Three-dimensional evaluation of pharyngeal airway changes after bimaxillary orthognathic surgery in Class III malocclusion

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Three-dimensional evaluation of pharyngeal airway changes after bimaxillary orthognathic surgery in Class III malocclusion

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감사의 글

부족한 저를 지도해주신 교수님들의 많은 가르침으로 이 논문을 완성할 수 있었습니다. 논문의 구상부터 완성되기까지 따뜻한 배려와 함께 세심한 지도와 격려를 아끼지 않으신 박영철 지도 교수님께 진심으로 감사드리며, 바쁘신 중에도 귀중한 시간을 내주시어 부족한 논문을 살펴주신 김경호 교수님, 유형석 교수님, 이상휘 교수님, 김성택 교수님께 깊이 감사드립니다. 또한 교정학을 공부할 수 있도록 기회를 주시고 인도해주신 백형선 교수님, 황충주 교수님, 이기준 교수님, 차정열 교수님, 정주령 교수님, 최윤정 교수님께도 감사드립니다.

이 논문이 나오기까지 힘들 때 마다 격려해주고 조언해주었던 교정과 동기들과 도움을 주었던 의국 후배들에게 이 자리를 빌어 고마운 마음을 전합니다.

항상 변함없는 사랑으로 돌봐주시고 무한한 신뢰와 지원을 아끼지 않으시는 부모님, 시부모님께 감사드리며, 마음속으로 응원해준 오빠 내외와 서방님 내외, 조카들에게도 감사의 마음을 전합니다.

늘 곁에서 힘이 되어주고 감싸주는 사랑하는 남편과 이 논문을 준비하는 동안 잘 놀아 주지 못해 미안했던 사랑하는 두 아들 재현, 재민에게 고마운 마음을 전합니다.

마지막으로 미처 언급하지는 못했지만 제 곁에 계시는 모든 분들께 고마움과 사랑의 마음을 올립니다. 감사합니다.

2014년 6 월

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ABSTRACT

Three-dimensional evaluation of pharyngeal airway changes after bimaxillary orthognathic surgery in Class III malocclusion

The aim of this study was to evaluate the pharyngeal airway changes in Class III patients after bimaxillary surgery with intraoral vertical ramus osteotomy (IVRO) using three-dimensional computed tomography (3-D CT).

Experimental group consisted of 52 Class III patients (27 males, 25 females; mean age, 21.6±4.8 years) who underwent bimaxillary surgery with mandibular setback via IVRO. All patients were divided into two groups according to maxillary movement pattern at PNS point; Group I as maxillary advancement group and Group II as maxillary setback group. 3-D CT images were taken at pre-surgery (T0), after surgery (T1) and 1 year after surgery (T2). The results were as follows:

1. After surgery (T0-T1), the nasopharynx volume, oropharynx-high volume and total pharynx volume significantly decreased in Group I ($p < 0.01$) and Group II ($p < 0.01$).

2. After 1 year follow-up (T1-T2), there was no significant change in the pharyngeal volume except for hypopharyngeal volume decrease in Group I ($p < 0.05$).

3. After surgery (T0−T1), cross sectional area (CSA) significantly decreased at PNS plane and CV1 plane in both two groups ($p < 0.001$). The CSA increased at CV3 ($p < 0.01$) and CV4 ($p < 0.05$) plane in Group II. After 1 year follow−up, CSA at PNS level recovered to pre−surgical measurements leaving CSA at CV1 level statistically significant ($p < 0.001$) (T0−T2).

4. Comparing before surgery and 1 year after surgery (T0−T2), the antero−posterior (AP) length significantly decreased at CV1 level in Group I ($p < 0.001$). In Group II, AP length decreased at CV1 level ($p < 0.001$) and increased at CV4 level ($p < 0.01$).

5. Comparing before surgery and 1 year after surgery (T0−T2), the transverse width (TW) significantly decreased at CV1 ($p < 0.001$), CV3 ($p < 0.05$), CV4 ($p < 0.01$) level in Group I. In Group II, TW decreased at CV1 level ($p < 0.001$).

The results indicate that bimaxillary surgery with mandibular setback in Class III patients lead to decrease in pharyngeal airway volume and there was no significant recovery for 1 year follow−up period except for decrease in hypopharynx volume. The changes of upper airway volume correlated to measurement of mandibular reference point (B point), thereby being useful to prevent the risk of pharyngeal airway volume decrease obstructive sleep apnea(OSA) caused by surgery.

Key words: 3−D CT, obstructive sleep apnea (OSA), pharyngeal airway, airway volume, Class III, orthognathic surgery, IVRO

Three-dimensional evaluation of pharyngeal airway changes after bimaxillary orthognathic surgery in Class III malocclusion

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I. Introduction

Bimaxillary surgery with mandibular setback is one of the widely applied surgery to mandibular prognathism for functional and esthetic reasons. Busby et al. (2002) reported that only mandibular setback surgery is used in less than 10% of mandibular prognathism patients; two-jaws surgery was preferred by about 40% of Class III patients. Bimaxillary surgery can improve occlusion, masticatory function, and esthetics by changing the position of the mandible. However, a positional change in the maxilla affects the nasopharyngeal space, and changes due to mandibular setback surgery can affect oropharyngeal area (Greco et al. 1990). The posterior shift of the tongue base is associated with an increase on the contact length between the soft palate and the tongue. This change appears to push the soft palate posteriorly, decrease the pharyngeal airway space (PAS) and increase the risk of obstructive sleep apnea (OSA) (Wenzel et al. 1989). OSA is considered a risk factor for systemic and pulmonary hypertension and cardiac arrhythmias and might increase mobidity and mortality (Chen et al. 2007). Many studies for evaluating the airway were carried out for this risk. Eggensperger et al. (2005), Enacar et al. (1994), Samman et al. (2002), Tselnik et al. (2000) reported decreased linear measurements in pharyngeal airway at cephalometric analysis after surgery. Athanasiou et al. (1991) reported that the airway might be restored to its original condition by physiologic adaptation after time. However, it was hard to convince physiologic recovery about that result, because there was no cephalometric evaluation right after surgery. Takagi et al. (1967) reported the minimal change in the antero-posterior relation of the hyoid bone to the cervical vertebrae, indicating that some physiologic mechanism operates to prevent lingual encroachment upon the pharyngeal airway.

Still, there are unsolved issues about the accuracy of the above studies, because the evaluation was mostly based on two-dimensional (2-D) linear measurements in sagittal plane. Although lateral cephalogram is useful and convenient for analyzing linear measurement, it does not depict the three-dimensional (3-D) airway anatomy accurately. The 3-D analysis method used recently not only adopts linear measurement, but also includes 3-D measurement of airway volume, which allows more realistic measurement of changes in airway.

The recent CT study results evaluated changes of airway after sagittal split ramus osteotomy (SSRO) using rigid fixation, but do not support enough reports of intraoral vertical ramus osteotomy (IVRO) using inter-maxillary fixation. Kitahara et al. (2010) compared pharyngeal airway of patients who underwent IVRO and SSRO surgery by lateral cephalometric radiography. The measurement of airway decreased right after surgery in SSRO group, whereas the measurement decreased after 1 year follow-up period in IVRO group. The present study evaluated how the upper airway changed after bimaxillary surgery including IVRO.

