

## Retrospective study on the airway obstruction aspects of computed tomography and lateral cephalometry and the correlation of polysomnography in obstructive sleep apnea patients

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**Abstract** (J Korean Assoc Oral Maxillofac Surg 2012;38:295-304)

**Objectives:** Lateral cephalometry, computed tomography (CT) and full-night polysomnography were used to examine the correlation of obstructive sleep apnea (OSA) severity.

**Materials and Methods:** A total of 29 patients (5 females, 24 males) diagnosed with OSA were evaluated by lateral cephalometry, CT and full-night polysomnography. Lateral cephalometry was performed in the closed and open mouth states. The radiographic and polysomnography measurements of the patients with OSA were evaluated statistically to determine the association with OSA severity.

**Results:** A significant relationship was observed between the increased respiratory disturbance index and closing lateral cephalometry. With mouth opening, the airway space narrowed and the OSA worsened. Lateral cephalometry revealed OSA patients to have an inferiorly positioned hyoid bone, longer-than-normal soft palate and narrowing airway space. As OSA was severe, the airway shape was ovoid in the CT horizontal view.

**Conclusion:** Polysomnography and the radiographic parameter can be used for diagnosing OSA.

**Key words:** Sleep apnea, Obstructive, Polysomnography, Cephalometry, Computed tomography

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### I. Introduction

Modern society is characterized by the trend of rapid increase in the number of sleep disorder patients due to stress and obesity as well as rapid increase in the number of aged people. According to the analysis of data on the payment of cost of health insurance treatment from 2006 to last year by Korean National Health Insurance Corporation, the number of patients treated for sleep disorder increased nearly twofold for the last 5 years. There is a wide range of sleep disorders including insomnia, sleep apnea, paroxysmal sleep, sleep-wake disorder, and hypersomnia. The most common types of

sleep disorders are insomnia and sleep apnea<sup>1,2</sup>.

The sleep apnea syndrome (SAS) is a disorder characterized by abnormal breathing during sleep and sleep fragmentation. At least 30 episodes of apnea occur during 7 hours of nocturnal sleep in these patients<sup>3,4</sup>. Apnea is defined as the cessation of airflow through the nostrils and mouth for at least 10 seconds. Bickelmann et al.<sup>5</sup> first described the Pickwickian syndrome characterized by obesity, hypersomnia, periodic apnea, and hypopnea in 1956. In 1966, Gastaut et al.<sup>6</sup> were the first investigators to demonstrate repeated apnea in patients with Pickwickian syndrome during sleep.

Sleep apnea patients have various symptoms and clinical manifestations. Almost all patients or their bed partners have a history of heavy, loud snoring. Patients with sleep apnea most often complain of excessive daytime sleepiness (EDS); they may be experiencing serious social, economic, and emotional problems as well as fatigue, depression, personality changes, and impotence.

SAS is associated with one or more of these systemic

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symptoms.

Central sleep apnea, obstructive sleep apnea (OSA), and mixed sleep apnea are the variations of apnea. In central sleep apnea, respiratory muscle activity ceases simultaneously with airflow at the mouth and nostrils. On the other hand, OSA is characterized by sleep-induced obstruction of the upper airway, resulting in the cessation of airflow with preservation of respiratory effort, respiratory center drive, and diaphragmatic contraction. As a combination of central and obstructive apnea, mixed sleep apnea begins with an episode of central apnea with no airflow detectable at the mouth and nostrils and no respiratory muscle activity. The pattern ends with an episode of obstructive apnea with only the cessation of airflow at the mouth and nostrils<sup>7</sup>. Accounting for 80-95% of sleep apnea cases<sup>8</sup>, OSA is frequently manifested in males older than middle age and by 6-10 times compared to females. Its prevalence rate is approximately 1-10%<sup>9,10</sup>.

Nocturnal polysomnography remains the golden standard for establishing the diagnosis of sleep apnea, quantifying its severity and determining the success of treatment modalities. Polysomnography is the simultaneous and continuous monitoring of several parameters during sleep to study normal and abnormal sleep. The study includes monitoring brain waves and assessing sleep stages and other physiological variables such as breathing, eye movements, and blood oxygen levels, which exhibit a disrupted pattern with sleep disturbances.

A diagnostic evaluation includes thorough history and physical examination, acoustic reflection technique, fiberoptic endoscopy, radiological evaluation, and polysomnography.

Lateral cephalometry and computed tomography (CT) were routinely obtained in the radiological evaluation of sleep apnea patients. Lateral cephalometric analysis is performed to check for any possible skeletal and soft tissue abnormality. The advantages of lateral cephalometry include easy access, low cost, and minimal radiation exposure. Note, however, that there are obvious limitations in the evaluation of a three-dimensional area with two-dimensional lateral cephalometry. CT scan has several disadvantages such as radiation exposure, high cost. As an alternative to cephalometry, however, it has been used to provide quantitative assessment of the upper airway at various levels.

Since the tendency of obstruction of the upper respiratory tract in OSA patients is greatly influenced by the anatomical state of respiratory tract, finding out the location of obstruction of the upper respiratory tract is extremely important in the diagnosis and treatment of OSA. Although there have been

numerous research studies that analyzed the indices of each of the OSA patients and lateral cephalometric radiograph and CT in OSA patients, and the specific anatomical state of the respiratory tract of OSA patients is well-known thanks to existing research for this purpose, research studies examining the relevance by comparing the 3 diagnostic tools together - polysomnography, lateral cephalometric radiograph, and CT - are rare.

