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The effect of body position on airway patency in obstructive sleep apnea: CT imaging analysis

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Abstract

Purpose Positional change during sleep influences upper airway patency. However, few studies have used imaging techniques to demonstrate the change. This study aims to determine the effect of positional change on the upper airway space.

Methods A total of 118 subjects with sleep breathing disorders were analyzed. Participants underwent upper airway CT scans in the supine and lateral decubitus positions (right and left). They were divided into non-obstructive sleep apnea ($n = 28$) and obstructive sleep apnea ($n = 90$) groups. We measured the minimal cross-sectional area of the retropalatal/retroglossal spaces and compared the differences of those two spaces in the supine and lateral positions. CT was performed while patients were awake.

Results The minimal cross-sectional area in the OSA group was significantly smaller than non-OSA group in both supine (median[interquartile range], 8.3[0.0–25.1] vs 22.2[1.0–39.6]; $P = 0.018$) and lateral decubitus positions (5.2[0.0–16.9] vs 21.3[6.1–38.4]; $P = 0.002$). As the body position of OSA patients shifted from supine to lateral, the retroglossal space increased significantly (67.3[25.1–116.3] vs 93.3[43.4–160.1]; $P < 0.001$). However, there was no significant difference in the retropalatal space between the supine and lateral decubitus positions.

Conclusions Positional change from the supine to lateral decubitus position expands the upper airway lumen, especially the retroglossal space. Positional OSA may be related to anatomical change of the upper airway lumen based on body position.

Keywords Obstructive sleep apnea · Sleep · Body position · Airway · Computed tomography

Introduction

Obstructive sleep apnea (OSA) is defined as a complete or partial intermittent pause of airflow in the upper airway during sleep [1]. The severity of respiratory disturbance in OSA can change depending on body position [2]. Positional OSA is diagnosed when an apnea-hypopnea index (AHI) is more than five per hour of total sleep time and is reduced by 50% or more in the non-supine position compared with the supine position [3, 4]. Positional OSA is a relatively common condition affecting approximately 40–50% of OSA patients. In mild to moderate OSA patients, the prevalence of positional OSA is greater than 60% [3].

Continuous positive airway pressure (CPAP) is the standard treatment for OSA [1]. However, the effect of CPAP is clinically limited because the adherence to CPAP is relatively low; it ranges from approximately 20 to 60% [5, 6]. Alternative treatments such as behavioral therapy, oral appliances, and surgery are recommended for OSA management if CPAP is not possible [1]. Among other alternatives, positional therapy is an effective secondary or supplementary treatment in addition to primary therapies, especially in the adults with positional OSA [7]. Moreover, it was demonstrated that the effect of positional therapy was almost comparable to that of CPAP, both in the relief of respiratory disturbance and the improvement of sleep quality [8]. The primary mechanism by which the level of AHI in positional OSA is relieved or aggravated by changing the sleeping position is not

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completely understood. The size of the upper airway lumen is significantly decreased in patients with severe OSA compared to non-OSA patients [9]. Presumably, the severity of OSA based on AHI is closely associated with anatomical changes of the upper airway lumen. However, to the best of our knowledge, few studies have measured changes in the cross-sectional area of the upper airway in different body positions using computed tomography (CT) [10]. The aim of this research was to investigate the changes in the minimal cross-sectional area (minCSA) of the upper airway depending on body position in order to elucidate the anatomical impact of the upper airway on positional OSA using an upper airway CT scan.

Materials and methods

Subjects

A total of 132 subjects with major symptoms of fatigue, daytime sleepiness, reported snoring, and apnea were enrolled between September 2008 and January 2010. Of these, 14 subjects' data were missing or inaccurate; overall 118 subjects' data were investigated. Subjects with craniofacial abnormalities, genetic anomalies, chronic medical diseases, and the history of upper airway surgery including tonsillectomy were excluded. Demographic and clinical information were obtained. All participants provided informed consent. The institutional review board of the Korea University Ansan Hospital reviewed and approved the research protocol.

Polysomnography

All subjects underwent a full-night polysomnography at the hospital sleep center. The diagnosis of OSA was based on standard computerized polysomnography (Alice 4, Respironics, Atlanta, GA, USA). Sixteen channels were used to measure the following parameters: four-channel electroencephalogram, electrooculogram, electrocardiogram, submental and leg electromyogram, airflow at the nose and mouth, chest and abdominal respiratory movements, oxygen saturation using pulse oximetry, snoring, and body position. A sleep technician observed subjects with an infrared camera inside the room to confirm their sleep position. Certified physicians reviewed and interpreted all sleep recordings based on the standard criteria of the AASM Manual for the Scoring of Sleep and Associated Events [11].