The patients who underwent genioplasty were excluded from the subject group. Abramson et al. (2011) reported significant enlargement of upper airway in those who underwent bimaxillary advancement accompanying genial tubercle advancement (Heller et al. 2006). For this reason, such patients who could affect the result of this study were excluded from the subject group.

The purpose of this study is to 1) evaluate the changes of the upper airway volume, cross sectional area, linear measurements after bimaxillary surgery with IVRO in skeletal Class III patients; 2) evaluate skeletal correlation variables that affect the airway volume changes.

II. Materials and methods

A. Subjects

The 3-D CT records of 52 subjects were obtained from the archives of the Orthodontic Department, Yonsei University (Seoul, Korea). The study sample was formed retrospectively using the records of 52 patients (25 females, 27 males; mean age, 21.6±4.8 years) who had been diagnosed with Class III skeletal deformities and had undergone surgical orthodontic treatment. They had undergone Le Fort I osteotomy and mandibular setback by IVRO. All of the operations were performed by the same surgeon of Oral and maxillofacial surgery department. Patients with craniofacial anomalies or psychological limitations, severe facial asymmetry were excluded. Patients with respiratory disease, genio advancement surgery were also excluded. The subjects were divided according to maxillary antero-posterior movement at PNS point: Group I (37 patients) underwent maxillary advancement surgery, and Group II (15 patients) underwent maxillary setback surgery.

Table 1. Characteristics of sample

Sample (Number=52)	Group I (Number=37)	Group II (Number=15)
Sample size	Male:21, Female:16	Male:6, Female:9
Mean age (T0)	21.3±3.5 (year)	22.4±3.1 (year)

Values are presented as number or mean ± standard deviation.

TO: before surgery

B. Method

1. CT scanning and 3-D image reconstruction

Each patient underwent 3-D CT examinations at 1 month before surgery (T0), 2 days after surgery (T1), and 1 year after surgery (T2). A spiral CT scanner (GE Medical System, Milwaukee, Wisconsin) was used for CT scans under conditions of 120 kV and 200 mA; the thickness of the axial image was 1.0 mm, and the table speed was 6 mm per second. The digital imaging and communication in medicine (DICOM) files were created in a 1.0 mm slice thickness after scanning. The DICOM files were reconstructed into 3-D images using *OnDemand* software (CyberMed Inc, Seoul, Korea). The FH plane, which was constructed on both sides of porion and left of orbitale was used as a horizontal reference plane, and the midsagittal plane was drawn perpendicular to the FH plane passing through nasion.

2. Set-up of landmarks, reference planes, volumetric area and measurements

2-1. Landmarks and reference planes

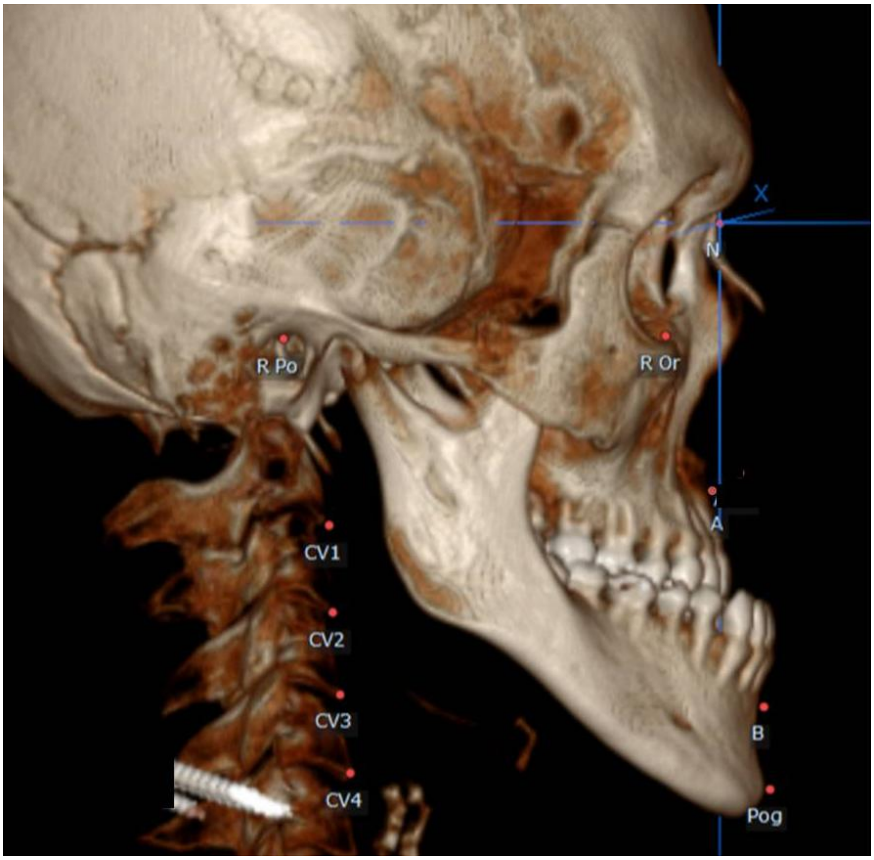

Figure 1. Reference points

N (Nasion): The most anterior point of the fronto-nasal suture in the midsagittal plane.

S (Sella): The center of the pituitary fossa of the sphenoid bone.

Or (Orbitale): The most inferior point of the orbital margin.

P (Porion): The superior point of the external auditory meatus.

A (A-point): The deepest anterior point in the concavity of the anterior maxilla.

B (B−point): The deepest anterior point in the concavity of the anterior mandible.

PNS (Posterior nasal spine): The posterior point of the hard palate.

Pog (Pogonion): The most anterior point on the contour of the symphysis.

CV1: most antero−inferior point of the first cervical vertebrae.

CV2: most antero−inferior point of the second cervical vertebrae.

CV3: most antero−inferior point of the third cervical vertebrae.

CV4: most antero−inferior point of the fourth cervical vertebrae.

