ORIGINAL ARTICLE

Assessment of skeletal and dental changes by maxillary protraction

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To further evaluate the effect of maxillary protraction on facial growth, cephalometric changes in 129 subjects with conditions diagnosed as skeletal Class III malocclusion and who had been treated with maxillary protraction were compared to 9 male and 12 female subjects with annual cephalometric records from the Yonsei growth study sample. The control subjects had Angle Class I malocclusions with normal overjet and overbite. More maxillary forward displacement and mandibular growth inhibition were observed in the protraction group during treatment, and the difference from the untreated controls was statistically significant. When changes due to treatment according to ages were compared, there was no statistical difference. The direction of maxillary growth was similar in the untreated and protraction groups. Maxillary protraction had a growth-stimulating effect on the maxilla during the treatment period. (Am J Orthod Dentofacial Orthop 1998;114:492-502)

There have been many studies on morphologic features, developmental features, and growth pattern of skeletal Class III malocclusion.[1-3] Camouflage treatment is possible in mild to moderate skeletal Class III cases; however, for growing patients with moderate to severe skeletal problems, orthopedic appliances such as chin cup and maxillary protraction headgear are indicated.[4-20]

Maxillary protraction is recommended for skeletal Class III patients with maxillary deficiency.[5-7] The principle of maxillary protraction is to apply tensile force on the circumaxillary sutures and thereby stimulate bone apposition in the suture areas; in doing so, the maxillary teeth become the point of force application,[9,11] and the face (forehead, chin, zygoma) or occipital area becomes the anchorage source.[8,15] In animal[21-23] and biomechanical studies,[24,25] histologic changes and stress distribution in suture areas strongly suggest the application in human subjects.

One of the most important factors to consider in treating skeletal Class III patients with orthopedic force is the optimal treatment timing.[26,27] Early intervention facilitates growth modification, but there may be difficulty in retaining treatment effects through the growth period, necessitating long-term treatment and patient cooperation.[10,16] Orthopedic treatment during the prepubertal and pubertal period can shorten treatment time, and if mandibular growth is properly controlled after the treatment, favorable anterior occlusion can be obtained.[11,20] Nonetheless, improvement of the facial profile is inferior to what can be achieved in surgical-orthodontic patients because the actual length of mandible, which is excessive in skeletal Class III patients, cannot be reduced.[14,28]

The effects of maxillary protraction that are seen on the lateral cephalogram include forward and downward movement of the maxillary bone and dentition, lingual inclination of mandibular teeth, and downward and backward rotation of the mandible.[12,13,18] These effects tend to turn Class III malocclusion into Class I occlusion and produce an orthognathic profile in a short period of time. Nevertheless, whether maxillary protraction can actually stimulate growth is still obscure, and questions have been raised as to the orthopedic effect in prepubertal or pubertal subjects.[14,16]

The purpose of this study was to examine whether maxillary protraction brings skeletal changes, how skeletal and dental changes progress with aging, and whether growth is actually stimulated by maxillary protraction, by comparing control and maxillary protraction groups during and after treatment.

MATERIAL AND METHODS

Subjects

The protraction group consisted of 129 subjects age 7 to 13 years, who were treated at Youngdong-Severance Hospital, Yonsei University. Their conditions were diagnosed as skeletal Class III malocclusion with a deficient maxilla as compared to the Korean norm.[19]

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Table I. Age and sex distribution of untreated and protraction subjects

Age interval (Years)	Untreated group			Protraction group		
	Male	*Female*	*Subtotal*	*Male*	*Female*	*Subtotal*
7-8	9	12	21	12	6	18
8-9	9	12	21	8	12	20
9-10	9	12	21	6	14	20
10-11	9	12	21	7	23	30
11-12	9	12	21	7	16	23
12-13	9	12	21	11	7	18
Total						129

For the untreated group, annual follow-up of 9-male and 12-female subjects was done from age 7 to 13.

Table II. Comparison of initial cephalometric values of the untreated and protraction groups

	Age 7				Age 12			
	Untreated		Protraction		Untreated		Protraction	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Angular (°)								
SNA	80.17	3.01 *	78.56	2.59	80.43	1.76*	78.35	2.76
SNB	74.93	2.54***	78.97	1.98	76.44	1.88 **	78.65	2.64
ANB	5.22	1.57***	–.49	1.88	3.98	1.37 ***	–.31	2.10
MP	32.98	3.40**	30.58	2.68	31.46	3.40	32.37	3.94
Linear (mm)								
MxL	46.20	2.49*	43.53	2.49	49.42	2.32 **	47.44	1.40
MnL	96.02	3.38 *	101.29	5.90	111.30	3.55	114.41	5.83
Wits	–1.48	4.08 ***	6.92	2.72	–2.73	1.74 ***	7.05	3.35
Number	22		18		21		18	

Paired *t* test between the untreated group and protraction group: *, $P < .05$; **, $P < .01$; ***, $P < .001$.

As untreated controls, 9 males and 12 females with longitudinal records who showed Angle Class I molar relationship on lateral cephalograms along with normal anterior overbite and overjet were selected from the Yonsei growth study sample. Both the protraction and untreated groups were divided into six age groups (Table I).

In addition, 22 children 10 to 12 years of age who came for follow-up checks after maxillary protraction were chosen as follow-up subjects. They were compared with the untreated group of age 11 patients for treatment effects, and with the untreated group of age 12 patients for 1 year posttreatment changes. In almost all the patients in the follow-up protraction group, night wear of a chin cup was recommended after crossbite correction, and was continued until the initiation of fixed appliance treatment.

Methods

Maxillary protraction device and methods. A rapid palatal expansion (RPE) appliance with bands on first molars and first premolars and a soldered palatal framework with jackscrew, or a labiolingual (La/Li) appliance with bands on first molars, was used as the intraoral appliance, and Delaire's face mask was used as the extraoral appliance. The RPE appliance was used for expansion in patients with a constricted maxilla. It was also used in some patients who needed no maxillary expansion because it holds the maxilla as one rigid unit. In the primary dentition of patients who needed expansion, primary canines and primary molars were banded for the RPE placement. The La/Li appliance was used only for mixed dentition patients who needed no expansion. Force from the face mask was applied to a hook that was positioned about 8 mm superior to the occlusal plane and at the mesial side of maxillary first premolar of RPE appliances, or at the posterior side of the deciduous canine of La/Li appliances. The force vector was about 25° downward and forward to the occlusal plane. The face mask was used for more than 12 hours a day, with about 300 to 400 gm forces on each side.

