ORIGINAL ARTICLE

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A cephalometric study on the velopharyngeal changes after maxillary protraction

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The purpose of this study was to investigate cephalometrically the short term static velopharyngeal changes in 25 patients (10 boys and 15 girls, aged from 5 years 9 months to 12 years 10 months in the beginning of treatment) with skeletal Class III malocclusions who underwent nonsurgical maxillary protraction therapy with a facemask. The linear, angular and ratio measurements were made on lateral cephalograms. Only the change in hard palatal plane angle was negatively correlated with the change in maxillary depth or N-perp to A ($p < 0.01$). The change in velar angle showed a statistically significant increase ($p < 0.001$). This change was influenced more by the soft palatal plane angle than by the hard palatal plane angle ($p < 0.001$). The changes in soft tissue nasopharyngeal depth and hard tissue nasopharyngeal depth showed statistically significant increases ($p < 0.001$). Correlations between the changes in soft tissue (or hard tissue) nasopharyngeal depth and the change in soft palatal plane angle were significant ($p < 0.05$). The increase in hard palate length was statistically significant ($p < 0.001$). The change in hard palate length was negatively correlated with the change in soft tissue nasopharyngeal depth ($p < 0.05$). The change in need ratio S (C) showed a statistically significant increase ($p < 0.001$). But this difference was within the normal range reported by previous studies. These findings indicate that the velopharyngeal competence was maintained even if the anatomical condition of the static velopharyngeal area were changed after maxillary protraction.

(**Key words:** Maxillary protraction, Velopharyngeal competence, Velar angle, Need ratio)

INTRODUCTION

A developing Class III malocclusion can present with maxillary skeletal retrusion, mandibular skeletal protrusion, or some combination of the two.[1] Some orthopedic appliances such as functional regulator or maxillary protraction headgear (facemask) have been used to treat skeletal Class III patients with maxillary deficiency depending on the severity of skeletal discrepancy. Many previous studies looking at the

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effects of maxillary protraction headgear have reported 2 ~ 4 mm of maxillary advancement, a downward and backward rotation of the mandible, counterclockwise rotation of the palatal plane, labial tipping of the maxillary incisors and lingual tipping of the mandibular incisors.[2-6] However, most of these studies have focused on the skeletal, dentoalveolar and soft tissue profile changes influenced by the age of patients, appliance design, the force level, the direction and point of application of force, and treatment time.

With forward and downward displacement of the nasomaxillary complex in normal growth, the hard palate and the soft palate move in a parallel manner, further away from the base of the skull.[7,8] In relation to the angular relationship between the soft palate and the hard palate, previous studies have shown that it may be more acute depending on aging in growing children or in adults.[7,9] Subtelny[7] reported that after 4 to 5 years of age, the growth in the length of the soft palate showed evidence of a slower increase in the average length up to late adolescence. Recently, Taylor et al[10] reported that the soft palate length increased about 1 mm every 3 years after age 9.

In previous studies regarding nasopharyngeal space, King[11] reported the distance between the anterior tubercle of the atlas and the posterior nasal spine remained remarkably stable with growth. On the other hand, Taylor et al[10] reported that this distance increased 0.7 mm every 3 years before age 12 years but did not change after age 12. Subtelny[7] reported that the distance from PNS to the soft tissue pharynx along the palatal plane increased approximately 1 mm every year from ages 6 to 15 in normal growth.

In a comparative study of velopharyngeal dimensions, Wu et al[12] reported that normal groups displayed greater velar length, greater hard palate length, smaller pharyngeal depth and smaller need ratio (Table 1) as compared with cleft patients with velopharyngeal incompetency.

In relation to the changes in the velopharyngeal mechanism in static and dynamic states following maxillary advancement surgery, Schendel et al[13] observed that the increase in velar angle was greater in the cleft group and the increase in velar length was greater in the noncleft group after maxillary Le Fort I advancement.

As is shown so far, a lot of studies have reported on the velopharyngeal changes and their correlations in normal growth and development, and after maxillary advancement surgery. However, very few studies have reported on changes in the velopharyngeal area following nonsurgical maxillary protraction in growing patients.

The purpose of this study was to evaluate the short term static velopharyngeal changes on lateral cephalograms of patients who underwent nonsurgical maxillary protraction by facemask.