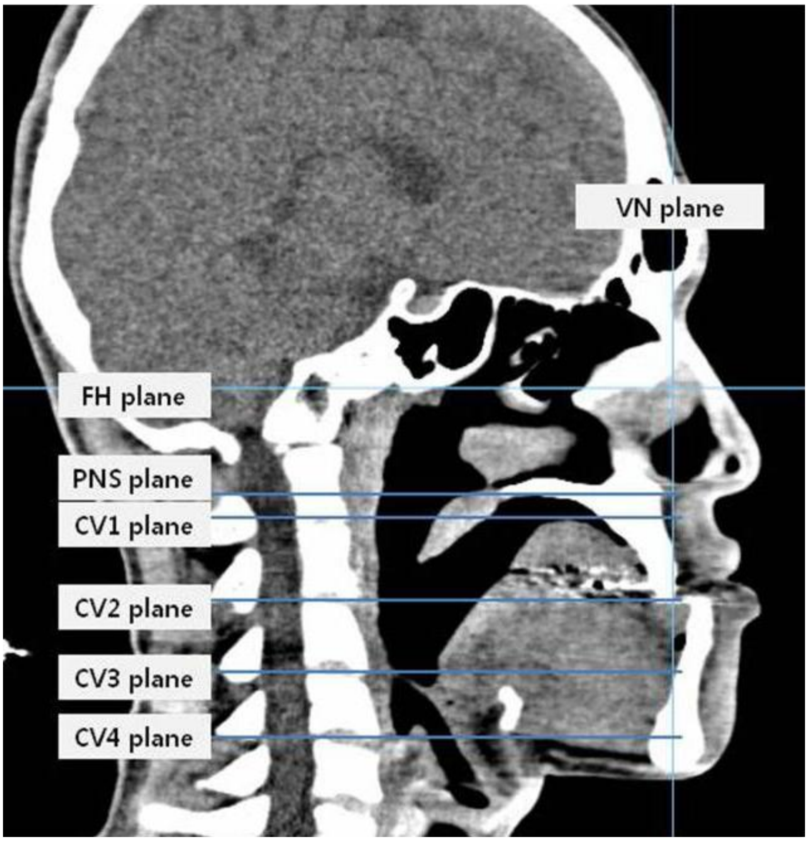

Figure 2. Reference planes

Frankfort horizontal (FH) plane: A plane constructed on the right and left porion (Po) and right of the orbitale (Or).

PNS plane: A plane parallel to the FH plane passing through posterior nasal spine (PNS).

CV1 plane: A plane parallel to the FH plane passing through CV1 point.

CV2 plane: A plane parallel to the FH plane passing through CV2 point.

CV3 plane: A plane parallel to the FH plane passing through CV3 point.

CV4 plane: A plane parallel to the FH plane passing through CV4 point.

2–2. volumetric measurements

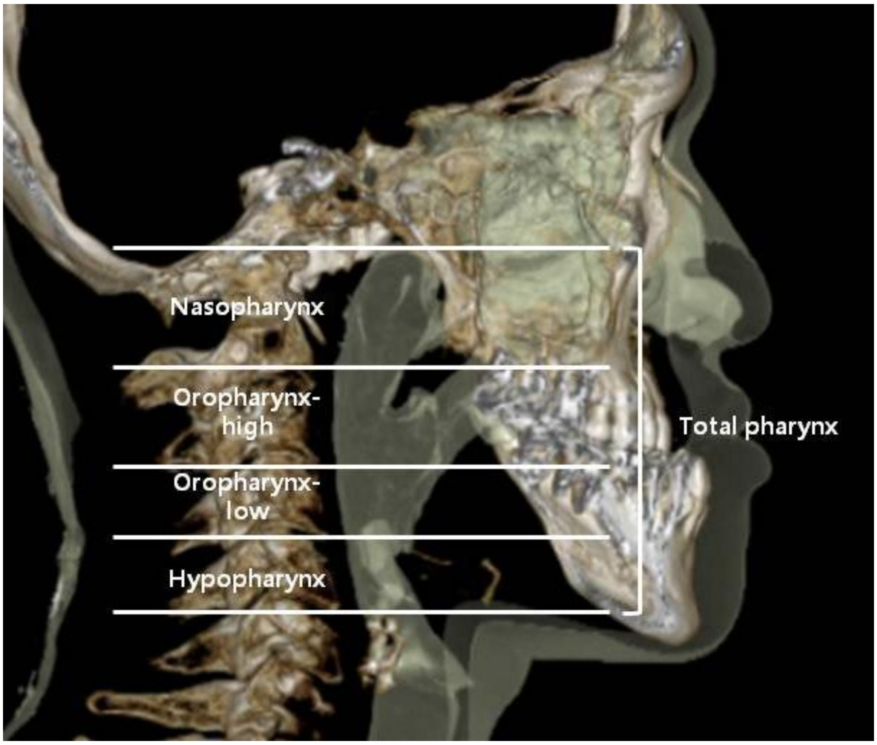

Figure 3. Classification of the upper airway

Nasopharynx: the airway space between ala of the vomer and CV1 plane.

Orophrynx–high: the airway space between CV1 plane and CV2 plane.

Orophrynx–low: the airway space between CV2 plane and CV3 plane.

Hypopharynx: the airway space between CV3 plane and CV4 plane.

Total pharynx: the airway space between ala of the vomer and CV4 plane.

2-3. Cross sectional area (CSA) measurement and linear measurement

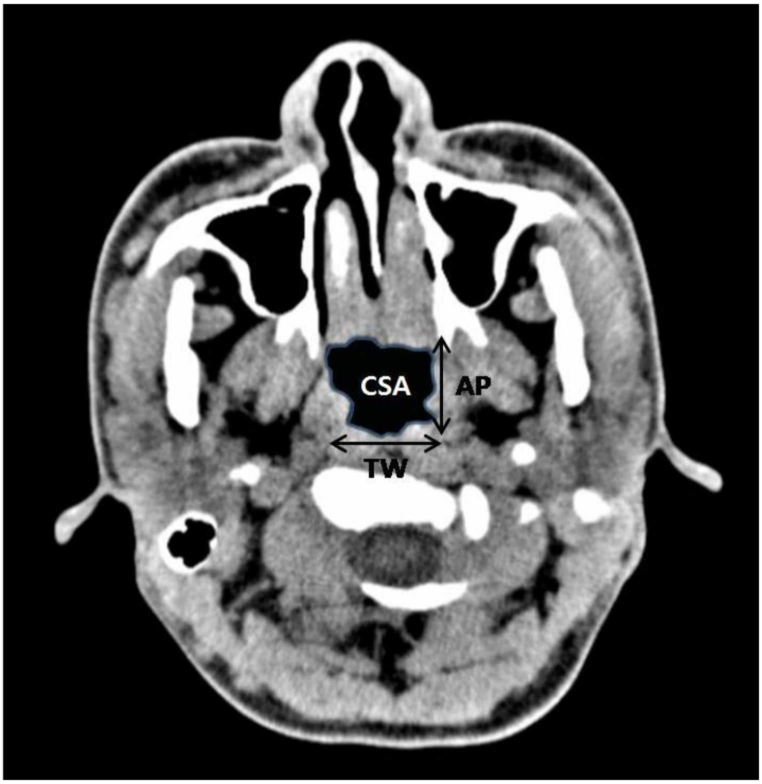

Figure 4. Cross sectional area and linear measurements in axial view

CSA and linear measurements were computed at 5 reference plane on axial view parallel to the FH plane with patient's 3-D CT.

CSA: cross sectional area.

AP: antero-posterior diameter in midsagittal plane.

TW (transverse width): transverse diameter between lateral pharyngeal walls perpendicular to midsagittal plane.

