliance phase of treatment (T_3–T_2), increases in face height and backward movement of the mandible were different from the control group. Significant anterior rotation of the mandible was observed in the control group. Although not statistically significant, forward movement of the maxilla after facemask therapy was less than in the controls.

Changes during the overall observation period (T_3–T_1) indicated no significant difference between the groups regarding maxillary changes, while backward movement and rotation of the mandible was significant and different from the controls. The overjet increased, the maxillary incisors protruded, and the lip relationship improved significantly in the treatment group.

Final evaluation at T_3 revealed a more orthognathic profile after treatment. However, the treated patients still presented Class III characteristics.

Address for correspondence

Professor Ufuk Toygar
Ankara Üniversitesi
Diş Hekimliği Fakültesi
Ortodonti Anabilim Dalı
06500 Beşevler-Ankara
Türkiye
E-mail: toygar@dentistry.ankara.edu.tr

Acknowledgements

We wish to thank Dr Ensar Baspinar (Ankara University, Faculty of Agriculture, Department of Genetics and Statistics) for managing the statistical procedures used in this study.

References

Arat Z M, Rübendüz M, Arman Akgül A 2003 The displacement of craniofacial reference landmarks during puberty: a comparison of three superimposition methods. Angle Orthodontist 73: 373–380

Arman A, Toygar T U, Abuhijleh E 2004 Profile changes associated with different orthopedic treatment approaches in Class III maloclussions. Angle Orthodontist 74: 731–740

Baccetti T, McGill J S, Franchi L, McNamara Jr J A, Tollaro I 1998 Skeletal effects of early treatment of Class III malocclusion with maxillary expansion and face-mask therapy. American Journal of Orthodontics and Dentofacial Orthopedics 113: 333–343

Baccetti T, Franchi L, McNamara Jr J A 2000 Treatment and posttreatment craniofacial changes after rapid maxillary expansion and facemask therapy. American Journal of Orthodontics and Dentofacial Orthopedics 118: 404–413

Baccetti T, Franchi L, McNamara Jr J A 2004 Cephalometric variables predicting the long-term success or failure of combined rapid maxillary expansion and facial mask therapy. American Journal of Orthodontics and Dentofacial Orthopedics 126: 16–22

Battagel J M, Orton H S 1995 A comparative study of the effects of customized facemask therapy or headgear to the lower arch on the developing Class III face. European Journal of Orthodontics 17: 467–482

Björk A, Skieller V 1983 Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalometric implant studies over a period of 25 years. European Journal of Orthodontics 5: 1–46

Campbell P M 1983 The dilemma of Class III treatment. Early or late? Angle Orthodontist 53: 175–191

Cha K-S 2003 Skeletal changes of maxillary protraction in patients exhibiting skeletal Class III malocclusion: a comparison of three skeletal maturation groups. Angle Orthodontist 73: 26–35

Deguchi T, Kuroda T, Minoshima Y, Graber T M 2002 Craniofacial features of patients with Class III abnormalities: growth-related changes and effects of short-term and long-term chincup therapy. American Journal of Orthodontics and Dentofacial Orthopedics 121: 84–92

Ellis III E, McNamara Jr J A 1984 Components of adult Class III open-bite malocclusion. Journal of Oral and Maxillofacial Surgery 42: 295–305

Enacar A, Giray B, Pehlivanoğlu M, Iplikçioğlu H 2003 Facemask therapy with rigid anchorage in a patient with maxillary hypoplasia and severe oligodontia. American Journal of Orthodontics and Dentofacial Orthopedics 123: 571–577

Fränkel R, Fränkel C 1989 Orofacial orthopedics with the function regulator. S. Karger, Munich

Gallagher R W, Miranda F, Buschang P H 1998 Maxillary protraction: treatment and posttreatment effects. American Journal of Orthodontics and Dentofacial Orthopedics 113: 612–619

Guyer E C, Ellis III E E, McNamara Jr J A, Behrents R G 1986 Components of Class III malocclusion in juveniles and adolescents. Angle Orthodontist 56: 7–30

Hägg U, Tse A, Bendeus M, Rabie A B M 2003 Long-term follow-up of early treatment with reverse headgear. European Journal of Orthodontics 25: 95–102