Therefore, this study sought to measure various anatomical items through physical measurements, lateral cephalometric radiograph, and CT on the upper respiratory tract areas, analyze the correlation between apnea-hypopnea index (AHI) of polysomnography, breathing disorder index, and lowest oxygen saturation level, and ultimately determine the diagnostic values of these indices for patients who visited the hospital with complaints of snoring and symptoms of sleep apnea.

## II. Materials and Methods

### 1. Study design

As a retrospective cohort study, this study recruited OSA patients from the departments of oral and maxillofacial surgery, neurology, and otolaryngology in Dong-A University Hospital (Busan, Korea) over a 31-month period (January 2009 to August 2011). The following were the inclusion criteria for the participants: 1) those diagnosed with OSA as confirmed by overnight polysomnography, and; 2) those

**Table 1.** Diagnostic criteria for obstructive sleep apnea patients (American Academy of Sleep Medicine, 1999)

The individual must fulfill criterion A or B plus criterion C

- A. Excessive daytime sleepiness that is not better explained by other factors
- B. Two or more of the following, which are not better explained by other factors:
  - Choking or gasping during sleep
  - Recurrent awakenings from sleep
  - Unsound sleep
  - Daytime fatigue
  - And/or impaired concentration
- C. Overnight monitoring reveals five or more obstructed breathing events per hour during sleep. These events may include any combination of obstructive apneas/hypopneas or respiratory effort-related arousals

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who have undergone lateral cephalometry and CT scans on the hard palate to the base of the epiglottis. Patients less than 20 years of age and who were on medication for disorders associated with cognition impairment such as mental retardation or dementia were excluded.

In this study, apnea meant more than 5 times per hour during sleep. Apnea was detected in patients by polysomnography. We used the diagnostic standards (Table 1) of the American Academy of Sleep Medicine (1999)<sup>11</sup> to diagnose OSA. After the consents of the 3 departments were obtained, a total of 29 patients were selected for analysis.

## 2. Methods

### 1) Anthropometric evaluations

The body mass index-adjusted body weight for individual weight differences in accordance with stature ( $\text{kg}/\text{m}^2$ ) was determined for each subject.

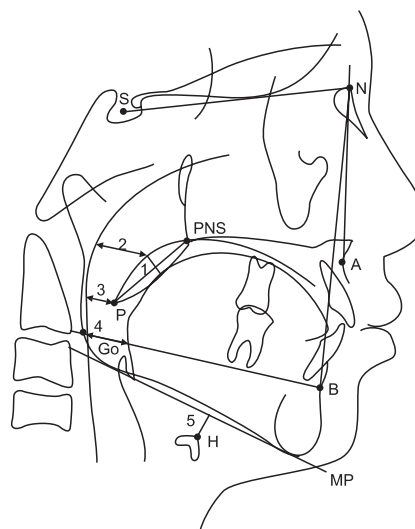
### 2) Polysomnography

Polysomnography is performed in a sleep laboratory; a patient's sleep is monitored overnight using Alice Sleepware (Philips Respironics, Andover, MA, USA) or Embla RemLogic 2.0 (Embla, Broomfield, CO, USA). Apnea is defined as the cessation of airflow through the nostrils and mouth for at least 10 seconds with preservation of respiratory effort. Hypopnea refers to at least 10 seconds' decrease in thoracoabdominal effort or airflow by at least 30%, and it was associated with 4% desaturation<sup>12,13</sup>. The AHI is the mean number of apneas and hypopneas per hour of sleep. As an abnormal respiratory event per hour, respiratory effort-related arousal (RERA) is associated with arousal<sup>14</sup>. Respiratory disturbance index (RDI) is defined as AHI and RERA<sup>14</sup>. A symptom with RDI greater than 5 was diagnosed as OSA<sup>11,15</sup>. RDI of more than 5 but less

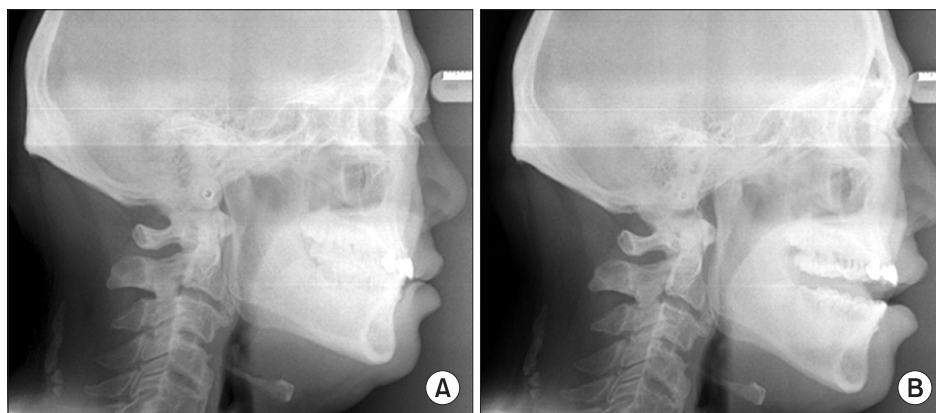
than 15 was classified as mild, more than 15 but less than 30, as moderate, and more than 30, as severe<sup>11,15</sup>. Average  $\text{SpO}_2$  ( $\text{ASpO}_2$ ) and lowest  $\text{SpO}_2$  ( $\text{LSpO}_2$ ) were measured during sleep.