2–4. Skeletal change

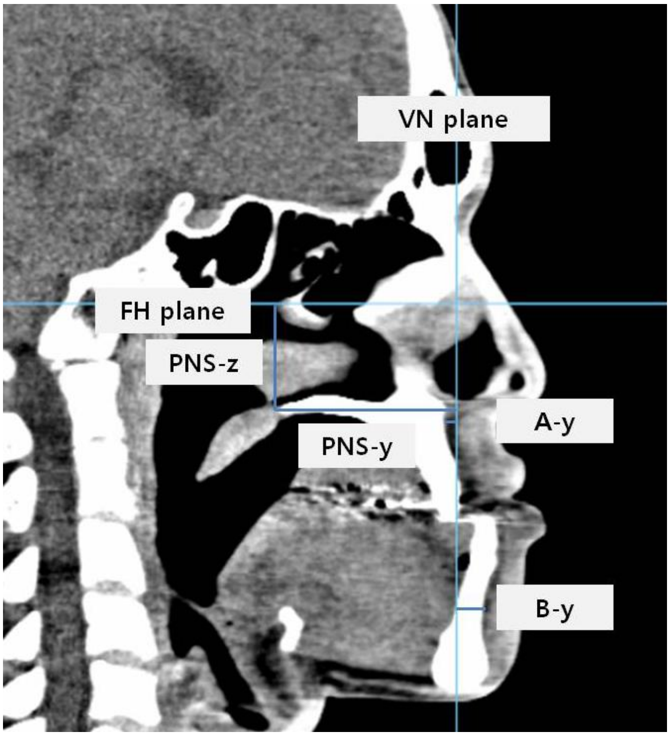

Figure 5. Skeletal measurements in sagittal view

FH plane: A plane constructed on the right and left porion (Po) and right of the orbitale (Or).

VN plane: vertical plane perpendicular to the FH plane passing through nasion.

A–y: linear distance between VN plane and A point (Maxilla antero posterior movement).

PNS–y: linear distance between VN plane and PNS point (Maxilla antero posterior movement).

PNS–z: linear distance between FH plane and PNS point (Maxilla Vertical movement).

B–y: linear distance between VN plane and B point (Mandible Set–back movement).

C. Statistical Analysis

To test intra−examiner reproducibility, 7 images selected randomly were measured repeatedly by the same examiner within a minimum of 1 week after the first measurements and compared with the first measurements by the same examiner using the paired T−test and the Spearman's correlation coefficients. The Shapiro−Wilk test was used to determine the normal distribution of data. $p < 0.05$ was considered to be the level of statistical significance. The arithmetic mean and standard deviation were calculated for all measurements. SPSS version 15.0 (SPSS Inc., Illinois, USA) was used for statistical analysis.

1. The intra−examiner reliability was tested using the paired T−test and the Spearman's correlation analysis.
2. Skeletal changes before (T0), after surgery (T1) and 1 year after surgery (T2) in 3−D images were tested using the paired T−test.
3. Volumetric, cross sectional area, linear changes before (T0), after surgery (T1) and 1 year after surgery (T2) in 3−D images were tested using the paired T−test.
4. Correlations between skeletal changes and volumetric changes were tested using the Pearson's correlation analysis. (T0−T1), (T0−T2)
5. Significance of differences between male group and female group in airway volume before surgery (T0) and volume changes after surgery (T0−T1) were tested using independent T−test.

III. Results

A. The intra−examiner reliability

The intra−examiner reliability test showed no significant differences ($p <$ 0.05). Intra−class correlation coefficients were found to be higher than 0.90(mean of 0.93, with range of 0.90−0.94).

B. Statistical analysis

1. Skeletal changes after surgery (T0−T1), 1 year after surgery (T1−T2) (Table 2)

In Group I, the maxilla moved forward average 2.86mm at PNS point, PNS impaction was 3.21mm and the mandibular setback movement was average 9.93mm after surgery (T0−T1).

In Group II, the maxilla moved backward average 2.88mm at PNS point, PNS impaction was 2.73mm and the mandibular setback movement was average 9.3mm after surgery (T0−T1).

Table2. Skeletal changes after surgery and 1 year after surgery

(measurement unit: mm)

	Measurement	T0-T1			T1-T2		
		Mean	SD	Sig	Mean	SD	Sig
Group I (N=37)	A-y	1.69	1.82	***	-0.77	1.27	**
	PNS-y	2.86	2.25	***	-1.26	1.89	***
	B-y	-9.93	6.04	***	0.60	4.03	NS
	PNS-z	-3.21	2.59	***	0.54	1.61	*
Group II (N=15)	A-y	-1.17	2.16	*	-0.80	0.89	**
	PNS-y	-2.88	2.63	**	0.78	2.69	NS
	B-y	-9.30	5.86	***	-0.64	2.68	NS
	PNS-z	-2.73	2.97	**	1.84	4.89	NS

Positive value means anterior or inferior movement of Maxilla or Mandible.

Negative value means posterior or superior movement of Maxilla or Mandible.

SD: standard deviation, Sig: significance, N: number

Group I: Maxilla advance group, Group II: Maxilla set back group

T0: before surgery, T1: after surgery, T2: 1 year after surgery

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

2. Volumetric changes in Group I and Group II (Table 3, Table 4)

In Group I, total airway volume significantly decreased from 15,718 mm^3 (T0) to 14,075 mm^3 (T1), mostly including decrease of nasopharynx ($p < 0.001$) and oropharynx-high volume($p < 0.001$). The mean reduction rate was 10.6%. For 1 year follow-up (T1-T2), there was significant decrease in hypopharynx volume($p < 0.05$). For T0-T2, there was significant decrease in nasopharynx volume($p < 0.01$), oropharynx-high volume($p < 0.05$) and total pharynx volume($p < 0.01$).

In Group II, total airway volume significantly decreased from 13,560 mm^3 (T0) to 12,006 mm^3 (T1) resulting 11.5% reduction rate. Nasopharynx and oropharynx−high volume was mostly decreased similar to Group I. The decreased volume was still maintained significantly 1 year after surgery (T0−T2).

There were few changes in oropharynx−low volume.

Table 3. Volumetric changes in Group I and Group II (T0, T1, T2)

(measurement unit: mm^3)

	Volume	T0		T1		T2	
		Mean	SD	Mean	SD	Mean	SD
Group I (N=37)	Naso	4,422	1,072	3,722	1,136	3,940	1,124
	Oro-High	4,202	1,197	3,240	969	3,099	2,426
	Oro-Low	3,300	1,017	3,157	1,051	3,265	971
	Hypo	3,791	1,335	3,954	1,301	3,580	1,102
	Total	15,718	3,571	14,075	3,258	13,886	3,627
Group II (N=15)	Naso	4,019	915	3,265	776	3,334	670
	Oro-High	3,730	1,043	2,442	617	2,650	887
	Oro-Low	2,728	864	2,998	888	2,759	744
	Hypo	3,081	819	3,300	914	2,969	733
	Total	13,560	2,790	12,006	2,680	11,713	2,080

SD: standard deviation, N: number

T0: before surgery, T1: after surgery, T2: 1−year after surgery

Group I: Maxilla advance group, Group II: Maxilla set back group

Naso : nasopharynx volume, Oro−High : oropharynx−high volume,

Oro−Low : oropharynx−low volume, Hypo : hypopharynx volume, Total: total pharynx volume

Table 4. Comparison of volumetric changes at the time after surgery (T0−T1) and 1 year after surgery (T1−T2)