Analysis of lateral cephalograms. For the protraction patients, lateral cephalograms were taken before and after anterior crossbite correction, which required 8 to 9 months for most children. For the untreated con-

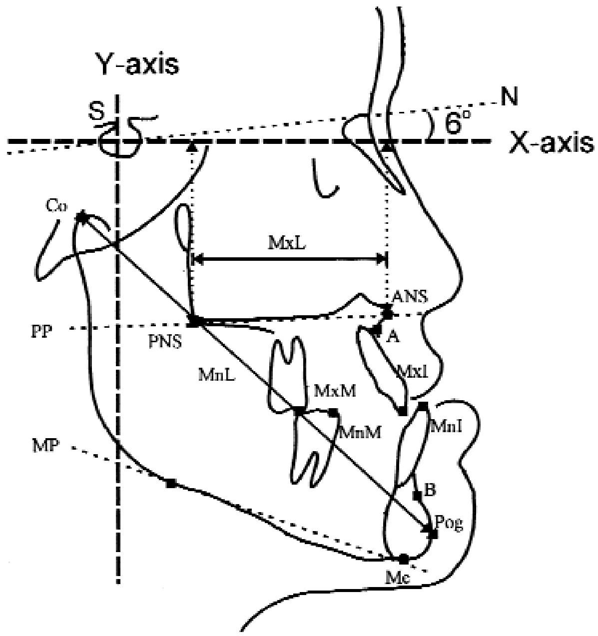

Fig 1. X-Y axis and cephalometric landmarks.

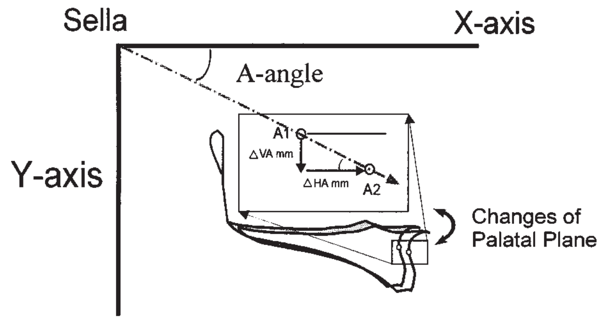

Fig 2. Assessment of direction of jaw displacement and rotation.

trol, cephalograms were taken annually from the age of 7 to 13. The S-N (sella-nasion) plane was used as a reference for overall superimposition; in consideration of the growth changes of sella and nasion, stable structures of the anterior cranial base were also used.[12,29] Cephalometric measurements were taken by one person, and to validate reproducibility of the measurements, 20 randomly selected cephalograms were retraced after a 1-week interval. Correlations between the double measurements were then analyzed in terms of vertical, horizontal, and angular measurements. The correlation coefficients between the double measurements in all three cases were over 0.9.[30]

A horizontal reference plane (X-axis) was created for the linear and angular measurements. This reference plane was set up from the point sella with a 6° downward inclination to S-N line. A line perpendicular to the X-axis at point sella was constructed as the vertical reference plane (Y-axis) (Fig. 1).

Vertical and horizontal linear measurements were made for the following seven points: point A, PNS, point B, incisal edge of the maxillary incisor (MxI), mesial cusp tip of the maxillary first molar (MxM), incisal edge of the mandibular incisor (MnI), and mesial cusp tip of the mandibular first molar (MnM). Maxillary length (MxL) was measured by the distance along the X-axis between ANS and PNS, and mandibular length (MnL) was measured by the distance between condylion (Co) and pogonion (Pog). Measurements of the SNA, SNB, and ANB angles and the Wits value were taken. The palatal plane angle (PP) and mandibular plane angle (MP) were measured to the X-axis. For the measurement of the direction of maxillary displacement, the angular displacement of point A to X-axis (A-angle) was calculated as *Arctangent [(vertical changes of point A) / (horizontal changes of point A)] * 57.3* (Fig. 2).

After the landmark location, the measurements were digitized and calculated by the Yonsei cephalometric analysis program on an IBM-compatible PC.

Statistical analysis. Annual growth amounts were measured by superimposition of cephalograms in the untreated group, and treatment changes were measured by the difference in landmark location before and after correction of anterior crossbite in the protraction group. The mean and standard deviation of the changes in all cephalometric measurements of all groups were calculated.

Paired *t* tests were performed to observe the significance of differences between the amounts of growth or treatment change within each group. A group *t* test was performed to compare growth of the untreated and protraction groups, to evaluate the orthopedic effect of maxillary protraction. Analysis of variance (ANOVA) was done among the different age groups of untreated and protraction patients to examine differences due to age.

RESULTS

There were statistically significant differences ($p < 0.001$) in growth amount of the untreated and protraction groups in the six groups that were divided according to ages.

Comparison of initial cephalometric values of the untreated and protraction groups (Table II)

At the ages of 7 and 12 years, the protraction group showed maxillary deficiency with decreased SNA angle and maxillary length, and moderate to severe skeletal Class III malocclusion tendency by the Wits