AHI was defined as the number of apnea and hypopnea events per hour of total sleep time. Subjects were grouped into non-OSA (AHI < 5/h) and OSA cases (AHI ≥ 5/h) according to AHI. Positional OSA was defined as an AHI twice higher in the supine than non-supine position.

Upper airway CT scan

CT images were obtained using a commercial 64-channel CT (Brilliance 64; Philips, Cleveland, OH, USA). All images were taken while subjects were awake. Scanning extended from the top of the head to the cricoid cartilage, with an interval of 3 mm and a time of 15 s. For each patient, images were obtained in the supine, right, and left lateral body positions. To avoid changes in the upper airway lumen during respiration, participants were asked to hold their breath at the end of expiration for each scan.

As a post-scan processing program, Rapidia® (Infinitt Co., Ltd., Seoul, Korea) was used to measure the cross-sectional area of the upper airway. The cross-sectional area in the lateral position was defined as the average of the right and left lateral position. We defined the retropalatal (RP) space as from the lower margin of the hard palate to the caudal margin of the soft palate. The retroglossal (RG) space was defined as from the caudal margin of the soft palate to the upper margin of the hyoid bone (Fig. 1). The cross-sectional areas of the retropalatal and retroglossal spaces were measured in an axial plane in units of square millimeters. The minimal cross-sectional areas of the

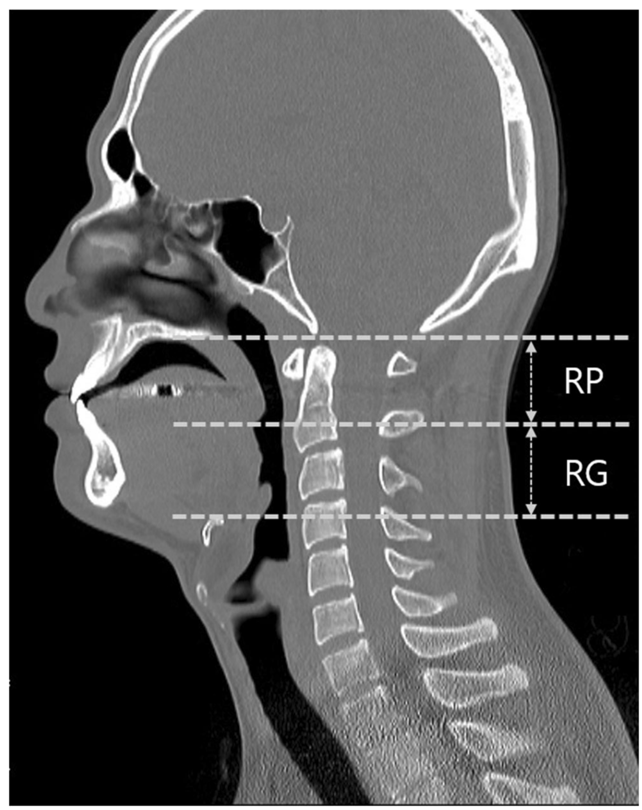

Fig. 1 Sagittal computed tomography image of the upper airway. Retropalatal (RP) space extends from the lower margin of hard palate down to the caudal margin of soft palate. Retroglossal (RG) space extends from the caudal margin of soft palate down to the upper margin of hyoid bone

retropalatal (minCSA_RP) and retroglossal (minCSA_RG) spaces were the smallest cross-sectional areas within the RP and RG spaces, respectively (Fig. 2). Parameters of the upper airway were measured twice by a single technician to maximize accuracy.

Statistical analysis

Demographic data for continuous variables were reported as mean ± standard deviation. Subjects were separated into non-OSA and OSA groups based on AHI criteria. Measured CT parameters for non-normal distribution were expressed as median values and interquartile ranges; results were compared using a Wilcoxon signed-rank test. P values < 0.05 were considered significant. Statistical analysis was performed using SPSS Statistics Version 20.0 (IBM Corp., Armonk, NY, USA).