SUBJECTS AND METHODS

The subjects consisted of 25 children (10 males and 15 females) with skeletal Class III malocclusions who were treated with a bonded or banded rapid maxillary expansion (RME) appliance followed by a facemask (350 to 400 gm of force per side) at the Department of Orthodontics, Kangnung National University Dental Hospital. Their mean age at the time of treatment was 9.9 years, ranging from 5.9 years to 12.8 years. Treatment time was from 5 to 12 months. They were in good health, had no cleft lip and palate and had no history of tonsillectomy or adenoidectomy.

Cephalograms

All lateral cephalograms analyzed in this study were taken using the Cranex 3+ ceph (Soredex, Helsinki, Finland). The object-focus distance was 150 cm, and the exposure time 0.6 ~ 1.0 second with an intensity of 10 mA, 79 kV. All subjects had lateral cephalograms taken with the teeth in centric occlusion while holding their breath without swallowing (with the velum at rest). The X-ray magnification was 1.13%. Lateral cephalometric radiographs were taken before (T0) and after anterior crossbite correction (T1).

Cephalometric analysis

A tracing of each lateral cephalogram was made by the same investigator. Subsequently, linear and angular

Table 1. Definition of angular measurements, linear measurements and ratio measurements

Angular measurements (°)	
SNA	S-N plane to N-A line
Maxillary depth	FH plane (Or-Po) to N-A line
Hard palatal plane angle	FH plane to hard palatal plane (ANS-PNS)
Soft palatal plane angle	FH plane to soft palatal plane (PNS-Uv)
Velar angle	Hard palatal plane to soft palatal plane
SNB	S-N plane to N-B line
Facial depth	FH plane to facial plane (N-Pog)
Mandibular plane angle	FH plane to mandibular plane (Go-Me)
Linear measurements (mm)	
Nasion perpendicular to point A (N-perp to A)	The length from point A to nasion perpendicular
Hard palate length	ANS-PNS length
Nasopharyngeal height (N height)	Cp-PNS length
Velar length S	The length from PNS to Uv in a straight line
Velar length C	The length from the PNS to Uv in curved line along nasal surface
Soft tissue nasopharyngeal depth (St N depth)	PNS-Upw length
Hard tissue nasopharyngeal depth (Hd N depth)	PNS-Aa length
Oropharyngeal depth (O depth)	Uv-Mpw length
Ratio measurements	
Need ratio S	St N depth / Velar length S
Need ratio C	St N depth / Velar length C

measurements were made in the software Quick Ceph Image Pro (version 4.4) using a numonics digitizer (Quick Ceph Systems, San Diego, USA). Also Image Pro PLUS (version 4.0) (Media Cybernetics, Silver spring, USA) was used for linear and angular measurements of the soft palate and pharynx. Linear measurements were read to 0.01 mm and angular measurements were read to 0.01 degree (Table 1). The reference points used for cephalometric analysis are illustrated in Fig 1.

Statistical analysis

The means and standard deviations of each measurement at T0 and T1 and their mean differences were calculated. A paired *t*-test was used to evaluate the significance of the treatment results. Pearson's correlation coefficient was determined to examine whether any correlation existed between the changes in the velopharyngeal area and the changes in maxillary sagittal measurements. Also Pearson's correlation coefficient was determined to examine whether any correlation existed among the changes in palate postures, lengths and pharyngeal depths. Multiple regression analysis was used to examine the extent to which the velar angle change could be predicted by the independent variables (hard palatal plane angle, soft palatal plane angle).