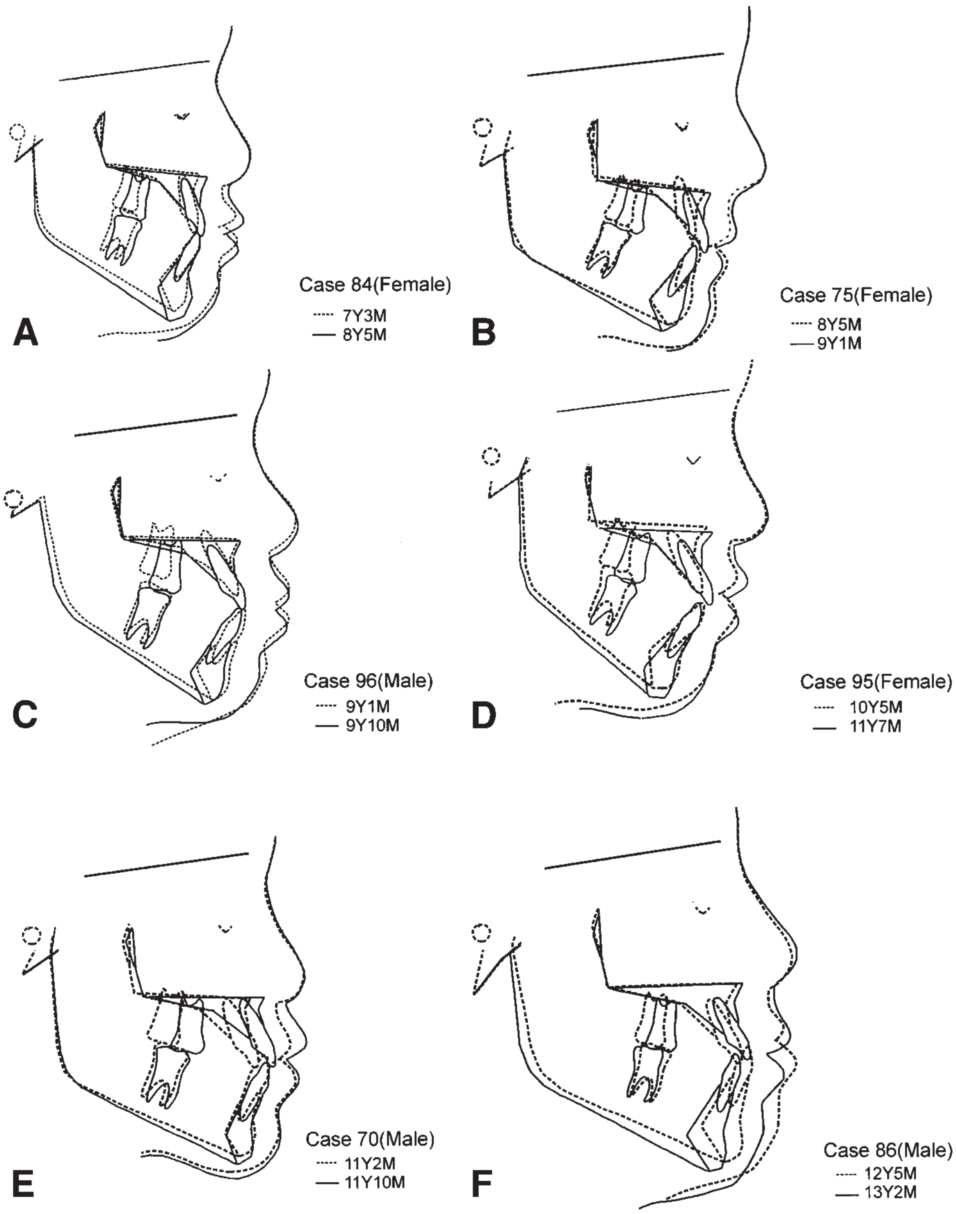

Fig 3. Superimposition of protraction cases of different age groups (before and after treatment).

analysis. In the untreated groups, there was a tendency for SNA and SNB to be smaller than the Korean norms, but the ANB angle and Wits value were within normal range.[19]

Statistical significance of the changes and gender difference

When the protraction group and untreated group were divided according to ages to make comparisons, significant differences were noted between the amount of changes and annual growth. There was almost no gender difference in either the protraction group or the untreated group according to ages, so the data for males and females were combined.

Comparison of the changes in the untreated and protraction groups (Table III)

The duration of treatment was between 7.8 and 9.1 months, and changes that occurred during this period were compared with the annual growth amount of the untreated group. The growth rate of the untreated group was similar to that of the Ann Arbor samples.[26] When the protraction and untreated groups of the same age were compared, vertical changes of point A were

Table III. Comparison of the changes of untreated and protraction groups according to ages

	Age 7				*Age 8*				*Age 9*			
	Untreated		*Protraction*		*Untreated*		*Protraction*		*Untreated*		*Protraction*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Horizontal (mm)												
A	0.3	0.9***	2.8	1.4	0.4	0.7***	2.0	1.2	0.8	0.8**	2.1	1.4
PNS	0.3	1.1***	1.1	0.9	–0.2	1.0***	0.7	1.2	0.4	1.0***	1.0	1.0
B	0.2	1.4*	–1.7	1.6	0.5	1.0*	–2.1	1.8	0.9	1.5*	–2.6	2.7
MxI	1.8	1.5***	4.8	2.8	1.9	1.4**	3.7	1.9	1.6	1.0	2.4	2.3
MxM	0.2	1.1***	3.6	1.7	0.5	1.1***	3.0	1.9	1.1	1.0**	3.3	2.7
MnI	1.6	1.8***	–0.8	1.9	1.4	1.3***	–1.5	1.6	1.2	0.9***	–2.4	2.2
MnM	0.9	1.0***	–0.2	1.3	0.7	l.1**	–0.7	1.7	1.0	1.1*	–0.4	2.1
Vertical (mm)												
A	1.4	0.7	1.3	1.3	1.7	0.8*	0.8	1.0	1.4	0.8	1.2	0.9
PNS	1.3	0.7	1.7	0.9	1.4	1.0	1.4	1.1	1.0	0.6**	1.8	1.1
B	2.5	1.3	2.8	2.4	2.5	0.9	2.7	1.5	2.6	0.9	3.2	2.3
MxI	3.2	4.5	2.6	3.4	3.3	3.6	1.6	1.4	2.7	1.8	2.1	1.6
MxM	3.7	2.1	3.5	1.9	2.7	1.4	3.0	1.5	2.1	0.6*	3.2	2.1
MNI	1.2	2.1	2.1	2.4	1.8	1.1	1.9	1.5	1.3	0.9	1.8	2.0
MnM	0.8	2.0	1.8	1.7	2.2	0.7*	1.6	1.0	2.0	0.6	2.4	1.8
Angular (°)												
SNA	–0.5	1.0***	2.1	1.5	–0.6	1.0***	1.7	1.1	0.2	1.0**	1.7	1.4
SNB	–0.0	0.7***	–1.4	1.1	–0.1	0.7***	–1.3	1.0	0.4	0.9***	–1.3	1.4
ANB	–0.4	0.7***	3.4	1.4	–0.5	0.7***	2.9	1.2	–0.1	0.7***	3.0	2.0
PP	0.1	1.1	–0.4	1.3	0.3	1.2**	–0.8	1.5	0.2	0.9**	–0.9	1.3
MP	0.0	1.2***	2.2	1.6	0.1	0.8***	1.7	1.1	–0.3	0.9***	1.6	1.4
Linear (mm)												
MxL	0.5	1.2***	1.5	1.5	0.7	1.1**	1.3	1.3	0.9	1.0*	1.3	1.2
MnL	3.3	0.8***	1.2	2.0	2.6	1.1***	0.6	1.9	2.4	1.4*	1.2	1.3
Wits	–0.1	2.9***	4.7	3.1	–0.1	2.9***	4.2	1.8	–0.3	1.6***	4.8	2.9
Age (yrs)	7.0	0.0	7.8	0.9	8.0	0.0	8.6	0.4	9.0	0.0	9.6	0.3
Period (mo)	12.0	0.0	8.4	2.4	12.0	0.0	7.8	3.9	12.0	0.0	8.9	3.8
Number	21		18		2l		20		21		20	

