Original Article

Skeletal Changes of Maxillary Protraction in Patients Exhibiting Skeletal Class III Malocclusion: A Comparison of Three Skeletal Maturation Groups

Kyung-Suk Cha, DDS, MS, PhD[a]

Abstract: This cephalometric study evaluated skeletal and dentoalveolar changes produced by rapid maxillary expansion and facial mask therapy in 85 subjects exhibiting a Class III malocclusion with a retruded maxilla. The skeletal maturity of individual patients was assessed on the basis of Fishman's skeletal maturity indicator (SMI), using hand-wrist radiographs at the initiation of treatment, to determine the relationship between the effect of maxillary protraction and skeletal age. Patients were divided into three groups: prepubertal growth peak group (SMI 1–3), pubertal growth peak group (SMI 4–7), and postpubertal growth peak group (SMI 8–11). The major findings of this cephalometric study were as follows: (1) there was no difference in the effects of maxillary advancement after maxillary protraction between the prepubertal growth peak and the pubertal growth peak group, but there was a decrease in the postpubertal growth peak group; (2) in the postpubertal growth peak group, there was a decrease in maxillary skeletal advancement, whereas the dentoalveolar effect was increased; (3) the posteroinferior rotation of mandible, the increase of lower facial height, and the eruption of maxillary molars showed no correlation with skeletal age. The results of our study emphasize the importance of performing a biologic evaluation of skeletal maturity and pubertal growth peak in individual patients in the diagnosis and treatment planning of Class III malocclusions. (*Angle Orthod* 2003;73:26–35.)

Key Words: Maxillary protraction; RME and facial mask; Skeletal maturity; Fishman's SMI

INTRODUCTION

There are various types of skeletal Class III malocclusions, and the selected treatment plan should directly reflect not only the type of Class III malocclusion but also the timing of the treatment. The chin cap can be used to treat excessive mandibular growth by redirecting mandibular growth[1] and maxillary protraction can be used in treating retruded maxillae by accelerating maxillary growth[2–5] in growing patients. When treating adult patients, orthodontic camouflage treatment can resolve the skeletal discrepancy in moderate cases, and orthognathic surgery should be considered in case of severe skeletal discrepancy.

The prevalence of Class III malocclusion in Koreans occupies approximately 16.7% of the population,[6] whereas the percentage of the Class III malocclusion in patients who visited the department of orthodontics was 47.49%.[7] Of patients exhibiting Class III malocclusions, maxillary retrognathism was prevalent in 42.5% according to Sanborn[8] and 30–40% according to Bell et al.[9] Jacobson et al[10] reported that the one-quarter of Class III malocclusions demonstrated retruded maxilla in the study of 149 subjects.

In 1944, Oppenheim[2] reported that it is impossible to move the mandible backward, but that it is possible to bring the maxilla forward to compensate for mandibular overgrowth when treating Class III malocclusions. In 1971, Delaire[3] tried to protract the maxilla using an orthopedic mask. Dellinger[4] reported that the maxilla separated from the pterygoid and repositioned anteriorly with orthopedic forces in *Macaca* monkeys. Nanda[5] has shown that the forward movement and the anterior displacement of the maxilla are because of the remodeling of the circummaxillary sutures, in particular the zygomaticomaxillary, zygomaticotemporal, and transverse palatine sutures, and reported that the type of displacement was related to the direction of force. Björk[11] reported that appositional growth in the maxillary tuberosity area related to the pyramidal process of the palate and the pterygoid process of the sphenoid is important in growth of the maxilla. McNamara and Brudon[12] reported that the treatment effects of the maxillary protraction included an inferioanterior movement of the maxilla and

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maxillary dentition, clockwise rotation of the mandible, retroclination of the mandibular incisor, and increase of the lower facial height.

Palatal expansion produces a forward and downward movement of the maxilla by affecting the intermaxillary and circummaxillary sutures, and the disruption of these sutures may allow for a more positive reaction to the protraction forces.[13] Kambara[14] suggested that reactions in the suture when protraction force are applied to the maxilla might occur as a result of an opening of the suture, stretching of sutural connective tissue fibers, new bone deposition, and homeostasis, which had maintained the sutural width.

One of the most important factors in considering facial mask treatment is the optimization of treatment timing. Irie and Nakamura[15] suggested that the period of Hellman's dental age IIC and IIIA is the optimal time. Cozzani[16] reported that when the patient is treated at age four years, the direction of the growth of the maxilla coincides with the direction of protraction, which results in increased stability. Kambara[14] and Jackson et al[17] reported that maxillary protraction should be carried out during the growing stage.

Because time, duration, and intensity of maxillofacial growth differ among individuals, the physiologic age has considerable influences on diagnosis, treatment planning, and ultimately the outcome of the treatment. The various assessment methods of growth and development are as follows: evaluation of increments in height, scoring of dental age using calcification and eruption stage of the developing dentition, the secondary sexual characteristics using the menarche and the pubertal voice, and evaluation of skeletal age by maturation of the hand-wrists or vertebrae.

Among various physiologic ages, bone age is indicative of trends in pubertal growth and the assessment of a hand-wrist radiograph has proven to be the most satisfactory method of determining skeletal age. Todd was one of the first investigators to evaluate skeletal maturation, in 1937.[18] Greulich and Pyle[19] have created a radiographic atlas of the skeletal development of the hand and wrist. Tanner et al[20,21] reported about the TW1 and TW2 methods of scoring bone maturity by biologic weighted system.

In 1982, Fishman[22] proposed the System of Skeletal Maturation Assessment (SMA) that identifies 11 main skeletal maturity indicators (SMIs) that are related to the adolescent period of development. These SMIs are located in six anatomic areas of the first, third, and fifth finger, and radius, and the SMI can be arbitrarily divided into periods of accelerating velocity (SMI 1–3), high velocity (SMI 4–7), and decelerating velocity (SMI 8–11).