RESULTS

Changes in measurements from T0 to T1

The means and standard deviations of each

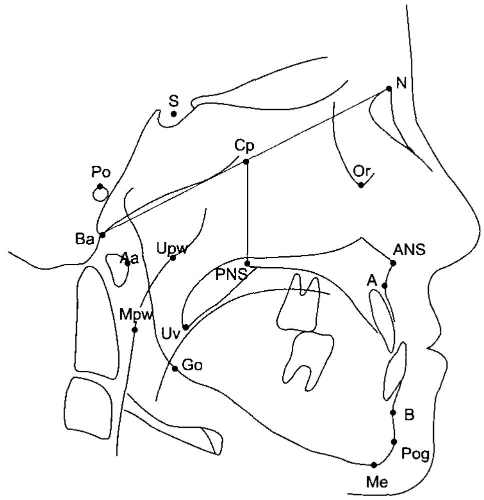

Fig 1. Cephalometric landmarks. *S*, Sella turcica; *N*, nasion; *Ba*, basion; *Or*, orbitale; *Po*, porion; *ANS*, anterior nasal spine; *PNS*, posterior nasal spine; *A*, point A; *B*, point B; *Pog*, pogonion; *Go*, gonion; *Me*, menton; *Uv*, the tip of the uvula; *Aa*, the most anterior point on the atlas vertebra; *Upw*, the intersection of the posterior pharyngeal wall with a line drawn through ANS and PNS; *Mpw*, the intersection of a line parallel to FH plane extending from Uv and the posterior pharyngeal wall; *Cp*, the intersection of a line perpendicular to palatal plane drawn from PNS and N-Ba plane.

Table 2. The means and standard deviations at T0, T1 and mean differences

Variables	*T0*		*T1*		*D*	*t-value*
	Mean	*SD*	*Mean*	*SD*		
SNA	79.11	3.40	80.99	3.76	1.88	7.55 ***
Maxillary depth	87.72	2.68	89.66	3.08	1.94	6.99 ***
Hard palatal plane angle	1.12	3.16	-0.64	3.68	-1.76	-5.14 ***
Soft palatal plane angle	128.63	5.70	131.92	5.16	3.29	3.54 **
Velar angle	127.54	6.99	132.24	6.51	4.70	4.63 ***
SNB	80.30	3.67	78.69	3.27	-1.60	-5.73 ***
Facial depth	88.76	3.24	87.58	2.92	-1.18	-3.44 **
Mandibular plane angle	27.26	7.29	28.50	7.63	1.25	2.88 **
N perp to A	-2.48	2.87	-0.42	3.33	2.06	7.13 ***
Hard palate length	47.82	2.63	49.37	2.86	1.55	7.98 ***
Velar length S	31.39	2.66	32.21	2.75	0.82	3.65 **
Velar length C	37.94	2.75	39.25	2.62	1.31	4.66 ***
N height	29.37	2.96	31.21	2.95	1.84	7.07 ***
St N depth	24.06	3.67	26.97	4.29	2.91	7.51 ***
Hd N depth	32.85	3.27	34.45	3.16	1.60	4.45 ***
Oropharyngeal depth	11.85	2.99	12.52	3.79	0.67	1.56
Need ratio S	0.77	0.13	0.85	0.16	0.08	5.07 ***
Need ratio C	0.64	0.15	0.69	0.17	0.05	5.12 ***

** $p < 0.01$; *** $p < 0.001$; *D* (Δ) = T1-T0 Mean difference, change amount between after (T1) and before anterior crossbite correction (T0); *SD*, standard deviation.

cephalometric variable at T0 and T1, and their differences are shown in Table 2. All measurements used in this study showed statistically significant differences ($p < 0.01$ or $p < 0.001$) with the exception of oropharyngeal depth.

Table 3. Correlation coefficients between the changes in the velopharyngeal area and the changes in maxillary sagittal measurements

	Δ *SNA*	Δ *Maxillary depth*	Δ *N-perp to A*
Δ Hard palatal plane angle	-0.3099	-0.5291 **	-0.5109 **
Δ Soft palatal plane angle	0.0055	-0.0461	-0.0278
Δ Velar angle	0.0560	0.0602	0.0791
Δ Hard palate length	0.0888	-0.0567	-0.0771
Δ Velar length S	-0.0117	0.0341	0.0276
Δ N height	0.3323	0.1782	0.1815
Δ St N depth	0.0472	0.1227	0.1513
Δ Hd N depth	0.0522	0.1379	0.1993
Δ O depth	-0.1386	0.0169	0.0311

** $p < 0.01$.

Table 4. Correlation coefficients among the changes in palate postures, lengths and pharyngeal depths

	Δ *St N depth*	Δ *Hd N depth*
Δ Hard palatal plane angle	-0.3511	0.0113
Δ Soft palatal plane angle	0.4915 *	0.4553 *
Δ Hard palate length	-0.4736 *	-0.0689
Δ Velar length S	-0.2059	0.2819
Δ Velar length C	0.1744	0.4165

* $p < 0.05$.