Group *t* test between the untreated group and protraction group: *, $P < .05$; **, $P < .01$; ***, $P < .001$.

similar or less, but horizontal changes in the protraction group were twice to four times those of the untreated group ($P < .05$). The horizontal changes of point B in the protraction group were from –1.7 to –2.7 mm, which were opposite to those of the untreated group (0.2 to 2.2 mm) (Figs. 3 and 4*B*). The mandibular plane angle decreased with age in the untreated group, and increased in the protraction group ($P < .001$). The palatal plane angle decreased slightly in the protraction group at all ages, but increased slightly or stayed the same in the untreated group.

The horizontal changes of maxillary central incisors were from 2.4 to 4.8 mm in the protraction group, which were greater than those of the untreated group (1.0 to 1.9 mm). In addition, the horizontal changes of the maxillary central incisors in the protraction group were greater than those of A point (1.7 to 2.8 mm). The vertical changes of maxillary molars in the protraction patients were 2.5 to 3.5 mm, which were similar to those of the untreated group (1.6 to 3.7 mm).

Comparison of follow-up subjects in the protraction and untreated groups (Table IV)

The horizontal changes of point A in the protraction group during the first year posttreatment decreased to one half of the amount during the active protraction period. The vertical changes of point A during posttreatment were similar to those during protraction, but one third of the amount in the 12-year-old untreated group. Mandibular length in the protraction group showed only a 0.4 mm increase during treatment, but it increased 2.7 mm during the posttreatment period. Nonetheless, it was still less than the annual growth amount of untreated group of age 12.

The mandibular plane angle increased 2.1° during treatment period, but it decreased 1.1° during 1 year

Age 10				*Age 11*				*Age 12*			
Untreated		*Protraction*		*Untreated*		*Protraction*		*Untreated*		*Protraction*	
Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
0.6	0.8***	2.2	1.2	1.3	1.0*	2.1	1.3	0.6	1.2*	1.7	0.6
–0.2	1.0***	1.2	1.3	0.6	1.0***	0.8	0.9	0.3	1.3*	0.8	0.7
0.7	1.0***	2.3	2.3	2.2	1.4	–2.0	2.5	0.4	1.8	–2.7	3.1
1.0	1.0***	3.1	2.2	1.9	1.3	2.9	2.8	1.0	1.4**	3.3	2.2
0.8	0.9***	3.9	2.7	2.1	1.5	3.4	2.6	1.0	1.8	2.1	1.5
1.2	1.0***	–1.8	1.9	1.9	1.3***	–1.3	1.8	0.5	1.6*	–1.4	2.5
1.1	0.7**	–0.3	1.8	2.4	1.3***	–0.4	1.3	1.9	1.6*	–0.3	2.2
1.4	0.7*	0.9	1.0	1.0	0.9	0.9	0.9	2.7	1.3*	1.3	1.1
1.1	1.0	1.6	1.0	1.3	0.9	1.4	1.2	1.5	0.7	1.4	0.6
2.4	1.0	2.9	1.5	1.9	1.0	2.8	1.8	4.7	2.2	4.1	2.5
1.9	0.9	1.3	1.1	1.1	0.9	1.3	1.4	3.5	1.0	2.2	2.0
1.6	0.6**	3.0	1.5	2.0	0.8	2.5	1.9	3.5	1.0	3.0	1.5
1.8	1.1	1.9	1.3	1.1	0.9**	2.4	1.8	3.3	1.2	3.0	2.3
1.8	0.8	2.1	1.1	1.9	1.0	2.0	1.5	2.1	1.0	2.8	1.9
0.0	0.9***	1.7	1.4	0.5	0.8***	2.0	1.3	0.3	1.0	1.0	0.9
0.2	0.6***	1.4	1.0	0.8	0.6***	–1.1	1.1	0.5	0.7**	–1.6	1.6
–0.2	0.7***	3.1	1.6	–0.3	0.8***	3.0	1.8	–0.2	0.5	2.5	2.0
0.3	1.4**	–1.1	1.9	0.2	1.1	–0.4	1.5	0.4	1.0	–0.4	2.1
0.0	0.7***	1.5	1.2	–1.1	0.9***	1.7	1.7	–0.5	1.1***	2.1	1.4
0.7	1.1*	1.2	1.0	0.7	1.2**	1.3	1.3	0.5	1.5*	1.2	1.0
2.6	1.6***	0.8	1.4	2.9	1.5***	0.4	1.5	4.8	2.4 ***	0.6	1.5
–0.6	1.3***	4.9	2.9	–0.1	1.2***	4.7	2.9	0.0	1.1**	4.2	3.9
10.0	0.0	10.6	0.3	11.0	0.0	11.5	0.5	12.0	0.0	12.7	0.4
12.0	0.0	7.9	2.2	12.0	0.0	8.3	3.4	12.0	0.0	9.1	3.6
21		30		21		23		21		18	

posttreatment. The mandibular teeth and point B moved more anteriorly during the posttreatment period (Fig. 4*A*).

DISCUSSION

In respect to the relationship between facial growth and development of malocclusion, Enlow[31] studied the prevalence of brachycephalic and prognathic facial profiles in the Far East and Central Europe. In the patient population at Youngdong-Severance Hospital, the prevalence of Angle Class III malocclusion is about 40%.[32] In many cases, both patients and parents prefer trying orthopedic treatment during growth to waiting for orthognathic surgery after growth completion; thus, maxillary protraction has become the first choice in orthopedic treatment of growing skeletal Class III malocclusion patients.

The effect of growth modification by maxillary protraction can be interpreted in terms of changes in size, position, and growth rate.[26] Because the mandible can be affected along with the maxilla, both must be considered. Sakamoto et al.[5] and Sugawara et al.[7] reported that although chin cup treatment temporarily reduces mandibular growth rate and alters growth direction, the treatment effect may be unstable because catch-up growth occurs once the application of orthopedic force stops.