### 3) Lateral cephalometry

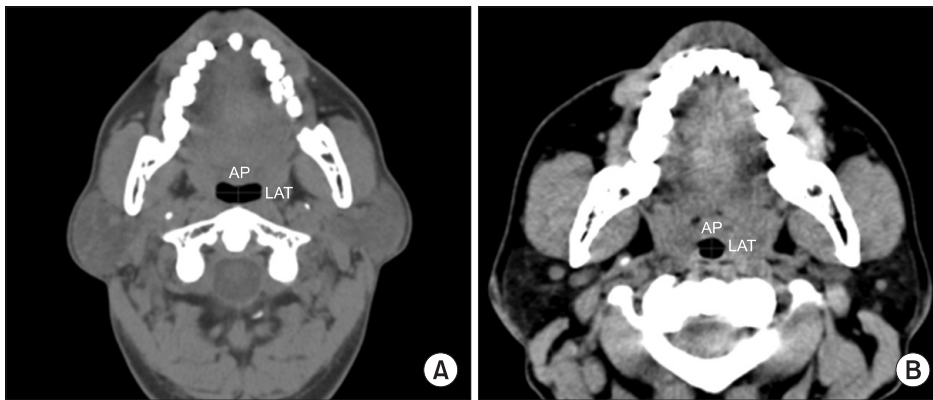
(1) All lateral cephalometries were taken with 165 cm focal film distance and 15 cm film distance from the sagittal plane of the patient under the following conditions: in upright position, and with the orbital-auricular plane (FH-plane)



**Fig. 2.** Reference points, lines, and linear measurements measured on lateral cephalometry. (Reference points S: sella, N: nasion, A: deepest anterior point in concavity of anterior maxilla, PNS: posterior nasal spine, P: palatal point, B: deepest anterior point in concavity of anterior mandible, Go: gonion, H: hyoid, MP: mandibular plane. Cephalometric angles SNA: angle between S-N and N-A, SNB: angle between S-N and N-B, ANB: angle between N-A and N-B. Cephalometric distances 1: PNS-P, 2: SPAS, 3: MAS, 4: IAS, 5: MP-H) Sun-Mi Jin et al: Retrospective study on the airway obstruction aspects of computed tomography and lateral cephalometry and the correlation of polysomnography in obstructive sleep apnea patients. *J Korean Assoc Oral Maxillofac Surg* 2012



**Fig. 1.** Lateral cephalometry was taken at mouth closing and opening postures. A. Closing cephalometry. B. Opening cephalometry. Sun-Mi Jin et al: Retrospective study on the airway obstruction aspects of computed tomography and lateral cephalometry and the correlation of polysomnography in obstructive sleep apnea patients. *J Korean Assoc Oral Maxillofac Surg* 2012



**Fig. 3.** The horizontal computed tomography views show the minimal anteroposterior diameter of the upper airway. A. The ratio of lateral to anteroposterior diameters is more than the 1.5 defined elliptical shape. B. The ratio of lateral to anteroposterior diameters is less than the 1.5 defined ovoid shape. (AP: anteroposterior diameter, LAT: lateral diameter)  
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**Table 2.** Cephalometric landmarks

Cephalometric landmarks		
S	Sella	Midpoint of fossa hypophysealis
N	Nasion	Anterior point at frontonasal suture
A	A-point	Deepest anterior point in concavity of anterior maxilla
B	B-point	Deepest anterior point in concavity of anterior mandible
PNS	Posterior nasal spine	Most posterior point of hard palate
P	Palatal point	Tip of soft palate
Go	Gonion	Mid-plane point at the gonial angle located by bisecting the posterior and inferior borders of the mandible
H	Hyoid	Most antero-superior point of hyoid

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**Table 3.** Cephalometric angles

Cephalometric angles (°)	
SNA	Angle between S-N and N-A
SNB	Angle between S-N and N-B
ANB	Angle between N-A and N-B

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held horizontally using PaX300C Plus (Vatech, Hwaseong, Korea) under 70 kVp, 10 mA. Majority of OSA patients display obstruction of the respiratory tract at the rear section of the soft palate during sleep; accordingly, many sleep with their mouths open and complain of dehydration of the oral cavity due to breathing through the mouth during sleep. Therefore, scanning was taken while the patients were in central occlusion (closed) state and in slightly open-mouthed state to reproduce the stature during sleep.(Fig. 1)

(2) The cephalometric measurements and reference lines used in this study are shown in Fig. 2 and Tables 2-4. To ensure consistency, all lateral cephalometries were traced and measured twice by a single investigator using EasyDent Viewer version 3.726 (Vatech).

**Table 4.** Cephalometric distances

Cephalometric distances (mm)	
SPAS	Distance from posterior pharyngeal wall to midpoint of PNS-P
MAS	Distance from posterior pharyngeal wall to uvula tip
IAS	Airway distance on Go-B plane
PNS-P	Length of soft palate (uvula length)
MP-H	Distance of hyoid-mandibular plane
NAS	Narrowest airway space

(SPAS: superior posterior airway space, MAS: middle airway space, IAS: inferior airway space, PNS-P: distance from posterior nasal spine to palatal point, MP-H: distance from hyoid to mandibular plane, NAS: narrowest airway space)

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#### 4) Acquisition of CT

CT scans were performed in supine position during wakefulness on patients with OSA using Somatom sensation 16 (Siemens, Forchhelm, Germany) or Aquilion ONE (Toshiba, Otawara, Japan). Scanning was done from the upper facial orbital to the lower portion of the 7th vertebrae and at the last aerobic phase in supine position to reproduce the state wherein the respiratory tract becomes narrowest. The conditions of scanning were 120 kVp, 250 mA, rotation time

of 0.5 second, pitch of 3, and high quality mode with slice thickness of 1.25 mm. It was later reconstructed with interval of 1 mm. The scanned radiography was analyzed through m-view version 5.4 (Marotech, Seoul, Korea).