Rune et al[23] reported that facial changes were not related to skeletal pattern, chronological age, growth peak, and treatment duration. Therefore, a prognosis of the effects was not possible. Sarnäs[24] also reported that the effects of maxillary protraction have no relation to the skeletal type, growth peak, or treatment period. Kapust et al[25] divided the patients into three chronological groups: 4–7, 7–10, and 10–14 years, and showed minimal statistical differences between the three age groups when comparing angular and linear measurements. Baik[26] and Takada[27] also divided patients into three groups and showed no statistical differences among the results in those three groups. Hwang et al[28] classified subjects into four groups: 5.8–8, 8–10, 10–12, and 12–14 years, but found no relation between maxillary protraction effect and treatment timing. Because the sample sizes in the above studies were too small and were based on chronological age rather than skeletal age, treatment timing relative to physiologic characteristics was not evaluated.

Clinically, a majority of patients exhibiting skeletal Class III malocclusion with maxillary retrognathism visit clinics after their pubertal growth spurt, and inevitably the rapid maxillary expansion (RME) and facial mask would be selected as nonsurgical treatment methods. In this study, we tried to define the correlation between the effects of maxillary protraction and the skeletal age level based on Fishman's System of SMA.

TABLE 1. Chronological Age and Treatment Period of Each Group

Classification	SMI	Number of Case	Chronological age (y)		Treatment period (y)	
			Mean	SD	Mean	SD
Group 1	1–3	34	9.82	1.50	1.16	0.42
Group 2	4–7	32	11.31	1.16	1.07	0.33
Group 3	8–11	19	13.07	1.43	1.06	0.38

MATERIALS AND METHODS

Subjects

Eighty-five subjects (26 males and 59 females) from the Dankook University Dental Hospital were diagnosed as skeletal Class III malocclusions with maxillary retrognathism, and treated using RME and facial mask.

Using hand-wrist radiographs, all subjects were divided into three developmental groups according to Fishman's System of SMA. Group 1, which represented the accelerating growth velocity subgroup (SMI 1–3), consisted of 34 subjects. The mean chronological age was 9.82 $\pm$ 1.50 years, and the mean treatment period was 1.16 $\pm$ 0.42 years. Group 2, which represented the high growth velocity subgroup (SMI 4–7), consisted of 32 subjects. The mean chronological age was 11.31 $\pm$ 1.16 years, and the mean treatment duration was 1.07 $\pm$ 0.33 years. Group 3, which represented the decelerating velocity subgroup (SMI 8–11), consisted of 19 subjects. The mean chronological age was 13.07 $\pm$ 1.43 years, and the mean treatment duration was 1.06 $\pm$ 0.38 years (Table 1).

RME and the facial mask

The Hyrax type of banded RME was constructed with soldered hooks at the maxillary first premolar or deciduous

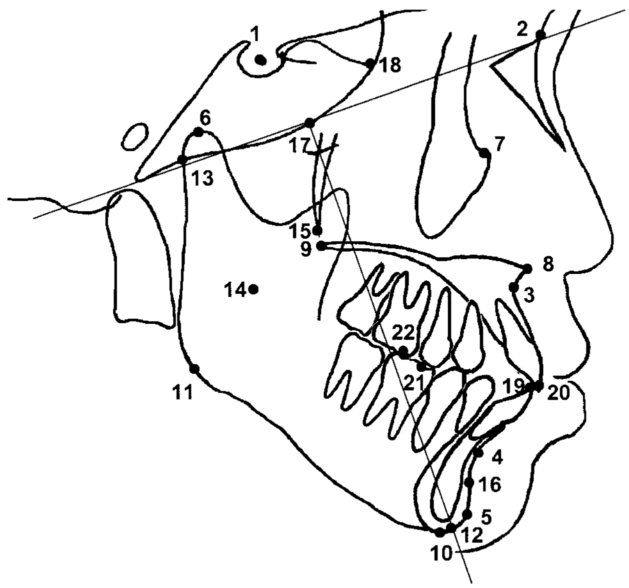

FIGURE 1. Reference points.

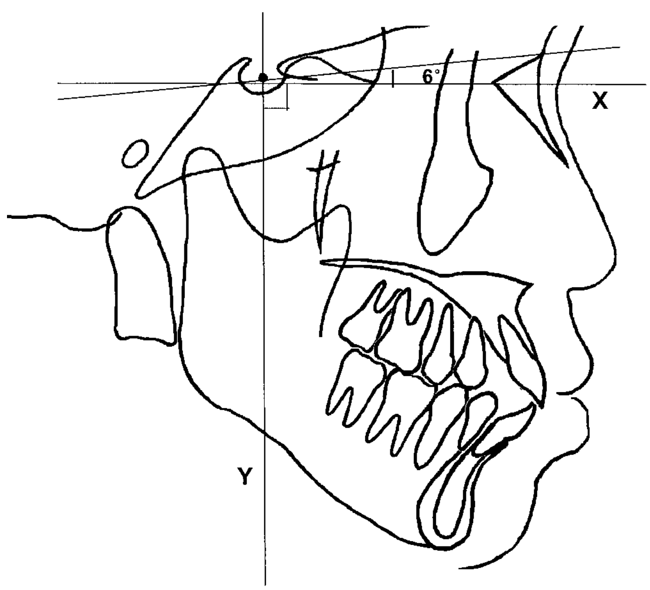

FIGURE 2. Reference lines.

molar, and was activated two turns a day (0.25 mm per turn) for 7–14 days according to the transverse discrepancy, resolving the posterior crossbite.

After activation of the RME, the Delaire's type of facial mask was used for 12 hours with 500 gm of force and positioned just below the lower lip to provide a downward and forward pull of 30° downward to the occlusal plane.