Changes in length of the jaws

In untreated children, the maxilla is displaced forward and downward from the anterior cranial base, the posterior portion of maxilla shows constant downward movement and there is an increase in maxillary body length.[33,34] The sutural reaction to protraction can be estimated by analyzing changes in the maxillary length on the lateral cephalogram; this can be obtained by either directly measuring the distance between anterior and posterior landmarks on maxilla[10,16] or comparing the spatial changes of anterior and posterior landmarks.[17,18] In this study, maxillary length was obtained

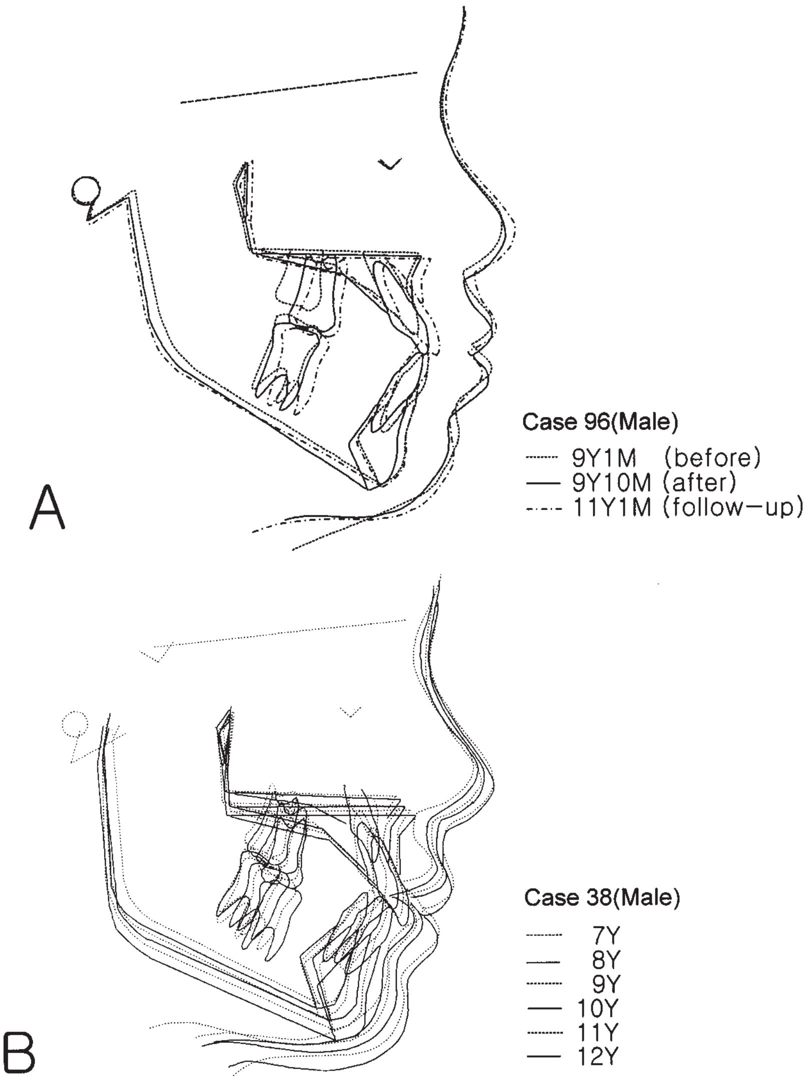

Fig 4. Comparison of protraction case and untreated case. **A**, Protraction case with before and after treatment and follow-up. **B**. Changes of untreated case age from 7 to 12.

by measuring the distance between points ANS and PNS along the X-axis. The mean changes of maxillary length in protraction group ranged from 1.2 mm to 1.5 mm compared with 0.5 mm to 0.9 mm in the untreated group, with a statistically significant difference (Table III). Thus, maxillary length increased more in the protraction group. This may be caused by more bone apposition occurring in the posterior portion of maxilla, indicating an orthopedic effect of maxillary protraction (Fig. 3*B*, 3*D* and 3*E*).[13,18]

Mandibular length in the untreated group showed a growth rate of 2.4 mm to 4.8 mm per year, and this surpassed the growth amount of maxilla; however, in the protraction group, the increase in mandibular length was less than 1.2 mm during treatment period (Table III). So the protraction group showed an inhibition of mandibular growth.[13,16,20] This is probably due to the retractive anchorage status of the chin cup of the face mask.

Changes as a function of age

Delaire[8] recommended that extraoral traction should start early, in the primary dentition stage if possible. Other investigations have suggested that the most suitable time for maxillary protraction can be selected based on the eruption of maxillary teeth,[11,17] the developmental status of circumaxillary sutures,[27] and the amount of growth potential.[26] The juvenile

Table IV. Comparison of follow-up subjects in the protraction and untreated groups