The lateral diameter and antero-posterior diameter (AP diameter) of the respiratory tract were each computed by finding the narrowest section in the overall length of the respiratory tract in the cross-sectional image of CT. The ratio of lateral diameter against the AP diameter (LAT/AP ratio) was then computed.(Fig. 3)

In the mid-sagittal plane image of CT, superior posterior airway space (SPAS), middle airway space (MAS), inferior airway space (IAS), and narrowest airway space (NAS) were computed by using the measurement point and line used in the lateral cephalometric radiograph.(Fig. 4)



**Fig. 4.** Mid-sagittal computed tomography airway parameters. (SPAS: superior posterior airway space, MAS: middle airway space, IAS: inferior airway space)

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### 5) Statistical analysis

Statistical analysis was performed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA). The level of significance was established at  $P < 0.05$ . Before conducting univariate analysis, the assumptions satisfying the parametric statistical analysis were checked. We used non-parametric statistics because the normality was not met. Mann-Whitney U test, Wilcoxon signed rank test, and Spearman's rank test were used to examine the research questions.

## III. Results

### 1. Anthropometric clinical characteristics of OSA patients (Table 5)

The demographics of the participants are shown in Table 1. Among 29 patients with OSA, 25 were male and 4 were female. The mean age of the participants was 45 years. The mean body mass index was 25.77.

### 2. Effectiveness of various airway indices in accordance with the severity of RDI (Table 6)

The score of closing NAS ( $4.28 \pm 1.32$ ) in the severe OSA group was lower than that in the moderate group ( $5.91 \pm 2.64$ ), and the difference was statistically significant ( $z =$

**Table 5.** Demographics of 29 obstructive sleep apnea patients (n=29)

Variable	Categorie	Number (%) / mean $\pm$ SD
Sex	Male	25 (86.21)
	Female	4 (13.79)
Age (yr)		45.72 $\pm$ 13.27
BMI (kg/m <sup>2</sup> )		25.77 $\pm$ 3.12

(SD: standard deviation, BMI: body mass index)

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**Table 6.** Comparisons of moderate and severe obstructive sleep apnea patients

Variable	OSA severity (mean $\pm$ SD)		z (P)
	Moderate (RDI < 30) (n=20)	Severe (RDI $\geq$ 30) (n=9)	
Closing NAS, mm	5.91 $\pm$ 2.64	4.28 $\pm$ 1.32	-2.358 (0.018)*
Closing MP-H, mm	14.99 $\pm$ 5.81	22.69 $\pm$ 5.21	-2.853 (0.004)**
Closing ANB, mm	2.46 $\pm$ 3.02	5.13 $\pm$ 1.95	-2.381 (0.017)*

(OSA: obstructive sleep apnea, RDI: respiratory disturbance index, NAS: narrowest airway space, MP-H: distance from hyoid to mandibular plane, ANB: angle between N-A and N-B, SD: standard deviation)

\* $P < 0.05$ , \*\* $P < 0.01$ .

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-2.358,  $P=0.018$ ). Patients in the severe group had higher closing distance from hyoid to mandibular plane (MP-H) and closing angle between N-A and N-B (ANB) than those in the moderate group, and the difference was statistically significant ( $z=-2.853$ ,  $P=0.004$  for closing MP-H,  $z=-2.381$ ,  $P=0.017$  for closing ANB).

3. Correlation between RDI and radiographic parameters

The correlations among various indices in RDI, closing cephalometry, opening cephalometry, and CT are shown in Table 7. The lower RDI was significantly related to closing NAS, and the higher RDI, to closing distance from posterior nasal spine to palatal point (PNS-P). This suggests that RDI increased when NAS in closing cephalometry decreased, and that RDI decreased when PNS-P in closing cephalometry increased.

4. Comparisons of closing and opening lateral cephalometric parameters in OSA patients

As a result of statistical analysis specifically computing the values of SPAS, MAS, IAS, NAS, PNS-P, and MP-H in the lateral cephalometric radiograph (closing cephalometry) while in central occlusion position and in the lateral cephalometric radiograph (opening cephalometry) while in opened position, significant differences were noted in all indices

**Table 7.** Correlation between RDI and radiographic parameters

Variable	r (P)
Closing NAS, mm	-0.498 (0.006)**
Closing PNS-P, mm	0.422 (0.023)*

(RDI: respiratory disturbance index, NAS: narrowest airway space, PNS-P: distance from posterior nasal spine to palatal point)  
\* $P<0.05$ , \*\* $P<0.01$ .

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**Table 8.** Comparisons of closing and opening lateral cephalometric parameters in obstructive sleep apnea patients

Variable	Closing cephalometry (mean±SD)	Opening cephalometry (mean±SD)	z (P)
MAS, mm	8.08±8.51	5.70±3.59	3.028 (0.002)**
IAS, mm	8.39±2.28	7.17±2.46	2.563 (0.010)*
NAS, mm	5.41±2.00	3.45±1.42	4.357 (<0.001)***
PNS-P, mm	38.40±3.81	40.38±4.38	2.163 (0.031)*
MP-H, mm	16.96±6.62	12.93±7.52	3.977 (<0.001)***

(MAS: middle airway space, IAS: inferior airway space, NAS: narrowest airway space, PNS-P: distance from posterior nasal spine to palatal point, MP-H: distance from hyoid to mandibular plane, SD: standard deviation)  
\* $P<0.05$ , \*\* $P<0.01$ , \*\*\* $P<0.001$ .