Hand-wrist radiograph

Hand-wrist radiographs were obtained from all patients before treatment and scored with the appropriate SMI as described by Fishman.

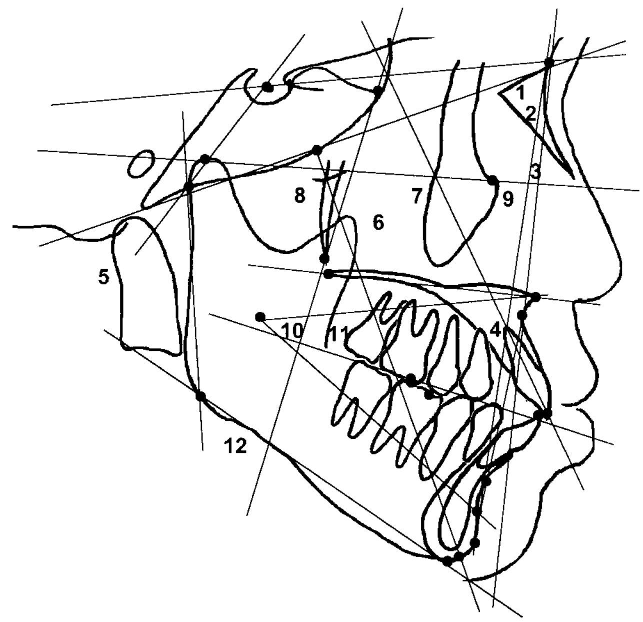

FIGURE 3. Angular measurements. (1) SNA, (2) SNB, (3) ANB, (4) facial convexity, (5) FMA, (6) FH/Pal Pl, (7) U1/FH, (8) Facial axis, (9) Facial angle, (10) LFH, (11) PMV/Occ. Pl, (12) PMV/Ra Pl.

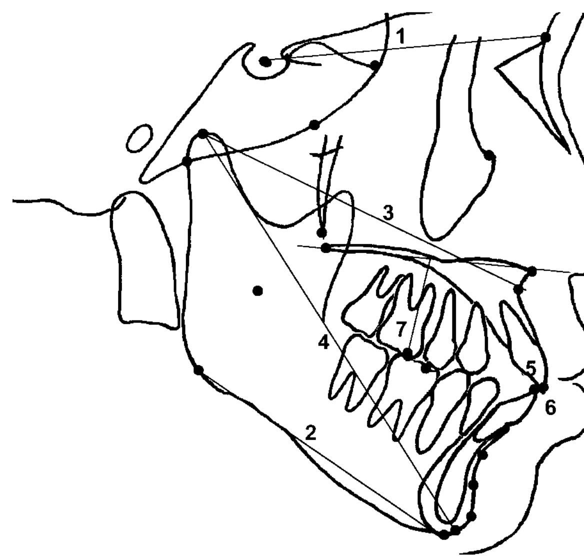

FIGURE 4. Linear measurements 1. (1) ACBL, (2) Mn Body Length, (3) Effective Mx Length, (4) Effective Mn Length, (5) Overbite, (6) Overjet, (7) U6-Pal Pl.

Cephalometric analysis

Cephalometric radiographs were taken before treatment (Pre-Tx) and just after correction of the anterior crossbite (Post-Tx), and traced by one author to avoid interoperate errors. The reference points are shown in Figure 1, and reference lines in Figure 2. The angular, linear, and rotational measurements are shown in Figures 3 through 5.

Reference points. (1) Sella (S), (2) nasion (N), (3) point A, (4) point B, (5) pogonion (Pg), (6) Condylion (Cd), (7)

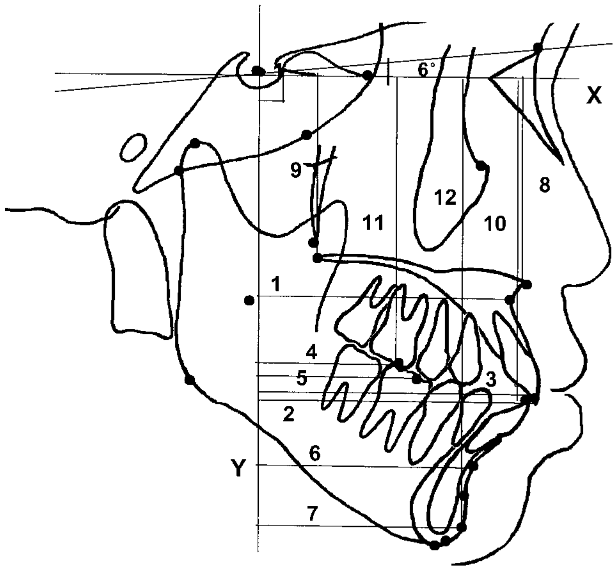

FIGURE 5. Linear measurements 2. (1) Y-A, (2) Y-Mx 1, (3) Y-Mn 1, (4) Y-Mx 6, (5) Y-Mn 6, (6) Y-B, (7) Y-Pg, (8) X-ANS, (9) X-PNS, (10) X-Mn 1, (11) X-Mx 6, (12) X-Pg.

orbitale (Or), (8) anterior nasal spine (ANS), (9) posterior nasal spine (PNS), (10) menton (Me), (11) gonion (Go), (12) Gnathion (Gn), (13) articulare (Ar), (14) Xi, (15) pterygomaxillary fissure (PT), (16) protuberance menti (PM), (17) CC, (18) sphenoethmoidal point (SE), (19) incision inferius (Mn 1), (20) incision superius (Mx 1), (21) molar inferius (Mn 6), (22) molar superius (Mx 6) (Figure 1).

Reference lines. (1) Horizontal reference line (X): 6° downward from sella-nasion (SN) line at sella. (2) Vertical reference line (Y): perpendicular to the horizontal reference line at sella (Figure 2).