Table 5. Multiple regression analysis for velar angle change to examine contributing independent variables

Independent variable	*Regression coefficient*	*p-value*
Δ Hard palatal plane angle	-0.5333	0.0206
Δ Soft palatal plane angle	1.0253	0.0001 ***

R^2 = 0.887; *** $p < 0.001$.

Correlation between changes in the velopharyngeal area and changes in maxillary sagittal measurements (Table 3)

Only the change in the hard palatal plane angle was negatively correlated with the change in maxillary depth or N-perp to A ($p < 0.01$). This indicates that the greater the maxilla grows forward, the lesser the anterior rotation of the hard palate.

Correlation among the changes in palate postures, lengths and pharyngeal depth (Table 4)

Correlations between the changes in St- or Hd- N depth and the change in soft palatal plane angle were significant ($p < 0.05$). This indicates that a greater change in soft palatal plane angle was associated with a greater change in pharyngeal depths. The change in St N depth was negatively correlated with the change in hard palate length ($p < 0.05$). This indicates that a greater change in St N depth tends to be related to a lesser change in hard palate length.

Change in velar angle was highly correlated with the change in the soft palatal plane angle (Table 5)

Multiple regression analysis was used to examine the extent to which the velar angle change could be predicted by the independent variables. The multivariate models showed high significance ($p < 0.001$). 88.7% of the variance could be explained by means of multiple linear regression. The results showed that the change in velar angle was influenced more by the soft palatal plane angle, although both of the angles appeared to influence the velar angle.

DISCUSSION

One of the major objectives of early treatment for a developing Class III malocclusion is to provide a more favorable environment for normal growth and an improved occlusal relationship.[14,15] Maxillary deficiency is a problem not only in width, but also in height and depth. The results of previous studies have indicated that facemask therapy produces anterior displacement of the maxilla, anterior rotation of the palatal plane and downward and backward rotation of the mandible.[3-6,16,17] Such findings were also observed in this study (Table 2).

Many studies have reported the velopharyngeal changes and their correlations in normal growth and development, and after maxillary advancement surgery.[7,9-13,18] But the changes in the velopharyngeal area before and after facemask therapy have rarely been reported in previous studies.

In this study, it was planned to explore the correlationship between the changes in the velopharyngeal area and the changes in maxillary sagittal measurements by facemask therapy. Only the change in the hard palatal plane angle was negatively correlated with the change in maxillary depth or N-perp to A ($p < 0.01$) (Table 3). Palatal plane rotation is supposed to be affected by both RME and maxillary protraction. Many studies have been reported regarding maxillary responses after RME only, but the change in the palatal plane are inconclusive (downward in an almost parallel manner, downward in backward rotation, downward in forward rotation).[19-22] In relation to maxillary protraction therapy, the palatal plane rotation occurs because the line of force is directed below the center of resistance of the maxilla, creating a moment for rotation.[2,5,18] This indicates that a greater forward maxillary growth tends to be related to a smaller amount of counterclockwise rotation of the hard palatal plane. Therefore, it might be suggested that the counterclockwise rotation of the palatal plane will be reduced if treatment is initiated at an early age when the circummaxillary sutures are less fused.

The mean velar angle value significantly increased from 127.54° to 132.24° (Table 2) unlike the decrease in velar angle observed in normal growth.[7] In relation to the increase in velar angle, the results of previous clinical studies indicated that maxillary advancement with Le Fort I osteotomy can produce an increase in velar angle and velar length.[13,18] Ko et al[18] proposed that this increase is part of the compensation occurring in the velopharyngeal mechanism, shown as stretching of the attached soft tissues of the soft palate, which aided in maintaining the vertical position of the soft palate. This increase in velar angle is supposed to stem from 2 possible changes, i.e. anterior tipping of the hard palate or compensation mechanism of the soft palate. Our study shows that the change in velar angle was highly correlated with the change in the soft palatal plane angle compared with the hard palate angle (Table 5). The soft palate consists of a fold of mucous membrane enclosing muscular fibers, an aponeurosis, vessels, nerves, adenoid tissue, and mucous glands. Related muscles are levator veli palatini muscle, tensor veli palatini muscle, uvulae muscle, palatoglossus muscle and palatopharyngeus muscle. While the levator veli palatini muscle, which occupies the intermediate 40% of the length of the soft palate, pulls the soft palate backward and upward, the palatoglossus muscle and palatopharyngeus muscle pull the soft palate downward.[23,24] Considering these mechanics, the changes in the position of the soft palate following maxillary protraction are considered to be the result of changes in the interaction of these muscles.[24]