Results

Demographic and PSG data

A total of 118 subjects (100 males, 18 females) were analyzed. The average age was 41.67 (SD = 11.86; range = 14–72). The mean AHI was 26.31/h (SD = 25.50) and the mean AHI in supine and lateral position was 17.7/h and 38.4/h, respectively. Of the 90 OSA patients, 59 (65.6%) patients were positional and 31 (34.4%) were non-positional. The subjects were categorized into non-OSA group ($n = 28$, 23.7%) with an AHI < 5/h and OSA group ($n = 90$, 76.3%) with an AHI ≥ 5/h. The OSA group had a higher BMI ($P = 0.001$), age ($P = 0.005$), and male to female ratio ($P = 0.002$). Demographic characteristics are summarized in Table 1.

Upper airway size according to OSA

The OSA group had a significantly smaller upper airway than non-OSA group in each body position; the median (interquartile ranges) minCSA in the supine position of the retropalatal space was 8.3 (0.0–25.1) mm^2 in OSA group and 22.2 (1.0–39.6) mm^2 in non-OSA ($P = 0.018$). The cross-sectional area in the lateral position of the retropalatal space was 5.2 (0.0–16.9) mm^2 in OSA and 21.3 (6.1–38.4) mm^2 in non-OSA ($P = 0.002$). However, the size difference in the retroglossal space between OSA and non-OSA was minimal and statistically not significant in both supine and lateral position (Table 2).

Upper airway size and positional change

The minCSA in the supine and lateral positions were analyzed for both retropalatal and retroglossal spaces (Table 2). In the retropalatal space, there was no significant difference in minCSA between the supine and lateral positions in either non-OSA or OSA groups ($P = 0.790$, $P = 0.273$, respectively). However, the minCSA of the retroglossal space significantly increased when the body position changed from supine to lateral in both non-OSA and OSA groups ($P = 0.001$, $P < 0.001$, respectively).

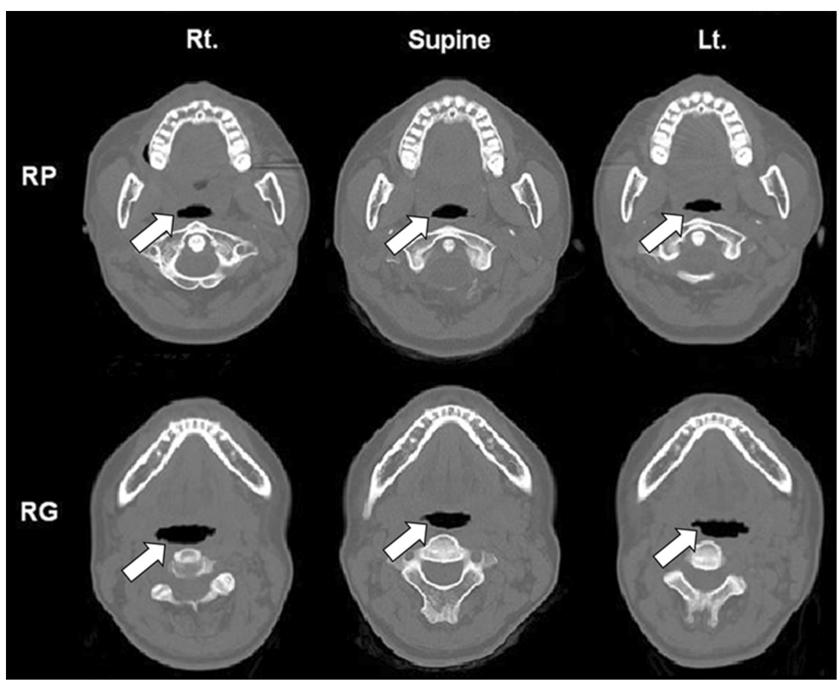

Fig. 2 Computed tomography images of minimal cross-sectional area (minCSA) in retropalatal (RP) and retroglossal (RG) space in three different positions: supine, right, and left decubitus (arrow). The upper airway space increases when the body shifts from the supine to the lateral position in the RG space level

Table 1 Demographic characteristics of study subjects ($n = 118$)

	Non-OSA patients (AHI < 5/h)	OSA patients (AHI ≥ 5/h)	Total	*P* value
n	28	90	118	
Sex (male:female)	18:10	82:8	100:18	0.002*
Age	35.54 ± 13.09	43.58 ± 10.84	41.67 ± 11.86	0.005*
Weight (kg)	68.80 ± 12.89	77.44 ± 12.64	75.38 ± 13.17	0.002*
Height (cm)	167.80 ± 9.77	168.98 ± 7.89	168.70 ± 8.35	0.644
BMI (kg/m^2)	24.44 ± 4.08	27.06 ± 3.52	26.44 ± 0.81	0.001*