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other than SPAS.(Table 8) Moreover, NAS and MP-H were found to exhibit the most significant changes. Compared to the closing cephalometry, the diameter of the actual respiratory tract relatively decreased with a decrease in MAS, IAS, and NAS during opening even though PNS-P, i.e., length of soft palate, increased. In addition, MP-H was observed to decrease at the time of opening as a result of shortening the distance between the lower jaw and hyoid bone due to opening.

5. Correlation among body mass index (BMI) and polysomnographic parameters and radiographic parameters

The relationships among BMI, polysomnography indices, and radiography indices using the Spearman rank correlation coefficient are shown in Table 9. There was significant

**Table 9.** Correlation between BMI and polysomnographic parameters and radiographic parameters

	Variable	r (P)
Polysomnographic parameter	BMI	1.00
	AHI	0.452 (0.014)*
	Average SpO <sub>2</sub>	-0.378 (0.043)*
Radiographic parameter	Lowest SpO <sub>2</sub>	-0.543 (0.002)**
	Opening IAS, mm	0.435 (0.018)*
	CT LAT diameter, mm	-0.583 (0.001)**
	CT LAT/AP	-0.589 (0.001)**
	diff SPAS	-0.411 (0.027)*
	diff MP-H	0.420 (0.029)*

(BMI: body mass index, AHI: apnea-hypopnea index, IAS: inferior airway space, CT LAT/AP: the ratio of the lateral diameter to the anteroposterior diameter in the narrowest section of the computed tomography transverse section, diff: differences between central occlusion position and open states in lateral cephalometry, SPAS: superior posterior airway space, MP-H: distance from hyoid to mandibular plane)  
\* $P<0.05$ , \*\* $P<0.01$ .

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positive relationship between BMI and AHI and two negative relationships among BMI, average oxygen saturation level (ASpO<sub>2</sub>), and lowest oxygen saturation level (LSpO<sub>2</sub>). This meant that higher BMI was related to higher AHI and lower ASpO<sub>2</sub> and LSpO<sub>2</sub>.

BMI and some radiographic variables such as opening IAS ( $r=0.435$ ,  $P=0.018$ ) and difference in MPH ( $r=0.420$ ,  $P=0.029$ ) were positively related. There were significant negative relationships between BMI and other radiographic variables such as the lateral diameter in the narrowest section ( $r=-0.583$ ,  $P=0.001$ ) and the ratio of the lateral diameter to the AP diameter in the narrowest section of the CT transverse section (LAT/AP ratio) ( $r=-0.589$ ,  $P=0.001$ ). This suggests that the lateral diameter in the CT transverse section decreases with an increase in body mass along with a decrease in the LAT/AP ratio. As BMI increased in the lateral cephalometric radiograph, IAS in open state decreased. There were also huge differences in SPAS and MP-H in central occlusion position and open state.

#### IV. Discussion

OSA is characterized by cessations of airflow or apneas caused by a recurrent collapse of the upper airway during sleep. Intermittent airway obstruction causes repetitive alveolar hypopnea with long-term sequelae including systemic and pulmonary hypertension, cardiac arrhythmias, and even sudden death. Sleep fragmentation as a result of continuous arousals is responsible for neuropsychiatric disorders such as EDS, personality changes, mental deterioration, and impotence.

The causes of obstruction of the respiratory tract are largely divided into obesity factor and non-obesity factor. The obesity factor causes an increase in the tendency toward obstruction of the respiratory tract due to the rear movement of the tongue as a result of the excessive accumulation of fat under the chin or reduction in the diameter of the respiratory tract owing to an increase in the volume of soft tissues around the respiratory tract. The non-obesity factor causes an increase in the tendency toward obstruction of the rear respiratory tract space because the low jaw bone is in the lower rear position as attributed to the increase in age and use of alcohol and drugs (muscle relaxant, etc.).

The pathological cause of obstruction of the respiratory tract in OSA patients has yet to be defined. Currently, the tendency toward obstruction of the respiratory tract during sleep is known to increase due to a reduction in the tension

of throat muscles by pathological factors, increase in age, consumption of alcohol, and administration of drugs such as anesthetics, muscle relaxant, and sedatives. Anatomical abnormalities such as adenotonsillary hypertrophy, retrognathia, micrognathia, macroglossia, large base of the tongue, deviated nasal septum, thick and short neck of obese people, and masses or tumors in the nasopharynx or hypopharynx may contribute to or produce airway obstruction during sleep<sup>4</sup>. In such case, apnea during sleep is manifested due to the obstruction of the respiratory tract attributed to the negative pressure instantaneously generated as a result of the remarkable increase in air flux in the narrowest section of the upper respiratory tract when air passes through the upper respiratory tract at the time of inhalation during sleep in accordance with Bernoulli's theorem. As such, since the tendency toward the obstruction of the upper respiratory tract in OSA patients is greatly influenced by the anatomical state of the respiratory tract<sup>16,17</sup>, finding the section of obstruction of the upper respiratory tract is a very important procedure in the diagnosis and treatment of OSA<sup>4</sup>.