	Age 11				*Age 12*				*Protraction*			
	Untreated		*Protraction (during treatment)*		*Untreated*		*Protraction (posttreatment)*		*During treatment*		*Posttreatment*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Horizontal (mm)												
A	1.3	1.0*	2.0	0.9	0.6	1.2	0.8	1.2	2.0	0.9***	0.8	1.2
PNS	0.6	1.0	0.9	0.7	0.3	1.3	0.0	1.2	0.9	0.7**	0.0	1.2
B	2.2	1.4***	–1.2	1.9	0.4	1.8*	1.9	2.1	–1.2	1.9***	1.9	2.1
MxI	1.9	1.3	2.6	1.2	1.0	1.4	1.9	2.2	2.6	1.2	1.9	2.2
MxM	2.1	1.5	2.3	0.8	1.0	1.8	0.9	2.2	2.3	0.8*	0.9	2.2
MnI	1.9	1.3***	–1.4	1.8	0.5	1.6*	2.1	1.6	–1.4	1.8***	2.1	1.6
MnM	2.4	1.3***	–0.1	1.2	1.9	1.6	1.9	2.3	–0.1	1.2***	1.9	2.3
Vertical (mm)												
A	1.0	0.9	0.8	0.5	2.7	1.3***	0.8	1.2	0.8	0.5	0.8	1.2
PNS	1.3	0.9	0.8	0.6	1.5	0.7*	0.6	1.2	0.8	0.6	0.6	1.2
B	1.9	1.0	2.1	1.2	4.7	2.2***	1.2	2.1	2.1	1.2	1.2	2.1
MxI	1.1	0.9	0.9	0.8	3.5	1.0***	0.4	1.2	0.9	0.8	0.4	1.2
MxM	2.0	0.8	1.5	0.9	3.5	1.0**	0.7	1.9	1.5	0.9	0.7	1.9
MnI	1.1	0.9	1.8	1.7	3.3	1.2***	0.5	1.1	1.8	1.7**	0.5	1.1
MnM	1.9	1.0	2.0	1.6	2.1	1.0***	0.4	1.2	2.0	1.6***	0.4	1.2
Angular (°)												
SNA	0.5	0.8**	1.5	1.0	0.3	1.0	0.3	1.1	1.5	1.0***	0.3	1.1
SNB	0.8	0.6***	–1.1	1.3	0.5	0.7	0.8	1.1	–1.1	1.3***	0.8	1.1
ANB	–0.3	0.8***	2.5	0.9	–0.2	0.5	–0.5	1.1	2.5	0.9***	–0.5	1.1
PP	0.2	1.1	–0.1	1.2	0.4	1.0*	0.0	1.4	–0.1	1.2	0.0	1.4
MP	–1.1	0.9***	2.1	1.9	–0.5	1.1*	–1.1	1.3	2.1	1.9***	–1.1	1.3
A-angle†	24.1	35.1	20.1	14.1	22.6	64.8	3.9	52.1	20.1	14.1	3.9	52.1
Linear (mm)												
MxL	0.8	1.2*	1.2	0.5	0.5	1.5*	0.9	1.5	1.2	0.5	0.9	1.5
MnL	2.9	1.5***	0.4	0.9	4.8	2.4*	2.7	1.9	0.4	0.9***	2.7	1.9
Wits	–0.1	1.2***	3.0	2.2	0.0	1.1	–0.9	2.2	3.0	2.2***	–0.9	2.2
Period (mo)	12***		8.0	2.9			11.9	5.4	8.0	2.9	11.9	5.4
Number	21		22		21		22		22		22	

†A-angle, The angular displacement of point A to X-axis.
Group t test between the untreated group and protraction group or between the protraction groups during treatment versus posttreatment: *, $P < .05$; ** $P < .01$; ***, $P < .001$.

growth spurt that exists in some individuals can act as an accelerating factor in general and skeletal growth.[6,36] During the pubertal growth, maxillofacial growth proceeds actively even though the increase in sutural complexity of the palatomaxillary area after the juvenile period can resist maxillary protraction force.[27,37] Thus, in order to get the maximum orthopedic effect with minimum forward sliding of the dental arch on the maxillary base,[12] the growth period must be considered as an important variable that can affect treatment results. In most previous studies, only subjects in juvenile period were selected, and subjects in prepubertal and pubertal period were combined in others. For this study, comparisons were made with clear distinctions between all age groups. The results showed that the amount of skeletal change among the protraction groups subdivided by age was not statistically significant, but changes of the maxillary central incisors in the group of age 7 were greater than any other group (Fig. 3 and Table V).

Table V. ANOVA test for protraction group according to ages

Measurements	*Age group*
Vertical changes of MxI	7 > 8,11.12
Horizontal changes of MxI	7 > 9,11,12

The greater than sign indicates relative amount of change ($P < .05$).

It is our opinion that greater changes in tooth position of the age 7 group resulted from two factors: (1) tooth eruption is very active in the age 7 group, and (2) the measurements of change in tooth position included maxillary movement, because the maxilla

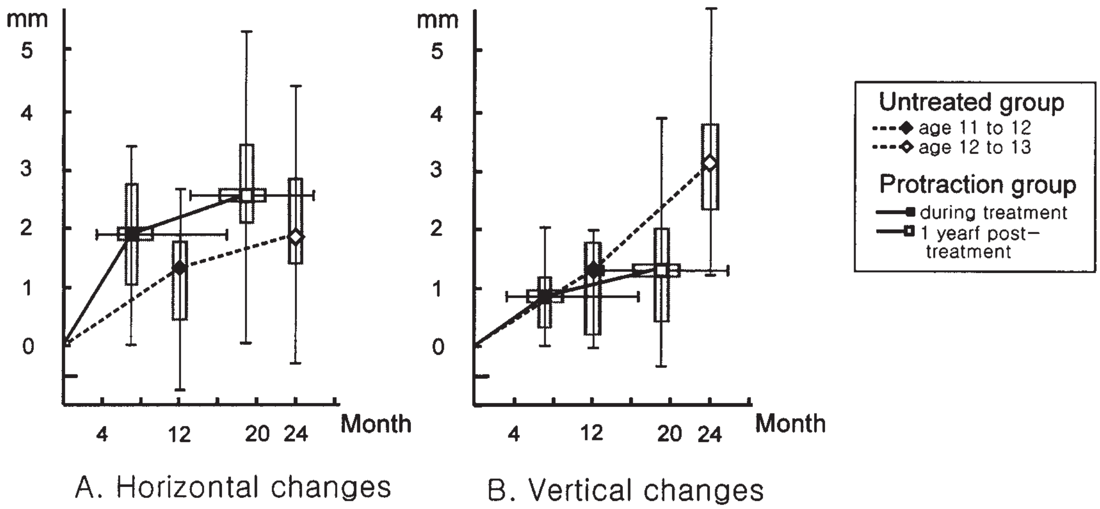

Fig 5. Comparison of time-related changes of point A between follow-up treated group and untreated group by box-and-whisker plot. **A**, Horizontal changes. **B**, Vertical changes.

Table VI. Comparison of the changes during treatment with other studies

	Protraction				*Control*		
	Wisth[13]	*Chong*[20]	*Sarnäs*[12]	*Sung & Baik*	*Wisth*	*Chong*	*Sung & Baik*
SNA	0.03	0.9	1.5	1.5	–0.1	–0.31	0.5
SNB	–0.9	–1.13	–0.85	–1.1	–0.4	0.19	0.8
PP	–0.1	–0.41		–0.1	0.3	4.38	2.9
MP	0.9	0.94	0.7	2.1	0	–0.77	–1.1
Wits (mm)		1.9		3.0		–0.13	–0.1
MnL (mm)	0.7	1.87		0.4	2.6	4.38	2.9
Age (yr)	5-10	6.8	11.8*	11	4-9	6.36	
Period (mo)	3-12	7.3	8	8	12	19.9*	12
Subjects	22	16	7	22	40	13	21
Device	Quad-hlix	La/Li	Cap splint (With Quad-hlix)	RPE or La/Li			

* Estimated period or ages according to measuring unit.

was not the reference object in measuring tooth movement.