Data are expressed as mean ± SD

OSA obstructive sleep apnea, *BMI* body mass index

*$P \leq 0.05$ for the test

Positional OSA and non-positional OSA

There was no difference in the retroglossal minCSA between positional OSA and non-positional OSA in supine position ($P = 0.878$). However, in the retropalatal space, the minCSA of the positional OSA patients was larger than the non-positional OSA patients ($P = 0.041$). In addition, in the retropalatal level, there was no statistically significant difference of minCSA between the supine and lateral position in both positional ($P = 0.906$) and non-positional ($P = 0.149$) OSA patients. Meanwhile, in the retroglossal level, both positional ($P = 0.002$) and non-positional ($P = 0.014$) OSA patients showed a significant minCSA increase after shifting from the supine to lateral position (Fig. 3).

Discussion

The present research was performed to measure the minCSA of the upper airway in 118 subjects. It demonstrated that the OSA group had significantly smaller minCSA of the upper airway than the non-OSA group regardless of body position. In addition, we found that the minCSA of the upper airway changed according to positional shifts. In particular, the minCSA of the retroglossal space significantly increased in the lateral position when compared to the supine position. However, there was no significant difference in the retropalatal space between the supine and lateral positions.

Positional OSA occurs due to changes in respiratory disturbance based on sleeping position [1, 2, 12]. Its mechanism has not been fully elucidated, yet several explanations have been introduced as potential etiologies for the positional dependency. Anatomically, the tongue and mandible are pulled posteriorly by gravity in the supine position, which decreases the upper airway lumen [13]. The effect of gravity is decreased in the lateral position. It has also been suggested that the shape of an upper airway plays a key factor; the greater upper airway transverse diameter decreases the collapsibility in the lateral position [10]. Susceptibility of hypopharyngeal structures to gravitation-induced collapse was also reported as a cause of positional dependency [14]. However, other possible contributing factors for the size of upper airway lumen such as tonsil size, upper airway collapsibility, and epiglottis size were not investigated here.

Our research showed that the minCSA of the upper airway in the OSA group is smaller than that of the non-OSA group. This tendency has been reported by several studies using different modalities, including CT, MRI, and flow dynamic series [15–17]. Donnelly et al. found that the greater change in diameter at the hypopharynx posterior to the tongue in OSA

Table 2 Minimal cross-sectional area of the upper airway in different body positions in non-obstructive ($n = 28$) and obstructive sleep apnea ($n = 90$) group

		Supine (*a*)	Right lateral (*b*)	Left lateral (*c*)	Lateral (*d*) $d = (b + c)/2$	*P* value (*a–b*)	*P* value (*a–c*)	*P* value (*a–d*)
min CSA_RP (mm^2)	C	22.2 [1.0–39.6]	17.0 [0.0–44.9]	26.5 [3.2–45.6]	21.3 [6.1–38.4]	0.648	0.840	0.790
	O	8.3 [0.0–25.1]	5.1 [0.0–18.0]	2.7 [0.0–18.8]	5.2 [0.0–16.9]	0.394	0.208	0.273
min CSA_RG (mm^2)	C	69.0 [38.9–115.2]	83.8 [50.2–190.6]	108.9 [66.3–194.1]	87.9 [66.7–184.1]	*0.003**	*0.002**	*0.001**
	O	67.3 [25.1–116.3]	92.2 [48.6–163-9]	87.9 [35.1–157.8]	93.3 [43.4–160.1]	*0.000**	*0.011**	*0.000**

Data are expressed as median [interquartile range]. Italicized values are all statistically significant

C control, non-obstructive apnea; *O* obstructive sleep apnea; *minCSA_RP* minimal cross-sectional area_retropalatal space; *minCSA_RG* minimal cross-sectional area_retroglossal space