Polysomnography is an essential examination for the diagnosis of sleep disorder patients. As indices of obstructive breathing disorder, apnea per hour, AHI as the measure of the frequency of hypopnea, and RDI as the indication of frequency of respiratory event-related arousals (RERA) are frequently used. In particular, RDI was used as diagnostic standard for OSA since it is deemed to show more accurate symptoms of respiratory disturbance as an index combining AHI and RERA<sup>4</sup>. In applying RDI as the diagnostic standard for sleep apnea, although RDI of less than 10 was set as the diagnostic standard for OSA since the positive ratio in aged people over 60 was found to be very high, there were a small number of patients over the age of 60; considering the fact that patients over the age of 60 all had severe cases of OSA, setting the diagnostic standard of RDI value to 5 for this study was deemed to cause no problem. Given the small number of specimens in this study, comparison with various indices in radiographic images was done by categorizing RDI of less than 30 as moderate and more than 30 as severe case of OSA.

There were significant differences between the 2 groups with regard to NAS, MP-H, and ANB in the lateral cephalometric radiograph scanned in central occlusion position. In the severe group with RDI of more than 30, the NAS value was low, whereas ANB and MP-H were much larger. The narrowest section of the respiratory tract found in this study was the rear section of the soft palate and rear

section of the root of the tongue; this finding was consistent with that of previous research studies<sup>18,19</sup>, suggesting that the narrowest anteroposterior diameter of the respiratory tract in comparison to the other indices of the upper respiratory tract found in the cephalometric radiograph had a close relationship with the intensity of the RDI. Rivlin et al.<sup>20</sup> reported OSA patients with posterior displacement of the mandible. Riley et al.<sup>21,22</sup> determined that OSA patients had inferiorly positioned hyoid bone, longer-than-normal soft palate, and narrowing at the base of the tongue. In this study, based on the finding that ANB values were high in the severe RDI group, OSA was deemed to be severer if the lower jaw was at the rear in comparison to the upper jaw. The position of the hyoid bone is important because it serves as a central anchor for the muscles of the tongue, thereby helping partly determine the tongue position. The mean MP-H distance for normal subjects is  $15.4 \pm 3$  mm. In this study, MP-H in the severe RDI group was  $22.69 \pm 5.21$  mm, which was longer than the mean value. Therefore, the thickness of the narrowest respiratory tract in the lateral cephalometric radiograph scanned in central occlusion position, position of the lower jaw against the upper jaw, and location of hyoid bone can be said to be related to the severity of OSA. (Table 6)

As a result of the analysis of correlation between RDI and various indices of radiographic scan, significant correlation was found between NSA and PNS-P in the lateral cephalometric radiograph taken in central occlusion position. As RDI increased, NSA in central occlusion position decreased, and PNS-P in central occlusion position, i.e., length of the soft palate, was found to increase. This is related to the results of previous research studies including that by Riley et al.<sup>21,22</sup> who reported that OSA patients displayed longer soft palate than normal subjects.

The polysomnography of OSA patients shows that they often sleep with their mouth open. Therefore, various indices and RDI values were compared by taking lateral cephalometric radiograph, with the respiratory tract during sleeping reproduced by slightly opening the mouth. (Fig. 1) Significant changes were observed in all indices except SPAS when compared with the lateral cephalometric radiograph in central occlusion position. (Table 8) Among these, the most significant changes were observed for NAS and MP-H. MAS, IAS, NAS, and MP-H were found to decrease based on the lower rear direction movement of the tongue when opening the mouth. Since the extent of obstruction can be said to worsen if the patients change to supine posture for sleep, such will provide useful diagnostic value. Although no

statistically significant difference in RDI was found between 2 groups for all indices, the authors believe that indices with statistical significance can be found if the number of research subjects is increased. Therefore, continuous research analysis is deemed to be essential in the future.

Most of the publications on the effect of body posture on sleep apnea have suggested that sleeping in supine posture contributes to the severity of sleep apnea<sup>23</sup>. Cartwright<sup>24</sup> divided the OSA patients into two groups - positional OSA patients (PP) and non-positional OSA patients (NPP) - according to the body posture, whereas sleeping has an effect on the OSA severity and events. Oksenberg et al.<sup>25</sup> recently confirmed Cartwright's data in a large, unselected OSA population (574 consecutive patients) diagnosed in their sleep unit and found that 55.9% were positional. In other words, PP represents the majority of the OSA patients. Thinner and younger than NPP on the average, PP had fewer, less severe breathing abnormalities than NPP, and their nocturnal sleep quality was better preserved<sup>24,25</sup>. This is due to the fact that there is a difference in the transverse section of the respiratory tract between the 2 patient groups. The shape of the transverse section of the upper respiratory tract is categorized as elliptical if the ratio of the lateral diameter against the anteroposterior diameter is more than 1.5, and as circular if less than 1.5. (Fig. 3) Although there are more elliptical types in positional patients, the more circular type is found in non-positional patients. Such difference is induced because the lateral diameter of the upper respiratory tract in positional patients is greater, although there is no difference in the anteroposterior diameter of the upper respiratory tract between the 2 patient groups<sup>26</sup>. During sleep in supine position, both PP and NPP will have breathing abnormalities due mainly to the gravitational effect on upper airway soft tissues; this in turn reduces the anteroposterior diameter significantly. When the PP group adopts the lateral position, the anteroposterior diameter increases since the lateral walls are sufficiently far apart, thereby preserving sufficient airway space to avoid a complete collapse of the upper airway. In the NPP group, changing to lateral position will continue to cause pharyngeal collapse since the lateral diameter in these patients is not sufficiently large to prevent such. Fairburn et al.<sup>27</sup> reported that OSA worsened with the decrease in the ratio of lateral diameter against the anteroposterior diameter. According to Saigusa et al.<sup>28</sup>, the most significant difference lies in the volume of soft tissue of the lateral pharyngeal wall of positional and non-positional patients. A collapse of the respiratory tract is manifested as the difference in