(measurement unit: mm^3)

	Region	⊿T0−T1				⊿T1−T2				⊿T0−T2			
		Mean	SD	p	Sig	Mean	SD	p	Sig	Mean	SD	p	Sig
Group I (N=37)	**Naso**	699	1,001	0.000	***	-217	1,027	0.206	NS	482	982	0.005	**
	Oro-H	962	1,292	0.000	***	140	2,747	0.758	NS	1,102	2,629	0.015	*
	Oro-L	143	1,042	0.409	NS	-107	920	0.481	NS	35	1,052	0.839	NS
	Hypo	-162	1,018	0.337	NS	374	153	0.020	*	211	989	0.201	NS
	total	1,642	2,993	0.002	**	189	3,625	0.752	NS	1,832	3,588	0.004	**
Group II (N=15)	**Naso**	754	799	0.003	**	-69	749	0.724	NS	684	977	0.017	*
	Oro-H	1,288	890	0.000	***	-208	875	0.373	NS	1,080	1,019	0.001	**
	Oro-L	-269	751	0.187	NS	238	692	0.203	NS	-30	617	0.851	NS
	Hypo	-219	626	0.197	NS	331	797	0.130	NS	112	704	0.547	NS
	Total	1,554	1,932	0.008	**	292	2,312	0.632	NS	1,846	2,501	0.013	**

Positive value means decreased volume.

Negative value means increased volume.

SD: standard deviation, Sig.: significance, N: number

T0: before surgery, T1: after surgery, T2: 1 year after surgery

Group I: Maxilla advance group, Group II: Maxilla set back group

Naso : nasopharynx volume, Oro−H : oropharynx−high volume,

Oro−L : oropharynx−low volume, Hypo : hypopharynx volume, Total : total pharynx volume

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

3. Comparison of cross sectional area, linear measurement changes before (T0), after (T1) and 1 year after (T2) surgery

3-1. CSA changes after (T0-T1) and 1 year after surgery (T1-T2) (Table 5)

After surgery (T0-T1), cross sectional area (CSA) significantly decreased at PNS plane, CV1 plane in both two groups ($p < 0.001$) and increased at CV3 ($p < 0.01$), CV4 ($p < 0.05$) plane in Group II.

For 1 year after surgery (T1-T2), CSA at PNS level significantly increased in both two groups. Therefore, there was significant decrease only at CV1 level ($p < 0.001$) compared before and 1 year after surgery (T0-T2).

Table 5. Cross sectional area changes after surgery (T0-T1) and 1 year after surgery (T1-T2)

(measurement unit: mm^2)

	Area	⊿T0-T1				⊿T1-T2				⊿T0-T2			
		Mean	SD	p	Sig	Mean	SD	p	Sig	Mean	SD	p	Sig
Group I (N=37)	**PNS**	179	128	0.000	***	-149	136	0.000	***	29	117	0.131	NS
	CV1	148	106	0.000	***	-54	106	0.004	**	93	96	0.000	***
	CV2	19	132	0.377	NS	4	114	0.829	NS	23	122	0.249	NS
	CV3	7	190	0.822	NS	33	172	0.244	NS	40	144	0.094	NS
	CV4	20	155	0.432	NS	30	120	0.138	NS	50	121	0.016	*
Group II (N=15)	**PNS**	117	68	0.000	***	-117	132	0.004	**	0	126	0.985	NS
	CV1	142	94	0.000	***	-24	89	0.317	NS	118	84	0.000	***
	CV2	-65	144	0.102	NS	58	110	0.061	NS	-7	90	0.757	NS
	CV3	-102	101	0.002	**	64	88	0.014	*	-37	94	0.145	NS
	CV4	-70	126	0.048	*	-1	73	0.981	NS	-71	146	0.080	NS

Positive value means decreased cross sectional area.

Negative value means increased cross sectional area.

Group I: Maxilla advance group, Group II: Maxilla set back group
PNS: cross sectional area in PNS level, CV1: cross sectional area in CV1 level,
CV2: cross sectional area in CV2 level, CV3: cross sectional area in CV3 level,
CV4: cross sectional area in CV4 level
SD: standard deviation, Sig.: significance
T0: before surgery, T1: after surgery, T2: 1 year after surgery
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

3-2. Linear measurement changes after (T0-T1) and 1 year after surgery (T1-T2) (Table 6, Table 7)

In Group I, The AP of airway significantly decreased at CV1 level after surgery ($p < 0.05$). The decreased measurements were maintained at T2 ($p < 0.001$).

The TW of airway decreased at PNS, CV1, CV2 ($p < 0.001$) and CV3 level ($p < 0.05$) after surgery in Group I, and there was certain recovery at PNS, CV1 level for 1 year follow-up period (T1-T2). The TW decrease of CV1 ($p < 0.001$), CV3 ($p < 0.05$), CV4 ($p < 0.01$) level at T2 was significant compared to that of T0.

In Group II, the AP length decreased at CV1 level ($p < 0.01$) and increased at CV2, CV3, CV4 level ($p < 0.05$) at T1. And there were significant decrease at CV1 level ($p < 0.001$), significant increase at CV4 level ($p < 0.01$) at T0-T2.

The TW significantly decreased in PNS and CV1 level at T1 and significant recovery occurred in PNS level for follow-up period (T1-T2). The TW at CV1 level significantly decreased after 1 year compared to that before surgery (T0-T2) ($p < 0.001$).

Table 6. Linear measurements changes after surgery (T0−T1) and 1 year after surgery (T1−T2) in Group I

(measurement unit: mm)

		⊿T0−T1				⊿T1−T2				⊿T0−T2			
		Mean	SD	p	Sig	Mean	SD	p	Sig	Mean	SD	p	Sig
AP	**PNS**	0.74	3.93	0.260	NS	-1.32	2.90	0.009	**	-0.58	3.01	0.249	NS
	CV1	1.62	3.76	0.013	*	0.51	3.99	0.435	NS	2.14	3.02	0.000	***
	CV2	-0.32	5.33	0.714	NS	0.57	4.46	0.440	NS	0.24	4.42	0.734	NS
	CV3	-0.60	6.27	0.561	NS	0.78	5.29	0.371	NS	0.18	4.42	0.802	NS
	CV4	0.34	4.45	0.642	NS	-0.27	3.82	0.667	NS	0.07	3.60	0.906	NS
TW	**PNS**	6.07	4.92	0.000	***	-5.30	4.15	0.000	***	0.77	3.91	0.239	NS
	CV1	8.24	4.45	0.000	***	-4.40	5.56	0.000	***	3.84	4.52	0.000	***
	CV2	3.65	5.18	0.000	***	-2.04	5.56	0.032	NS	1.60	4.91	0.054	NS
	CV3	3.43	8.74	0.022	*	-0.38	9.49	0.806	NS	3.04	7.45	0.018	*
	CV4	0.81	10.35	0.635	NS	2.20	9.46	0.166	NS	3.01	5.90	0.004	**

Positive value means decreased linear measurement.

Negative value means increased linear measurement.