*$P \leq 0.05$ for the test

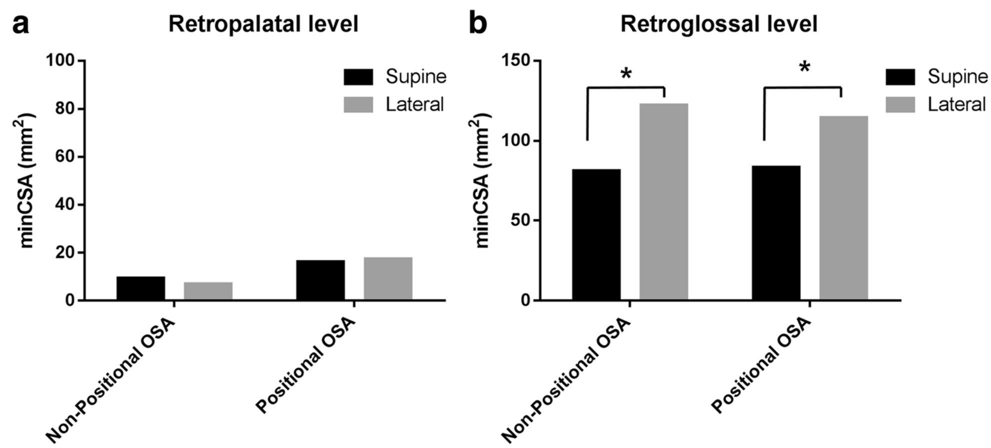

Fig. 3 Minimal cross-sectional area (minCSA) change by position in **a** retropalatal and **b** retroglossal space of positional OSA and non-positional OSA patients. $^*P \leq 0.05$

may contribute to the different cross-sectional areas between the groups. Other studies have suggested that obesity can be associated with high collapsibility of airway tissue in OSA [18, 19]. In this study, the OSA patients had a higher BMI than non-OSA patients. In addition, Ogawa et al. speculated that the smaller airway in OSA patients can be due to one of the three factors: the loss of pharyngeal muscle, rigidity of the fascia, or accumulation of fat [15].

The positional shift from the supine to lateral position during sleep relieves objective respiratory and sleep parameters including AHI, arousal index, and minimal oxygen saturation [20]. CT scan has been used for the evaluation of an upper airway, because it possesses advantages in the detection of the airway space, bone, and soft tissue landmarks [21]. In this study, the CT scan was used (1) to identify differences of the upper airway between OSA and non-OSA groups and (2) to illustrate how the lateral position increases the upper airway lumen compared with the supine position. To assess the change in the upper airway in different positions, a single parameter of minCSA was analyzed. minCSA is the parameter most commonly used to reflect the patency of the upper airway lumen [22]. First, pressure drop and flow resistance in the upper airway are predominantly caused by minCSA [16]. Second, the minCSA is easily measurable and most reliable regardless of expertise or experience [23]. Likewise, its use as a single reasonable parameter can be supported.

As discussed, the minCSA increases from the supine to the lateral position in the retroglossal space, but not in the retropalatal (RP) space. This finding is secondary to a greater effect of gravity on the tongue compared to the soft palate. Given our data, it seems that the soft palate was not significantly influenced by gravity in any position. In contrast, the effect of gravity on the tongue has a substantial influence on the retroglossal space depending on body position. There are a few other studies that support that the tongue has a more important role than the palate in positional dependency. Lee et al. included 100 patients in mandibular advancement treatment and proved that patients with positional dependency showed better outcomes than patients with non-positional dependency [24]. Recent research also suggested that a higher rate of tongue obstruction was seen in positional-dependent patients, and positional therapy can be more beneficial in positional-dependent patients [14]. The result that retroglossal obstruction is more commonly seen in positional-dependent patients can be a strong evidence supporting our idea.

There are several limitations to this study. First, CT images may not accurately reflect the changes of the upper airway during sleep because the CT scan was obtained while patients were awake, and there may be a difference in muscle tone and respiratory drive between sleeping and waking states. However, considering that muscle tone decreases during sleep, the framework of the upper airway would be more affected by gravity. Second, although we confirmed that the positional shift is related to changes in the upper airway lumen size, we did not investigate whether the change in the upper airway in different positions can directly affect respiratory disturbance. Third, all participants were Asians. It has been reported that Asians are more prone to positional dependency up to 87% in some researches. Therefore, this study may not reflect a generalized conclusion in all ethnicity [25]. Fourth, in this study, we investigated only minCSA of retropalatal/retroglossal spaces. However, as the upper airway is a complex three-dimensional structure, there are various structures to be considered including tonsil size, oropharyngeal collapsibility, epiglottis, and tongue base. Future studies could be designed focusing on these structures to overcome this limitation.

Conclusion

This study used CT imagery to demonstrate that the minCSA of the upper airway, especially the retroglossal space, significantly increases when the body shifts from the supine to lateral position. It also showed that patients with OSA have smaller upper airway lumens than non-OSA patients. Therefore, we suggest that the change in respiratory disturbance in positional OSA may be related to anatomical changes of the upper airway lumen, which is dependent on body position.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

Ethical approval The institutional review board reviewed and approved the research protocol.

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