Direction of jaw displacement and rotation

Maxillary protraction is indicated when an anteroposteriorly deficient maxilla needs to be displaced forward. It will work most effectively when the potential growth direction of patients correlates with the direction of maxillary protraction.[9] Björk[33] reported that in untreated cases, point A moves 51° on the average (range, 0° to 82°) forward and downward in relation to anterior cranial fossa, and there are individual variations such as to move solely forward or downward, Brodie[38] said that there is no change in SN-palatal plane angle during growth period.

According to animal experiments, biomechanical studies, and clinical reports on maxillary protraction, upward and forward rotation of the maxilla occurs when protraction force on molars is applied parallel to the occlusal plane. This type of maxillary rotation can be minimized when the force is applied in the canine area, 20° to 30° below the occlusal plane.[22-25]

The clinical point of force application depends largely on the anchor teeth and appliance design. The maxillary canine is the last to erupt during the second transitional period, and it is positioned labially in the presence of crowding. In such cases, it becomes hard to band these teeth for the placement of rigid intraoral appliances. Naturally, maxillary first premolars are often selected as the anchor teeth for RPE.

Table VII. Comparison of the changes during post-treatment with other studies

	Protraction				Control		
	Wisth[13]	*Chong*[20]	*Sarnäs*[12]	*Sung & Baik*	*Wisth*	*Chong*	*Sung & Baik*
SNA	–0.1	0	–0.2	0.3	0	1.31	0.3
SNB	0.6	1.63	0.5	0.8	0.4	1.96	0.5
MP	–1.3	–1.75	–0.65	–1.1	–0.9	–0.73	–0.5
PP	0.6	1.44		0	0.3	0	0.4
Wits (mm)		–0.79		–0.9		–0.6	0
MnL (mm)	2.8	9.3		2.7	1.9	10.46	4.8
Period (mo) (SD)	6-48	42.8* (24.8)*		11.9 (5.4)	12	44.6* (6)*	12

SD, Standard deviation.
*Estimated period or ages according to measuring unit.

In this study, the angular displacement of point A (A-angle) and the palatal plane angle were considered for the purpose of predicting maxillary rotation and displacement. In the untreated group, the A-angle was 24.1° at age 11 and 22.6° at age 12 in relation to the X-axis, and the palatal plane angle showed an average annual increase of 0.2° to 0.4° (Table IV). In the protraction group, A-angle was 20.1°, and the palatal plane angle decreased by 0.1° during treatment period. So the maxillary displacement of the protraction group during treatment was similar to that of the untreated group of age 11, but the changes in the A-angle during 1 year posttreatment were various (range, –78.6° to 88°) with no changes in palatal plane angle (Table IV).

Although the millimeter changes represented by these angular changes are small, there is a distinct statistical significance between the untreated and protraction group of age 11; this data will be valuable in validating the center of resistance of the maxilla, which is estimated with the use of biomechanical studies.

The mandibular plane angle tended to decrease in the untreated group but markedly increased in the protraction group during treatment,[12,13,16,18] and the difference was significant (Fig. 4*A* and *B*, Table III). The increase in mandibular plane angle with treatment may be due to incomplete compensation of the short-term downward displacement of maxilla by the vertical growth of the ramus. One year after protraction, the mandibular plane angle decreased,[12,13,20] and this value was significantly smaller than that of the untreated group of age 12 (Fig. 4*A*, Table IV). The increase in the mandibular plane angle with treatment may be due to (1) the relapse of the treatment that induces vertical increase of anterior facial height and clockwise rotation of the mandible, and (2) chin cup effects after protraction.

Changes in growth rate during treatment and follow-up periods

Growth acceleration involves a quantitative increase in size as well as less time to attain a given size. In this study, the protraction group revealed significant annual increases in the SNA angle and maxillary length, compared with the control group during treatment.[14,16] A larger increase in maxillary length was also observed in the follow-up protraction group, 1.2 mm during both the treatment period and 0.9 mm during the posttreatment period (Table IV).[13]

The rate of horizontal change of point A in the follow-up protraction group during treatment was greater than the untreated group of age 11, but after treatment, the two groups showed similar changes. Nonetheless, the rate of the vertical change of point A in the follow-up protraction group was significantly smaller than the untreated group of age 12 both during treatment period and posttreatment period (Fig. 5*A* and *B*, Table IV). So maxillary protraction can bring a retruded maxilla forward in a short period of time.

In Tables VI and VII, changes during and after treatment with maxillary protraction are compared with the results from other studies. The duration of follow-up in studies by Chong[20] and Wisth[13] were longer than our study; overall measurements studies showed similar results, but Chong's study samples showed greater increases in mandibular length during as well as after treatment. In this study, the chin cup that was worn during the follow-up period was not so effective in restricting the linear growth of mandible; the growth amounts were similar with other studies that used no chin cups.

Other considerations

This study differs from some others in that an estimated true horizontal line (6° below the S-N plane) was used to measure the displacement of jaws and teeth. This would reduce the vertical skeletal changes and increase the horizontal changes in comparison to other data sets. Projecting changes to the true horizontal, however, provides the most realistic profile changes and therefore is preferred for the studies of skeletal change. For the comparison of the treatment changes in the protraction group and the growth changes of the untreated groups, an untreated Class III control group would be most ideal, enabling us to estimate the treatment effect directly. But, because of the ethical concerns, we were not able to form such a control group.[5,6,20] The protraction group of the present study consisted of cases in which the anterior crossbite was corrected and the posterior occlusion was stabilized. Severe crossbite or poor patient cooperation with face mask therapy may lead to longer treatment time and reduced treatment effects. Thus, the results might be different from the average values of this study. Finally, it should be noted that the authors considered annualized analysis of the changes in protraction group unnecessary, because the result from the direct comparison was obvious enough to demonstrate the treatment effects of protraction; the changes produced by protraction over less than a year were greater than the annual growth amount in the untreated group.[6]

CONCLUSIONS

1. Maxillary forward displacement and mandibular growth inhibition were observed in the protraction group compared with the untreated group, and there was a statistically significant difference.
2. When the measurements of treatment effect according to ages were compared, there was no statistically significant difference.
3. The direction of maxillary growth was similar in both the untreated and protraction groups.
4. Maxillary protraction had a growth stimulating effect on the maxilla during the treatment period.