AP: anteroposterior diameter of pharyngeal wall, TW: transverse diameter of pharyngeal wall

PNS: linear measurements in PNS level, CV1: linear measurements in CV1 level,

CV2: linear measurements in CV2 level, CV3: linear measurements in CV3 level,

CV4: linear measurements in CV4 level

SD: standard deviation, Sig.: significance

T0: before surgery, T1: after surgery, T2: 1 year after surgery

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

Table 7. Linear measurements changes after surgery (T0−T1) and 1 year after surgery (T1−T2) in Group II

(measurement unit: mm)

		⊿T0−T1				⊿T1−T2				⊿T0−T2			
		Mean	SD	p	Sig	Mean	SD	p	Sig	Mean	SD	p	Sig
AP	**PNS**	0.26	2.93	0.730	NS	-0.44	3.14	0.591	NS	-0.18	2.33	0.770	NS
	CV1	2.01	2.19	0.003	**	1.23	2.85	0.116	NS	3.24	2.35	0.000	***
	CV2	-2.88	4.60	0.029	*	1.70	3.57	0.085	NS	-1.18	3.17	0.172	NS
	CV3	-3.04	3.53	0.005	**	1.41	1.87	0.011	*	-1.62	3.08	0.060	NS
	CV4	-3.11	4.03	0.010	*	-0.54	4.02	0.607	NS	-3.66	4.46	0.007	**
TW	**PNS**	6.37	3.46	0.000	***	-5.14	3.69	0.000	***	1.22	3.09	0.147	NS
	CV1	9.05	5.79	0.000	***	-3.38	6.16	0.052	NS	5.66	5.17	0.001	***
	CV2	0.33	6.72	0.850	NS	-1.51	6.24	0.364	NS	-1.18	3.91	0.262	NS
	CV3	-2.92	7.17	0.137	NS	1.24	6.25	0.456	NS	-1.68	7.38	0.391	NS
	CV4	-2.09	5.98	0.197	NS	1.79	6.32	0.291	NS	-0.30	7.59	0.881	NS

Positive value means decreased linear measurement.

Negative value means increased linear measurement.

AP: anteroposterior diameter of pharyngeal wall, TW: transverse diameter of pharyngeal wall

PNS: linear measurements in PNS level, CV1: linear measurements in CV1 level,

CV2: linear measurements in CV2 level, CV3: linear measurements in CV3 level,

CV4: linear measurements in CV4 level

SD: standard deviation, Sig.: significance

T0: before surgery, T1: after surgery, T2: 1 year after surgery

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

4. Correlations between skeletal changes and volumetric changes (Table 8)

Important variables affecting the volumetric changes of airway following maxillary or mandibular movement were verified.

The Pearson's correlation analysis showed that the extent of change at B point correlated with the volumetric change of the oropharynx−high (correlation coefficient: 0.29, $p < 0.05$), the hypopharynx (correlation coefficient: 0.30, $p < 0.05$) and total pharynx (correlation coefficient: 0.38, $p < 0.05$).

Table 8. Correlations between skeletal changes and volumetric changes

	Variable 1 (Mx, Mn changes)	Variable 2 (volume changes)	R	p−value	Sig.(2−tailed)
T0−T1	B−y	Oro−High	0.29	0.035	*
	B−y	Hypopharynx	0.30	0.046	*
	B−y	Total pharynx	0.38	0.010	*
T0−T2	PNS−y	Oro−Low	−0.34	0.013	*

Sig.: significance, R : Pearson's correlation coefficient

Mx: Maxilla, Mn: Mandible

T0: before surgery, T1: after surgery, T2: 1 year after surgery

Oro−High: oropharynx−high volume, Oro−Low: oropharynx−low volume,

Hypopharynx: hypopharynx volume, Total pharynx: total pharynx volume

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

5. **Differences between male group and female group in airway volume before surgery and volume changes after surgery (Table 9)**

Male group presented significantly larger nasopharynx, oropharynx, hypopharynx and total pharynx volume than female group at T0. The male group's volume (16,774 mm^3) exceeded the female group's volume (13,282 mm^3) by 20% on average.
However, the gender differences in volumetric changes after surgery were statistically insignificant except for hypopharynx volume (TO−T1).

Table 9. Differences between male group and female group in airway volume

	Volume (mm^3)	Male (N=27)		Female (N=25)		p−value	Sig.
		Mean	SD	Mean	SD		
T0	Nasopharynx	4,695	1,046	3,885	864	0.004	**
	Oropharynx−High	4,500	1,264	3,597	843	0.004	**
	Oropharynx−Low	3,431	1,143	2,816	717	0.026	*
	Hypopharynx	4,147	1,387	2,982	688	0.000	***
	Total pharynx	16,774	3,595	13,282	2,269	0.000	***
T0−T1	Nasopharynx	792	1122	632	707	0.544	NS
	Oropharynx−High	1262	1439	833	819	0.197	NS
	Oropharynx−Low	31	1189	16	708	0.957	NS
	Hypopharynx	-425	1020	87	719	0.040	*
	Total pharynx	1660	3287	1569	1984	0.903	NS
T1−T2	Nasopharynx	-182	887	-167	1033	0.955	NS
	Oropharynx−High	-230	880	331	3287	0.415	NS
	Oropharynx−Low	59	993	-79	724	0.565	NS
	Hypopharynx	538	873	171	887	0.140	NS
	Total pharynx	184	2185	256	4202	0.939	NS

SD: standard deviation, Sig.: significance, N: number

T0: before surgery, T1: after surgery, T2: 1 year after surgery

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS: not significant

IV. Discussion

1. Volume changes after surgery and during the 1 year post-operative follow-up

Recently, airway measurement in 3-D analyses have been carried out with 3-D CT. Analysis of the airway by lateral cephalometric radiography has the limitation of measuring only the antero-posterior width change of the airway; analysis of the airway by frontal cephalometric radiography, which confirms the transverse width, has limitations due to obstruction caused by hard tissue overlapping.

CT has significant advantages over 2-D cephalometric radiography because it allows greater delineation of soft tissue and air, and thus more accurate measurements of upper airway morphology can be performed. Skeletal maxillary and mandibular changes may be described by changes in only the sagittal dimensions, whereas soft tissue pharyngeal changes must be considered in all 3 dimensions (Hochban et al. 1996).

With 3-D CT imaging, it is possible to visualize the pharyngeal airway 3-dimensionally without obstruction from hard tissue structures. Therefore, measuring the CT volume through a 3-D reconstruction of different planes of the patient's airway is necessary for a more accurate assessment.

In this study, 3-D CT images of Class III malocclusion patients who underwent bimaxillary surgery with IVRO were evaluated to determine whether airway changes occurred after surgery and if such changes are recoverable

After surgery (T0-T1), the total airway volume decreased in both Group I and Group II. The main regions of volumetric decrease were the nasopharynx and the oropharynx-high area. When evaluating each pharyngeal region in both groups, the volumetric decrease of the oropharynx−high area was markedly larger in Group II than in Group I. Posterior movement of the maxilla resulted in large volumetric decreases in the pharynx behind the maxilla and relatively small volumetric decreases in other areas of Group II. There were increase in the oropharynx−low and hypopharynx volume, although statistically insignificant, resulting from the steep decrease in oropharynx−high volume of Group II. However, the changes in volume in each area reduced after 1 year follow−up as the volume decrease concentrated in the posterior maxillary set back area dispersed into other areas.