Angular measurements. (1) SNA, (2) SNB, (3) ANB, (4) facial convexity, (5) FMA, (6) FH/Pal Pl, (7) U1/FH, (8) Facial axis, (9) Facial angle, (10) LFH (11) PMV/Oc. Pl, (12) PMV/Ra Pl. (Figure 3).

Linear measurements. (1) ACBL, (2) Mn. Body Length, (3) Effective Mx Length, (4) Effective Mn Length, (5) Overbite, (6) Overjet, (7) U6-Pal Pl, (8) Y-A, (9) Y-Mx 1, (10) Y-Mn 1, (11) Y-Mx 6, (12) Y-Mn 6, (13) Y-B, (14) Y-Pg, (15) X-ANS, (16) X-PNS, (17) X-Mn 1, (18) X-Mx 6, (19) X-Pg (Figures 4 and 5).

Statistical analysis

The means and standard deviations of the changes in various measurements were obtained with SPSS 10.0 windows software. There was no significant difference between male and female groups relative to treatment results except changes in FMA and X-Pg ($P < .05$).

To evaluate the effects of facial mask, a paired *t*-test was performed between before and after treatment measurements. The one-way analysis of variance (ANOVA) was carried out to compare the effects between three groups and Sheffe's multiple-range test was used as post hoc multiple comparison. The Pearson correlation analysis was used between changes of overjet and other measurements.

RESULTS

Pretreatment cephalometric values

The mean and standard deviation of initial cephalometric values were calculated (Tables 2 and 3). The mean values for angular measurements for 85 subjects were SNA 79.00°, SNB 80.78°, and facial convexity −2.49°. The maxillary and mandibular length was 81.54 and 117.14 mm, showing skeletal Class III malocclusion with mandibular prognathism and maxillary retrognathism.

Effects of protraction in groups 1, 2 and 3

The changes in group 1 were statistically significant except PMV/OcPl, overbite, and Y-Mn6 ($P < .05$) and the changes in group 2 were statistically significant except PMV/OcPl, overbite, and Y-Mn6 (Tables 4 and 5). The changes in group 3 were statistically significant except F. angle, PMV/OcPl, PMV/RaPl, overbite, and Y-Mn6 ($P < .05$) and had decreased significance in Y-B and Y-Pg.

TABLE 2. Pre-Tx. Cephalometric Values; Angular Measurements

	Group 1		Group 2		Group 3		Total	
Changes	Mean	SD	Mean	SD	Mean	SD	Mean	SD
SNA	78.69	3.06	78.8	3.33	79.98	2.92	79.00	3.14
SNB	80.06	3.47	81.39	3.95	81.12	2.61	80.78	3.55
ANB	−1.44	1.98	−2.55	1.95	−1.17	1.98	−1.83	2.03
Facial conv	−1.21	4.79	−4.41	5.17	−1.30	4.47	−2.49	5.08
FMA	30.84	4.51	28.94	4.62	30.87	5.15	30.09	4.71
FH/Pa Pl	−0.08	3.10	−1.11	3.08	−0.83	2.69	−0.63	3.02
U1/FH Pl	114.69	6.99	117.69	5.92	117.30	5.39	116.36	6.40
Fac axis	86.49	4.77	88.66	4.76	86.33	4.02	87.32	4.71
Fac angle	89.44	3.19	91.34	3.02	90.60	2.79	90.41	3.14
LFH	48.5	4.19	46.75	4.18	48.20	5.45	47.75	4.46
PMV/Oc Pl	95.09	4.58	94.33	4.46	96.33	6.05	95.02	4.82
PMV/Ra Pl	19.18	5.08	17.89	4.87	13.67	3.24	17.65	5.06

TABLE 3. Pre-Tx. Cephalometric values; Linear Measurements

	Group 1		Group 2		Group 3		Total	
Changes	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ACBL	65.32	2.67	67.08	2.97	67.00	2.56	66.33	2.87
Mn.BL	69.27	4.90	72.97	4.45	75.07	4.79	71.80	5.18
Eff Mx.L	79.31	4.40	82.77	4.31	83.97	4.84	81.54	4.81
Eff Mn.L	112.75	5.90	119.66	6.58	121.70	5.55	117.14	7.15
Overbite	1.43	2.38	1.41	2.61	0.53	1.81	1.25	2.38
Overjet	−2.88	1.86	−2.39	1.87	−1.73	1.17	−2.46	1.80
Y-ANS	64.43	3.57	65.89	5.33	66.8	4.26	65.44	4.51
Y-A	60.15	4.07	61.84	4.88	62.83	5.00	61.32	4.64
Y-Mx1	62.41	5.58	65.33	6.63	66.63	5.43	64.35	6.16
Y-Mn1	65.29	5.63	67.73	6.64	68.23	5.58	66.80	6.11
Y-Mx6	33.09	5.19	35.20	5.25	35.60	5.44	34.39	5.31
Y-Mn6	37.41	5.75	41.55	5.58	42.13	4.11	39.92	5.77
Y-B	58.96	7.28	62.70	8.34	62.47	6.46	61.09	7.71
Y-Pg	56.88	8.71	61.70	9.59	60.67	7.24	59.49	9.01
X-ANS	46.18	3.47	47.94	3.07	50.43	2.46	47.66	3.48
X-PNS	43.90	3.38	45.48	4.17	47.87	2.15	45.26	3.79
X-Mn1	72.07	4.10	73.64	5.76	78.93	3.98	73.96	5.70
X-Mx6	65.04	4.19	68.58	4.31	71.80	3.39	67.69	4.79
X-Pg	106.87	6.18	110.44	7.02	116.03	5.55	109.08	7.17

Comparison of treatment effect between three groups

The changes did not show any statistical significance between groups 1 and 2 (Tables 4 and 5). When comparing the treatment effect between groups 1 and 3, and between groups 2 and 3, there were statistically significant differences at SNA, ANB, effective Mx. length, Y-A, Y-Mx1, and U1/FH ($P < .05$).