The change in St- or Hd- N depth from T0 to T1 increased significantly but the increase in orpharyngeal depth was not significant (Table 2), indicating that oropharyngeal airway space is maintained but nasopharyngeal airway space is increased. In our study, the mean increases of St N depth and Hd N depth were 2.91 mm and 1.60 mm respectively. Also these increases were positively correlated with the increased change in soft palatal plane angle ($p < 0.05$) (Table 4). In normal growth, Taylor et al[10] noted that this increase in airway size from 6 to 9 years was probably due to the continued growth of the pharynx and the onset of adenoidal regression around age 8, while the significant increase in airway size from 12 to 15 years was due to the pubertal growth spurt and complete adenoidal regression. Considering that the duration of treatment was less than a year, the changes in distance was relatively larger than previous studies.[7,10] The relatively large amount of increase is considered to be partly due to the result of the orthopedic effect of maxillary protraction. This might be attributed to the fact that bone apposition in the posterior portion of the maxilla and the increase in the size of the atlas failed to catch up with the rate of orthopedic change. Besides the maxillary protraction factor which affects the above-mentioned velopharyngeal measurements, there are other factors known to affect these velopharyngeal measurements.[25-27] In previous studies of surgical mandibular advancement, it was reported that the velar angle became more upright and the pharyngeal airway space at the level of the oropharynx showed an increase in the sagittal dimension at the short term follow up.[24,26] Subtelny[27] indicated long term thumb sucking habit as one of the factors which affect the growth of the soft and hard palate.

The "need ratio", a means of evaluating velopharyngeal insufficiency, is a ratio obtained by dividing the pharyngeal depth by the velar length at rest. Simpson and Austin[25] reported that the average need ratio in normal patients was 0.87 with a range of 0.68 to 1.19. Subtelny[7] found that from 6 months to 15 years of age, the mean need ratio seemed remarkably stable, ranging from 0.66 to 0.7. Schendel et al[13] reported that a need ratio change greater than 1.1 following maxillary advancement surgery is apparently consistent with a structural velopharyngeal incompetence. The change in need ratio in our study was within the normal range compared with previously published data (Table 2).[7,25] According to this result, we suggest that maxillary protraction therapy does not cause velopharyngeal insufficiency such as increased nasality and inaccurate pronunciation in non-cleft skeletal Class III patients.

Although lateral cephalograms are clinically practical, noninvasive, and reliable for evaluating the short term velopharyngeal changes, the 2-dimensional analysis method fails to reflect the static or functioning velopharyngeal mechanism. Therefore, in order to investigate the 3-dimensional size, shape and volume changes of the velopharyngeal area or the functioning velopharyngeal mechanism following maxillary protraction, the use of ultrasound, computerized tomography, cinefluoroscopy, multiview videofluoroscopy, videonasopharyngoscopy and nasometer should be considered in further studies. At the same time, a long term follow-up study should be carried out to evaluate the stability of the changes in the velopharyngeal area. Also it should be considered that the changes in the velar angle and the nasopharyngeal depth are influenced by the changes in the position of the tongue or the cervical vertebrae.

CONCLUSION

The findings of this study demonstrate that a change in the anatomical condition of the static velopharyngeal area following maxillary protraction is obviously different, compared with the results of previous growth studies[7,10] in which the velar angle decreased and the St- or Hd- N depth increased. However, it might be suggested that the velopharyngeal competence was maintained, because the change in the need ratio was within the normal range compared with previously published data.[7,21] We suggest that maxillary protraction therapy does not cause velopharyngeal insufficiency such as increased nasality and inaccurate pronunciation in non-cleft skeletal Class III patients.