At the 1 year follow−up, the decreased volume was maintained without any statistically significant recovery in Group II. In Group I, there was a significant decrease in hypopharynx volume from T1 to T2.

Since the CSA decrease also occurred mainly in the PNS and CV1 planes, CSA decreases in these areas were found to coincide with the volume decreases in such planes. Due to recovery, the CSA in the PNS plane measured 1 year after surgery did not show a statistical difference compared to that measured before surgery. However, the CSA in the CV1 plane measured 1 year after surgery showed a statistical difference compared to that measured before surgery.

Additionally, linear measurement results demonstrated an AP decrease in CV1, and a TW decrease in the PNS and CV1 areas. Therefore, the largest decrease in airway was found in the PNS and CV1 plane at T1. This result coincides with those of previous studies (Degerliyurt et al. 2008, Bae 2001). When comparing airway changes after surgery to previous studies, volume, CSA, AP, and TW changes between the CV1 and CV2 planes were reported as common results. Degerliyurt et al.(2008) measured the CSA, AP, and TW of bimaxillary surgery patients, including Mn. setback, after 3 months by CT, and reported only that the AP length decreased at the soft palate level with statistical significance. Moreover, Park et al. (2011) measured the airways of Class III patients who underwent bimaxillary surgery, including Mx. advancement by CBCT, and reported that the volume of the airway between CV1 and CV2 decreased. The patients who underwent only Mn. setback surgery showed a steeper volume decrease between CV1 and CV2 than patients who underwent bimaxillary surgery. They concluded that the airway volume decrease can be diminished by bimaxillary surgery. Moreover, Lee et al. (2012) reported that the volume between CV1 and CV3 decreased after 6 months in patients who underwent bimaxillary surgery, including Mx. advancement and Mn. setback. In linear measurements, AP length decreased in the CV1 plane with statistical significance.

In this study, the area with the largest volumetric decrease was between the CV1 and CV2 planes at T2, and the CSA, AP, and TW decreases were statistically significant in the CV1 plane in both groups.

Kyung et al. (2004) investigated airway changes using CT imaging of patients diagnosed with OSA between pre-trials and post-trials of oral appliance that protruded the mandible. As a result, airway changes were greater in the TW than in the AP. Mandibular anterior repositioning affected both the TW and AP width because the pharyngeal muscle is circumferential. In this study, the TW decrease was larger than the AP decrease at the PNS, CV1, CV2, CV3 and CV4 planes resulting from the Mn. setback movement in Group I (T0-T1, T0-T2).

There are many studies on the time durations of airway changes after surgery. Wenzel et al. (1989) measured the airway of a patient who underwent Mn. setback surgery after only 1 year. The AP length of the PNS plane decreased, and the decrease was maintained for 1 year. Tselnik et al. (2000) and Holmberg et al. (1979) measured the pharyngeal AP space of the tongue base position by cephalometric radiography. The decreased value was maintained after 1 year as well. Chen et al. (2007) reported that changes in airway measurements showed no significant changes at 3 months, 6 months, and 2 years after surgery. Kawamata et al. (2005) also reported no significant recovery in the average rate of pharyngeal narrowing at either 6 months or 1 year after surgery. Gu et al. (2000) stated that the maximum forward relapse of the pogonion occurred mainly within 6 months after surgery. Bailey et al. (1998) concluded that 90% of patients with a Class III correction who underwent surgery showed no clinically significant long-term changes, suggesting that most relapses occur within the first postoperative year. In conclusion, the above studies support that no particular change occurs in the pharyngeal airway 6 months after surgery, unless there is a noticeable skeletal relapse.

2. Relationship between skeletal changes and volume changes

In a study by Kawamata et al. (2000), although volume was not measured, the mandibular set back amount and AP width at the CV2 level showed a correlation, similar to the results of this study. In a study by Lee et al. (2012), the variable that affected changes of the upper part of the airway was the vertical surgical correction of Pogonion and ANS, and that of the lower part of the airway was the vertical surgical correction of the PNS. This result is caused by a vertical decrease, which (a) causes an occlusal plane change of the maxilla, (b) affects the setback amount of the mandible, and (c) eventually affects the upper and lower airway volumes.

In this study, as a result of analyzing the relationship using Pearson's correlation, oropharynx-high volume, hypopharynx volume, and total pharynx volume were related to the posterior movement of the B point. With a linear regression analysis, a formula was calculated for predicting the volumetric decrease.

Oropharynx-high volume (T0-T1) = 53.28 × B - y(T0-T1) + 626.37

3. Differences between IVRO and SSRO measurements by 3-D CT after surgery

According to Kawamata et al. (2000), in patient cases with SSRO and IVRO, AP width and lateral width measurements of the pharyngeal airway decreased in both groups, and there were no significant differences between the 2 groups. However, Kitahara et al. (2010) compared changes of the hyoid bone, uvula, and tongue base of IVRO and SSRO patients on lateral cephalometric radiography images, and reported that the antero-posterior decrease of the airway became steeper in the IVRO group than in the SSRO group 1 year after surgery. In particular, the position of the hyoid bone significantly moved forward in the SSRO group and the position of the hyoid bone, uvula, and tongue base moved backward in the IVRO group.

As the measurements were difficult to compare directly, we compared the volumetric changes of Park's (2012) two-jaws group (Mx. Advancement + SSRO) and Group I (Mx. Advancement + IVRO) in this study. In the SSRO study, the volume between the CV1 and CV2 planes was decreased at T1 and increased at T2. On the other hand, the volume between the CV1 and CV2 planes was decreased at T1 and more decreased at T2 in this IVRO study. These results corresponded with the Mn. movement pattern for the retention period after each surgery.

4. OSA possibility after Class III surgery

To evaluate the potential risk of the development of OSA, postoperative pharyngeal airway space values should be compared to normal values for PAS. Most researchers agree that obstruction can be observed at any level of the upper airway. However, the obstruction was often recorded behind the soft palate or at the oropharyngeal level (Bohlman 1983, Gavin 1989). Partinen et al. (1988) reported that a reduction of posterior upper airway space to 5 mm or less correlated with a high apnea index independently of the body mass index. Galvin et al. (1989) and Avrahami et al. (1995) reported that the minimal cross sectional area associated with breathing disturbances was approximately 50 mm^2 or less. Moreover, the minimal cross sectional area at the nasopharyngeal level for healthy subjects was reported to be 134.2 ± 56.6 mm^2. However, the risk of OSA is minimal because the airway sizes of most Class III patients are larger than those of normal patients, and the decrease in amount is similar to that of a normal patient (Samman 2002, Hochban 1996).

In this study, there was only 1 patient whose AP length decreased below 5 mm and whose CSA decreased below 50 mm^2 in the CV3 plane. The AP length and CSA value were close to the borderline, and the values obtained were greater than 5 mm and 50 mm^2 1 year after surgery, respectively.