Correlation between the change of overjet and other changes

The change of overjet correlated with changes of SNA, FMA, LFH, Y-A, Y-Mx.1, X-Mn.1, and X-Pg in groups 1 and 2, with that of U1/FH, Y-Mn1 in group 3, and with that of SNB, Facial axis, Y-Pg, Y-B, and U6-PaPl in all groups (Table 6).

Skeletal and dentoalveolar changes contributing to overjet and molar relation correction

The correction of overjet was because of 80.1% skeletal and 19.9% dentoalveolar effect in group 1, 84.0% skeletal and 16.0% dentoalveolar effect in group 2, and 63.6% skeletal and 36.4% dentoalveolar effect in group 3 (Figures 6 through 8). The correction of molar relation was because of 112.5% skeletal and −12.5% dentoalveolar effect in group 1, 86.5% skeletal and 13.5% dentoalveolar effect in

TABLE 4. Changes Between Pre-Tx and Post-Tx and Comparison of the Treatment Effect Between Three Groups; Angular Measurements[a]

	Group 1			Group 2			Group 3			Significance		
Changes	Mean	SD	Significance	Mean	SD	Significance	Mean	SD	Significance	1 vs 2	2 vs 3	1 vs 3
SNA	2.18	0.91	0.000***	2.03	1.19	0.000***	0.53	0.40	0.000***	0.832 NS	0.000***	0.000***
SNB	−1.09	1.07	0.000***	−1.33	1.40	0.000***	−1.03	1.36	0.011*	0.743 NS	0.758 NS	0.990 NS
ANB	3.44	1.74	0.000***	3.48	1.32	0.000***	1.77	1.05	0.000***	0.993 NS	0.002**	0.002**
Facial conv	6.07	3.00	0.000***	6.03	3.37	0.000***	3.13	2.50	0.000***	0.998 NS	0.014*	0.011*
FMA	1.69	1.81	0.000***	1.80	1.57	0.000***	1.47	1.62	0.003**	0.968 NS	0.822 NS	0.912 NS
FH/Pa Pl	−1.13	1.03	0.000***	−1.12	1.40	0.000***	−0.80	0.75	0.001***	1.000 NS	0.666 NS	0.649 NS
U1/FH Pl	4.04	3.76	0.000***	3.38	2.73	0.000***	6.47	2.27	0.000***	0.689 NS	0.009**	0.050*
Fac axis	−1.51	1.98	0.000***	−1.89	1.54	0.000***	−1.53	1.62	0.003**	0.685 NS	0.809 NS	0.999 NS
Fac angle	−1.13	1.29	0.000***	−1.30	1.39	0.000***	−0.1	3.40	0.853 NS	0.938 NS	0.169 NS	0.266 NS
LFH	0.91	1.30	0.000***	1.73	2.31	0.000***	1.30	1.19	0.001***	0.171 NS	0.733 NS	0.776 NS
PMV/Oc Pl	−0.38	3.05	0.470 NS	−0.03	2.84	0.951 NS	−0.50	3.01	0.531 NS	0.891 NS	0.880 NS	0.992 NS
PMV/Ra Pl	−3.15	3.26	0.000***	−3.05	2.54	0.000***	−1.57	3.61	0.114 NS	0.991 NS	0.309 NS	0.257 NS

[a] NS indicates non significance.
* $P < .05$.
** $P < .01$.
*** $P < .001$.

TABLE 5. Changes Between Pre-Tx and Post-Tx and Comparison of the Treatment Effect Between Three Groups; Linear Measurements[a]

	Group 1			Group 2			Group 3			Significance		
Changes	Mean	SD	Significance	Mean	SD	Significance	Mean	SD	Significance	1 vs 2	2 vs 3	1 vs 3
ACBL	0.72	0.57	0.000***	0.75	0.72	0.000***	0.13	0.30	0.104 NS	0.980 NS	0.006**	0.009**
Mn BL	2.27	1.14	0.000***	2.19	1.02	0.000***	1.16	1.41	0.000***	0.962 NS	0.215 NS	0.140 NS
Eff Mx.L	3.60	1.75	0.000***	3.22	1.22	0.000***	1.67	1.39	0.000***	0.582 NS	0.006**	0.000***
Eff Mn.L	2.53	1.68	0.000***	2.58	1.71	0.000***	1.80	1.78	0.002**	0.993 NS	0.353 NS	0.393 NS
Overbite	0.27	2.19	0.487 NS	−0.56	2.55	0.221 NS	−0.27	1.27	0.428 NS	0.332 NS	0.913 NS	0.742 NS
Overjet	5.53	2.08	0.000***	5.48	2.08	0.000***	4.00	1.58	0.000***	0.936 NS	0.053 NS	0.094 NS
Y-A	2.69	1.18	0.000***	2.69	1.14	0.000***	0.97	0.67	0.000***	1.000 NS	0.000***	0.000***
Y-Mx1	4.25	2.15	0.000***	3.84	2.01	0.000***	2.20	1.19	0.000***	0.709 NS	0.035*	0.006**
Y-Mn1	−1.37	2.33	0.002**	−1.69	2.12	0.000***	−1.83	1.93	0.001***	0.838 NS	0.997 NS	0.790 NS
Y-Mx6	4.74	2.35	0.000***	5.52	2.58	0.000***	3.90	2.52	0.000**	0.444 NS	0.120 NS	0.555 NS
Y-Mn6	0.63	1.90	0.061 NS	0.20	2.18	0.602 NS	−0.33	1.75	0.473 NS	0.683 NS	0.692 NS	0.300 NS
Y-B	−1.30	2.43	0.004**	−1.69	2.58	0.001***	−1.80	2.48	0.014*	0.828 NS	0.990 NS	0.819 NS
Y-Pg	−1.93	2.83	0.000***	−1.91	2.91	0.001***	−1.57	2.77	0.046*	1.000 NS	0.930 NS	0.921 NS
X-ANS	1.60	1.09	0.000***	1.20	0.79	0.000***	0.93	0.50	0.000***	0.199 NS	0.629 NS	0.060 NS
X-PNS	2.69	2.22	0.000***	2.38	1.72	0.000***	1.43	0.46	0.000***	0.780 NS	0.261 NS	0.090 NS
X-Mn1	2.37	2.36	0.000***	3.05	4.24	0.000***	1.67	1.50	0.000***	0.683 NS	0.380 NS	0.773 NS
X-Mx6	4.10	1.62	0.000***	3.73	1.60	0.000***	3.20	2.04	0.000***	0.688 NS	0.615 NS	0.247 NS
X-Pg	4.67	2.08	0.000***	5.36	3.39	0.000***	3.23	1.96	0.000***	0.583 NS	0.044*	0.223 NS