pressure within the respiratory tract and pressure of soft tissues. Since the non-positional patients frequently had high body mass index with high volume of soft tissue on the lateral pharyngeal wall, collapse of the respiratory tract can occur in both supine and laterally reclined positions due to the increased gravitational effect. In positional patients with relatively low severity of OSA and body mass index, the transverse sectional shape of the respiratory tract becomes more like an ellipse; as the transverse sectional shape of the respiratory tract becomes more like a circle, the severity of OSA and body mass index increase. Therefore, since obesity and increased neck circumference induce an increase in the volume of soft tissues of the upper respiratory tract, these are factors that most directly affect the reduction of diameter of the upper respiratory tract.

Body mass exhibited significant association with AHI, average oxygen saturation level, and lowest oxygen saturation level at the time of polysomnography. As BMI increased, AHI increased whereas the average oxygen saturation level and lowest oxygen saturation level decreased. Therefore, the severity of OSA can be said to increase as BMI increases. (Table 9)

As BMI increased, the ratio of the lateral diameter against the anteroposterior diameter of the respiratory tract decreased in the CT transverse section scan of the narrowest respiratory tract section; thus causing the transverse sectional shape of the respiratory tract to become more like a circle and increasing the severity of OSA. The differences in SPAS and HP-H in central occlusion position and open states can be said to be large since BMI in the lateral cephalometric radiograph increases whereas IAS in open state decreases. (Table 9) Therefore, the extent of decrease in the respiratory tract in open state can be said to be greater as BMI increases. The severity of OSA can be forecast through the appearance of reduction of the respiratory tract as displayed in the lateral cephalometric radiograph taken in open state based on this principle.

Since the lateral cephalometric radiograph is scanned in upright posture, such cannot be deemed to reflect accurately the upper respiratory tract of patients in lying-down posture during sleep. Nonetheless, Kim et al.<sup>29</sup> reported no significant difference in the measured value of the 2 groups in terms of sitting and lying position as a result of comparing the cephalometric radiograph images due to the level of muscular tension. In the clinical setting, it is difficult to reproduce the posture during sleep; since similar values can be obtained even if the cephalometric radiograph can be taken while the

subject is standing comfortably as in scanning while lying down, this study also used the scanned images taken while the subjects are in standing position considering the ease of carrying out this study.

Since CT is taken while patients are in supine position to reproduce the posture during sleep, it has the disadvantage of taking the scan while the subject is in awakened state. According to Martin et al.<sup>30</sup>, although OSA patients in seated position had smaller upper airway transverse section areas than normal subjects, there was no difference between the groups observed in lateral and supine postures. This suggests that OSA patients, at least in awakened state, may tend to protect themselves against upper airway collapse secondary to increased gravitational load on the tongue<sup>30</sup>. Therefore, the CT scan poorly reproduces the airway in sleeping state. Accordingly, with the exception of polysomnography, all diagnostic tools have difficulties in accurately reproducing the state of sleep since the patients are scanned in awakened state. As such, an important task is to pursue research on observing the anatomical changes in the upper respiratory tract during sleep.

Based on the finding with regard to the association among the BMI of OSA patients, RDI as revealed through the results of polysomnography, and indices in the radiograph particularly the finding that the indices of the lateral cephalometric radiograph taken in central occlusion position and open states are related to the severity of OSA, more significant and useful indices may be discovered if the number of research subjects is increased. The lateral cephalometric radiograph is expected to be enormously helpful in confirming and diagnosing the sleeping status and location of obstruction of OSA patients since scanning is relatively convenient, economical, and reproducible.

## V. Conclusion

The association among the various indices found in polysomnography, lateral cephalometric radiograph taken in central occlusion position and open states, and CT scan of OSA patients was analyzed.

1. When the patients were divided into moderate and severe groups in terms of RDI as the index of the extent of respiratory disturbance during sleep, the 3 indices - NAS, MP-H, and ANB - in lateral cephalometric radiograph taken in central occlusion position showed significant differences between the 2 groups. The NAS value was found to be small in the severe group with

RDI of more than 30, whereas ANB and MP-H were found to be larger.

2. In the lateral cephalometric radiograph, the diameter of the rear respiratory tract particularly NSA was reduced as the posture changed from the central occlusion position to open state; the difference was statistically significant.
3. As BMI increased, AHI in polysomnography increased, and respiratory disturbance worsened with the reduction in ASpO<sub>2</sub> and LSpO<sub>2</sub>.
4. As BMI increased, the transverse sectional shape of the respiratory tract in CT became more like a circle.