Helm S, Siersbæk-Nielsen S, Skieller U, Björk A 1971 Skeletal maturation of the hand in relation to maximum pubertal growth in body height. Tandlægebladet 75: 1223–1233

İşeri H, Özsoy S 2004 Semirapid maxillary expansion—a study of long-term transverse effects in older adolescents and adults. Angle Orthodontist 74: 71–78

Jackson G W, Kokich V G, Shapiro P A 1979 Experimental and postexperimental response to anteriorly directed extraoral force in young *Macaca nemesterina*. American Journal of Orthodontics 75: 318–333

Kajiyama K, Murakami T, Suzuki A 2000 Evaluation of the modified protractor applied to Class III malocclusion with retruded maxilla in early mixed dentition. American Journal of Orthodontics and Dentofacial Orthopedics 118: 549–559

Lertpitayakun P, Miyajima K, Kanomi R, Sinha P K 2001 Cephalometric changes after long-term early treatment with facemask and maxillary intraoral appliance therapy. Seminars in Orthodontics 7: 169–179

MacDonald K E, Kapust A J, Turley P K 1999 Cephalometric changes after the correction of Class III malocclusion with maxillary expansion/ facemask therapy. American Journal of Orthodontics and Dentofacial Orthopedics 116: 13–24

McIntyre G T 2004 Treatment planning in Class III malocclusion. Dental Update 31: 13–20

McNamara Jr J A, Brudon W L 1993 Orthodontic and orthopedic treatment in the mixed dentition. Needham Press Inc., Ann Arbor, p. 117

Merwin D, Ngan P, Hägg U, Yiu C, Wei S H Y 1997 Timing for effective application of anteriorly directed orthopedic force to the maxilla. American Journal of Orthodontics and Dentofacial Orthopedics 112: 292–299

Nanda R 1978 Protraction of maxilla in rhesus monkeys by controlled extraoral forces. American Journal of Orthodontics 74: 121–141

Nartallo-Turley P E, Turley P K 1998 Cephalometric effects of combined palatal expansion and facemask therapy on Class III malocclusion. Angle Orthodontist 68: 217–224

Ngan P, Yiu C, Hu A, Hägg U, Wei S H Y, Gunel E 1998 Cephalometric and occlusal changes following maxillary expansion and protraction. European Journal of Orthodontics 20: 237–254

Proffit W R 1986 Contemporary orthodontics. C.V. Mosby Co, St. Louis, p. 115

Shanker S *et al.* 1996 Cephalometric A point changes during and after maxillary protraction and expansion. American Journal of Orthodontics and Dentofacial Orthopedics 110: 423–430

Singer S L, Henry P J, Rosenberg I 2000 Osseointegrated implants as an adjunct to facemask therapy: a case report. Angle Orthodontist 70: 253–262

Skieller V, Björk A, Linde-Hansen T 1984 Prediction of mandibular growth rotation evaluated from a longitudinal implant sample. American Journal of Orthodontics 86: 359–370

Sugawara J, Asano T, Endo N, Mitani H 1990 Long-term effects of chincup therapy on skeletal profile in mandibular prognathism. American Journal of Orthodontics and Dentofacial Orthopedics 98: 127–133

Tanne K, Sakuda M 1991 Biomechanical and clinical changes of the craniofacial complex from orthopedic maxillary protraction. Angle Orthodontist 61: 145–152

Turley P K 2002 Managing the developing Class III malocclusion with palatal expansion and facemask therapy. American Journal of Orthodontics and Dentofacial Orthopedics 122: 349–352

Üçüncü N, Üçem T T, Yüksel S 2000 A comparison of chincap and maxillary protraction appliances in the treatment of skeletal Class III malocclusions. European Journal of Orthodontics 22: 43–51

Westwood P V, McNamara Jr J A, Baccetti T, Franchi L, Sarver D M 2003 Long-term effects of Class III treatment with rapid maxillary expansion and facemask therapy followed by fixed appliances. American Journal of Orthodontics and Dentofacial Orthopedics 123: 306–320

Yüksel S, Üçem T T, Keykubat A 2001 Early and late facemask therapy. European Journal of Orthodontics 23: 559–568