- 국문초록 -

상악골 전방견인치료후 구개범인두 변화에 대한 단기간의 측모두부방사선 계측학적 연구

이남기 · 차봉근

이 연구의 목적은 훼이스마스크로 상악 전방견인치료를 받은 성장기 골격성 III급 부정교합자 25명(남 10, 여 15, 평균나이 9.9세)에서 단기간의 정적인 구개범인두 변화를 측모두부방사선 계측사진상에서 선 계측, 각도 계측 및 비율 계측을 시행하여 평가하는 것이다. 경구개 평면각의 변화량은 maxillary depth 또는 N-perp to A의 변화량과 음의 상관관계를 보였다 ($p < 0.01$). 경-연구개 각의 증가는 유의성이 있었으며, 이는 경구개 평면각의 변화보다 연구개 평면각의 변화의 영향을 더 받았다 ($p < 0.001$). 연조직- 과 경조직- 비인두 깊이의 증가는 유의성이 있었으며 ($p < 0.001$), 이들의 변화량과 연구개 평면각의 변화량간에는 양의 상관관계를 보였다 ($p < 0.05$). 경구개 길이의 증가는 유의성이 있었으며 ($p < 0.001$), 이는 연조직 비인두 깊이의 증가량과 음의 상관관계를 보였다 ($p < 0.05$). Need 비율 S (C)의 증가는 유의성이 있었으나 ($p < 0.001$), 이러한 증가는 이전 연구에서 보고된 Need 비율 S (C)의 정상 범위 내에 있었다. 이 연구로 상악골의 전방견인 후에 정적인 구개범인두 부위에 변화가 있을지라도 구개범인두의 적격성이 유지됨을 알 수 있었다.

(**주요 단어**: 상악골 전방견인, 구개범인두의 적격성, 경-연구개 각, Need 비율)

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COMMENTARY

The purpose of this study was to evaluate the velopharyngeal changes following maxillary protraction with a facemask in Class III non-cleft palate patients. The author concluded that maxillary protraction took place with morphological changes in the velopharyngeal area, but that these changes did not cause velopharyngeal dysfunction.

In previous clinical studies on developing Class III malocclusion, there was not much research interest in this type of thing since the amount of forward repositioning of the maxilla was very limited in non-surgical protraction and, as far I know, patients have never complained about complications with oral function such as articulation after maxillary protraction treatment. However there may be some merit in investigating the influences of maxillary protraction on the velopharyngeal region from a biological viewpoint. Before making comment on the results of this study, there are some questions with this paper which need addressing, particularly with regard to the subjects and methods.

Firstly, the subjects are too heterogeneous; the age range at the beginning of treatment was too varied from 5.9 to 12.10 years-old. This means that some patients belonged to the prepubertal period and some others were already in the pubertal growth period. In addition, sexual dimorphism should be taken into consideration in such a study.

Secondly, there should have been a control group set up in this study; otherwise, it is impossible to differentiate the effects of the maxillary protracting appliance from the natural changes which occur due to Class III maxillary growth. It would not have been so difficult to have set up a control group since the actual treatment periods were so short-less than a year.

Thirdly, as the authors realized, the short-term effects following orthopedic treatment are not particularly significant because of the high possibility that short-term effects may diminish during the adolescent and post-adolescent growth periods.[1,2] In modern orthodontics, orthopedic effects should be discussed on the basis of long-term data.

And fourthly, the authors suggested that maxillary protraction therapy does not cause velopharyngeal insufficiency, but no functional evaluation with regard to articulation or nasality was performed and no mention was made of it. Although this study was similar to the research conducted by Ko et al,[3] the speech evaluation they performed included assessment of air pressure flow, hypernasality, and articulation.

Recently, maxillary distraction osteogenesis has gained popularity for the treatment of Class III malocclusions with maxillary deficiency including cleft palate patients. Harada et al[4] suggested that maxillary distraction of less than "15 mm" may not markedly affect velopharyngeal function in cleft patients. Judging from the result of their study, the conclusion of this study which suggested that the velopharyngeal competence was maintained after maxillary protraction with facemask in non-cleft palate Class III patients makes sense. The significance of this study was to remind us of the importance of adaptation and compensation mechanism to the environmental changes in the human body.

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