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REFERENCES

1. Sandborn RT. Differences between the facial skeletal patterns of Class III malocclusion and normal occlusion. Angle Orthod 1955;25:208-22.
2. Chang HP, Kinoshita Z, Kawamoto T. Craniofacial pattern of Class III deciduous dentition. Angle Orthod 1992;62:139-44.
3. Guyer EC, Ellis EE, McNamara JA, Behrents RG. Components of Class III malocclusion in juveniles and adolescents. Angle Orthod 1986;56:7-30.
4. Graber LW. Chincup therapy for mandibular prognathism. Am J Orthod 1977;72:23-41.
5. Sakamoto T, Iwase I, Uka A, Nakamura S. A roentgenocephalometric study of skeletal changes during and after chin cup treatment. Am J Orthod 1984;85:341-50.
6. Ritucci R, Nand R. The effect of chin cup therapy on the growth and development of the cranial base and midface. Am J Orthod Dentofacial Orthop 1986;90:475-83.
7. Sugawara J, Asano T, Endo N, Mitani H. Long-term effects of chincap therapy on skeletal profile in mandibular prognathism. Am J Orthod Dentofacial Orthop 1990;98:127-33.
8. Delaire J. Considerations sur la croissance faciale (en particulier du maxillaire supérieur). Déductions thérapeutiques. Rev Stomatol 1971;72:57.
9. Cozzani G. Extraoral traction and Class III treatment. Am J Orthod 1981;80:638-50.
10. Simonsen R. The effect of face mask therapy [abstract]. Am J Orthod 1982;82:439.
11. Campbell PM. The dilemma of Class III treatment: early or late? Angle Orthod 1983;53:175-91.
12. Sarnäs KV, Rune B. Extraoral traction to maxilla with face mask: a follow-up of 17 consecutively treated patients with and without cleft lip and palate. Cleft Palate J 1987;24:95-103.
13. Wisth PJ, Tritrapunt A, Rygh P, Boe OE, Norderval K. The effect of maxillary protraction on front malocclusion and facial morphology. Acta Odont Scand 1987;45:227-37.
14. Mermigos J, Full CA, Andreasen G. Protraction of the maxillofacial complex. Am J Orthod Dentofacial Orthop 1990;98:47-55.
15. Hickham JH, Miethke RR. Protraction: its use and abuse. Praktische Kieferorthopadie 1991;5:115-32.
16. Takada K, Petdachai S, Sakuda M. Changes in dentofacial morphology in skeletal Class III children treated by a modified maxillary protraction headgear and a chin cup: a longitudinal cephalometric appraisal. Eur J Orthod 1993;15:211-21.
17. Tindlund RS. Skeletal response to maxillary protraction in patients with cleft lip and palate before age 10 years. Cleft Palate-Craniofacial J 1994;31:295-308.
18. Buschang PH, Porter C, Genecov E, Genecov D, Sayler KE. Face mask therapy of preadolescents with unilateral cleft lip and palate. Angle Orthod 1994;64:145-50.
19. Baik HS. Clinical results of maxillary protraction in Korean children. Am J Orthod Dentofacial Orthop 1995;108:583-927.
20. Chong YH, Ive JC, Årtun J. Changes following the use of protraction headgear for early correction of Class III malocclusion. Angle Orthod 1996;66:351-62.
21. Kambara T. Dentofacial changes produced by extraoral forward force in the Macaca irus. Am J Orthod 1977;71:249-76.
22. Nanda R. Protraction of maxilla in rhesus monkey by controlled extraoral forces. Am J Orthod 1978;74:121-41.
23. Jackson GW, Kokich VG, Shapiro PA. Experimental and postexperimental response to anteriorly directed extraoral force in young Macaca nemsestrina. Am J Orthod 1979;75:318-33.
24. Kang HS. A laser holographic study on the initial reaction of maxillofacial complex to maxillary protraction. Korean J Orthod 1988;18:367-81.
25. Miyasaka-Hiraga J, Tanne K, Nakamura S. Finite element analysis for stress in the craniofacial sutures produced by maxillary protraction forces applied at the upper canines. Br J Orthod 1994;21:343-8.
26. Proffit WR. Contemporary orthodontics. St Louis: CV Mosby; 1992. p. 91-2, 229-44.
27. Melsen B, Melsen F. The postnatal development of palatomaxillary region studied on human autopsy material. Am J Orthod 1982;82:329-42.
28. Athanasiou AE. Morphologic and functional implications of the surgical-orthodontic management of mandibular prognathism: a comprehensive review. Am J Orthod Dentofacial Orthop 1993;103:439-47.
29. Bjork A, Skieller V. Normal and abnormal growth of the mandible: a synthesis of longitudinal cephalometric implant studies over a period of 25 years. APPENDIX; Superimposition of profile radiographs by the structural method. Eur J Orthod 1983;5:1-48.
30. Houston WJB. The analysis of errors in orthodontic measurements. Am J Orthod 1983;83:382-90.
31. Enlow DH. Handbook of facial growth. Philadelphia: W.B. Saunders; 1992. p. 5,198.
32. Baik HS, Kim KH, Park Y. The distribution and trends in malocclusion patients: a 10 year study of 2155 patients from YDSH. Korean J Orthod 1995;25:87-100.
33. Björk A. Sutural growth of the upper face studied by the implant method. Trans Eur Orthod Soc 1964;40:1-17.
34. Baumrind S, Korn EL, Ben-Bassat Y, West EE. Quantitation of maxillary remodeling 2. Masking of remodeling effects when an “anatomical” method of superimposition is used in the absence of metallic implants. Am J Orthod Dentofacial Orthop 1987;91:463-74.
35. Grandori F, Merlini C, Amelotti C, Piasente M, Tadini G, Ravazzani P. A mathematical model for computation of the forces exerted by the facial orthopedic mask. Am J Orthod Dentofacial Orthop 1992;101:441-8.
36. Bambha JK. Longitudinal cephalometric roentgenographic study of the face and cranium in relation to body height. J Am Dent Assoc 1961;63:776-99.
37. Vardimon AD, Graber TM, Stutzmann J, Voss L, Petrovic AG. Reaction of the pterygomaxillary fissure and the condylar cartilage to intermaxillary Class III magnetic mechanics. Am J Orthod Dentofacial Orthop 1994;105:401-13.
38. Brodie AG. Late growth changes in the human face. Angle Orthod 1953;23:146-57.