## References

1. Foresman BH. Sleep and breathing disorders: the genesis of obstructive sleep apnea. *J Am Osteopath Assoc* 2000;100(8 Suppl): S1-8.
2. Morin CM, Colecchi C, Stone J, Sood R, Brink D. Behavioral and pharmacological therapies for late-life insomnia: a randomized controlled trial. *JAMA* 1999;281:991-9.
3. Brouillette RT, Thach BT. A neuromuscular mechanism maintaining extrathoracic airway patency. *J Appl Physiol* 1979;46:772-9.
4. Tiner BD, Waite PD. Surgical and nonsurgical management of obstructive sleep apnea. In: Peterson LJ, Indresano AT, Marciani RD, Roser SM, eds. *Principles of oral and maxillofacial surgery*. 6th ed. Philadelphia: J.B Lippincott Company; 1992:1531-48.
5. Bickelmann AG, Burwell CS, Robin ED, Whaley RD. Extreme obesity associated with alveolar hypoventilation; a Pickwickian syndrome. *Am J Med* 1956;21:811-8.
6. Gastaut H, Tassinari CA, Duron B. Polygraphic study of the episodic diurnal and nocturnal (hypnic and respiratory) manifestations of the Pickwick syndrome. *Brain Res* 1966;1:167-86.
7. Choi JY, Engelke W. Cephalometric and nasopharyngeal endoscopic study in patients with obstructive sleep apnea. *J Korean Assoc Maxillofac Plast Reconstr Surg* 1999;21:149-65.
8. White DP. Central sleep apnea. *Med Clin North Am* 1985;69: 1205-19.
9. Cisneros GJ, Trieger N. Sleep apnea. In: Bell WH, ed. *Modern practice in orthognathic and reconstructive surgery*. 9th ed. Philadelphia: W.B. Saunders Company; 1992:2020-41.
10. Partinen M, Telakivi T. Epidemiology of obstructive sleep apnea syndrome. *Sleep* 1992;15(6 Suppl):S1-4.
11. Sleep-related breathing disorders in adults: recommendations for syndrome definition and measurement techniques in clinical research. The Report of an American Academy of Sleep Medicine Task Force. *Sleep* 1999;22:667-89.
12. Meoli AL, Casey KR, Clark RW, Coleman JA Jr, Fayle RW, Troell RJ, et al; Clinical Practice Review Committee. Hypopnea in sleep-disordered breathing in adults. *Sleep* 2001;24:469-70.
13. Raj R, Hirshkowitz M. Effect of the new Medicare guideline on patient qualification for positive airway pressure therapy. *Sleep Med* 2003;4:29-33.
14. Meir HK, Thomas R, William CD. *Management of obstructive sleep apnea-hypopnea syndrome: overview*. 4th ed. New York: Elsevier; 2006:1111-4.
15. Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep-disordered breathing among middle-aged adults. *N Engl J Med* 1993;328:1230-5.
16. Shepard JW Jr, Geftter WB, Guilleminault C, Hoffman EA, Hoffstein V, Hudgel DW, et al. Evaluation of the upper airway in patients with obstructive sleep apnea. *Sleep* 1991;14:361-71.
17. Goldberg AN, Schwab RJ. Identifying the patient with sleep apnea: upper airway assessment and physical examination. *Otolaryngol Clin North Am* 1998;31:919-30.
18. Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. *Sleep* 1996;19:156-77.
19. Fujita S, Conway W, Zorick F, Roth T. Surgical correction of anatomic abnormalities in obstructive sleep apnea syndrome: uvulopalatopharyngoplasty. *Otolaryngol Head Neck Surg* 1981;89: 923-34.
20. Rivlin J, Hoffstein V, Kalbfleisch J, McNicholas W, Zamel N, Bryan AC. Upper airway morphology in patients with idiopathic obstructive sleep apnea. *Am Rev Respir Dis* 1984;129:355-60.
21. Riley R, Guilleminault C, Herran J, Powell N. Cephalometric analyses and flow-volume loops in obstructive sleep apnea patients. *Sleep* 1983;6:303-11.
22. Riley R, Guilleminault C, Powell N, Simmons FB. Palatopharyngoplasty failure, cephalometric roentgenograms, and obstructive sleep apnea. *Otolaryngol Head Neck Surg* 1985;93:240-4.
23. Oksenberg A, Silverberg DS. The effect of body posture on sleep-related breathing disorders: facts and therapeutic implications. *Sleep Med Rev* 1998;2:139-62.
24. Cartwright RD. Effect of sleep position on sleep apnea severity. *Sleep* 1984;7:110-4.
25. Oksenberg A, Silverberg DS, Arons E, Radwan H. Positional vs nonpositional obstructive sleep apnea patients: anthropomorphic, nocturnal polysomnographic, and multiple sleep latency test data. *Chest* 1997;112:629-39.
26. Pevernagie DA, Stanson AW, Sheedy PF 2nd, Daniels BK, Shepard JW Jr. Effects of body position on the upper airway of patients with obstructive sleep apnea. *Am J Respir Crit Care Med* 1995;152:179-85.
27. Fairburn SC, Waite PD, Vilos G, Harding SM, Bernreuter W, Cure J, et al. Three-dimensional changes in upper airways of patients with obstructive sleep apnea following maxillomandibular advancement. *J Oral Maxillofac Surg* 2007;65:6-12.
28. Saigusa H, Suzuki M, Higurashi N, Kodera K. Three-dimensional morphological analyses of positional dependence in patients with obstructive sleep apnea syndrome. *Anesthesiology* 2009;110:885-90.
29. Kim TK, Yang DK, Chung IK, Kim JR, Roh HJ. Cephalometric analysis of snoring and obstructive sleep apnea. *J Korean Assoc Maxillofac Plast Reconstr Surg* 1996;18:463-9.
30. Martin SE, Marshall I, Douglas NJ. The effect of posture on airway caliber with the sleep-apnea/hypopnea syndrome. *Am J Respir Crit Care Med* 1995;152:721-4.