[a] NS indicates nonsignificance.
* $P < .05$.
** $P < .01$.
*** $P < .001$.

TABLE 6. Correlation of the Overjet Change and Other Treatment Changes[a]

	Group 1		Group 2		Group 3	
Changes	Pearson Correlation	Significance	Pearson Correlation	Significance	Pearson Correlation	Significance
SNA	0.416	0.014*	0.409	0.020*	−0.113	0.688 NS
SNB	−0.626	0.000***	−0.569	0.001***	−0.908	0.000***
FMA	0.645	0.000***	0.635	0.000***	0.467	0.079 NS
FH/Pa Pl	−0.392	0.022*	0.194	0.289 NS	−0.105	0.709 NS
U1/FH Pl	0.308	0.076 NS	0.372	0.056 NS	0.607	0.017*
F. axis	−0.339	0.050*	−0.667	0.000***	0.690	0.004**
U6-Pa Pl	0.417	0.014*	0.692	0.000***	0.600	0.018*
LFH	−0.568	0.000***	0.544	0.001***	0.464	0.081 NS
Y-A	0.401	0.023*	0.439	0.012*	−0.169	0.546 NS
Y-Mx1	0.357	0.038*	0.483	0.005**	−0.006	0.814 NS
Y-Mn1	−0.336	0.052 NS	−0.391	0.027*	−0.019	0.000***
Y-Mx6	0.049	0.785 NS	0.278	0.124 NS	0.352	0.198 NS
Y-Mn6	−0.326	0.060 NS	−0.195	0.284 NS	−0.789	0.000***
Y-B	−0.532	0.001***	−0.690	0.004**	−0.812	0.000***
Y-Pg	−0.606	0.000***	−0.536	0.002**	−0.771	0.001***
X-ANS	−0.223	0.205 NS	0.067	0.714 NS	0.205	0.463 NS
X-PNS	−0.239	0.174 NS	0.154	0.399 NS	0.296	0.284 NS
X-Mn1	0.430	0.011*	0.395	0.025*	0.408	0.131 NS
X-Mx6	0.314	0.070 NS	0.255	0.159 NS	0.514	0.050*
X-B	0.452	0.007**	0.686	0.000***	0.195	0.485 NS
X-Pg	0.385	0.030**	0.518	0.002**	0.380	0.163 NS

[a] NS indicates non significance.
* $P < .05$.
** $P < .01$.
*** $P < .001$.

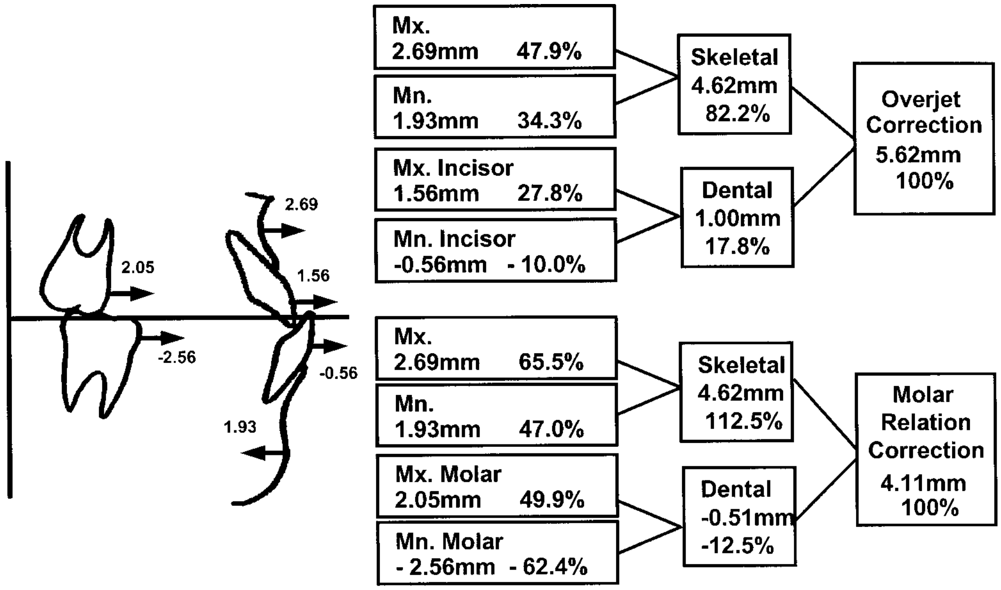

FIGURE 6. Skeletal and dentoalveolar changes contributing to overjet and molar relation correction (in group 1).