OSA mainly occurs in the supine position because of deformation of the upper pharyngeal tissue by gravity and relaxation of muscle tone. Images of patients taken in a supine position rather than in an upright position would be suitable to reproduce this environment and to evaluate the airway, which was the method adopted in this study.

5. Limitations of this study

This study was a retrospective study using 3-D CT, and did not include information about the respiration, phonation, or deglutition of the enrolled patients.

Additionally, the difference in the antero-posterior movement of the maxilla was not large for the following reasons:

(a) in terms of posterior movement of the maxilla, a large amount of posterior movement is difficult because there are many anatomically important structures that escalate the risks of surgery;

(b) in terms of anterior movement, large movement is not necessary in Class III patients compared to mandible movement.

If the study samples demonstrated large differences in maxillary antero-posterior movements, the difference in volumetric changes between maxillary movement patterns may have shown a statistically significant difference.

Kawakami et al. (2005) suggested that 1 month after surgery was adequate to allow post-operative swelling in the soft tissues to reduce, which contributes to narrowing of the airway. However, CT images taken immediately after surgery and 1 year post-operatively were used in this study. Having 1, 2 month post-operative data may have been helpful in evaluating the airway in the recovery stage.

V. Conclusion

The aim of this study was to evaluate the pharyngeal airway changes in Class III patients after bimaxillary surgery with intraoral vertical ramus osteotomy(IVRO) using three-dimensional facial computed tomography (3-D CT).

Experimental group consisted of 52 Class III patients (27 males, 25 females; mean age, 21.6±4.8 years) who underwent bimaxillary surgery with mandibular setback via IVRO. All patients were divided into two groups according to maxillary movement pattern at PNS point; Group I as maxillary advancement group and Group II as maxillary setback group. 3-D CT images were taken at pre-surgery (T0), after surgery (T1) and 1 year after surgery (T2). The results were as follows:

1. After surgery (T0-T1), the nasopharynx volume, oropharynx-high volume and total pharynx volume significantly decreased in Group I ($p < 0.01$) and Group II ($p < 0.01$).

2. After 1 year follow-up (T1-T2), there was no significant change in the pharyngeal volume except for hypopharyngeal volume decrease in Group I ($p < 0.05$).

3. After surgery (T0-T1), cross sectional area (CSA) significantly decreased at PNS plane and CV1 plane in both two groups ($p < 0.001$). The CSA increased at CV3 ($p < 0.01$) and CV4 ($p < 0.05$) plane in Group II. After 1 year follow-up, CSA at PNS level recovered to pre-surgical measurements leaving CSA at CV1 level statistically significant ($p < 0.001$) (T0-T2).

4. Comparing before surgery and 1 year after surgery (T0−T2), the antero−posterior (AP) length significantly decreased at CV1 level in Group I ($p < 0.001$). In Group II, AP length decreased at CV1 level ($p < 0.001$) and increased at CV4 level ($p < 0.01$).

5. Comparing before surgery and 1 year after surgery (T0−T2), the transverse width (TW) significantly decreased at CV1 ($p < 0.001$), CV3 ($p < 0.05$) and CV4 ($p < 0.01$) level in Group I. In Group II, TW decreased at CV1 level ($p < 0.001$).

The results indicate that bimaxillary surgery with mandibular setback in Class III patients lead to decrease in pharyngeal airway volume and there was no significant recovery for 1 year follow−up period except for decrease in hypopharynx volume. The changes of upper airway volume correlated to measurement of mandibular reference point (B point), thereby being useful to prevent the risk of pharyngeal airway volume decrease obstructive sleep apnea(OSA) caused by surgery.

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국 문 요 약

삼차원 전산화 단층 촬영 영상을 이용한 골격성 III급 부정교합자의 악교정 수술 후 인두 기도 변화의 평가

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이 연구의 목적은 골격성 III급 부정교합으로 악교정 수술을 받은 환자에서 인두 기도의 부피와 모양의 변화를 3-D CT를 이용하여 평가하는 것이다.

52 명의 하악골 후퇴술을 동반한 양악 수술을 받은 III급 부정교합 환자(남성: 27명, 여성: 25명; 평균 나이: 21.6±4.8세)를 대상으로 3-D CT를 수술 전, 수술 직 후, 수술 후 1년 뒤에 촬영하여 평가하였다.

수술 시 상악골의 전후방적 이동 양상에 따라 상악골의 전방 이동 군을 Group I, 상악골의 후방 이동 군을 Group II, 두 개의 군으로 나누어 평가하였으며 그 결과는 다음과 같다.

1. 수술 직후(T0-T1), Group I 과 Group II 모두에서 통계적으로 유의한 상인두 부피(nasopharynx volume, oropharynx-high volume, total pharynx volume)의 감소가 나타났다($p < 0.01$).

2. 수술 1년 뒤에 시행한 평가에서(T1-T2) Group I의 hypopharynx 부피 감소($p < 0.05$)외에 통계적으로 유의한 부피의 변화는 없었다.

3. 수술 후에(T0−T1) 측정한 단면적은 두 그룹 모두에서 PNS plane과 CV1 plane에서 통계적으로 유의하게 감소하였고(p < 0.001), Group II의 CV3 (p < 0.01), CV4 plane(p < 0.05)에서는 증가하였다. 수술 1년 후에 PNS 부위의 단면적은 수술 전과 비슷하게 회복이 되었으며, 수술 전과 비교하여 (T0−T2) CV1 plane에서의 단면적 감소만이 통계적으로 유의하였다 (p < 0.001).

4. 인두의 전후방 길이는 수술 1년 후 수술 전과 비교해서(T0−T2) Group I에서는 CV1 level에서 길이 감소(p < 0.001)가 유의하게 나타났고, Group II에서는 CV1 level에서 길이 감소(p < 0.001)와 CV4 level에서 길이 증가 (p < 0.01)가 통계적으로 유의하게 나타났다.

5. 인두의 측방 길이는 수술 1년 후 수술 전과 비교해서(T0−T2) Group I에서는 CV1(p < 0.001), CV3(p < 0.05), CV4(p < 0.01) level에서의 감소가 나타났으며, Group II에서는 CV1 level에서의 감소가 유의하게 나타났다(p < 0.001).

이상의 결과를 통해서 골격성 III급 부정교합 환자에서 수직적 하악지 절단 하악골 후퇴술을 동반한 양악 수술을 시행하였을 때 인두 기도의 부피 감소가 나타나고 1년간 경과 관찰 기간에 hypopharynx 부피의 감소를 제외하고는 뚜렷한 변화는 나타나지 않음을 확인하였다. 부피의 변화량은 하악골의 전후방 변화량과 상관관계가 있으므로 수술 전 기도가 좁은 환자의 경우 수술에 의한 폐쇄성 무호흡 위험에 대비하는 데에 활용될 수 있을 것이다.

핵심되는 말: 3차원 전산화 단층사진, 수면성 무호흡, 상기도, 인두 기도 부피, 골격성 III급 부정교합, 수직적 하악지 절단 후퇴술, 양악 수술