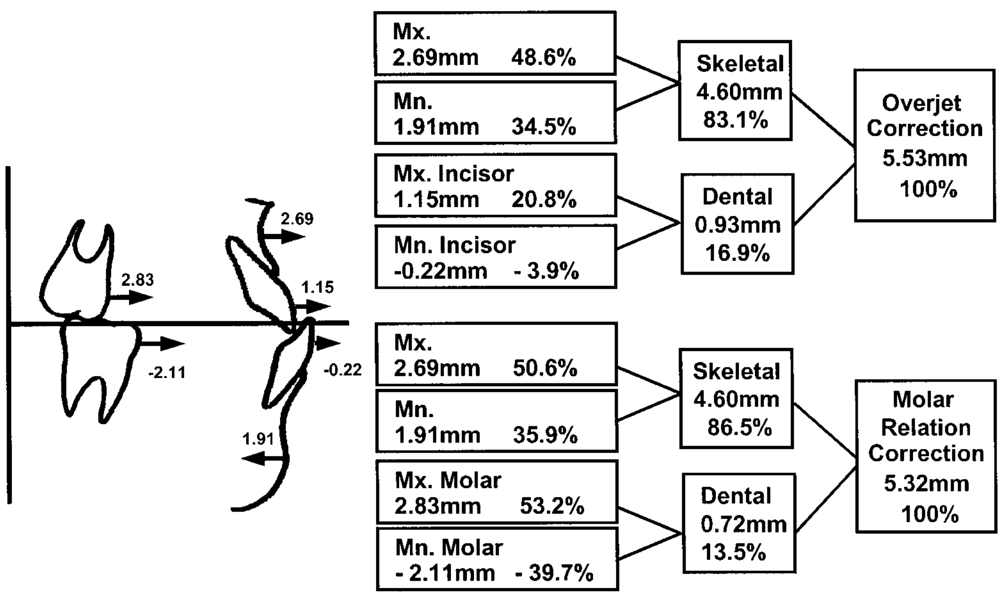

FIGURE 7. Skeletal and dentoalveolar changes contributing to overjet and molar relation correction (in group 2).

group 2, and 60.0% skeletal and 40.0% dentoalveolar effect in group 3.

DISCUSSION

Before 1970, skeletal Class III malocclusion was believed to result from a prognathic mandible. Consequently skeletal Class III malocclusions were treated with a chin cap to inhibit mandibular growth, or by orthognathic surgery after completion of growth. In recent years, however, face mask therapy has become a common technique used to correct the developing Class III malocclusion because of the increasing acceptance of a significant influence of maxillary deficiency in Class III structural etiology. In addition, numerous clinical reports suggest this approach is more successful than other techniques such as chin cap, functional appliance, or camouflage therapy.

Kambara's animal study[14] with *Macaca irus* showed that forward movement and anterior displacement of the maxilla by extra oral forward force are because of the remodeling of the circummaxillary suture and the maxillary tuberosity. The extra oral forward forces are most effective when used as early as possible because of the high degree of cellular activity in the suture area during this time. In her description of the development of sutures involved in the area of

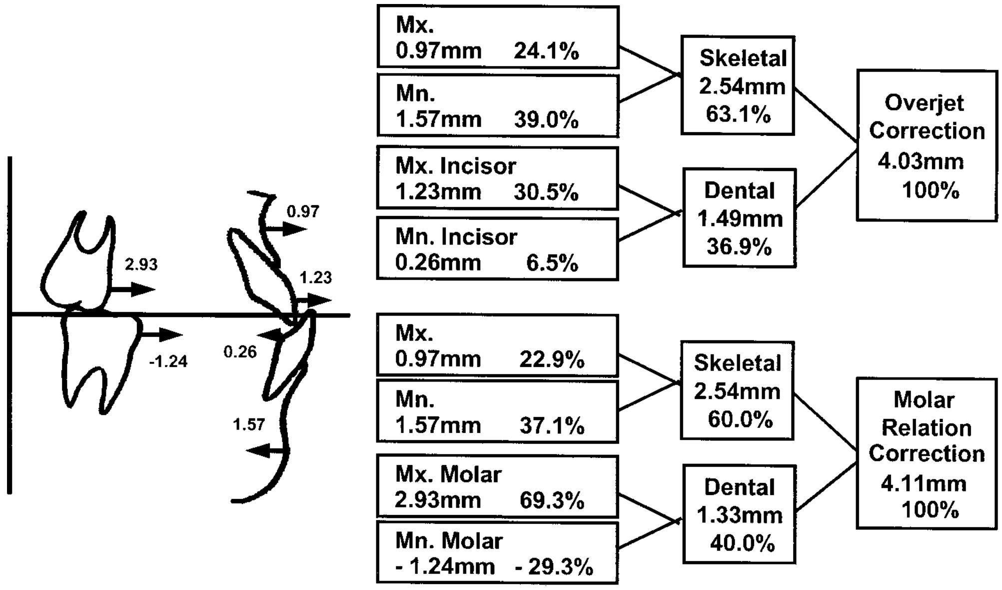

FIGURE 8. Skeletal and dentoalveolar changes contributing to overjet and molar relation correction (in group 3).

the maxilla, the palatine bone, and the sphenoid bones, Melsen[29] reported that with increasing age and the developing complexity of the sutural system, attempted disarticulation during the late juvenile and early adolescent periods was always accompanied by fracture of the heavily interdigitated osseous surface.

Hass[13] reported that palatal expansion by RME produced a forward and downward movement of maxilla by affecting the intermaxillary and circummaxillary sutures and the disruption of these sutures may help initiate cellular response in the sutures, allowing for a more positive reaction to protraction force. Because the anterior portion of maxilla can be constricted with maxillary protraction[30,31] and maxillary retrognathic patients also have posterior crossbites because of the transverse maxillary deficiency, the RME is useful in these patients.

One of the most important factors to consider about treatment of skeletal discrepancies is the optimal treatment timing and prognosis of growth by the evaluation of skeletal maturity. Although growth is a sequential phenomenon common to everyone, the onset, intensity, and duration of adolescent growth varies greatly between individuals. Individual growth and development should be evaluated by physiologic age and not by chronological age. Skeletal age can assess the skeletal maturity by the developmental status of individual bones. Radiographs of the hand and wrist are very useful in assessing skeletal maturity because of successive changes from the birth to the completion of growth, in addition to the convenience in taking such radiographs when compared with other regions. Intramembranous ossification is observed around the circummaxillary sutures, and these sutures have an adaptability in the growing facial skeleton.[32] Suda et al[33] have reported that although the hand-wrist film is based on the endochondral ossification of RUS bones, the skeletal age of facial mask patients was closely correlated with the forward movement of maxilla and increase in palatal length, and consequently, with remodeling of circummaxillary sutures.

Pretreatment cephalometric values

The mean of the 85 subjects for the angle was SNA 79.00° and for SNB 80.78° (Tables 2 and 3). In a comparison with the norm, determined in a previous investigation by Baik[34] for the 10–12 age group, the SNA angle was 81° and the SNB was 78°. The lengths of the maxillae and mandibles in our study were 81.52 and 117.14 mm, respectively. This is somewhat different from the results of the study reported by Kwon.[35] He found average maxillary sizes for male and female subjects of 86.2 and 83.6 mm, respectively, and average mandibular sizes of 111.0 and 108.5 mm in normal 11-year-old children. The subjects in our study showed skeletal Class III malocclusion with both maxillary retrognathism and mandibular prognathism.

Effects of maxillary protraction in each group

In all groups, the maxilla moved forward and the palatal plane rotated in a counterclockwise direction (Tables 4 and 5). The mandible moved downward and backward, the facial convexity and the lower face height were increased, coincident with other investment.[15,26,30,36–41] There were no significant differences in the changes in overbite and horizontal molar movement.

Comparison of the treatment effect between three groups

The changes of all measurements did not show any significant statistical differences between groups 1 and 2 and, therefore, no significant differences in the protraction effect between prepubertal and pubertal growth peak group (Tables 4 and 5).

There were significant differences in SNA, ANB, effective Mx length, Y-A, Y-Mx 1, and U1/FH ($P < .05$) between groups 1 and 3, and between groups 2 and 3. The horizontal anterior movement of the maxilla was decreased and the proclination of maxillary anterior teeth was increased in group 3. These results suggest the decrease in skeletal anterior movement of the maxilla and the increase in dentoalveolar effect.

The changes in SNA showed greater response in groups 1 and 2 with an average of 2.18° and 2.03°, respectively, decreasing to 0.53° in group 3. The changes in effective maxillary length were 3.60 and 3.22 mm in groups 1 and 2, decreasing to 1.67 mm in group 3. Rune,[23] Sarnas,[24] Kapust,[25] Baik,[26] Takada[27], and Whang et al[28] reported that the changes of the maxillary protraction in older children were similar to the changes in younger children. But the changes of the maxillary protraction in prepubertal and pubertal growth peak were larger in postpubertal growth peak in our investigation, because we divided groups according to the skeletal age not to the chronological age.

Correlation between the change of overjet and other changes

As the change of overjet correlated with changes of SNA, FMA, LFH, Y-A, Y-Mx1, X-Mn1, X-B, and X-Pg in groups 1 and 2, the correction of overjet came from the anterior movement of the maxilla and the increased movement of the vertical dimension (Table 6). Because the change of overjet correlated with changes of SNB, Facial axis, U6-Pal Pl, Y-B, and Y-Pg in group 3, the correction of overjet resulted from the posteroinferior rotation of the mandible and vertical eruption of maxillary molars.

Skeletal and dentoalveolar changes contributing to overjet and molar relation correction

The maxillary anterior movement in group 3 was 0.97 mm, ie, one-third of group 1 (2.69 mm) and group 2 (2.69 mm) (Figures 6 through 8). Nanda[42] reported that the maxilla move anteriorly 1–3 mm and the maxillary teeth 1–4 mm with maxillary protraction in 20 subjects for six months. In this study, the anterior displacements of maxillary anterior teeth were 4.25, 3.84, and 2.20 mm in groups 1, 2, and 3. The anterior displacements of maxillary molars were 4.74, 5.52, and 3.90 mm in groups 1, 2, and 3.

In the correction of overjet and molar relation, the anterior displacement of maxilla contributed about 50% in groups 1 and 2, and below 25% in group 3. The correction of overjet and molar relation by maxillary protraction is because of the skeletal effect at prepubertal and pubertal growth spurt, and to the increased dentoalveolar effect at postpubertal growth spurt. According to Kambara's study[14] that used facial mask for *Macaca irus* monkeys, the skeletal displacement could easily be obtained in the deciduous dentition group, but dentoalveolar change occurred in the mixed dentition group.

CONCLUSION

This cephalometric study evaluated skeletal and dentoalveolar changes induced by RME and facial mask in three groups of 85 subjects exhibiting Class III malocclusion with retruded maxilla.

The major findings were as follows.

1. There was no difference in the effects of maxillary advancement after maxillary protraction between the prepubertal growth peak and the pubertal growth peak group, but there was a decrease in the postpubertal growth peak group.
2. In the postpubertal growth peak group, there was a decrease in maxillary skeletal advancement, although the dentoalveolar effect increased.
3. The posteroinferior rotation of mandible, the increase of lower facial height, and the eruption of maxillary molars showed no correlation with skeletal age.

The results of our study emphasize the importance of performing a biologic evaluation of skeletal maturity and pubertal growth peak in individual patients in the diagnosis and treatment planning of Class III malocclusions.

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